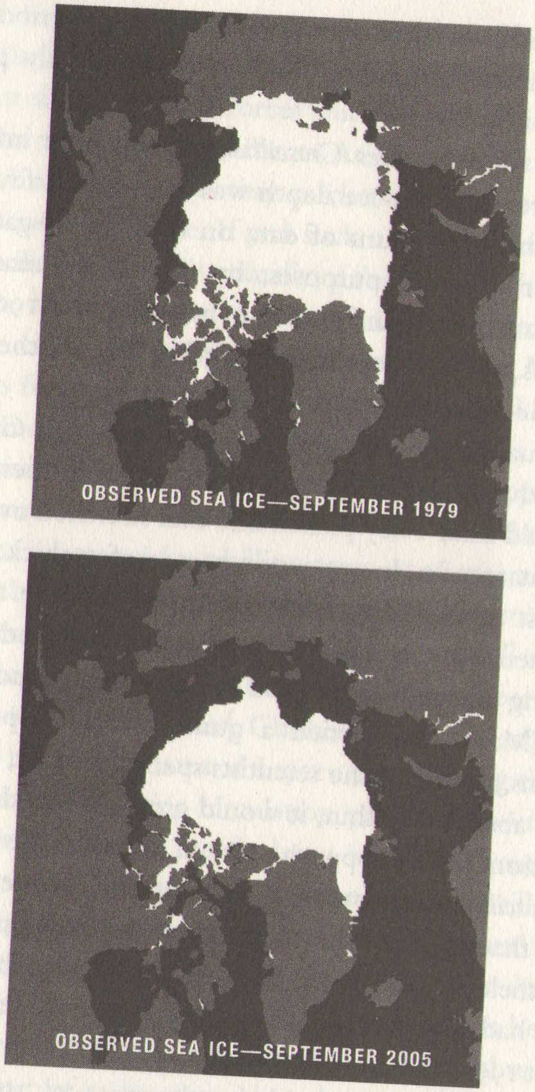


The extent of the Arctic's perennial sea ice has declined dramatically in recent years. Credit: F. Fetterer and K. Knowles, Sea Ice Index, *National Snow and Ice Data Center.*

Donald Perovich has studied sea ice for thirty years, and on a rainy day not long after I got back from Deadhorse, I went to visit him at his office in Hanover, New Hampshire. Perovich works for the Cold Regions Research and Engineering Laboratory, or CRREL (pronounced "crell"). CRREL is a division of the U.S. Army that was established in 1961 in anticipation of a very cold war. (The assumption was that if the Soviets invaded, they would probably do so from the north.) He is a tall man with black hair, very black eyebrows, and an earnest manner. His office is decorated with photographs from the *Des Groseilliers* expedition, for which he served as the lead scientist; there are shots of the ship, the tents, and, if you look closely enough, the bears. One grainy-looking photo shows someone dressed up as Santa Claus, celebrating Christmas in the darkness out on the ice. "The most fun you could ever have" was how Perovich described the expedition to me.

Perovich's particular area of expertise, in the words of his CRREL biography, is "the interaction of solar radiation with sea ice." During the *Des Groseilliers* expedition, Perovich spent most of his time monitoring conditions on the floe using a device known as a spectroradiometer. Facing toward the sun, a spectroradiometer measures incident light, and facing toward earth, it measures reflected light. By dividing the latter by the former, you get a quantity known as albedo. (The term comes from the Latin word for "whiteness.") During April and May, when conditions on the floe were relatively stable, Perovich took measurements with his spectroradiometer once a week, and during June, July, and August, when they were changing more rapidly, he took measurements every other day. The arrangement allowed him to plot exactly how the albedo varied as the snow on top of the ice turned to slush, and then the slush became puddles, and, finally, some of the puddles melted through to the water below.

An ideal white surface, which reflected all the light that shone on it, would have an albedo of one, and an ideal black surface, which absorbed all the light, would have an albedo of zero. The albedo of the earth, in aggregate, is 0.3, meaning that a little less than a third of the sunlight that strikes it is reflected back out. Anything that changes the earth's albedo changes how much energy the planet absorbs, with potentially dramatic consequences. "I like it because it deals with simple concepts, but it's important," Perovich told me.

