Introducing a series on Meeting the Climate Challenge. For a close look at one option, biofuels, see "Green Dreams," page 38.

ESSAY BY **BILL McKIBBEN**

Carbon's New Math

To deal with global warming, the first step is to do the numbers.

Here's how it works. Before the industrial revolution, the Earth's atmosphere contained about 280 parts per million of carbon dioxide. That was a good amount—"good" defined as "what we were used to." Since the molecular structure of carbon dioxide traps heat near the planet's surface that would otherwise radiate back out to space, civilization grew up in a world whose thermostat was set by that number. It equated to a global average temperature of about 57 degrees Fahrenheit, which in turn equated to all the places we built our cities, all the crops we learned to grow and eat, all the water supplies we learned to depend on, even the passage of the seasons that, at higher latitudes, set our psychological calendars.

Once we started burning coal and gas and oil to power our lives, that 280 number started to rise. When we began measuring in the late 1950s, it had already reached the 315 level. Now it's at 380, and increasing by roughly two parts per million annually. That doesn't sound like very much, but it turns out that the extra heat that CO_2 traps, a couple of watts per square meter of the Earth's surface, is

Never mind the steam spewing from a coal-fired power plant. The problem is what you can't see: greenhouse gases, mainly CO_2. Plants like this generate a quarter of humankind's CO_2 emissions.

MITCH EPSTEIN, GETTY IMAGES

Global warming presents the greatest test humans have yet faced. New technologies and new habits offer some promise, but only if we move quickly and decisively.

enough to warm the planet considerably. We've raised the temperature more than a degree Fahrenheit already. It's impossible to precisely predict the consequences of any further increase in CO_2 in the atmosphere. But the warming we've seen so far has started almost everything frozen on Earth to melting; it has changed seasons and rainfall patterns; it's set the sea to rising.

No matter what we do now, that warming will increase some—there's a lag time before the heat fully plays out in the atmosphere. That is, we can't stop global warming. Our task is less inspiring: to contain the damage, to keep things from getting out of control. And even that is not easy. For one thing, until recently there's been no clear data suggesting the point where catastrophe looms. Now we're getting a better picture—the past couple of years have seen a series of reports indicating that 450 parts per million CO_2 is a threshold we'd be wise to respect. Beyond that point, scientists believe future centuries will likely face the melting of the Greenland and West Antarctic ice sheets and a subsequent rise in sea level of giant proportion. Four hundred fifty parts per million is still a best guess (and it doesn't include the witches' brew of other, lesser, greenhouse gases like methane and nitrous oxide). But it will serve as a target of sorts for the world to aim at. A target that's moving, fast. If concentrations keep increasing by two parts per million per year, we're only three and a half decades away.

Bill McKibben's 11th book on environmental topics, The Bill McKibben Reader: Pieces from an Active Life, *will be published this winter.*

So the math isn't complicated—but that doesn't mean it isn't intimidating. So far only the Europeans and Japanese have even begun to trim their carbon emissions, and they may not meet their own modest targets. Meanwhile, U.S. carbon emissions, a quarter of the world's total, continue to rise steadily—earlier this year we told the United Nations we'd be producing 20 percent more carbon in 2020 than we had in 2000. China and India are suddenly starting to produce huge quantities of CO_2 as well. On a per capita basis (which is really the only sensible way to think about the morality of the situation), they aren't anywhere close to American figures, but their populations are so huge, and their economic growth so rapid, that they make the prospect of a worldwide decline in emissions seem much more daunting. The Chinese are currently building a coal-fired power plant every week or so. That's a lot of carbon.

Everyone involved knows what the basic outlines of a deal that could avert catastrophe would look like: rapid, sustained, and dramatic cuts in emissions by the technologically advanced countries, coupled with large-scale technology transfer to China, India, and the rest of the developing world so that they can power up their emerging economies without burning up their coal. Everyone knows the big questions, too: Are such rapid cuts even possible? Do we have the political will to make them and to extend them overseas?

The first question—is it even possible?—is usually addressed by fixating on some single new technology (hydrogen! ethanol!) and imagining it will solve our troubles. But the scale of the problem means we'll need many strategies. Three years ago a Princeton team made one of the best assessments of the possibilities. Stephen Pacala and Robert Socolow published a paper in *Science* detailing 15 "stabilization wedges"—changes big enough to really matter, and for which the technology was already available or clearly on the horizon. Most people have heard of some of them: more fuel-efficient cars, better-built homes, wind turbines, biofuels like ethanol. Others are newer and less sure: plans for building coal-fired power plants that can separate carbon from the

SOYBEANS

WIND TURBINE

SOLAR PANEL

COMPACT FLUORESCENT BULB

exhaust so it can be "sequestered" underground.

These approaches have one thing in common: They're more difficult than simply burning fossil fuel. They force us to realize that we've already had our magic fuel and that what comes next will be more expensive and more difficult. The price tag for the global transition will be in the trillions of dollars. Of course, along the way it will create myriad new jobs, and when it's complete, it may be a much more elegant system. (Once you've built the windmill, the wind is free; you don't need to guard it against terrorists or build a massive army to control the countries from which it blows.) And since we're wasting so much energy now, some of the first tasks would be relatively easy. If we replaced every incandescent bulb that burned out in the next decade anyplace in the world with a compact fluorescent, we'd make an impressive start on one of the 15 wedges. But in that same decade we'd need to build 400,000 large wind turbines—clearly possible, but only with real commitment. We'd need to follow the lead of Germany and Japan and seriously subsidize rooftop solar panels; we'd need to get most of the world's farmers plowing their fields less, to build back the carbon their soils have lost. We'd need to do everything all at once.

