CHAPTER 5

WHAT DO AL GORE AND MOUNT PINATUBO HAVE IN COMMON?

The headlines have been harrowing, to say the least.

"Some experts believe that mankind is on the threshold of a new pattern of adverse global climate for which it is ill-prepared," one *New York Times* article declared. It quoted climate researchers who argued that "this climatic change poses a threat to the people of the world."

A *Newsweek* article, citing a National Academy of Sciences report, warned that climate change "would force economic and social adjustments on a worldwide scale." Worse yet, "climatologists are pessimistic that political leaders will take any positive action to compensate for the climatic change or even to allay its effects."

Who in his or her right mind wouldn't be scared of global warming?

But that's not what these scientists were talking about. These articles, published in the mid-1970s, were predicting the effects of global *cooling*.

Alarm bells had rung because the average ground temperature in

the Northern Hemisphere had fallen by .5 degrees Fahrenheit (.28 degrees Celsius) from 1945 to 1968. Furthermore, there had been a large increase in snow cover and, between 1964 and 1972, a decrease of 1.3 percent in the amount of sunshine hitting the United States. *Newsweek* reported that the temperature decline, while relatively small in absolute terms, "has taken the planet about a sixth of the way toward the Ice Age average."

The big fear was a collapse of the agricultural system. In Britain, cooling had already shortened the growing season by two weeks. "[T]he resulting famines could be catastrophic," warned the *Newsweek* article. Some scientists proposed radical warming solutions such as "melting the arctic ice cap by covering it with black soot."

These days, of course, the threat is the opposite. The earth is no longer thought to be too cool but rather too warm. And black soot, rather than saving us, is seen as a chief villain. We have cast endless streams of carbon emissions skyward, the residue of all the fossil fuels we burn to heat and cool and feed and transport and entertain ourselves.

By so doing, we have apparently turned our tender planet into a greenhouse, fashioning in the sky a chemical scrim that traps too much of the sun's warmth and prevents it from escaping back into space. The "global cooling" phase notwithstanding, the average global ground temperature over the past hundred years has risen 1.3 degrees Fahrenheit (.7 degrees Celsius), and this warming has accelerated of late.

"[W]e are now so abusing the Earth," writes James Lovelock, the renowned environmental scientist, "that it may rise and move back to the hot state it was in fifty-five million years ago, and if it does most of us, and our descendants, will die."

There is essentially a consensus among climate scientists that the earth's temperature has been rising and, increasingly, agreement that human activity has played an important role. But the ways humans affect the climate aren't always as obvious as they seem.

It is generally believed that cars and trucks and airplanes contribute an ungodly share of greenhouse gases. This has recently led many right-minded people to buy a Prius or other hybrid car. But every time a Prius owner drives to the grocery store, she may be canceling out its emission-reducing benefit, at least if she shops in the meat section.

How so? Because cows—as well as sheep and other cud-chewing animals called ruminants—are wicked polluters. Their exhalation and flatulence and belching and manure emit methane, which by one common measure is about *twenty-five times more potent* as a greenhouse gas than the carbon dioxide released by cars (and, by the way, humans). The world's ruminants are responsible for about 50 percent more greenhouse gas than the entire transportation sector.

Even the "locavore" movement, which encourages people to eat locally grown food, doesn't help in this regard. A recent study by two Carnegie Mellon researchers, Christopher Weber and H. Scott Matthews, found that buying locally produced food actually *increases* greenhouse-gas emissions. Why?

More than 80 percent of the emissions associated with food are in the production phase, and big farms are far more efficient than small farms. Transportation represents only 11 percent of food emissions, with delivery from producer to retailer representing only 4 percent. The best way to help, Weber and Matthews suggest, is to subtly change your diet. "Shifting less than one day per week's worth of calories from red meat and dairy products to chicken, fish, eggs, or a vegetable-based diet achieves more greenhouse-gas reduction than buying all locally sourced food," they write.

You could also switch from eating beef to eating kangaroo—because kangaroo farts, as fate would have it, don't contain methane. But just imagine the marketing campaign that would be needed to get Americans to take up 'roo-burgers. And think how hard the cattle ranchers would lobby Washington to ban kangaroo meat. Fortunately, a team of

Australian scientists is attacking this problem from the opposite direction, trying to replicate the digestive bacteria in kangaroos' stomachs so it can be transplanted to cows.

For a variety of reasons, global warming is a uniquely thorny problem.

First, climate scientists can't run experiments. In this regard, they are more like economists than physicists or biologists, their goal being to tease out relationships from existing data without the ability to, say, invoke a ten-year ban on cars (or cows).

Second, the science is extraordinarily complex. The impact of any single human activity—let's pretend we tripled the number of airplane flights, for instance—depends on many different factors: the gases emitted, yes, but also how the planes affect things like convection and cloud formation.

To predict global surface temperatures, one must take into account these and many other factors, including evaporation, rainfall, and, yes, animal emissions. But even the most sophisticated climate models don't do a very good job of representing such variables, and that obviously makes predicting the climatic future very difficult. By comparison, the risk models used by modern financial institutions seem quite reliable—but, as recent banking meltdowns have shown, that isn't always the case.

The imprecision inherent in climate science means we don't know with any certainty whether our current path will lead temperatures to rise two degrees or ten degrees. Nor do we really know if even a steep rise means an inconvenience or the end of civilization as we know it.

It is this specter of catastrophe, no matter how remote, that has propelled global warming to the forefront of public policy. If we were certain that warming would impose large and defined costs, the economics of the problem would come down to a simple cost-benefit

analysis. Do the future benefits from cutting emissions outweigh the costs of doing so? Or are we better off waiting to cut emissions later—or even, perhaps, polluting at will and just learning to live in a hotter world?

The economist Martin Weitzman analyzed the best available climate models and concluded the future holds a 5 percent chance of a terrible-case scenario—a rise of more than 10 degrees Celsius.

There is of course great uncertainty even in this estimate of uncertainty. So how should we place a value on this relatively small chance of worldwide catastrophe?

The economist Nicholas Stern, who prepared an encyclopedic report on global warming for the British government, suggested we spend 1.5 percent of global gross domestic product each year—that would be a $1.2 trillion bill as of today—to attack the problem.

But as most economists know, people are generally unwilling to spend a lot of money to avert a future problem, especially when its likelihood is so uncertain. One good reason for waiting is that we might have options in the future to avert the problem that cost far less than today's options.

Although economists are trained to be cold-blooded enough to sit around and calmly discuss the trade-offs involved in global catastrophe, the rest of us are a bit more excitable. And most people respond to uncertainty with more emotion—fear, blame, paralysis—than might be advisable. Uncertainty also has a nasty way of making us conjure up the very worst possibilities. (Think about the last time you heard a bump in the night outside your bedroom door.) With global warming, the worst possibilities are downright biblical: rising seas, hellish temperatures, plague upon plague, a planet in chaos.

It is understandable, therefore, that the movement to stop global warming has taken on the feel of a religion. The core belief is that humankind inherited a pristine Eden, has sinned greatly by polluting it,

and must now suffer lest we all perish in a fiery apocalypse. James Lovelock, who might be considered a high priest of this religion, writes in a confessional language that would feel at home in any liturgy: "[W]e misused energy and overpopulated the Earth . . . [I]t is much too late for sustainable development; what we need is a sustainable retreat."

A "sustainable retreat" sounds a bit like wearing a sackcloth. To citizens of the developed world in particular, this would mean consuming less, using less, driving less—and, though it's uncouth to say it aloud, learning to live with a gradual depopulation of the earth.

If the modern conservation movement has a patron saint, it is surely Al Gore, the former vice president and recent Nobel laureate. His documentary film *An Inconvenient Truth* hammered home for millions the dangers of overconsumption. He has since founded the Alliance for Climate Protection, which describes itself as "an unprecedented mass persuasion exercise." Its centerpiece is a $300 million public-service campaign called "We," which urges Americans to change their profligate ways.

Any religion, meanwhile, has its heretics, and global warming is no exception. Boris Johnson, a classically educated journalist who managed to become mayor of London, has read Lovelock—he calls him a "sacerdotal figure"—and concluded the following: "Like all the best religions, fear of climate change satisfies our need for guilt, and self-disgust, and that eternal human sense that technological progress must be punished by the gods. And the fear of climate change is like a religion in this vital sense, that it is veiled in mystery, and you can never tell whether your acts of propitiation or atonement have been in any way successful."