At one point, Perovich asked me to imagine that we were looking down at the earth from a spaceship hovering above the North Pole. "It's springtime, and the ice is covered with snow, and it's really bright and white," he said. "It reflects over 80 percent of the incident sunlight. The albedo's around 0.8, 0.9. Now, let's suppose that we melt that ice away and we're left with the ocean. The albedo of the ocean is less than 0.1; it's like 0.07.

"Not only is the albedo of the snow-covered ice high; it's the highest of anything we find on earth," he went on. "And not only is the albedo of water low; it's pretty much as low as anything you can find on earth. So what you're

doing is you're replacing the best reflector with the worst reflector." The more open water that's exposed, the more solar energy goes into heating the ocean. The result is a positive feedback, similar to the one between thawing permafrost and carbon releases, only more direct. This so-called ice-albedo feedback is believed to be a major reason that the Arctic is warming so rapidly.

"As we melt that ice back, we can put more heat into the system, which means we can melt the ice back even more, which means we can put more heat into it, and, you see, it just kind of builds on itself," Perovich said. "It takes a small nudge to the climate system and amplifies it into a big change."

A few dozen miles to the east of CRREL, not far from the Maine–New Hampshire border, is a small park called the Madison Boulder Natural Area. The park's major—indeed, only—attraction is a block of granite the size of a two-story house. The Madison Boulder is thirty-seven feet wide and eighty-three feet long and weighs about ten million pounds. It was plucked out of the White Mountains and deposited in its current location eleven thousand years ago, and it illustrates how relatively minor changes to the climate system can, when amplified, yield monumental results.

Geologically speaking, we are now living in a warm period after an ice age. Over the past two million years, huge ice sheets have advanced across the Northern Hemisphere and retreated again more than twenty times. (Each long-term prospects for the Arctic. Perovich noted that the earth's climate system is so vast that it is not easily altered. "On the one hand, you think, It's the earth's climate system; it's big, it's robust. And, indeed, it has to be somewhat robust or else it would be changing all the time." On the other hand, the climate record shows that it would be a mistake to assume that change, when it comes, will come gradually. Perovich offered a comparison that he had heard from a glaciologist friend. The friend likened the climate system to a rowboat: "You can tip and then you'll just go back. You can tip it and just go back. And then you tip it and you get to the other stable state, which is upside down."

Perovich said that he also liked a regional analogy. "The way I've been thinking about it, riding my bike around here, is, You ride by all these pastures and they've got these big granite boulders in the middle of them. You've got a big boulder sitting there on this rolling hill. You can't just go by this boulder. You've got to try to push it. So you start rocking it, and you get a bunch of friends, and they start rocking it, and finally it starts moving. And then you realize, Maybe this wasn't the best idea. That's what we're doing as a society. This climate, if it starts rolling, we don't really know where it will stop."

Chapter 2

A WARMER SKY

AS A CAUSE for alarm, global warming could be said to be a 1970s idea; as pure science, however, it is much older than that. In the late 1850s, an Irish physicist named John Tyndall set out to study the absorptive properties of various gases. What he discovered led him to propose the first accurate account of how the atmosphere functions.

Tyndall, who was born in County Carlow in 1820, left school at the age of seventeen or eighteen and went to work as a surveyor for the British government. Pursuing his education at night, he subsequently became a mathematics teacher, and then, although he spoke no German, set off for Marburg to study with Robert Wilhelm Bunsen (for whom the Bunsen burner would later be named). After Tyndall received his Ph.D.—the degree was at the time just being established—he had trouble supporting himself until, in 1853, he was invited to deliver a single lecture at London's Royal Institution, then one of Britain's leading scientific centers. Based on the talk's success, Tyndall was invited to deliver another, and then another, to inhabit areas that, periodically at least, will be inundated. "There is a flood market emerging," Zevenbergen told me.

From the company's headquarters, it was about an hour's drive to Maasbommel. By the time I arrived, the sun was starting to sink, and in the afternoon light, the Meuse was glowing silver.

