Carbon’s New Math

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

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

Once we started burning coal and gas and oil to power our lives, that 280 number started to rise. When we began measuring in the late 1950s, it had already reached the 315 level. Now it’s at 380, and increasing by roughly two parts per million annually. That doesn’t sound like very much, but it turns out that the extra heat that CO₂ traps, a couple of watts per square meter of the Earth’s surface,
Global warming presents the greatest test humans have yet faced. New technologies and new habits offer some promise, but only if we move quickly and decisively.

enough to warm the planet considerably. We’ve raised the temperature more than a degree Fahrenheit already. It’s impossible to precisely predict the consequences of any further increase in CO₂ in the atmosphere. But the warming we’ve seen so far has started almost everything frozen on Earth to melting; it has changed seasons and rainfall patterns; it’s set the sea to rising.

No matter what we do now, that warming will increase some—there’s a lag time before the heat fully plays out in the atmosphere. That is, we can’t stop global warming. Our task is less inspiring: to contain the damage, to keep things from getting out of control. And even that is not easy. For one thing, until recently there’s been no clear data suggesting the point where catastrophe looms. Now we’re getting a better picture—the past couple of years have seen a series of reports indicating that 450 parts per million CO₂ is a threshold we’d be wise to respect. Beyond that point, scientists believe future centuries will likely face the melting of the Greenland and West Antarctic ice sheets and a subsequent rise in sea level of giant proportion. Four hundred fifty parts per million is still a best guess (and it doesn’t include the witches’ brew of other, lesser, greenhouse gases like methane and nitrous oxide). But it will serve as a target of sorts for the world to aim at. A target that’s moving, fast. If concentrations keep increasing by two parts per million per year, we’re only three and a half decades away.

So the math isn’t complicated—but that doesn’t mean it isn’t intimidating. So far only the Europeans and Japanese have even begun to trim their carbon emissions, and they may not meet their own modest targets. Meanwhile, U.S. carbon emissions, a quarter of the world’s total, continue to rise steadily—earlier this year we told the United Nations we’d be producing 20 percent more carbon in 2020 than we had in 2000. China and India are suddenly starting to produce huge quantities of CO₂ as well. On a per capita basis (which is really the only sensible way to think about the morality of the situation), they aren’t anywhere close to American figures, but their populations are so huge, and their economic growth so rapid, that they make the prospect of a worldwide decline in emissions seem much more daunting. The Chinese are currently building a coal-fired power plant every week or so. That’s a lot of carbon.

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

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

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

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

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

Scientists warn that current CO₂ emissions should be cut by at least half over the next 50 years to avert a future global warming disaster. Princeton researchers Robert Socolow and Stephen Pacala have described 15 "stabilization wedges" (far right) to realize that goal using existing technologies. Each carbon-cutting wedge would reduce emissions by a billion metric tons a year by 2057. Adopting any combination of these strategies that equals 12 wedges could lower emissions 50 percent.

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

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

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

**CARBON CAPTURE AND STORAGE**
- Introduce systems to capture CO₂ and store it underground at 800 large coal-fired plants or 1,600 natural-gas-fired plants.
- Use capture systems at coal-derived hydrogen plants producing fuel for a billion cars.
- Use capture systems in coal-derived synthetic fuel plants producing 30 million barrels a day.

**LOW-CARBON FUELS**
- Replace 1,400 large coal-fired power plants with natural-gas-fired plants.
- Displace coal by increasing production of nuclear power to three times today’s capacity.

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

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