So while the true believers bemoan the desecration of our earthly Eden, the heretics point out that this Eden, long before humans arrived, once became so naturally thick with methane smog that it was rendered nearly lifeless. When Al Gore urges the citizenry to sacrifice

their plastic shopping bags, their air-conditioning, their extraneous travel, the agnostics grumble that human activity accounts for just 2 percent of global carbon-dioxide emissions, with the remainder generated by natural processes like plant decay.

Once you strip away the religious fervor and scientific complexity, an incredibly simple dilemma lies at the heart of global warming. Economists fondly call it an *externality*.

What's an externality? It's what happens when someone takes an action but someone else, without agreeing, pays some or all the costs of that action. An externality is an economic version of taxation without representation.

If you happen to live downwind from a fertilizer factory, the ammonium stench is an externality. When your neighbors throw a big party (and don't have the courtesy to invite you), their ruckus is an externality. Secondhand cigarette smoke is an externality, as is the stray gunshot one drug dealer meant for another that instead hit a child on the playground.

The greenhouse gases thought to be responsible for global warming are primarily externalities. When you have a bonfire in your backyard, you're not just toasting marshmallows. You're also emitting gases that, in a tiny way, help to heat the whole planet. Every time you get behind the wheel of a car, or eat a hamburger, or fly in an airplane, you are generating some by-products you're not paying for.

Imagine a fellow named Jack who lives in a lovely house—he built it himself—and comes home from work on the first warm day of summer. All he wants is to relax and cool off. So he cranks the air conditioner all the way up. Maybe he thinks for a moment about the extra dollar or two he'll pay on his next electricity bill, but the cost isn't enough to deter him.

What he *doesn't* think about is the black smoke from the power plant

that burns the coal that heats the water that turns to steam that fills the turbine that spins the generator that makes the power that cools the house that Jack built.

Nor will he think about the environmental costs associated with mining and trucking away that coal, or the associated dangers. In the United States alone, more than 100,000 coal miners died on the job over the past century, with another estimated 200,000 dying later from black lung disease. Now *those* are externalities. Thankfully, coal-mining deaths have plummeted in the United States, to a current average of about 36 per year. But if Jack happened to live in China, the local death externality would be much steeper: at least 3,000 Chinese coal miners die on the job each year.

It's hard to blame Jack for not thinking about externalities. Modern technology is so proficient that it often masks the costs associated with our consumption. There's nothing visibly dirty about the electricity that feeds Jack's air conditioner. It just magically appears, as if out of a fairy tale.

If there were only a few Jacks in the world, or even a few million, no one would care. But as the global population hurtles toward 7 billion, all those externalities add up. So who should be paying for them?

In principle, this shouldn't be such a hard problem. If we knew how much it cost humankind every time someone used a tank of gas, we could simply levy a tax of that magnitude on the driver. The tax wouldn't necessarily convince him to cancel his trip, nor should it. The point of the tax is to make sure the driver faces the full costs of his actions (or, in economist-speak, to *internalize the externality*).

The revenues raised from these taxes could then be spread out across the folks who suffer the effects of a changing climate—people living in Bangladeshi lowlands, for instance, who will be flooded if the oceans rise precipitously. If we chose exactly the right tax, the revenues could properly compensate the victims of climate change.

But when it comes to *actually* solving climate-change externalities through taxes, all we can say is good luck. Besides the obvious obstacles—like determining the right size of the tax and getting someone to collect it—there's the fact that greenhouse gases do not adhere to national boundaries. The earth's atmosphere is in constant, complex motion, which means that your emissions become mine and mine yours. Thus, *global* warming.

If, say, Australia decided overnight to eliminate its carbon emissions, that fine nation wouldn't enjoy the benefits of its costly and painful behavior unless everyone else joined in. Nor does one nation have the right to tell another what to do. The United States has in recent years sporadically attempted to lower its emissions. But when it leans on China or India to do the same, those countries can hardly be blamed for saying, *Hey, you got to free-ride your way to industrial superpowerdom, so why shouldn't we?*

When people aren't compelled to pay the full cost of their actions, they have little incentive to change their behavior. Back when the world's big cities were choked with horse manure, people didn't switch to the car because it was good for society; they switched because it was in their economic interest to do so. Today, people are being asked to change their behavior not out of self-interest but rather out of selflessness. This might make global warming seem like a hopeless problem unless—and this is what Al Gore is banking on—people are willing to put aside their self-interest and do the right thing even if it's personally costly. Gore is appealing to our altruistic selves, our externality-hating better angels.

Keep in mind that externalities aren't always as obvious as they seem.

To keep their cars from being stolen off the street, a lot of people lock the steering wheel with an anti-theft device like the Club. The

Club is big and highly visible (it even comes in neon pink). By using a Club, you are explicitly telling a potential thief that your car will be hard to steal. The *implicit* signal, meanwhile, is that your neighbor's car—the one without a Club—is a much better target. So your Club produces a negative externality for your non-Club-using neighbor in the form of a higher risk that *his* car will be stolen. The Club is a perfect exercise in self-interest.

A device called LoJack, meanwhile, is in many ways the opposite of the Club. It is a small radio transmitter, not much larger than a deck of cards, hidden somewhere in or beneath the car where a thief can't see it. But if the car is stolen, the police can remotely activate the transmitter and follow its signal straight to the car.

Unlike the Club, LoJack doesn't stop a thief from stealing your car. So why bother installing it?

For one, it helps you recover the car, and fast. When it comes to auto theft, fast is important. Once your car has been missing more than a few days, you generally don't *want* it back, because it likely will have been stripped. Even if you don't want your car to be found, your insurance company does. So a second reason to install LoJack is that insurers will discount your premium. But perhaps the best reason is that LoJack actually makes it fun to have your car stolen.

There's a certain thrill to tracking a LoJack-equipped car, as if the hounds have just been released. The police spring into action, follow the radio signal, and nab the car thief before he knows what's happening. If you're lucky, he may even have filled up the gas tank for you.

Most stolen cars end up in chop shops, clandestine mini-factories that remove the car's most valuable parts and scrap the remains. The police have a hard time rooting out these operations—until, that is, LoJack comes around. Now the police simply follow the radio signal and, often, find the chop shop.

The people who run chop shops aren't stupid, of course. Once they realize what's happening, they change their procedure. The thief, rather than driving the car straight to the shop, will leave it in a parking lot for a few days. If the car is gone when he returns, he knows it had LoJack. If not, he assumes it's safe to deliver it to the chop shop.

But the police aren't stupid either. When they find a stolen car in a parking lot, they may choose not to reclaim it right away. Instead, they watch the vehicle until the thief returns and let him lead them to the chop shop.

Just how difficult has LoJack made life for auto thieves?

For every additional percentage point of cars that have LoJack in a given city, overall thefts fall by as much as 20 percent. Since a thief can't tell which cars have LoJack, he's less willing to take a chance on any car. LoJack is relatively expensive, about $700, which means it isn't all that popular, installed in fewer than 2 percent of new cars. Even so, those cars create a rare and wonderful thing—a *positive* externality—for all the drivers who are too cheap to buy LoJack, because it protects their cars too.

That's right: not all externalities are negative. Good public schools create positive externalities because we all benefit from a society of well-educated people. (They also drive up property values.) Fruit farmers and beekeepers create positive externalities for each other: the trees provide free pollen for the bees and the bees pollinate the fruit trees, also at no charge. That's why beekeepers and fruit farmers often set up shop next to each other.

One of the unlikeliest positive externalities on record came cloaked in a natural disaster.

In 1991, an eroded, wooded mountain on the Philippine island of Luzon began to rumble and spew sulfuric ash. It turned out that beloved old Mount Pinatubo was a dormant volcano. The nearby farmers

and townspeople were reluctant to evacuate, but the geologists, seismologists, and volcanologists who rushed in ultimately persuaded most of them to leave.

Good thing, too: on June 15, Pinatubo erupted for nine furious hours. The explosions were so massive that the top of the mountain caved in on itself, forming what is known as a caldera, a huge bowl-shaped crater, its new peak 850 feet lower than the original mountaintop. Worse yet, the region was simultaneously being lashed by a typhoon. According to one account, the sky poured down "heavy rain and ash with pumice lumps the size of golf balls." Around 250 people died, mainly from collapsed roofs, and more died in the following days from mudslides. Still, thanks to the scientists' warnings, the death toll was relatively small.

Mount Pinatubo was the most powerful volcanic eruption in nearly one hundred years. Within two hours of the main blast, sulfuric ash had reached twenty-two miles into the sky. By the time it was done, Pinatubo had discharged more than 20 million tons of sulfur dioxide into the stratosphere. What effect did that have on the environment?