The amphibious homes all look alike. They are tall and narrow, with flat sides and curved metal roofs, so that standing next to one another they resemble a row of toasters. Each one is moored to a metal pole and sits on a set of hollow concrete pontoons. Assuming that all goes according to plan, when the Meuse floods, the homes will bob up and then, when the water recedes, they will gently be deposited back on land. At the point that I visited, a half a dozen families were occupying their amphibious houses. Anna van der Molen, a nurse and mother of four, gave me a tour of hers. She was enthusiastic about life on the river. "Not one day is the same," she told me. In the future, she said, she expected that people all over the world would live in floating houses, since, as she put it, "the water is coming up, and we have to live with it, not fight it—it's just not possible."

Chapter 7

BUSINESS AS USUAL

IN CLIMATE-SCIENCE CIRCLES, a future in which current emissions trends continue, unchecked, is known as "business as usual," or BAU. About five years ago, Robert Socolow, a professor of engineering at Princeton, began to think about BAU and what it implied for the fate of mankind. At that point, Socolow had recently become codirector of the Carbon Mitigation Initiative, a project funded by BP and Ford, but he still considered himself an outsider to the field of climate science. Talking to insiders, he was struck by the degree of their alarm. "I've been involved in a number of fields where there's a lay opinion and a scientific opinion," he told me when I went to visit him at his office shortly after returning from the Netherlands. "And, in most of the cases, it's the lay community that is more exercised, more anxious. If you take an extreme example, it would be nuclear power, where most of the people who work in nuclear science are relatively relaxed about very low levels of radiation. But, in the climate case, the experts—the people who work with the climate models every day, the people who do ice cores—they are *more* concerned. They're going out of their way to say, 'Wake up! This is not a good thing to be doing.' "

Socolow, who is sixty-seven, is a trim man with wire-rimmed glasses and gray, vaguely Einsteinian hair. Although by training he is a theoretical physicist—he did his doctoral research on quarks—he has spent most of his career working on problems of a more human scale, like how to prevent nuclear proliferation or construct buildings that don't leak heat. In the 1970s, Socolow helped design an energy-efficient housing development in Twin Rivers, New Jersey. At another point, he developed a system—never commercially viable—to provide air-conditioning in the summer using ice created in the winter. When Socolow became codirector of the Carbon Mitigation Initiative, he decided that the first thing he needed to do was get a handle on the scale of the carbon problem. He found that the existing literature on the subject offered almost too much information. In addition to BAU, a dozen or so alternative scenarios, known by code names like A1 and B1, had been devised; these all tended to jumble together in his mind, like so many Scrabble tiles. "I'm pretty quantitative, but I could not remember these graphs from one day to the next," he recalled. He decided to try to streamline the problem, mainly so that he could understand it.

Here in the United States, most of us begin generating CO_2 as soon as we get out of bed. Seventy percent of our electricity is generated by burning fossil fuels—a little

more than 50 percent from burning coal and another 17 percent from natural gas—so that to turn on the lights is, indirectly at least, to pump carbon dioxide into the atmosphere. Making a pot of coffee, either on an electric or a gas range, adds more emissions, as does taking a hot shower, watching the morning news on TV, and driving to work. Exactly how much CO_2 any particular action produces depends on a variety of factors. Though all fossil fuels produce carbon dioxide as an inevitable product of combustion, some fuels, most notably coal, give off more than others for each unit of power generated. A kilowatt-hour of electricity delivered from a coal-fired plant will produce slightly more than half a pound of carbon, while if the power is originating from a plant that runs on natural gas, it will produce roughly half that amount. (When measuring CO_2, it is customary to count not the full weight of the gas, but just the weight of the carbon—to convert back, multiply by 3.7.) Every gallon of gasoline that is consumed produces about five pounds of carbon, meaning that in the course of a forty-mile commute, a vehicle like a Ford Explorer or a GM Yukon throws about a dozen pounds of carbon into the air. On average, every single person in America generates twelve thousand pounds of carbon per year. (If you would like to figure out your own annual contribution to greenhouse warming, go to the Environmental Protection Agency's Web site and plug various facts about your lifestyle—what kind of car you drive, how much of your trash you recycle, and so on—into the "personal emissions calculator" provided there.) The largest single source of carbon emissions in the United States is electricity production, at 39 percent, followed by transportation, at 32 percent. In a country like France, where three quarters of the power is produced by nuclear plants, this ratio is very different, and it's different again in countries like Bhutan, where many people don't even have access to electricity and where they burn wood and animal waste to cook and heat their homes.