As precedents for such collective effort, people sometimes point to the Manhattan Project to build a nuclear weapon or the Apollo Program to put a man on the moon. But those analogies don't really work. They demanded the intense concentration of money and intelligence on a single small niche in our technosphere. Now we need almost the opposite: a commitment to take what we already know how to do and somehow spread it into every corner of our economies, and indeed our most basic activities. It's as if NASA's goal had been to put all of us on the moon.

Not all the answers are technological, of course—maybe not even most of them. Many of the paths to stabilization run straight through our daily lives, and in every case they will demand difficult changes. Air travel is one of the fastest growing sources of carbon emissions around the world, for instance, but even many of us who are noble about changing lightbulbs and happy to drive hybrid cars chafe at the thought of not jetting around the country or the world. By now we're used to ordering take-out food from every corner of the world every night of our lives—according to one study, the average bite of food has traveled nearly 1,500 miles before it reaches an American's lips, which means it's been marinated in (crude) oil. We drive alone, because it's more convenient than adjusting our schedules for public transit. We build ever bigger homes even as our family sizes shrink, and we watch ever

CLOCKWISE FROM TOP LEFT: ROBERT CLARK; JORG GREUEL, GETTY IMAGES; ROBERT CLARK; VICTORIA SNOWBER, GETTY IMAGES bigger TVs, and—well, enough said. We need to figure out how to change those habits.

Probably the only way that will happen is if fossil fuel costs us considerably more. All the schemes to cut carbon emissions—the so-called cap-and-trade systems, for instance, that would let businesses bid for permission to emit—are ways to make coal and gas and oil progressively more expensive, and thus to change the direction in which economic gravity pulls when it applies to energy. If what we paid for a gallon of gas reflected even a portion of its huge environmental cost, we'd be driving small cars to the train station, just like the Europeans. And we'd be riding bikes when the sun shone.

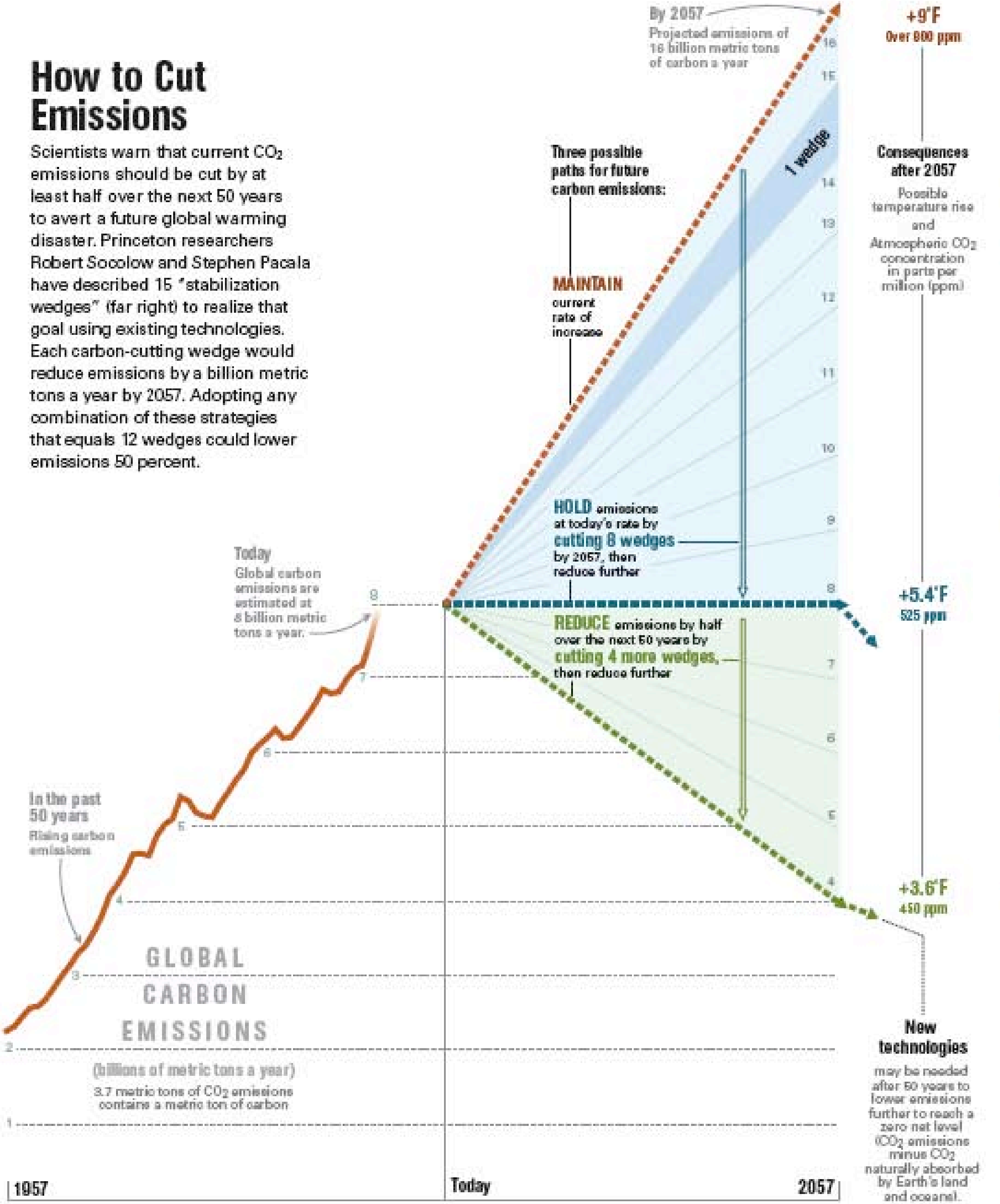
The most straightforward way to raise the price would be a tax on carbon. But that's not easy. Since everyone needs to use fuel, it would be regressive—you'd have to figure out how to keep from hurting poor people unduly. And we'd need to be grown-up enough to have a real conversation about taxes—say, about switching away from taxes on things we like (employment) to taxes on things we hate (global warming). That may be too much to ask for—but if it is, then what chance is there we'll be able to take on the even more difficult task of persuading the Chinese, the Indians, and all who are lined up behind them to forgo a coal-powered future in favor of something more manageable? We know it's possible—earlier this year a UN panel estimated that the total cost for the energy transition, once all the pluses and minuses were netted out, would be just over 0.1 percent of the world's economy each year for the next quarter century. A small price to pay.