As it turned out, the stratospheric haze of sulfur dioxide acted like a layer of sunscreen, reducing the amount of solar radiation reaching the earth. For the next two years, as the haze was settling out, the earth cooled off by an average of nearly 1 degree Fahrenheit, or .5 degrees Celsius. A single volcanic eruption practically reversed, albeit temporarily, the cumulative global warming of the previous hundred years.

Pinatubo created some other positive externalities too. Forests around the world grew more vigorously because trees prefer their sunlight a bit diffused. And all that sulfur dioxide in the stratosphere created some of the prettiest sunsets that people had ever seen.

Of course it was the global cooling that got scientists' attention. A paper in *Science* concluded that a Pinatubo-size eruption every few years would "offset much of the anthropogenic warming expected over the next century."

Even James Lovelock conceded the point: "[W]e might be saved," he wrote, "by an unexpected event such as a series of volcanic eruptions severe enough to block out sunlight and so cool the Earth. But only losers would bet their lives on such poor odds."

True, it probably would take a loser, or at least a fool, to believe a volcano could be persuaded to spew its protective effluvia into the sky at the proper intervals. But what if some foolish people thought Pinatubo could perhaps serve as a blueprint to stop global warming? The same sort of fools who, for instance, once believed that women *didn't* have to die in childbirth, that worldwide famine was *not* foreordained? While they're at it, could they also make their solution cheap and simple?

And if so, where might such fools be found?

In a nondescript section of Bellevue, Washington, a suburb of Seattle, lies a particularly nondescript series of buildings. There's a heating-and-air-conditioning company, a boat maker, a shop that fabricates marble tiles, and another building that used to be a Harley-Davidson repair shop. This last one is a windowless, charmless structure of about twenty thousand square feet whose occupant is identified only by a sheet of paper taped to the glass door. It reads "Intellectual Ventures."

Inside is one of the most unusual laboratories in the world. There are lathes and mold makers and 3D printers and many powerful computers, of course, but there is also an insectary where mosquitoes are bred so they can be placed in an empty fish tank and, from more than a hundred feet away, assassinated by a laser. This experiment is designed to thwart malaria. The disease is spread only by certain species of female mosquito, so the laser's tracking system identifies the females by wing-beat frequency—they flap more slowly than males because they are heavier—and zaps them.

Intellectual Ventures is an invention company. The lab, in addition to all the gear, is stocked with an elite assemblage of brainpower, scientists and puzzle-solvers of every variety. They dream up processes and products and then file patent applications, more than five hundred a year. The company also acquires patents from outside inventors, ranging from Fortune 500 companies to solo geniuses toiling in basements. IV operates much like a private-equity firm, raising investment capital and paying returns when its patents are licensed. The company currently controls more than twenty thousand patents, more than all but a few dozen companies in the world. This has led to some grumbling that IV is a "patent troll," accumulating patents so it can extort money from other companies, via lawsuit if necessary. But there is little hard evidence for such claims. A more realistic assessment is that IV has created the first mass market for intellectual property.

Its ringleader is a gregarious man named Nathan, the same Nathan we met earlier, the one who hopes to enfeeble hurricanes by seeding the ocean with skirted truck tires. Yes, that apparatus is an IV invention. Internally it is known as the Salter Sink because it sinks warm surface water and was originally developed by Stephen Salter, a renowned British engineer who has been working for decades to harness the power of ocean waves.

By now it should be apparent that Nathan isn't just some weekend inventor. He is Nathan Myhrvold, the former chief technology officer at Microsoft. He co-founded IV in 2000 with Edward Jung, a biophysicist who was Microsoft's chief software architect. Myhrvold played a variety of roles at Microsoft: futurist, strategist, founder of its research lab, and whisperer-in-chief to Bill Gates. "I don't know anyone I would say is smarter than Nathan," Gates once observed.

Myhrvold, who is fifty years old, has been smart for a long time. Growing up in Seattle, he graduated from high school at fourteen and by the time he was twenty-three had earned, primarily at UCLA and

Princeton, a bachelor's degree (mathematics), two master's degrees (geophysics/space physics and mathematical economics), and a Ph.D. (mathematical physics). He then went to Cambridge University to do quantum cosmology research with Stephen Hawking.

Myhrvold recalls watching the British science-fiction TV show *Dr. Who* when he was young: "The Doctor introduces himself to someone, who says, 'Doctor? Are you some kind of scientist?' And he says, 'Sir, I am *every* kind of scientist.' And I was, like, Yes! *Yes!* That is what I want to be: *every* kind of scientist!"

He is so polymathic as to make an everyday polymath tremble with shame. In addition to his scientific interests, he is an accomplished nature photographer, chef, mountain climber, and a collector of rare books, rocket engines, antique scientific instruments, and, especially, dinosaur bones: he is co-leader of a project that has dug up more *T. rex* skeletons than anyone else in the world. He is also—and this is hardly unrelated to his hobbies—very wealthy. In 1999, when he left Microsoft, he appeared on the Forbes list of the four hundred richest Americans.

At the same time—and this is how Myhrvold has managed to *stay* wealthy—he is famously cheap. As he walks through the IV lab pointing out his favorite tools and gadgets, his greatest pride is reserved for the items he bought on eBay or at bankruptcy sales. Though Myhrvold understands complexity as well as anyone, he is a firm believer that solutions should be cheap and simple whenever possible.

He and his compatriots are currently working on, among other projects: a better internal combustion engine; a way to reduce an airplane's "skin drag" and thus increase its fuel efficiency; and a new kind of nuclear power plant that would radically improve the future of worldwide electricity production. Although many of their ideas are just that—ideas—some have already started saving lives. The company has invented a process whereby a neurosurgeon who is attempting to repair an aneurysm can send IV the patient's brain-scan data, which are fed

into a 3D printer that produces a life-size plastic model of the aneurysm. The model is shipped overnight to the surgeon, who can make a detailed plan to attack the aneurysm *before* cutting through the patient's skull.

It takes a healthy dose of collective arrogance for a small group of scientists and engineers to think they could simultaneously tackle many of the world's toughest problems. Fortunately, these folks have the requisite amount. They have already sent satellites to the moon, helped defend the United States against missile attack and, via computing advances, changed the way the world works. (Bill Gates is not only an investor in IV but an occasional inventor as well. The mosquito-zapping laser was a response to his philanthropic quest to eradicate malaria.) They have also conducted definitive scientific research in many fields, including climate science.

So it was only a matter of time before they began thinking about global warming. On the day we visited IV, Myhrvold convened roughly a dozen of his colleagues to talk about the problem and possible solutions. They sat around a long oval conference table, Myhrvold near one end.

They are a roomful of wizards, and yet without doubt Myhrvold is their Harry Potter. For the next ten or so hours, fueled by an astonishing amount of diet soda, he prodded and amplified, interjected and challenged.

Everyone in the room agrees that the earth has been getting warmer and they generally suspect that human activity has something to do with it. But they also agree that the standard global-warming rhetoric in the media and political circles is oversimplified and exaggerated. Too many accounts, Myhrvold says, suffer from "people who get on their high horse and say that that our species will be exterminated."

Does he believe this?

"Probably not."

When *An Inconvenient Truth* is mentioned, the table erupts in a sea of groans. The film's purpose, Myhrvold believes, was "to scare the crap out of people." Although Al Gore "isn't technically lying," he says, some of the nightmare scenarios Gore describes—the state of Florida disappearing under rising seas, for instance—"don't have any basis in physical reality in any reasonable time frame. No climate model shows them happening."

But the scientific community is also at fault. The current generation of climate-prediction models are, as Lowell Wood puts it, "enormously crude." Wood is a heavyset and spectacularly talkative astrophysicist in his sixties who calls to mind a sane Ignatius P. Reilly. Long ago, Wood was Myhrvold's academic mentor. (Wood himself was a protégé of the physicist Edward Teller.) Myhrvold thinks Wood is one the smartest men in the universe. Off the top of his head, Wood seems to know quite a bit about practically anything: the melt rate of the Greenland ice core (80 cubic kilometers per year); the percentage of unsanctioned Chinese power plants that went online in the previous year (about 20 percent); the number of times that metastatic cancer cells travel through the bloodstream before they land ("as many as a million").

Wood has achieved a great deal in science, on behalf of universities, private firms, and the U.S. government. It was Wood who dreamed up IV's mosquito laser assassination system—which, if it seems vaguely familiar, is because Wood also worked on the "Star Wars" missile-defense system at the Lawrence Livermore National Laboratory, from which he recently retired. (From fighting Soviet nukes to malarial mosquitoes: talk about a peace dividend!)