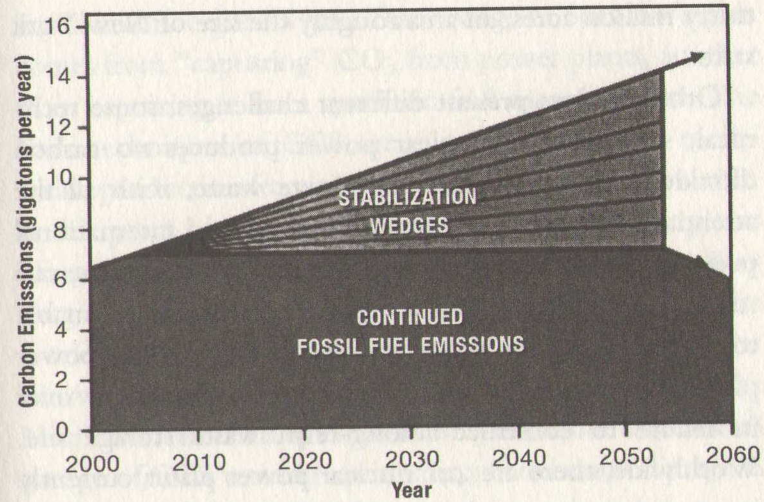
In the future, the growth of carbon emissions is likely to be determined by several forces. One is the rate of population growth; estimates of how many people will be living on the planet in 2050 range from a low of 7.4 billion to a high of 10.6 billion. Another is economic growth. A third factor is the rate at which new technologies are adopted. Particularly in the developing world, the demand for electricity is increasing rapidly; in China, for example, electricity consumption is expected to more than double by 2025. If developing nations satisfy this demand by adopting the latest, most energy-efficient technologies, then emissions will grow at one rate. (This possibility is sometimes referred to as "leapfrogging," since it would require developing countries to "leapfrog" ahead of industrialized nations.) If they satisfy demand by deploying less efficient—but often cheaper—technologies, emissions will increase at a much faster rate.

"Business as usual" refers to a whole range of projections, all of which take as their primary assumption that

emissions will continue to grow without regard to the climate. In 2005, global emissions amounted to roughly 7 billion metric tons of carbon. Under a midrange BAU projection, they will grow to 10.5 billion metric tons a year by 2029, and 14 billion tons a year by 2054. Under this same projection, CO_2 levels in the atmosphere will reach 500 parts per million by the middle of the century, and if things continue on the same trajectory, CO_2 will reach 750 parts per million, or roughly three times preindustrial levels, by the year 2100.

Looking at these figures, Socolow reached a couple of conclusions right away. The first was that to avoid exceeding CO_2 concentrations of 500 parts per million, immediate action would be needed. The second was that to meet this target, emissions growth would have to be held essentially to zero. Stabilizing CO_2 emissions would be such an enormous undertaking that Socolow decided to break the problem down into more manageable blocks, which he called "stabilization wedges." For simplicity's sake, he defined a stabilization wedge as a step that would be sufficient to prevent a billion metric tons of carbon per year from being emitted by 2054. Since annual carbon emissions now amount to 7 billion metric tons, and in fifty years are expected to reach 14 billion metric tons, seven wedges would be needed to hold emissions constant at today's level. With the help of a Princeton colleague, Stephen Pacala, Socolow eventually came up with fifteen different wedges—theoretically, at least, eight more than would be necessary. In August 2004, Socolow and Pacala published their findings in a paper in *Science* that received a great deal of attention. The paper was at once upbeat—"Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century," it declared—and deeply sobering. "There is no easy wedge" is how Socolow put it to me.