In the end, global warming presents the greatest test we humans have yet faced. Are we ready to change, in dramatic and prolonged ways, in order to offer a workable future to subsequent generations and diverse forms of life? If we are, new technologies and new habits offer some promise. But only if we move quickly and decisively—and with a maturity we've rarely shown as a society or a species. It's our coming-of-age moment, and there are no certainties or guarantees. Only a window of possibility, closing fast but still ajar enough to let in some hope. □

Warming Trends For more on climate from National Geographic and NPR, visit ngm.com/climateconnections and npr.org/climateconnections.

How to Cut Emissions

Scientists warn that current CO_2 emissions should be cut by at least half over the next 50 years to avert a future global warming disaster. Princeton researchers Robert Socolow and Stephen Pacala have described 15 "stabilization wedges" (far right) to realize that goal using existing technologies. Each carbon-cutting wedge would reduce emissions by a billion metric tons a year by 2057. Adopting any combination of these strategies that equals 12 wedges could lower emissions 50 percent.



ONE WEDGE AT A TIME

Each strategy listed below would, by 2057, reduce annual carbon emissions by a billion metric tons.

EFFICIENCY AND CONSERVATION

- Improve fuel economy of the two billion cars expected on the road by 2057 to 60 mpg from 30 mpg.
- Reduce miles traveled annually per car from 10,000 to 5,000.
- Increase efficiency in heating, cooling, lighting, and appliances by 25 percent.
- Improve coal-fired power plant efficiency to 60 percent from 40 percent.

CARBON CAPTURE AND STORAGE

- Introduce systems to capture CO_2 and store it underground at 800 large coal-fired plants or 1,600 natural-gas-fired plants.
- Use capture systems at coal-derived hydrogen plants producing fuel for a billion cars.
- Use capture systems in coal-derived synthetic fuel plants producing 30 million barrels a day.

LOW-CARBON FUELS

- Replace 1,400 large coal-fired power plants with natural-gas-fired plants.
- Displace coal by increasing production of nuclear power to three times todays capacity.

RENEWABLES AND BIOSTORAGE

- Increase wind-generated power to 25 times current capacity.
- Increase solar power to 700 times current capacity.
- Increase wind power to 50 times current capacity to make hydrogen for fuel-cell cars.
- Increase ethanol biofuel production to 50 times current capacity. About one-sixth of the world's cropland would be needed.
- Stop all deforestation.
- Expand conservation tillage to all cropland (normal plowing releases carbon by speeding decomposition of organic matter).

SOURCES: ROBERT H. SOCOLOW AND STEPHEN W. PACALA, PRINCETON UNIVERSITY (UPDATED REPORT); OAK RIDGE NATIONAL LABORATORY (GLOBAL CARBON EMISSIONS DATA). ICONS BY JONATHAN AVERY. GRAPHIC BY JUAN VELASCO, NGM ART

Outlook: EXTREME

As the planet warms, look for more floods where it's already wet and deeper drought where water is scarce.

CHINA In July 2007 nine inches of rain in 24 hours turned a Chongqing stairway into a waterfall. At the same time in the north, more than a million people faced severe water shortages.

CHINA DAILY/REUTERS/CORBIS

BY ELIZABETH KOLBERT

The world's first empire, known as Akkad, was founded some 4,300 years ago, between the Tigris and the Euphrates Rivers. The empire was ruled from a city—also known as Akkad—that is believed to have lain just south of modern-day Baghdad, and its influence extended north into what is now Syria, west into Anatolia, and east into Iran. The Akkadians were well organized and well armed and, as a result, also wealthy: Texts from the time testify to the riches, from rare woods to precious metals, that poured into the capital from faraway lands.

Then, about a century after it was founded, the Akkad empire suddenly collapsed. During one three-year period four men in succession briefly claimed to be emperor. "Who was king? Who was not king?" a register known as the Sumerian King List asks.

For many years, scholars blamed the empire's fall on politics. But about a decade ago, climate scientists examining records from lake bottoms and the ocean floor discovered that right around the time that the empire disintegrated, rainfall in the region dropped dramatically. It is now believed that Akkad's collapse was caused by a devastating drought. Other civilizations whose demise has recently been linked to shifts in rainfall include the Old Kingdom of Egypt, which fell right around the same time as Akkad; the Tiwanacu civilization, which thrived near Lake Titicaca, in the Andes, for more than a millennium before its fields were abandoned around A.D. 1100; and the Classic Maya civilization, which collapsed at the height of its development, around A.D. 800.

The rainfall changes that devastated these early civilizations long predate industrialization; they were triggered by naturally occurring climate shifts whose causes remain uncertain. By contrast, climate change brought about by increasing greenhouse gas concentrations is our own doing. It, too, will influence precipitation patterns, in ways that, though not always easy to predict, could prove equally damaging.

Warm air holds more water vapor—itself a greenhouse gas—so a hotter world is a world where the atmosphere contains more moisture. (For every degree Celsius that air temperatures increase, a given amount of air near the surface holds roughly 7 percent more water vapor.) This will not necessarily translate into more rain—in fact, most scientists believe that total precipitation

Elizabeth Kolbert is a staff writer for the New Yorker *and author of* Field Notes from a Catastrophe: Man, Nature, and Climate Change.