Today, at the IV think session, Wood is wearing a rainbow tie-dyed short-sleeve dress shirt with a matching necktie.

"The climate models are crude in space and they're crude in time," he continues. "So there's an enormous amount of natural phenomena they can't model. They can't do even giant storms like hurricanes."

There are several reasons for this, Myhrvold explains. Today's models use a grid of cells to map the earth, and those grids are too large to allow for the modeling of actual weather. Smaller and more accurate grids would require better modeling software, which would require more computing power. "We're trying to predict climate change twenty to thirty years from now," he says, "but it will take us almost the same amount of time for the computer industry to give us fast enough computers to do the job."

That said, most current climate models tend to produce similar predictions. This might lead one to reasonably conclude that climate scientists have a pretty good handle on the future.

Not so, says Wood.

"Everybody turns their knobs"—that is, adjusts the control parameters and coefficients of their models—"so they aren't the outlier, because the outlying model is going to have difficulty getting funded." In other words, the economic reality of research funding, rather than a disinterested and uncoordinated scientific consensus, leads the models to approximately match one another. It isn't that current climate models should be ignored, Wood says—but, when considering the fate of the planet, one should properly appreciate their limited nature.

As Wood, Myhrvold, and the other scientists discuss the various conventional wisdoms surrounding global warming, few, if any, survive unscathed.

The emphasis on carbon dioxide? "Misplaced," says Wood.

Why?

"Because carbon dioxide is not the major greenhouse gas. The major greenhouse gas is water vapor." But current climate models "do not know how to handle water vapor and various types of clouds. That is the elephant in the corner of this room. I hope we'll have good numbers on water vapor by 2020 or thereabouts."

Myhrvold cites a recent paper asserting that carbon dioxide may

have had little to do with recent warming. Instead, all the heavy-particulate pollution we generated in earlier decades seems to have *cooled* the atmosphere by dimming the sun. That was the global cooling that caught scientists' attention in the 1970s. The trend began to reverse when we started cleaning up our air.

"So most of the warming seen over the past few decades," Myhrvold says, "might actually be due to *good environmental stewardship*!"

Not so many years ago, schoolchildren were taught that carbon dioxide is the naturally occurring lifeblood of plants, just as oxygen is ours. Today, children are more likely to think of carbon dioxide as a poison. That's because the amount of carbon dioxide in the atmosphere has increased substantially over the past one hundred years, from about 280 parts per million to 380.

But what people don't know, the IV scientists say, is that the carbon dioxide level some 80 million years ago—back when our mammalian ancestors were evolving—was at least 1,000 parts per million. In fact, that is the concentration of carbon dioxide you regularly breathe if you work in a new energy-efficient office building, for that is the level established by the engineering group that sets standards for heating and ventilation systems.

So not only is carbon dioxide plainly not poisonous, but changes in carbon-dioxide levels don't necessarily mirror human activity. Nor does atmospheric carbon dioxide necessarily warm the earth: ice-cap evidence shows that over the past several hundred thousand years, carbon dioxide levels have risen *after* a rise in temperature, not the other way around.

Beside Myhrvold sits Ken Caldeira, a soft-spoken man with a boyish face and a halo of curly hair. He runs an ecology lab at Stanford for the Carnegie Institution. Caldeira is among the most respected climate scientists in the world, his research cited approvingly by the most fervent environmentalists. He and a co-author coined the phrase "ocean

acidification," the process by which the seas absorb so much carbon dioxide that corals and other shallow-water organisms are threatened. He also contributes research to the Intergovernmental Panel on Climate Change, which shared the 2007 Nobel Peace Prize with Al Gore for sounding the alarm on global warming. (Yes, Caldeira got a Nobel certificate.)

If you met Caldeira at a party, you would likely place him in the fervent-environmentalist camp himself. He was a philosophy major in college, for goodness' sake, and his very name—a variant of *caldera*, the craterlike rim of a volcano—aligns him with the natural world. In his youth (he is fifty-three now), he was a hard-charging environmental activist and all-around peacenik.

Caldeira is thoroughly convinced that human activity is responsible for some global warming and is more pessimistic than Myhrvold about how future climate will affect humankind. He believes "we are being incredibly foolish emitting carbon dioxide" as we currently do.

Yet his research tells him that carbon dioxide is not the right villain in this fight. For starters, as greenhouse gases go, it's not particularly efficient. "A doubling of carbon dioxide traps less than 2 percent of the outgoing radiation emitted by the earth," he says. Furthermore, atmospheric carbon dioxide is governed by the law of diminishing returns: each gigaton added to the air has less radiative impact than the previous one.

Caldeira mentions a study he undertook that considered the impact of higher carbon-dioxide levels on plant life. While plants get their water from the soil, they get their food—carbon dioxide, that is—from the air.

"Plants pay exceedingly dearly for carbon dioxide," Lowell Wood jumps in. "A plant has to raise about a hundred times as much water from the soil as it gets carbon dioxide from the air, on a molecule-lost-per-molecule-gained basis. Most plants, especially during the active

part of the growing season, are water-stressed. They bleed very seriously to get their food."

So an increase in carbon dioxide means that plants require less water to grow. And what happens to productivity?

Caldeira's study showed that doubling the amount of carbon dioxide while holding steady all other inputs—water, nutrients, and so forth—yields a 70 percent increase in plant growth, an obvious boon to agricultural productivity.

"That's why most commercial hydroponic greenhouses have supplemental carbon dioxide," Myhrvold says. "And they typically run at 1,400 parts per million."

"Twenty thousand years ago," Caldeira says, "carbon-dioxide levels were lower, sea level was lower—and trees were in a near state of asphyxiation for lack of carbon dioxide. There's nothing special about today's carbon-dioxide level, or today's sea level, or today's temperature. What damages us are *rapid* rates of change. Overall, more carbon dioxide is probably a *good* thing for the biosphere—it's just that it's increasing too fast."

The gentlemen of IV abound with further examples of global warming memes that are all wrong.

Rising sea levels, for instance, "aren't being driven primarily by glaciers melting," Wood says, no matter how useful that image may be for environmental activists. The truth is far less sexy. "It is driven mostly by water-warming—literally, the thermal expansion of ocean water as it warms up."

Sea levels *are* rising, Wood says—and have been for roughly twelve thousand years, since the end of the last ice age. The oceans are about 425 feet higher today, but the bulk of that rise occurred in the first thousand years. In the past century, the seas have risen less than eight inches.

As to the future: rather than the catastrophic thirty-foot rise some

people have predicted over the next century—good-bye, Florida!—Wood notes that the most authoritative literature on the subject suggests a rise of about one and a half feet by 2100. That's much less than the twice-daily tidal variation in most coastal locations. "So it's a little bit difficult," he says, "to understand what the purported crisis is about."

Caldeira, with something of a pained look on his face, mentions a most surprising environmental scourge: trees. Yes, trees. As much as Caldeira personally lives the green life—his Stanford office is cooled by a misting water chamber rather than air-conditioning—his research has found that planting trees in certain locations actually exacerbates warming because comparatively dark leaves absorb more incoming sunlight than, say, grassy plains, sandy deserts, or snow-covered expanses.

Then there's this little-discussed fact about global warming: while the drumbeat of doom has grown louder over the past several years, the average global temperature during that time has in fact *decreased*.

In the darkened conference room, Myhrvold cues up an overhead slide that summarizes IV's views of the current slate of proposed global-warming solutions. The slide says:

- Too little
- Too late
- Too optimistic

Too little means that typical conservation efforts simply won't make much of a difference. "If you believe there's a problem worth solving," Myhrvold says, "then these solutions won't be enough to solve it. Wind power and most other alternative energy things are cute, but they don't

scale to a sufficient degree. At this point, wind farms are a government subsidy scheme, fundamentally." What about the beloved Prius and other low-emission vehicles? "They're great," he says, "except that transportation is just not that big of a sector."

Also, coal is so cheap that trying to generate electricity without it would be economic suicide, especially for developing countries. Myhrvold argues that cap-and-trade agreements, whereby coal emissions are limited by quota and cost, can't help much, in part because it is already . . .

Too late. The half-life of atmospheric carbon dioxide is roughly one hundred years, and some of it remains in the atmosphere for thousands of years. So even if humankind immediately stopped burning all fossil fuel, the existing carbon dioxide would remain in the atmosphere for several generations. Pretend the United States (and perhaps Europe) miraculously converted overnight and became zero-carbon societies. Then pretend they persuaded China (and perhaps India) to demolish every coal-burning power plant and diesel truck. As far as atmospheric carbon dioxide is concerned, it might not matter all that much. And by the way, that zero-carbon society you were dreamily thinking about is way . . .