Consider wedge No. 11. This is the photovoltaic, or solar power, wedge—probably the most appealing of all the alternatives, at least in the abstract. Photovoltaic cells, which have been around for more than fifty years, are already in use in all sorts of small-scale applications and in some larger ones where the cost of connecting to the electrical grid is prohibitively high. The technology, once installed, is completely emissions-free, producing no waste products, not even water. For the purpose of their calculations, Socolow and Pacala assumed that a one-thousand-megawatt coal-fired power plant would produce about 1.5 million tons of carbon a year. (Today's coal plants actually produce some 2 million tons of carbon a year, but in the future, plants are expected to become more efficient.) To reduce emissions by a billion metric tons a year, enough solar cells would therefore have to be installed to obviate the need for nearly seven hundred thousand-megawatt coal plants. Since sunshine is not constant—it is interrupted by nightfall and by clouds—some two million megawatts of capacity would be needed. This, it



One "wedge" would prevent a billion tons of carbon a year from being emitted by 2054. Credit: S. Pacala and R. Socolow, Science, *vol. 305 (2004).*

turns out, would require PV arrays covering a surface area of five million acres—approximately the size of Connecticut.

Wedge No. 10 is wind electricity. Again, the technology has the advantage of being both safe and emissions-free. A large turbine can generate two megawatts of power, but since the wind, like sunlight, is intermittent, to get a wedge out of wind power would require at least a million two-megawatt turbines. Wind turbines are generally installed either offshore, or on hilltops or windy plains. When they are installed on land, the area around them can be used for other purposes, such as farming, but a million turbines would effectively "occupy" thirty million acres, an area roughly the size of New York state.

Other wedges present different challenges, some technical, some social. Nuclear power produces no carbon dioxide, but it generates radioactive waste, with all the attendant difficulties of storage, disposal, and international policing. More than forty years after the first commercial reactors went online, the United States has been unable to solve its nuclear waste problems, and several power plant operators have sued the federal government over its failure to construct a long-term waste storage site. Worldwide, there are 441 nuclear power plants currently in operation; one wedge could be achieved by doubling their capacity. There is also one heating and lighting wedge, which would result from cutting energy use in residential and commercial buildings by a quarter, and two automobile wedges. The first auto wedge would require that every car in the world be driven half as much as it is today, the second that it be twice as efficient. (Since the late 1980s, the fuel efficiency of passenger vehicles in the United States has actually declined, by more than 5 percent.)

Another possible option is a technology known as "carbon capture and storage," or CCS. As the name suggests, with CCS carbon dioxide is "captured" at the source—presumably a large emitter—and then injected at very high pressure into geological formations, such as depleted oil fields, underground. (At such pressure, CO_2 becomes "supercritical," a phase in which it is not quite a

liquid and not quite a gas.) One wedge in Socolow's plan comes from "capturing" CO_2 from power plants, another from capturing it from synthetic-fuel manufacturers. The basic techniques of CCS are currently employed to increase production from oil and natural gas wells. However, at this point, there are no synthetic-fuel or power plants using the process. Nor does anyone know for certain how long CO_2 injected underground will remain there. The world's longest-running CCS effort, maintained by the Norwegian oil company Statoil at a natural gas field in the North Sea, has been operational only for about a decade. A wedge of CCS would require thirty-five hundred projects on the scale of Statoil's.

In a world like today's, where there is, for the most part, no direct cost to emitting CO_2, none of Socolow's wedges are apt to be implemented; this is, of course, why they represent a departure from "business as usual." To alter the economics against carbon requires government intervention. Countries could set a strict limit on CO_2, and then let emitters buy and sell carbon "credits." (In the United States, this same basic strategy has been used successfully with sulfur dioxide in order to curb acid rain.) Another alternative is to levy a tax on carbon. Both of these options have been extensively studied by economists; using their work, Socolow estimates that the cost of emitting carbon would have to rise to around a hundred dollars a ton to provide a sufficient incentive to adopt many of the options he has proposed. Assuming that the cost were passed on to consumers, a hundred dollars a ton would raise the price of a kilowatt-hour of coal-generated electricity by about two cents, which would add roughly fifteen dollars a month to the average American family's electricity bill.