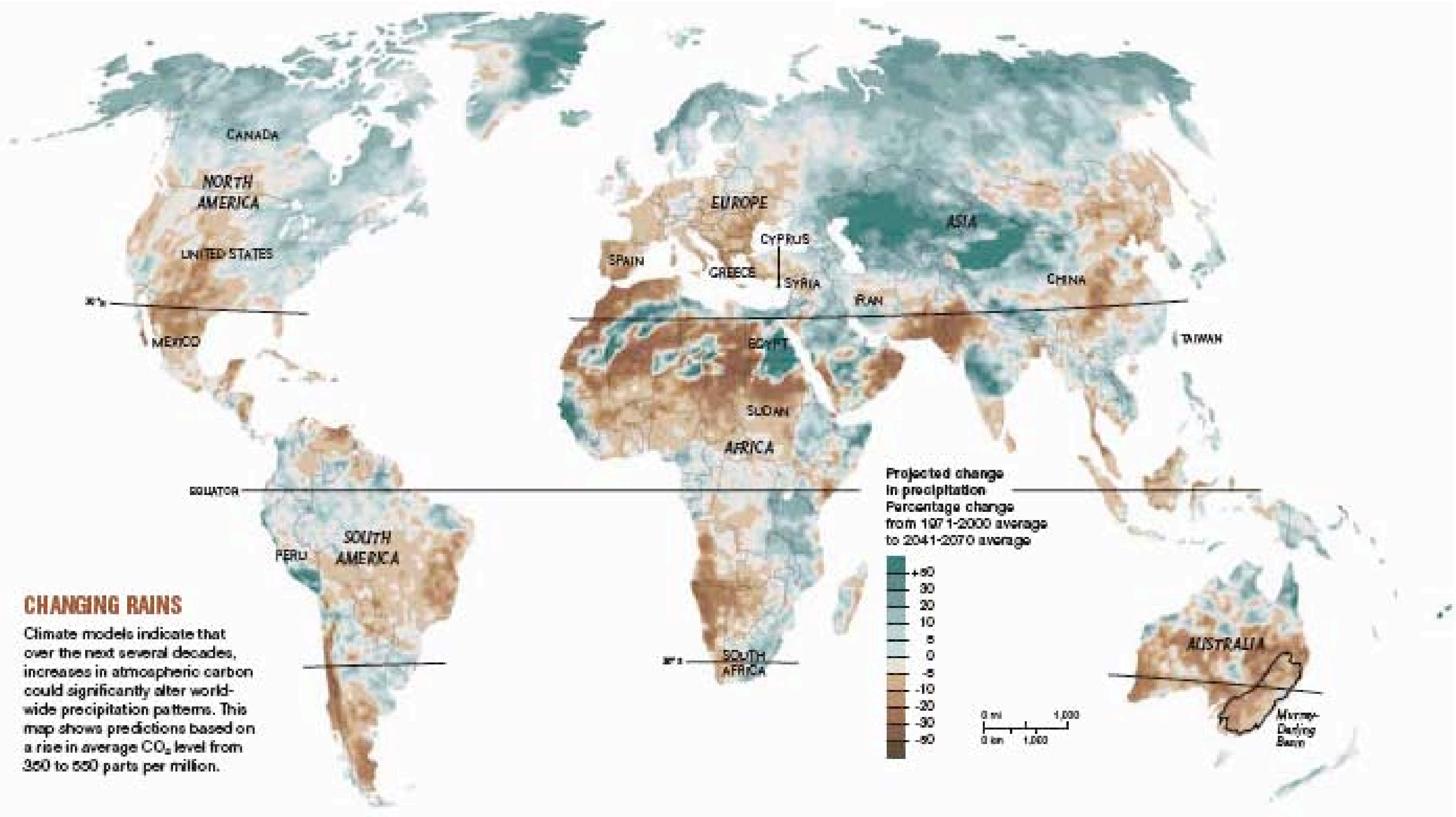
will increase only modestly—but it is likely to translate into changes in where the rain falls. It will amplify the basic dynamics that govern rainfall: In certain parts of the world, moist air tends to rise, and in others, the moisture tends to drop out as rain and snow.

"The basic argument would be that the transfers of water are going to get bigger," explains Isaac Held, a scientist at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory at Princeton University. Climate models generally agree that over the coming century, the polar and subpolar regions will receive more precipitation, and the subtropics—the area between the tropical and temperate zones—will receive less. On a regional scale, the models disagree about some trends. But there is a consensus that the Mediterranean Basin will become more arid. So, too, will Mexico, the southwestern United States, South Africa, and southern Australia. Canada and northern Europe, for their part, will grow damper.

A good general rule of thumb, Held says, is that "wet areas are going to get wetter, and dry areas drier." Since higher temperatures lead to increased evaporation, even areas that continue to receive the same amount of overall precipitation will become more prone to drought. This poses a particular risk for regions that already subsist on minimal rainfall or that depend on rain-fed agriculture.

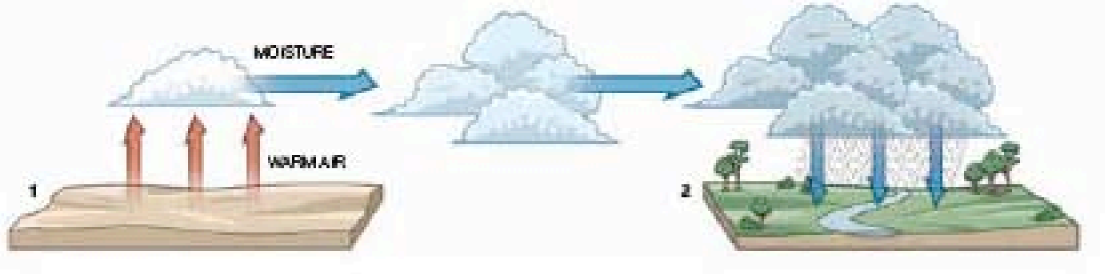
"If you look at Africa, only about 6 percent of its cropland is irrigated," notes Sandra Postel, an expert on freshwater resources and director of the Global Water Policy Project. "So it's a very vulnerable region."