Too optimistic. "A lot of the things that people say would be a good thing probably aren't," Myhrvold says. As an example he points to solar power. "The problem with solar cells is that they're black, because they are designed to absorb light from the sun. But only about 12 percent gets turned into electricity, and the rest is reradiated as heat—which contributes to global warming."

Although a widespread conversion to solar power might seem appealing, the reality is tricky. The energy consumed by building the thousands of new solar plants necessary to replace coal-burning and other power plants would create a huge long-term "warming debt," as Myhrvold calls it. "Eventually, we'd have a great carbon-free energy

infrastructure but only after making emissions and global warming worse every year until we're done building out the solar plants, which could take thirty to fifty years."

This hardly means the energy problem should be dismissed. That's why IV—along with inventors all over the world—are working toward the holy grail: cheaper and cleaner forms of energy.

But from an atmospheric perspective, energy represents what might be called the input dilemma. How about the *output* dilemma? What if the greenhouse gases we've already emitted *do* produce an ecological disaster?

Myhrvold is not blind to the possibility. He has probably thought about such scenarios in greater scientific detail than any climate doomsayer: a collapse of massive ice sheets in Greenland or Antarctica; a release of huge amounts of methane caused by the melting of arctic permafrost; and, as he describes it, "a breakdown of the thermohaline circulation system in the North Atlantic, which would put an end to the Gulf Stream."

So what happens if the doomsayers turn out to be right? What if the earth *is* becoming dangerously warmer, whether because of our fossil-fuel profligacy or some natural climate cycle? We don't really want to sit back and stew in our own juices, do we?

In 1980, when Myhrvold was a grad student at Princeton, Mount St. Helens erupted back home in Washington State. Even though he was nearly three thousand miles away, Myhrvold saw a thin layer of ash accumulating on his windowsill. "It's hard not to think about volcanic dust when it's raining down on your dorm room," he says, "although to be honest, my room was messy in many other ways."

Even as a kid, Myhrvold was fascinated by geophysical phenomena—volcanoes, sunspots, and the like—and their history of affecting the

climate. The Little Ice Age intrigued him so much that he forced his family to visit the northern tip of Newfoundland, where Leif Eriksson and his Vikings reputedly made camp a thousand years earlier.

The connection between volcanoes and climate is hardly a new idea. Another polymath, Benjamin Franklin, wrote what seems to be the first scientific paper on the topic. In "Meteorological Imaginations and Conjectures," published in 1784, Franklin posited that recent volcanic eruptions in Iceland had caused a particularly harsh winter and a cool summer with "constant fog over all Europe, and [a] great part of North America." In 1815, the gargantuan eruption of Mount Tambora in Indonesia produced "The Year Without a Summer," a worldwide disaster that killed crops, prompted widespread starvation and food riots, and brought snow to New England as late as June.

As Myhrvold puts it: "All really big-ass volcanoes have some climate effects."

Volcanoes erupt all the time, all over the world, but truly "big-ass" ones are rare. If they weren't—well, we probably wouldn't be around to worry about global warming. The anthropologist Stanley Ambrose has argued that a supervolcanic explosion at Lake Toba on Sumatra, roughly seventy thousand years ago, blocked the sun so badly that it triggered an ice age that nearly wiped out *Homo sapiens*.

What distinguishes a big-ass volcano isn't just how much stuff it ejaculates, but where the ejaculate goes. The typical volcano sends sulfur dioxide into the troposphere, the atmospheric layer closest to the earth's surface. This is similar to what a coal-burning power plant does with its sulfur emissions. In both cases, the gas stays in the sky only a week or so before falling back to the ground as acid rain, generally within a few hundred miles of its origin.

But a big volcano shoots sulfur dioxide far higher, into the stratosphere. That's the layer that begins at about seven miles above the earth's surface, or six miles at the poles. Above that threshold altitude,

there is a drastic change in a variety of atmospheric phenomena. The sulfur dioxide, rather than quickly returning to the earth's surface, absorbs stratospheric water vapor and forms an aerosol cloud that circulates rapidly, blanketing most of the globe. In the stratosphere, sulfur dioxide can linger for a year or more, and will thereby affect the global climate.

That's what happened in 1991 when Mount Pinatubo erupted in the Philippines. Pinatubo made Mount St. Helens look like a hiccup; it put more sulfur dioxide into the stratosphere than any volcano since Krakatoa, more than a century earlier. In the period between those two eruptions, the state of science had progressed considerably. A worldwide cadre of scientists was on watch at Pinatubo, equipped with modern technology to capture every measurable piece of data. The atmospheric aftereffects of Pinatubo were undeniable: a decrease in ozone, more diffuse sunlight, and, yes, a sustained drop in global temperature.

Nathan Myhrvold was working at Microsoft then, but he still followed the scientific literature on geophysical phenomena. He took note of the Pinatubo climate effects and, one year later, a 900-page report from the National Academy of Sciences called *Policy Implications of Greenhouse Warming*. It included a chapter on geoengineering, which the NAS defined as "large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry."

In other words: if human activity is warming up the planet, could human ingenuity cool it down?

People have been trying to manipulate the weather forever. Just about every religion ever invented has a rain-making prayer. But secularists have stepped it up in recent decades. In the late 1940s, three General Electric scientists in Schenectady, New York, successfully seeded clouds with silver iodide. The trio included a chemist named

Bernard Vonnegut; the project's public-relations man was his younger brother Kurt, who went on to become a world-class novelist—and in his writing, he used a good bit of the far-out science he picked up in Schenectady.

The 1992 NAS report gave a credibility boost to geoengineering, which until then had largely been seen as the province of crackpots and rogue governments. Still, some of the NAS proposals would have seemed outlandish even in a Vonnegut novel. A "multiple balloon screen," for instance, was meant to deflect sunlight by launching billions of aluminized balloons into the sky. A "space mirror" scheme called for fifty-five thousand reflective sails to orbit high above the earth.

The NAS report also raised the possibility of intentionally spreading sulfur dioxide in the stratosphere. The idea was attributed to a Belarusian climate scientist named Mikhail Budyko. After Pinatubo, there was no doubt that stratospheric sulfur dioxide cooled the earth. But wouldn't it be nice to not have to rely on volcanoes to do the job?

Unfortunately, the proposals for getting sulfur dioxide into the stratosphere were complex, costly, and impractical. Loading up artillery shells, for instance, and firing them into the sky. Or launching a fleet of fighter jets with high-sulfur fuel and letting their exhaust paint the stratosphere. "It was more science fiction than science," says Myhrvold. "None of the plans made any economic or practical sense."

The other problem was that many scientists, particularly nature-friendly ones like Ken Caldeira, found the very idea abhorrent. Dump chemicals in the atmosphere to reverse the damage caused by . . . dumping chemicals in the atmosphere? It was a crazy, hair-of-the-dog scheme that seemed to violate every tenet of environmentalism. Those who saw global warming as a religious issue could hardly imagine a more grievous sacrilege.

But the best reason to reject the idea, Caldeira thought, was that it simply wouldn't work.

That was his conclusion after hearing Lowell Wood give a lecture on stratospheric sulfur dioxide at a 1998 climate conference in Aspen. But being a scientist who prefers data to dogma—even if the environmental dogma in this case lay close to his heart—Caldeira ran a climate model to test Wood's claims. "The intent," he says, "was to put an end to all the geoengineering talk."

He failed. As much as Caldeira disliked the concept, his model backed up Wood's claims that geoengineering could stabilize the climate even in the face of a large spike in atmospheric carbon dioxide, and he wrote a paper saying so. Caldeira, the most reluctant geoengineer imaginable, became a convert—willing, at least, to explore the idea.

Which is how it comes to pass that, more than ten years later, Caldeira, Wood, and Myhrvold—the onetime peacenik, the onetime weapons architect, and the onetime Viking fanboy—are huddled together in a former Harley-Davidson repair shop showing off their scheme to stop global warming.

It wasn't just the cooling potential of stratospheric sulfur dioxide that surprised Caldeira. It was how little was needed to do the job: about thirty-four gallons per minute, not much more than the amount of water that comes out of a heavy-duty garden hose.

Warming is largely a polar phenomenon, which means that high-latitude areas are four times more sensitive to climate change than the equator. By IV's estimations, 100,000 tons of sulfur dioxide per year would effectively reverse warming in the high Arctic and reduce it in much of the Northern Hemisphere.