All of Socolow's calculations are based on the notion—clearly hypothetical—that steps to stabilize emissions will be taken immediately, or at least within the next few years. This assumption is key not only because we are constantly pumping more CO_2 into the atmosphere but also because we are constantly building infrastructure that, in effect, guarantees that that much additional CO_2 will be released in the future. In the United States, the average new car gets about twenty miles to the gallon; if it is driven a hundred thousand miles, it will produce more than eleven metric tons of carbon. A thousand-megawatt coal plant built today, meanwhile, is likely to last fifty years and to emit some hundred million tons of carbon during its life. The overriding message of Socolow's wedges is that the longer we wait—and the more infrastructure we build without regard to its impact on emissions—the more daunting the task of keeping CO_2 levels below 500 parts per million will become.

Indeed, even if we were to hold emissions steady for the next half century, Socolow's graphs show that much steeper cuts would be needed in the following half century to keep CO_2 concentrations from exceeding that level. Carbon dioxide is a persistent gas; it lasts for about a

century. Thus, while it is possible to increase CO_2 concentrations relatively quickly, the opposite is not the case. (The effect might be compared to driving a car equipped with an accelerator but no brakes.) After a while, I asked Socolow whether he thought that stabilizing emissions was a politically practical goal. He frowned.

"I'm always being asked, 'What can you say about the practicability of various targets?' " he told me. "I really think that's the wrong question. These things can all be done.

"What kind of issue is like this that we faced in the past?" he continued. "I think it's the kind of issue where something looked extremely difficult, and not worth it, and then people changed their minds. Take child labor. We decided we would not have child labor and goods would become more expensive. It's a changed preference system. Slavery also had some of those characteristics a hundred and fifty years ago. Some people thought it was wrong, and they made their arguments, and they didn't carry the day. And then something happened and all of a sudden it was wrong and we didn't do it anymore. And there were social costs to that. I suppose cotton was more expensive. We said, 'That's the trade-off; we don't want to do this anymore.' So we may look at this and say, 'We are tampering with the earth.' The earth is a twitchy system. It's clear from the record that it does things that we don't fully understand. And we're not going to understand them in the time period we have to make these decisions. We just know they're there. We may say, 'We just don't want to do this to ourselves.' If it's a problem like that, then asking whether it's practical or not is really not going to help very much. Whether it's practical depends on how much we give a damn."

Marty Hoffert is a professor of physics at New York University. He is big and bearish, with a wide face and silvery hair. Hoffert got his undergraduate degree in aeronautical engineering, and one of his first jobs, in the mid-1960s, was helping to develop the United States's antiballistic-missile system. During the week, Hoffert worked at a lab in New York, and sometimes he would go down to Washington to meet with Pentagon officials. Over the weekend, on occasion, he would travel back to Washington to protest Pentagon policy. Eventually, he decided that he wanted to work on something, in his words, "more productive." In this way, he became involved in climate research. He calls himself a "technological optimist," and a lot of his ideas about electric power have a wouldn't-it-be-cool, Buck Rogers sound to them. On other topics, though, Hoffert is a killjoy.

"We have to face the quantitative nature of the challenge," he told me one day over lunch at the NYU faculty club. "Right now, we're going to just burn everything up; we're going to heat the atmosphere to the temperature it was in the Cretaceous, when there were crocodiles at the poles. And then everything will collapse."

Hoffert is primarily interested in finding new, carbon-

free ways to generate energy. Currently, the technology that he is pushing is space-based solar power, or SSP. In theory, at least, SSP involves launching into space satellites equipped with massive photovoltaic arrays. Once a satellite is in orbit, the array would unfold or, according to some plans, inflate. SSP has two important advantages over conventional, land-based solar power. In the first place, there is more sunlight in space—roughly eight times as much, per unit of area—and, in the second, this sunlight is constant: satellites are not affected by clouds or by nightfall. The obstacles, meanwhile, are several. No full-scale test of SSP has ever been conducted. (In the 1970s, NASA studied the idea of sending a photovoltaic array the size of Manhattan into space, but the project never, as it were, got off the ground.) Then, there is the expense of launching satellites. Finally, once the arrays are up, there is the difficulty of getting the energy down. Hoffert imagines solving this last problem by using microwave beams of the sort used by cell phone towers, only much more tightly focused. He believes, as he put it to me, that SSP has a great deal of "long-term promise"; however, he is quick to point out that he is open to other ideas, like putting solar collectors on the moon, or using superconducting wires to transmit electricity with minimal energy loss, or generating wind power using turbines suspended in the jet stream. The important thing, he says, is not *which* new technology will work but simply that *some* new technology be found: "There's an argument that our civilization can continue to exist with the savings would amount—very roughly—to 1.3 billion tons of carbon over the next several decades. Meanwhile, the lifetime emissions just from the new coal plants China is expected to build would amount to some 25 billion tons of carbon. To put this somewhat differently, China's new plants would burn through all of Burlington's savings—past, present, and future—in less than two and a half hours.