Meanwhile, when rain does come, it will likely arrive in more intense bursts, increasing the risk of flooding—even in areas that are drying out. A recent report by the United Nations' Intergovernmental Panel on Climate Change (IPCC) notes that "heavy precipitation events are projected to become more frequent" and that an increase in such events is probably already contributing to disaster. In the single decade between 1996 and 2005 there were twice as many inland flood catastrophes



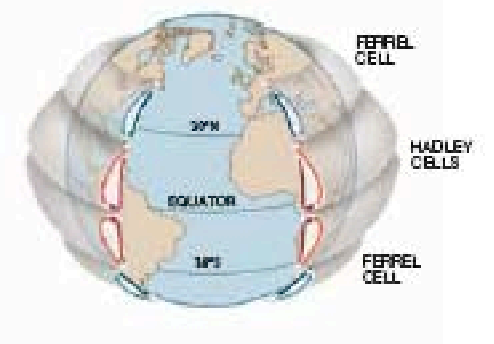
CHANGING RAINS

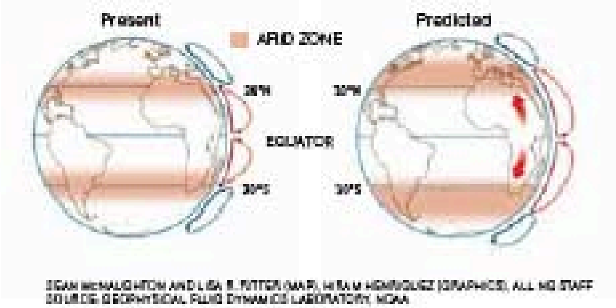
Climate models indicate that over the next several decades, increases in atmospheric carbon could significantly alter worldwide precipitation patterns. This map shows predictions based on a rise in average CO_2 level from 350 to 550 parts per million.



DROUGHT AND DELUGE

Warm air holds more moisture, carrying it away from dry areas (1) and toward wetter ones (2). Thus as global temperatures rise, dry areas will likely get drier and wet areas wetter. Seasonal extremes will likewise intensify, as moisture accumulated in the dry season is shed in downpours in cooler times, leading to seasonal floods in regions otherwise prone to drought.





SPREADING DESERTS

Atmospheric warming is also predicted to affect rainfall by altering global air circulation. At present, warm air carried from the tropics by circulation loops called Hadley cells meets cool polar air carried by Ferrel cells in zones around 30° north and south, creating arid zones. As the planet warms, these zones are expected to expand and shift toward the Poles.

SEAN MCNAUGHTON AND LISA R. RITTER (MAP), HIRAM HENRIQUEZ (GRAPHICS), ALL NG STAFF
SOURCE: GEOPHYSICAL FLUID DYNAMICS LABORATORY, NOAA

SUDAN Drought scars the earth in Northern Darfur in October 2005. The UN calls this region "a tragic example of the social breakdown that can result from ecological collapse."

U.S.A. Neighbors in Fredonia, Kansas, helped each other salvage treasured possessions after flash floods, driven by days of record-breaking rainfall, saturated homes in June 2007.

as in the three decades between 1950 and 1980.

"It happens not just spatially, but also in time," says Brian Soden, a professor of marine and atmospheric science at the University of Miami. "And so the dry periods become drier, and the wet periods become wetter."

Quantifying the effects of global warming on rainfall patterns is challenging. Rain is what scientists call a "noisy" phenomenon, meaning that there is a great deal of natural variability from year to year. Experts say that it may not be until the middle of this century that some long-term changes in precipitation emerge from the background clatter of year-to-year fluctuations. But others are already discernible. Between 1925 and 1999, the area between 40 and 70 degrees north latitude grew rainier, while the area between zero and 30 degrees north grew drier. In keeping with this broad trend, northern Europe seems to be growing wetter, while the southern part of the continent grows more arid. The Spanish Environment Ministry has estimated that, owing to the combined effects of climate change and poor land-use practices, fully a third of the country is at risk of desertification. Meanwhile, the island of Cyprus has become so parched that in the summer of 2008, with its reservoir levels at just 7 percent, it was forced to start shipping in water from Greece.

"I worry," says Cyprus's environment commissioner, Charalambos Theopemptou. "The IPCC is talking about a 20 or 30 percent reduction of rainfall in this area, which means that the problem is here to stay. And this combined with higher temperatures—I think it is going to make life very hard in the whole of the Mediterranean."

Other problems could follow from changes not so much in the amount of precipitation as in the type. It is estimated that more than a billion people—about a sixth of the world's population—live in regions whose water supply depends, at least in part, on runoff from glaciers or seasonal snowmelt. As the world warms, more precipitation will fall as rain and less as snow, so this storage system may break down. The Peruvian city of Cusco, for instance, relies in part on runoff from the glaciers of the Quelccaya ice cap to provide water in summer. In recent years, as the glaciers have receded owing to rising temperatures, Cusco has periodically had to resort to water rationing.