That may sound like a lot but, relatively speaking, it is a smidge. At least 200 *million* tons of sulfur dioxide already go into the atmosphere each year, roughly 25 percent from volcanoes, 25 percent from human

sources like motor vehicles and coal-fired power plants, and the rest from other natural sources like sea spray.

So all that would be needed to produce a globe-changing effect is one-twentieth of 1 percent of current sulfur emissions, simply relocated to a higher point in the sky. How can this be? Myhrvold's answer: "Leverage!"

Leverage is the secret ingredient that distinguishes physics from, say, chemistry. Think back to the Salter Sink, IV's device for preventing hurricanes. Hurricanes are destructive because they gather up the thermal energy in the ocean's surface and convert it into physical force, a primordial act of leverage creation. The Salter Sink ruptures that process by using wave power to continually sink the warm water all through hurricane season.

"A kilogram of sulfur dioxide, emitted by a truck or a bus or a power plant into the troposphere, does much less good for you than in the stratosphere," Myhrvold says. "So you get a huge leverage, and that's a pretty cool thing. That's why Archimedes said, 'If you give me a fulcrum, I can move the world.'"*

So once you eliminate the moralism and the angst, the task of reversing global warming boils down to a straightforward engineering problem: how to get thirty-four gallons per minute of sulfur dioxide into the stratosphere?

The answer: a very long hose.

That's what IV calls this project—a "garden hose to the sky." Or, when they're feeling slightly more technical, a "stratospheric shield for climate stabilization." Considering its scientific forebear and the way it wraps the planet in a protective layer, perhaps it should be called Budyko's Blanket.

*Lowell Wood challenged Myhrvold's quote of Archimedes: "Actually, he asked for a sufficiently long *lever*." To which Myhrvold huffed: "He needed a fulcrum too!"

For anyone who loves cheap and simple solutions, things don't get much better. Here's how it works. At a base station, sulfur would be burned into sulfur dioxide and then liquefied. "The technology for doing this is well known," says Wood, "because early in the twentieth century, sulfur dioxide was the major refrigerant gas."

The hose, stretching from the base station into the stratosphere, would be about eighteen miles long but extremely light. "The diameter is just a couple inches, not some giant-ass pipe," says Myhrvold. "It's literally a specialized fire hose."

The hose would be suspended from a series of high-strength, helium-filled balloons fastened to the hose at 100- to 300-yard intervals (a "string of pearls," IV calls it), ranging in diameter from 25 feet near the ground to 100 feet near the top.

The liquefied sulfur dioxide would be sent skyward by a series of pumps, affixed to the hose at every 100 yards. These too would be relatively light, about forty-five pounds each—"smaller than the pumps in my swimming pool," Myhrvold says. There are several advantages to using many small pumps rather than one monster pump at the base station: a big ground pump would create more pressure, which, in turn, would require a far heavier hose; even if a few of the small pumps failed, the mission itself wouldn't; and using small, standardized units would keep costs down.

At the end of the hose, a cluster of nozzles would spritz the stratosphere with a fine mist of colorless liquid sulfur dioxide.

Thanks to stratospheric winds that typically reach one hundred miles per hour, the spritz would wrap around the earth in roughly ten days' time. That's how long it would take to create Budyko's Blanket. Because stratospheric air naturally spirals toward the poles, and because the arctic regions are more vulnerable to global warming, it makes sense to spray the sulfur aerosol at high latitude—with perhaps one hose in the Southern Hemisphere and another in the Northern.

Myhrvold, in his recent travels, happened upon one potentially perfect site. Along with Bill Gates and Warren Buffett, he was taking a whirlwind educational tour of various energy producers—a nuclear plant, a wind farm, and so on. One of their destinations was the Athabasca Oil Sands in northern Alberta, Canada.

Billions of barrels of petroleum can be found there, but it is heavy, mucky crude. Rather than lying in a liquid pool beneath the earth's crust, it is mixed in, like molasses, with the surface dirt. In Athabasca you don't drill for oil; you mine it, scooping up gigantic shovels of earth and then separating the oil from its waste components.

One of the most plentiful waste components is sulfur, which commands such a low price that oil companies simply stockpile it. "There were big yellow mountains of it, like a hundred meters high by a thousand meters wide!" says Myhrvold. "And they stair-step them, like a Mexican pyramid. So you could put one little pumping facility up there, and with one corner of one of those sulfur mountains, you could solve the whole global warming problem for the Northern Hemisphere."

It is interesting to think what might have happened if Myhrvold was around one hundred years ago, when New York and other cities were choking on horse manure. One wonders if, while everyone else looked at the mountains of dung and saw calamity, he might have seen opportunity.

On balance, Budyko's Blanket is a fiendishly simple plan. Considering the complexity of climate in general and how much we don't know, it probably makes sense to start small. With the fire-hose approach, you could begin with a trickle of sulfur and monitor the results. The amount could be easily dialed up or down—or, if need be, turned off. There is nothing permanent or irreversible about the process.

And it would be startlingly cheap. IV estimates the "Save the Arctic" plan could be set up in just two years at a cost of roughly $20 million, with an annual operating cost of about $10 million. If cooling the poles

alone proved insufficient, IV has drawn up a "Save the Planet" version, with five worldwide base stations instead of two, and three hoses at each site. This would put about three to five times the amount of sulfur dioxide into the stratosphere. Even so, that would still represent less than 1 percent of current worldwide sulfur emissions. IV estimates this plan could be up and running in about three years, with a startup cost of $150 million and annual operating costs of $100 million.

So Budyko's Blanket could effectively reverse global warming at a total cost of $250 million. Compared with the $1.2 trillion that Nicholas Stern proposes spending each year to attack the problem, IV's idea is, well, practically free. It would cost $50 million less to stop global warming than what Al Gore's foundation is paying just to increase public awareness about global warming.

And there lies the key to the question we asked at the beginning of this chapter: *What do Al Gore and Mount Pinatubo have in common?* The answer is that Gore and Pinatubo both suggest a way to cool the planet, albeit with methods whose cost-effectiveness are a universe apart.

This is not to dismiss the potential objections to Budyko's Blanket, which are legion. First of all, would it work?

The scientific evidence says yes. It is basically a controlled mimicry of Mount Pinatubo's eruption, whose cooling effects were exhaustively studied and remain unchallenged.

Perhaps the stoutest scientific argument in favor of the plan came from Paul Crutzen, a Dutch atmospheric scientist whose environmentalist bona fides run even deeper than Caldeira's. Crutzen won a Nobel Prize in 1995 for his research on atmospheric ozone depletion. And yet in 2006, he wrote an essay in the journal *Climatic Change* lamenting the "grossly unsuccessful" efforts to emit fewer greenhouse gases and acknowledging that an injection of sulfur in the stratosphere "is the

only option available to rapidly reduce temperature rises and counteract other climatic effects."

Crutzen's embrace of geoengineering was considered such a heresy within the climate-science community that some peers tried to stop publication of his essay. How could the man reverently known as "Dr. Ozone" possibly endorse such a scheme? Wouldn't the environmental damage outweigh the benefits?

Actually, no. Crutzen concluded that damage to the ozone would be minimal. The sulfur dioxide would eventually settle out in the polar regions but in such relatively small amounts that there, too, significant harm was unlikely. If a problem did arise, Crutzen wrote, the sulfur injection "could be stopped on short notice . . . which would allow the atmosphere to return to its prior state within a few years."

Another fundamental objection to geoengineering is that it intentionally alters the earth's natural state. To that, Myhrvold has a simple answer: "We've *already* geoengineered the earth."

In just a few centuries, we will have burned up most of the fossil fuel that took 300 million years of biological accumulation to make. Compared with that, injecting a bit of sulfur into the sky seems pretty mild. As Lowell Wood points out, sulfur isn't even the optimal chemical for a stratospheric shield. Other, less noxious-sounding materials—aluminized plastic micro beads, for instance—could make an even more efficient sunscreen. But sulfur is the most palatable choice "simply because we've got the volcano proof of feasibility," Wood says, "and along with that, a proof of harmlessness."

Wood and Myhrvold do worry that Budyko's Blanket might create an "excuse to pollute." That is, rather than buying time for us to create new energy solutions, it would lure people into complacency. But blaming geoengineering for this, Myhrvold says, is like blaming a heart surgeon for saving the life of someone who fails to exercise and eats too many french fries.

Perhaps the single best objection to the garden hose idea is that it is *too* simple and *too* cheap. As of this writing, there is no regulatory framework to prohibit anyone—a government, a private institution, even an individual—from putting sulfur dioxide in the atmosphere. (If there were, many of the world's nearly eight thousand coal-burning electricity units would be in a lot of trouble.) Still, Myhrvold admits that "it would freak people out" if someone unilaterally built the thing. But of course this depends on the individual. If it were Al Gore, he might snag a second Nobel Peace Prize. If it were Hugo Chávez, he'd probably get a prompt visit from some U.S. fighter jets.