Despair might seem the logical response to such figures. In this way, the hazard of looking objectively at global warming can be almost as great as refusing to see the problem at all. Hawkins, though, is an optimist—perhaps by professional necessity. "If you're looking at global warming, you look at what the emissions are from the large industrial and industrializing countries," he told me. "And it doesn't take very long to conclude that you can't solve this problem unless you deal with the United States and China, and if you deal with the United States and China, you can solve this problem."

"China is in the takeoff stage," he went on. "So there's an opportunity to build things there using modern technology rather than to build them using pickup technology. And that's the challenge for us: to do things that convince the Chinese that that's the better strategy for them."

Right now, he pointed out, China is industrializing according to a model set in the United States forty or fifty years ago: its factories rely on obsolete and highly inefficient motors; its electricity transmission system is antiquated; and although it is the world's primary manufacturer of compact fluorescent bulbs, it barely uses any. (Per unit of gross

domestic product, China consumes two and a half times as much energy as the United States and nearly nine times as much as Japan.) Were China to bring its factories up to date and fill even a modest amount of its projected energy demand from renewable sources, it is estimated that the number of new coal-fired plants it would need to build could be cut by nearly a third.

At this point, China is building only conventional coal-fired plants. For technical reasons, "carbon capture and storage," or CCS, isn't feasible with this type of plant. But if China were to shift to a method known as coal gasification, then—potentially at least—the CO_2 emissions from the new plants could be captured and sequestered. In that case, their carbon emissions would be substantially lower—possibly zero. It is estimated that together, coal gasification technology and carbon capture and storage would add 40 percent to the costs of a new plant. (This is an imprecise figure, since CCS has never actually been tried at a commercial power plant.) Hawkins has calculated that even assuming such a high differential cost, the added expense of carbon capture and storage for all the new coal plants expected to be built in all of the world's developing nations could be paid for through a one percent tax on the electricity bills of consumers in developed nations. "So it is affordable," he told me.

China's growth is often cited as a justification for U.S. inaction. What's the point of going to a lot of trouble if, in the end, your efforts won't make a difference? Hawkins maintains that this argument gets things completely backward. What America does, China in the long run will do too. "This isn't theory," he said. "We saw it with automobile pollution controls. We adopted those in the seventies and those modern pollution controls are being required around the world today. Sulfur dioxide scrubbers on power plants—we applied them; China is now applying them. There's a very practical reason why this works, and that is if a country like the United States embraces a cleanup technology, then the market starts to drive the price down, and other countries start to see that it is doable." Although no new coal-fired power plants have been built in the United States in recent years, many analysts expect this to change in the coming decade. Hawkins argues that American utilities should be prohibited from constructing any new plants without CCS capability.

"If we can get policies adopted that prevent the U.S. from building new coal plants that don't capture their emissions and create incentives for the Chinese to build new coal plants that will capture their emissions, then it doesn't matter if there's an international treaty or not," he said. "If we get the facts on the ground right, we've bought time."

Chapter 10

MAN IN THE ANTHROPOCENE

A FEW YEARS AGO, in an essay in *Nature*, the Nobel Prize–winning Dutch chemist Paul Crutzen coined a term. No longer, he wrote, should we think of ourselves as living in the Holocene. Instead, an epoch unlike any of those which preceded it had begun. This new age was defined by one creature—man—who had become so dominant that he was capable of altering the planet on a geological scale. Crutzen dubbed this age the "Anthropocene."