Several recent reports, including a National Intelligence Assessment prepared for American policymakers in 2008, predict that over the next few decades, climate change will emerge as a significant source of political instability. (It was no coincidence, perhaps, that the drought-parched Akkad empire was governed in the end by a flurry of teetering monarchies.) Water shortages in particular are likely to create or exacerbate international tensions. "In some areas of the Middle East, tensions over water already exist," notes a study prepared by a panel of retired U.S. military officials. Rising temperatures may already be swelling the ranks of international refugees—"Climate change is today one of the main drivers of forced displacement," the United Nations High Commissioner for Refugees, António Guterres, has said—and contributing to armed clashes. Some experts see a connection between the fighting in Darfur, which has claimed an estimated 300,000 lives, and changes in rainfall in the region, bringing nomadic herders into conflict with farmers.

Will the rainfall changes of the future affect societies as severely as some of the changes of the past? The American Southwest, to look at one example, has historically been prone to droughts severe enough to wipe out—or at least disperse—local populations. (It is believed that one such megadrought at the end of the 13th century contributed to the demise of the Anasazi civilization, centered in what currently is the Four Corners.) Nowadays, of course, water-management techniques are a good deal more sophisticated than they once were, and the Southwest is supported by what Richard Seager, an expert on the climatic history of the region, calls "plumbing on a continental scale." Just how vulnerable is it to the aridity likely to result from global warming?

"We do not know, because we have not been at this point before," Seager observes. "But as man changes the climate, we may be about to find out." j

LYNSEY ADDARIO (LEFT); LARRY W. SMITH, EPA/CORBIS (RIGHT)

World oil demand is surging as supplies approach their limits.

Tapped Out

BY PAUL ROBERTS

From a drilling platform off Newfoundland to a bustling gas station in Lianyungang, China, oil addiction is driving us to search farther and spend more for fuel.

IN 2000 A SAUDI OIL GEOLOGIST named Sadad I. Al Husseini made a startling discovery. Husseini, then head of exploration and production for the state-owned oil company, Saudi Aramco, had long been skeptical of the oil industry's upbeat forecasts for future production. Since the mid-1990s he had been studying data from the 250 or so major oil fields that produce most of the world's oil. He looked at how much crude remained in each one and how rapidly it was being depleted, then added all the new fields that oil companies hoped to bring on line in coming decades. When he tallied the numbers, Husseini says he realized that many oil experts "were either misreading the global reserves and oil-production data or obfuscating it."

Where mainstream forecasts showed output rising steadily each year in a great upward curve that kept up with global demand, Husseini's calculations showed output leveling off, starting as early as 2004. Just as alarming, this production plateau would last 15 years at best, after which the output of conventional oil would begin "a gradual but irreversible decline."

That is hardly the kind of scenario we've come to expect from Saudi Aramco, which sits atop the world's largest proven oil reserves—some 260 billion barrels, or roughly a fifth of the world's known crude—and routinely claims that oil will remain plentiful for many more decades. Indeed, according to an industry source, Saudi oil minister Ali al-Naimi took a dim view of Husseini's report, and in 2004 Husseini retired from Aramco to become an industry consultant. But if he is right, a dramatic shift lies just ahead for a world whose critical systems, from defense to transportation to food production, all run on cheap, abundant oil.

Husseini isn't the first to raise the specter

RANDY OLSON (TOP); WANG CHUN CHINA FOTO PRESS/GETTY IMAGES of a peak in global oil output. For decades oil geologists have theorized that when half the world's original endowment of oil has been extracted, getting more out of the ground each year will become increasingly difficult, and eventually impossible. Global output, which has risen steadily from fewer than a million barrels a day in 1900 to around 85 million barrels today, will essentially stall. Ready or not, we will face a post-oil future—a future that could be marked by recession and even war, as the United States and other big oil importers jockey for access to secure oil resources.

Forecasts of peak oil are highly controversial—not because anyone thinks oil will last forever, but because no one really knows how much oil remains underground and thus how close we are to reaching the halfway point. So-called oil pessimists contend that a peak is imminent or has actually arrived, as Husseini believes, hidden behind day-to-day fluctuations in production. That might help explain why crude oil prices have been rising steadily and topped a hundred dollars a barrel early this year.

Optimists, by contrast, insist the turning point is decades away, because the world has so much oil yet to be tapped or even discovered, as well as huge reserves of "unconventional" oil, such as the massive tar-sand deposits in western Canada. Optimists also note that in the past, whenever doomsayers have predicted an "imminent" peak, a new oil-field discovery or oil-extraction technology allowed output to keep rising. Indeed, when Husseini first published his forecasts in 2004, he says, optimists dismissed his conclusions "as curious footnotes."

Many industry experts continue to argue that today's high prices are temporary, the result of technical bottlenecks, sharply rising demand from Asia, and a plummeting dollar. "People will run out of demand before they run out of oil," BP's chief economist declared at a meeting early this year. Other optimists, however, are wavering. Not only have oil prices soared to historic levels, but unlike past spikes, those prices haven't generated a surge in new output. Ordinarily, higher prices encourage oil companies to invest more in new exploration technologies and go after difficult-to-reach oil fields. The price surge that followed the Iran-Iraq war in the 1980s, for example, eventually unleashed so much new oil that markets were glutted. But for the past few years, despite a sustained rise in price, global conventional oil output has hovered around 85 million barrels a day, which happens to be just where Husseini's calculations suggested output would begin to level off.

The change is so stark that the oil industry itself has lost some of its cockiness. Last fall, after the International Energy Agency released a forecast showing global oil demand rising more than a third by 2030, to 116 million barrels a day, several oil-company executives voiced doubts that production could ever keep pace. Speaking to an industry conference in London, Christophe de Margerie, head of the French oil giant Total, flatly declared that the "optimistic case" for maximum daily output was 100 million barrels—meaning global demand could outstrip supply before 2020. And in January, Royal Dutch Shell's CEO, Jeroen van der Veer, estimated that "after 2015 supplies of easy-to-access oil and gas will no longer keep up with demand."