One can also imagine the wars that might break out over who controls the dials on Budyko's Blanket. A government that depends on high oil prices might like to crank up the sulfur to keep things extra cool; others, meanwhile, might be happier with longer growing seasons.

Lowell Wood recounts a lecture he once gave, during which he mentioned that a stratospheric shield could also filter out damaging ultraviolet rays. An audience member suggested that fewer ultraviolet rays would lead to more people getting rickets.

"My response," Wood says, "was that your pharmacist can take care of that with vitamin D, and it'll be better for your overall health as well."

All the rocket scientists, climate scientists, physicists, and engineers around the IV conference table chuckle at Wood's riposte. Then someone asks if IV, with Budyko's Blanket up its sleeve, should be working toward a rickets-prevention patent. Now they laugh louder.

But it's not entirely a joke. Unlike most of the patents IV owns, Budyko's Blanket has no clear route to profits. "If you were an investor of mine," Myhrvold says, "you might ask: 'Remind me again why you're working on this?'" Indeed, many of IV's most time-consuming projects, including a variety of AIDS and malaria solutions, are substantially pro bono work.

"This is the world's greatest philanthropist sitting on the other side

of the table," Wood says with a chuckle and a nod toward Myhrvold. "Involuntarily so, but there he is."

As dismissive as Myhrvold can be toward the prevailing sentiments on global warming, he is quick to deny that he dismisses global warming itself. (If that were the case, he'd hardly spend so much of his company's resources working on solutions.) Nor is he arguing for an immediate deployment of Budyko's Blanket—but, rather, that technologies like it be researched and tested so they are ready to use if the worst climate predictions were to come true.

"It's a bit like having fire sprinklers in a building," he says. "On the one hand, you should make every effort not to have a fire. But you also need something to fall back on in case the fire occurs anyway." Just as important, he says, "it gives you breathing room to move to carbon-free energy sources."

He is also eager to get geoengineering moving forward because of what he sees as "a real head of steam" that global-warming activists have gathered in recent years.

"They are seriously proposing doing a set of things that could have enormous impact—and we think probably negative impact—on human life," he says. "They want to divert a huge amount of economic value toward immediate and precipitous anti-carbon initiatives, without thinking things through. This will have a huge drag on the world economy. There are billions of poor people who will be greatly delayed, if not entirely precluded, from attaining a First World standard of living. In this country, we can pretty much afford the luxury of doing whatever we want on the energy-and-environment front, but other parts of the world would seriously suffer."

Certain new ideas, no matter how useful, are invariably seen as repugnant. As we mentioned earlier, a market for human organs—even

though it might save tens of thousands of lives each year—is one such example.

Over time, some ideas do cross the repugnance barrier to become reality. Charging interest on loans. Selling human sperm and eggs. Profiting from a loved one's premature death. This last example of course describes how life insurance works. Today it is standard practice to wager on your own death in order to provide for your family. Until the mid-nineteenth century, life insurance was considered "a profanation," as the sociologist Viviana Zelizer writes, "which transformed the sacred event of death into a vulgar commodity."

Budyko's Blanket may simply be too repugnant a scheme to ever be given a chance. Intentional pollution? Futzing with the stratosphere? Putting the planet's weather in the hands of a few arrogant souls from Seattle? It is one thing for climate heavyweights like Paul Crutzen and Ken Caldeira to endorse such a solution. But they are mere scientists. The real heavyweights in this fight are people like Al Gore.

And what does he think of geoengineering?

"In a word," Gore says, "I think it's nuts."

If the garden-hose-to-the-sky idea doesn't fly, IV has another proposal that relies on the same science but is perhaps slightly less repugnant. As it turns out, the amount of stratospheric sulfur necessary to cool the planet is equal to the amount that just a handful of coal-burning power plants already belch out. This second plan calls for simply extending the smokestacks at a few strategically located plants. So instead of spewing their sulfur-laden smoke several hundred feet into the air, these smokestacks would release it some eighteen miles high, into the stratosphere, where it would have the same net cooling effect as the garden-hose scheme.

This plan is appealing because it simply repurposes existing pollution without adding any more. Although an eighteen-mile-high smokestack

might sound like a hard thing to build, IV has figured out how—essentially by attaching a long, skinny hot-air balloon to an existing power-plant smokestack, creating a channel that lets the hot sulfur gases rise by their own buoyancy into the stratosphere. This project is dubbed, naturally, "chimney to the sky."

And if even *that* plan is too repugnant, IV has something entirely different, a plan that is practically heavenly: a sky full of puffy white clouds.

This is the brainchild of John Latham, a British climate scientist who recently joined the IV stable of inventors. Latham is a gentle, soft-spoken man in his late sixties who is also a rather serious poet. So it caught his ear when, long ago, he stood on a mountaintop in North Wales with his eight-year-old son Mike, gazing down at a sunset, and the boy, pointing out how shiny the clouds were, called them "soggy mirrors."

Precisely!

"On balance, the role of clouds is to produce a cooling," says Latham. "If clouds didn't exist in the atmosphere, the earth would be a lot hotter than it is now."

Even man-made clouds—the contrails from a jet plane, for instance—have a cooling effect. After the September 11 terrorist attacks, all commercial flights in the United States were grounded for three days. Using data from more than four thousand weather stations across the country, scientists found that the sudden absence of contrails accounted for a subsequent rise in ground temperature of nearly 2 degrees Fahrenheit, or 1.1 degrees Celsius.

There are at least three essential ingredients for the formation of clouds: ascending air, water vapor, and solid particles known as cloud condensation nuclei. When planes fly, particles in the exhaust plume serve as the nuclei. Over landmasses, dust particles do the job. But

there are far fewer cloud-friendly nuclei over the world's oceans, Latham explains, so the clouds contain fewer droplets and are therefore less reflective. As a result, more sunlight reaches the earth's surface. The ocean, because it is dark, is particularly good at absorbing the sun's heat.

By Latham's calculations, an increase of just 10 or 12 percent of the reflectivity of oceanic clouds would cool the earth enough to counteract even a doubling of current greenhouse gas levels. His solution: use the ocean itself to make more clouds.

As it happens, the salt-rich spray from seawater creates excellent nuclei for cloud formation. All you have to do is get the spray into the air several yards above the ocean's surface. From there, it naturally lofts upward to the altitude where clouds form.

IV has considered a variety of ways to make this happen. At the moment, the favorite idea is a fleet of wind-powered fiberglass boats, designed by Stephen Salter, with underwater turbines that produce enough thrust to kick up a steady stream of spray. Because there is no engine, there is no pollution. The only ingredients—seawater and air—are of course free. The volume of spray (and, therefore, of cloud reflectivity) would be easily adjustable. Nor would the clouds reach land, where sunshine is so important to agriculture. The estimated price tag: less than $50 million for the first prototypes and then a few billion dollars for a fleet of vessels large enough to offset projected warming at least until 2050. In the annals of cheap and simple solutions to vexing problems, it is hard to think of a more elegant example than John Latham's soggy mirrors—geoengineering that the greenest green could love.

That said, Myhrvold fears that even IV's gentlest proposals will find little favor within certain environmentalist circles. To him, this doesn't compute.

"If you believe that the scary stories could be true, or even possible,

then you should also admit that relying only on reducing carbon-dioxide emissions is not a very good answer," he says. In other words: it's illogical to believe in a carbon-induced warming apocalypse *and* believe that such an apocalypse can be averted simply by curtailing new carbon emissions. "The scary scenarios could occur even if we make herculean efforts to reduce our emissions, in which case the only real answer is geoengineering."

Al Gore, meanwhile, counters with his own logic. "If we don't know enough to stop putting 70 million tons of global-warming pollution into the atmosphere every day," he says, "how in God's name can we know enough to precisely counteract that?"

But if you think like a cold-blooded economist instead of a warm-hearted humanist, Gore's reasoning doesn't track. It's not that we don't *know how* to stop polluting the atmosphere. We don't *want* to stop, or aren't willing to pay the price.

Most pollution, remember, is a negative externality of our consumption. As hard as engineering or physics may be, getting human beings to change their behavior is probably harder. At present, the rewards for limiting consumption are weak, as are the penalties for overconsuming. Gore and other environmentalists are pleading for humankind to consume less and therefore pollute less, and that is a noble invitation. But as incentives go, it's not a very strong one.