Crutzen's was not the first such neologism. Already in the 1870s, the Italian geologist Antonio Stoppani argued that human influence was ushering in a new age, which he called the "anthropozoic era." A few decades later, the Russian geochemist Vladimir Ivanovich Vernadsky proposed that the earth was entering a new stage—the "noosphere"—dominated by human thought. But while these earlier terms had had a positive slant—"I look forward with great optimism . . . We live in a transition to the noosphere," Vernadsky wrote—the connotations of the Anthropocene were distinctly cautionary. Humans had

"More by luck than by wisdom this catastrophic situation did not develop," he has written.

In the case of global warming, a much longer interval separates theory and observation. According to Crutzen, the Anthropocene began all the way back in the 1780s, the decade in which James Watt perfected his steam engine. Arrhenius undertook his pen and paper calculations in the 1890s. The retreat of the Arctic sea ice, the warming of the oceans, the rapid shrinking of the glaciers, the redistribution of species, the thawing of the permafrost—these are all new phenomena. It is only in the last five or ten years that global warming has finally emerged from the background "noise" of climate variability. And even so, the changes that can be seen lag behind the changes that have been set in motion. The warming that has been observed so far is probably only about half the amount required to bring the planet back into energy balance. This means that even if carbon dioxide were to remain stable at today's levels, temperatures would still continue to rise, glaciers to melt, and weather patterns to change for decades to come.

But CO_2 levels are *not* going to remain stable. Just to slow the growth, as Socolow and Pacala's "wedge" scheme illustrates, is a hugely ambitious undertaking, one that would require new patterns of consumption, new technologies, and new politics. Whether the threshold for "dangerous anthropogenic interference" is 450 parts per million of CO_2 or 500, or even 550 or 600, the world is rapidly approaching the point at which, for all practical

purposes, the crossing of that threshold will become impossible to prevent. To refuse to act, on the grounds that still more study is needed or that meaningful efforts are too costly or that they impose an unfair burden on industrialized nations, is not to put off the consequences, but to rush toward them. The British magazine *New Scientist* recently ran a global warming Q&A, which ended with the question, "How worried should we be?" The answer was another question: "How lucky do you feel?"

Luck and resourcefulness are, of course, essential human qualities. People are always imagining new ways to live, and then figuring out ways to remake the world to suit what they've imagined. This capacity has allowed us, collectively, to overcome any number of threats in the past, some imposed by nature and some by ourselves. It could be argued, taking this long view, that global warming will turn out to be just one more test in a sequence that already stretches from plague and pestilence to the prospect of nuclear annihilation. If, at this moment, the bind that we're in seems insoluble, once we've thought long and hard enough about it we'll find—or perhaps, float—our way clear.

But it's also possible to take an even longer view of the situation. The climate record provided by Greenland ice cores gives a highly resolved history going back more than a hundred thousand years and the Antarctic cores a history stretching back more than four hundred thousand years. What these records show, in addition to a clear correlation between CO_2 levels and global temperatures, is that the last glaciation was a time of frequent and traumatic climate swings. During that period, humans who were, genetically speaking, just like ourselves wandered the globe, producing nothing more permanent than isolated cave paintings and large piles of mastodon bones. Then, ten thousand years ago, the weather changed. As the climate settled down, so did we. People built villages, towns, and, finally, cities, along the way inventing all the basic technologies—agriculture, metallurgy, writing—that future civilizations would rely upon. These developments would not have been possible without human ingenuity, but, until the climate cooperated, ingenuity, it seems, wasn't enough.

Ice core records also show that we are steadily drawing closer to the temperature peaks of the last interglacial, when sea levels were some fifteen feet higher than they are today. Just a few degrees more and the earth will be hotter than it has been at any time since our species evolved. The feedbacks that have been identified in the climate system—the ice-albedo feedback, the water vapor feedback, the feedback between temperatures and carbon storage in the permafrost—take small changes to the system and amplify them into much larger forces. Perhaps the most unpredictable feedback of all is the human one. With six billion people on the planet, the risks are everywhere apparent. A disruption in monsoon patterns, a shift in ocean currents, a major drought—any one of these could easily produce streams of refugees numbering in the millions. As the effects of global warming become more and more difficult

to ignore, will we react by finally fashioning a global response? Or will we retreat into ever narrower and more destructive forms of self-interest? It may seem impossible to imagine that a technologically advanced society could choose, in essence, to destroy itself, but that is what we are now in the process of doing.