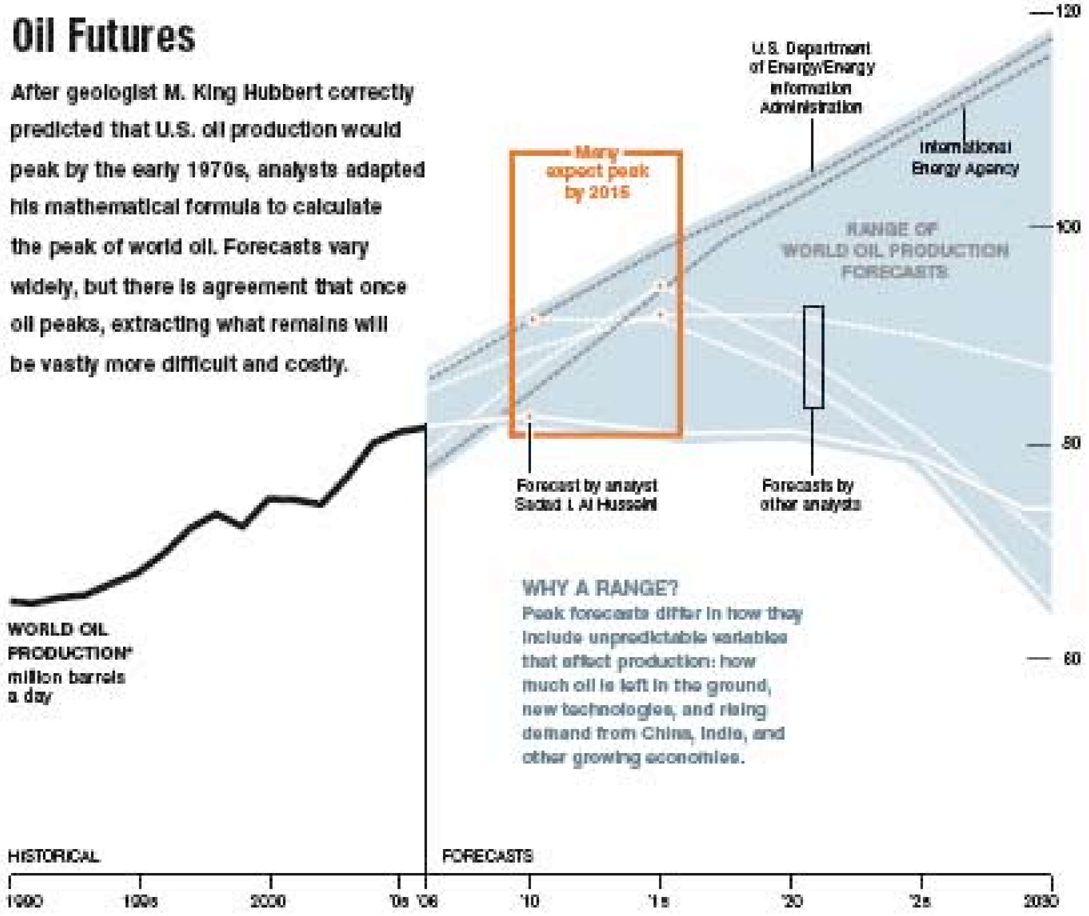
To be sure, veteran oilmen like de Margerie and van der Veer don't talk about peak oil in a geologic sense. In their view, political and economic factors above ground, rather than geologic ones below, are the main obstacles to raising output. War-torn Iraq is said to have huge underground oil reserves, yet because of poor security, it produces about a fifth as much

PEAK OIL
How much oil remains in the Earth cannot be known. But even the most optimistic scenarios hold that before mid-century we will hit peak oil, the point at which half the world's supply has been extracted.

Paul Roberts is author of The End of Oil, *published in 2004. His new book,* The End of Food, *will be out this summer from Houghton Mifflin Harcourt.*

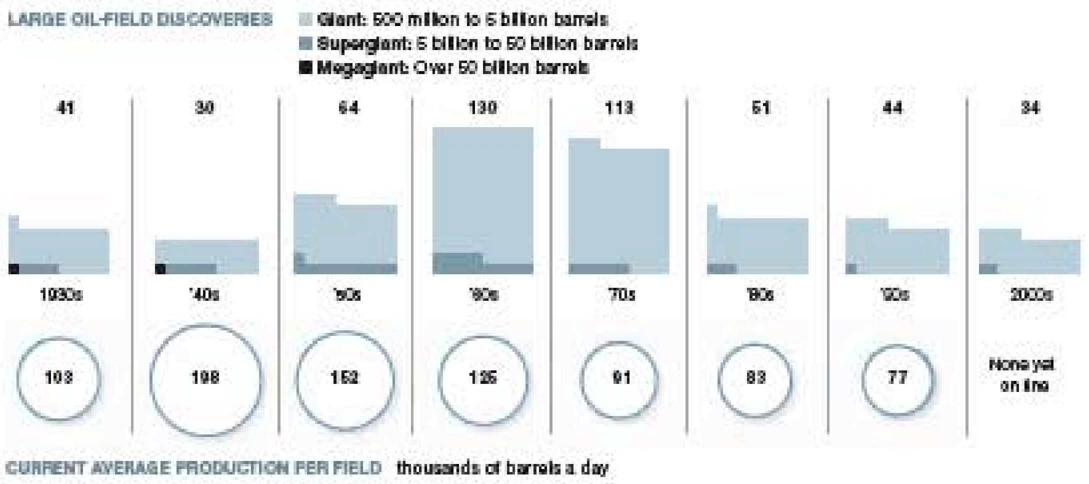
Oil Futures

After geologist M. King Hubbert correctly predicted that U.S. oil production would peak by the early 1970s, analysts adapted his mathematical formula to calculate the peak of world oil. Forecasts vary widely, but there is agreement that once oil peaks, extracting what remains will be vastly more difficult and costly.