And *collective* behavior change, as beguiling as that may sound, can be maddeningly elusive. Just ask Ignatz Semmelweis.

Back in 1847, when he solved the mystery of puerperal fever, Semmelweis was hailed as a hero—wasn't he?

Quite the opposite. Yes, the death rate in Vienna General's maternity ward plummeted when he ordered doctors to wash their hands after performing autopsies. Elsewhere, however, doctors ignored

Semmelweis's findings. They even ridiculed him. Surely, they reasoned, such a ravaging illness could not be prevented simply by washing one's hands! Moreover, doctors of that era—not the humblest lot—couldn't accept the idea that they were the root of the trouble.

Semmelweis grew frustrated, and in time his frustration curdled into vitriol. He cast himself as a scorned messiah, labeling every critic of his theory a murderer of women and babies. His arguments were often nonsensical; his personal behavior became odd, marked by lewdness and sexual impropriety. In retrospect, it's safe to say that Ignatz Semmelweis was going mad. At the age of forty-seven, he was tricked into entering a sanitarium. He tried to escape, was forcibly restrained, and died within two weeks, his reputation shattered.

But that doesn't mean he wasn't right. Semmelweis was posthumously vindicated by Louis Pasteur's research in germ theory, after which it became standard practice for doctors to scrupulously clean their hands before treating patients.

So do contemporary doctors follow Semmelweis's orders?

A raft of recent studies have shown that hospital personnel wash or disinfect their hands in *fewer than half* the instances they should. And doctors are the worst offenders, more lax than either nurses or aides.

This failure seems puzzling. In the modern world, we tend to believe that dangerous behaviors are best solved by education. That is the thinking behind nearly every public-awareness campaign ever undertaken, from global warming to AIDS prevention to drunk driving. And doctors are the most educated people in the hospital.

In a 1999 report called "To Err Is Human," the Institute of Medicine estimated that between 44,000 and 98,000 Americans die each year because of preventable hospital errors—more than deaths from motor-vehicle crashes or breast cancer—and that one of the leading errors is wound infection. The best medicine for stopping infections? Getting doctors to wash their hands more frequently.

In the wake of this report, hospitals all over the country hustled to fix the problem. Even a world-class hospital like Cedars-Sinai Medical Center in Los Angeles found it needed improvement, with a hand-hygiene rate of just 65 percent. Its senior administrators formed a committee to identify the reasons for this failure.

For one, they acknowledged, doctors are incredibly busy, and time spent washing hands is time not spent treating patients. Craig Feied, our emergency-room revolutionary from Washington, estimates that he often interacted with more than one hundred patients per shift. "If I ran to wash my hands every time I touched a patient, following the protocol, I'd spend nearly half my time just standing over a sink."

Sinks, furthermore, aren't always as accessible as they should be and, in patient rooms especially, they are sometimes barricaded by equipment or furniture. Cedars-Sinai, like a lot of other hospitals, had wall-mounted Purell dispensers for handy disinfection, but these too were often ignored.

Doctors' hand-washing failures also seem to have psychological components. The first might be (generously) called a perception deficit. During a five-month study in the intensive-care unit of an Australian children's hospital, doctors were asked to track their own hand-washing frequency. Their self-reported rate? Seventy-three percent. Not perfect, but not so terrible either.

Unbeknownst to these doctors, however, their nurses were spying on them, and recorded the docs' actual hand-hygiene rate: a paltry 9 percent.

Paul Silka, an emergency-room doctor at Cedars-Sinai who also served as the hospital's chief of staff, points to a second psychological factor: arrogance. "The ego can kick in after you've been in practice a while," he explains. "You say: 'Hey, *I* couldn't be carrying the bad bugs. It's the *other* hospital personnel.'"

Silka and the other administrators at Cedars-Sinai set out to change

their colleagues' behavior. They tried all sorts of incentives: gentle cajoling via posters and e-mail messages; greeting doctors every morning with a bottle of Purell; establishing a Hand Hygiene Safety Posse that roamed the wards, giving a $10 Starbucks card to doctors who were seen properly washing their hands. You might think the highest earners in a hospital would be immune to a $10 incentive. "But none of them turned down the card," Silka says.

After several weeks, the hand-hygiene rate at Cedars-Sinai had increased but not nearly enough. This news was delivered by Rekha Murthy, the hospital's epidemiologist, during a lunch meeting of the Chief of Staff Advisory Committee. There were roughly twenty members, most of them top doctors in the hospital. They were openly discouraged by the report. When lunch was over, Murthy handed each of them an agar plate—a sterile petri dish loaded with a spongy layer of agar. "I would love to culture your hand," she told them.

They pressed their palms into the plates, which Murthy sent to the lab. The resulting images, Silka recalls, "were disgusting and striking, with gobs of colonies of bacteria."

Here were the most important people in the hospital, telling everyone else how to change their behavior, and yet even their own hands weren't clean! (And, most disturbingly, this took place at a lunch meeting.)

It may have been tempting to sweep this information under the rug. Instead, the administration decided to harness the disgusting power of the bacteria-laden handprints by installing one of them as the screen saver on computers throughout the hospital. For doctors—lifesavers by training, and by oath—this grisly warning proved more powerful than any other incentive. Hand-hygiene compliance at Cedars-Sinai promptly shot up to nearly 100 percent.

As word got around, other hospitals began copying the screen-saver solution. And why not? It was cheap, simple, and effective.

A happy ending, right?

Yes, but . . . think about it for a moment. Why did it take so much effort to persuade doctors to do what they have known to do since the age of Semmelweis? Why was it so hard to change their behavior when the price of compliance (a simple hand-wash) is so low and the potential cost of failure (the loss of a human life) so high?

Once again, as with pollution, the answer has to do with externalities.

When a doctor fails to wash his hands, his own life isn't the one that is primarily endangered. It is the next patient he treats, the one with the open wound or the compromised immune system. The dangerous bacteria that patient receives are a negative externality of the doctor's actions—just as pollution is a negative externality of anyone who drives a car, jacks up the air conditioner, or sends coal exhaust up a smokestack. The polluter has insufficient incentive to not pollute, and the doctor has insufficient incentive to wash his hands.

This is what makes the science of behavior change so difficult.

So instead of collectively wringing our filthy hands about behavior that is so hard to change, what if we can come up with engineering or design or incentive solutions that supersede the need for such change?

That's what Intellectual Ventures has in mind for global warming, and that is what public-health officials have finally embraced to cut down on hospital-acquired infections. Among the best solutions: using disposable blood-pressure cuffs on incoming patients; infusing hospital equipment with silver ion particles to create an antimicrobial shield; and forbidding doctors to wear neckties because, as the U.K. Department of Health has noted, they "are rarely laundered," "perform no beneficial function in patient care," and "have been shown to be colonized by pathogens."

That's why Craig Feied has worn bow ties for years. He has also helped develop a virtual-reality interface that allows a gowned and

gloved-up surgeon to scroll through X-rays on a computer without actually touching it—because computer keyboards and mice tend to collect pathogens at least as effectively as a doctor's necktie. And the next time you find yourself in a hospital room, don't pick up the TV remote control until you've disinfected the daylights out of it.

Perhaps it's not so surprising that it's hard to change people's behavior when someone else stands to reap most of the benefit. But surely we are capable of behavior change when our own welfare is at stake, yes?

Sadly, no. If we were, every diet would always work (and there would be no need for diets in the first place). If we were, most smokers would be ex-smokers. If we were, no one who ever took a sex-ed class would be party to an unwanted pregnancy. But knowing and doing are two different things, especially when pleasure is involved.

Consider the high rate of HIV and AIDS in Africa. For years, public-health officials from around the world have been fighting this problem. They have preached all sorts of behavior change—using condoms, limiting the number of sexual partners, and so on. Recently, however, a French researcher named Bertran Auvert ran a medical trial in South Africa and came upon findings so encouraging that the trial was halted so the new preventive measure could be applied at once.

What was this magical treatment?

Circumcision. For reasons Auvert and other scientists do not fully understand, circumcision was found to reduce the risk of HIV transmission by as much as 60 percent in heterosexual men. Subsequent studies in Kenya and Uganda corroborated Auvert's results.

All over Africa, foreskins began to fall. "People are used to policies that target behaviors," said one South African health official, "but circumcision is a surgical intervention—it's cold, hard steel."

The decision to undergo an adult circumcision is obviously a deeply personal one. We would hardly presume to counsel anyone in either direction. But for those who *do* choose circumcision, a simple word of advice: before the doctor gets anywhere near you, please make sure he washes his hands.