Draining the Reliable Giants

More than a third of the world's oil comes from large fields, relatively easy to tap. But discovery of new giants, and average production for each field, has declined for decades. The largest single producer remains a Saudi Arabia megagiant found in the 1940s.



*WORLD OIL PRODUCTION INCLUDES CRUDE OIL, NATURAL GAS PLANT LIQUIDS, OTHER LIQUIDS, AND REFINERY PROCESSING GAINS OR LOSSES.

HIRAM HENRIQUEZ, NG STAFF
SOURCES: BRITISH PETROLEUM; M. K. HORN; NATIONAL PETROLEUM COUNCIL; PEAK OIL NETHERLANDS FOUNDATION

as Saudi Arabia does. And in countries such as Venezuela and Russia, foreign oil companies face restrictive laws that hamper their ability to develop new wells and other infrastructure. "The issue over the medium term is not whether there is oil to be produced," says Edward Morse, a former State Department oil expert who now analyzes markets for Lehman Brothers, "but rather how to overcome political obstacles to production."

Yet even oil optimists concede that physical limits are beginning to loom. Consider the issue of discovery rates. Oil can't be pumped from the ground until it has been found, and yet the volume discovered each year has steadily fallen since the early 1960s—despite dazzling technological advances, including computer-assisted seismic imaging that allows companies to "see" oil deep below the Earth's surface. One reason for the decline is simple mathematics: Most of the big, easily located fields—the so-called "elephants"—were discovered decades ago, and the remaining fields tend to be small. Not only are they harder to find than big fields, but they must also be found in greater numbers to produce as much oil. Last November, for example, oil executives were ecstatic over the discovery off the Brazilian coast of a field called Tupi, thought to be the biggest find in seven years. And yet with as much as eight billion barrels, Tupi is about a fifteenth the size of Saudi Arabia's legendary Ghawar, which held about 120 billion barrels at its discovery in 1948.

Smaller fields also cost more to operate than larger ones do. "The world has zillions of little fields," says Matt Simmons, a Houston investment banker who has studied the oil discovery trend. "But the problem is, you need a zillion oil rigs to get at them all." This cost disparity is one reason the industry prefers to rely on large fields—and why they supply more than a third of our daily output. Unfortunately, because most of the biggest finds were made decades ago, much of our oil is coming from mature fields that are now approaching their peaks, or are even in decline; output is plummeting in once prolific regions such as the North Sea and Alaska's North Slope.

Worldwide, output from existing fields is falling by as much as 8 percent a year, which means that oil companies must develop up to seven million barrels a day in additional capacity simply to keep current output steady—plus many more millions of barrels to meet the growth in demand of about 1.5 percent a year. And yet, with declining field sizes, rising costs, and political barriers, finding those new barrels is getting harder and harder. Many of the biggest oil companies, including Shell and Mexico's state-owned Pemex, are actually finding less oil each year than they sell.

As more and more existing fields mature,

Other options

As liquid oil becomes more costly and hard to find, researchers and entrepreneurs are searching for ways to squeeze fuel from alternative sources.

BIOFUELS
Renewable fuels made from grains, stalks, and plant oils may help offset some of our oil appetite. Already, corn-based ethanol is a popular but controversial additive to gasoline.

COAL TO OIL
Under great pressure and high temperatures, coal—a relatively abundant resource—can be liquefied into fuel. But the process remains expensive and emits large amounts of carbon dioxide.

TAR SANDS
Tar can be extracted from the sands, found in large deposits in western Canada, and turned into crude oil. The process requires huge amounts of water and energy, often from natural gas.

Bright as a bull's-eye, a tanker cruises the English Channel. As the struggle for oil intensifies, experts worry crucial infrastructure, including pipelines, rigs, and ships, could provide easy targets for terrorists.

and as global oil demand continues to grow, the deficit will widen substantially. By 2010, according to James Mulva, CEO of ConocoPhillips, nearly 40 percent of the world's daily oil output will have to come from fields that have not been tapped—or even discovered. By 2030 nearly all our oil will come from fields not currently in operation. Mulva, for one, isn't sure enough new oil can be pumped. At a conference in New York last fall, he predicted output would stall at 100 million barrels a day—the same figure Total's chief had projected. "And the reason," Mulva said, "is, where is all that going to come from?"

Whatever the ceiling turns out to be, one prediction seems secure: The era of cheap oil is behind us. If the past is any guide, the world may be in for a rough ride. In the early 1970s, during the Arab oil embargo, U.S. policymakers considered desperate measures to keep oil supplies flowing, even drawing up contingency plans to seize Middle Eastern oil fields.

Washington backed away from military action then, but such tensions are likely to reemerge. Since Saudi Arabia and other members of the Organization of Petroleum Exporting Countries control 75 percent of the world's total oil reserves, their output will peak substantially later than that of other oil regions, giving them even more power over prices and the world economy. A peak or plateau in oil production will also mean that, with rising population, the amount of gasoline, kerosene, and diesel available for each person on the planet may be significantly less than it is today. And if that's bad news for energy-intensive economies, such as the United States, it could be disastrous for the developing world, which relies on petroleum fuels not just for transport but also for cooking, lighting, and irrigation.

Husseini worries that the world has been slow to wake up to the prospect. Fuel-efficient cars and alternatives such as biofuels will compensate for some of the depleted oil supplies, but the bigger challenge may be inducing oil-hungry societies to curb demand. Any meaningful discussion about changes in our energy-intensive lifestyles, says Husseini, "is still off the table." With the inexorable arithmetic of oil depletion, it may not stay off the table much longer. j

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0 **After Oil** What fuels will drive the world economy if rising demand for oil outpaces supply? Find out more at ngm.com.

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