CHAPTER 14
The Predicament

WHAT WOULD IT TAKE TO FIX GLOBAL WARMING?

The global warming problem isn't going to be solved tomorrow, next week, or next year: we're in this one for the long haul, and there clearly isn't any single solution. A multifaceted approach could include governments agreeing to and enforcing targets, innovators developing low-carbon energy sources and improving efficiency, and individuals and organizations doing their best to reduce their own carbon footprints (and motivating others to do so). These three approaches are explored in the following chapters, but first, let's take a look at the problem—and what we need to do to solve it—as a whole.

Looking at the global-scale challenge before us, the most obvious worry is the sheer momentum that needs to be overcome. We've already added a great deal of greenhouse gas to the atmosphere, and we're adding more each year than the year before. Even if we can lower emissions, there's enough inertia in the physical drivers of climate to keep us rolling toward an ever-warmer future for many years to come. In short, then, if we're to reduce the chance of long-term climate trouble, we need to take real action on multiple levels sooner rather than later.

Understanding the goals

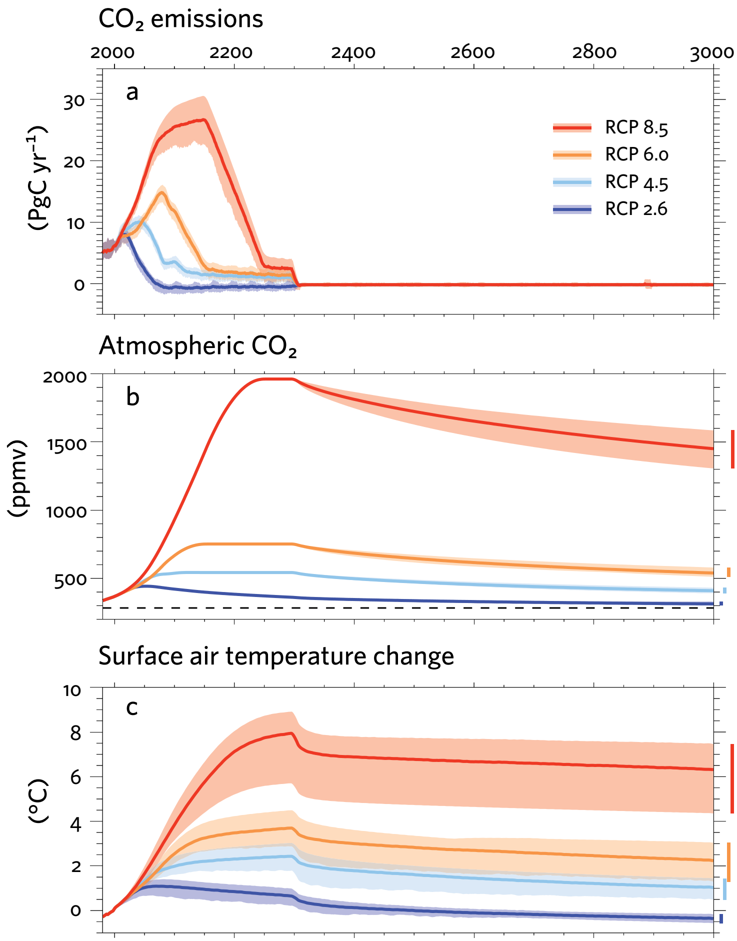
In terms of reducing emissions to mitigate climate change, at least three types of goals are commonly discussed by policymakers and activists working in the field of climate change.

- **Stabilizing emissions.** Making sure that each year we emit no more than the year before, and ideally less.
- **Stabilizing concentrations.** Reducing emissions enough so that the amount of greenhouse gas in the atmosphere levels off at a target and stays there (or falls back down).
- **Stabilizing temperature.** Keeping the atmosphere from warming beyond a certain point.

Obviously, these three types of goals overlap. Our emissions build up in the atmosphere, changing the concentration of greenhouse gases, which in turn alters the temperature. The graphic at right shows how these three quantities evolve along the four pathways outlined in the latest IPCC report.

Packed inside this complex-looking graphic are a few distinct messages. First off, you can see that simply leveling off emissions won't be enough to stabilize concentration and therefore temperature, because elevated levels of carbon dioxide persist in the atmosphere for many years, even centuries. After all, if water's flowing into a bathtub faster than it can drain out, you need to *reduce* the flow—not just keep it constant. And even though stabilizing global emissions would be an enormous short-term achievement, we actually need to go much further and make significant *cuts* in emissions (the "downhill" side of the four emission curves shown in the top graphic) in order to keep the world from getting significantly hotter. As we'll see later, some countries have already managed to stabilize or reduce their emissions, but globally, there's a long way to go.

Moreover, there's the **time-lag** factor to consider. If warmer temperatures bring lasting changes to the Earth system, such as the loss of major ice sheets or the release of trapped methane, then substantial climate change could be locked in for centuries to come. As the graphic shows, even if we do manage to make significant emissions cuts, it will take decades for the concentration to begin leveling off and more than a century for the temperature to stop rising—that is, unless we can implement major year-over-year reductions in global emissions starting in the 2020s and continuing thereafter (the RCP2.6 scenario).



Earth system models of intermediate complexity (EMICs) are detailed enough to capture important processes, yet simplified enough so that very long-term simulations are feasible. This graphic shows how EMIC runs carried out in support of the 2013 IPCC assessment depict three key variables over the next thousand years—carbon dioxide emissions (top), CO_2 concentrations (middle), and global surface air temperature (bottom)—for each of the four IPCC emission pathways, or RCPs. Temperature change is relative to the period 1986–2005. To determine the total temperature change since preindustrial times (1850–1900), add roughly 0.6°C (1.1°F). See p. 16 for RCP details. Shaded bands show the range for each model ensemble, with each solid line denoting an ensemble mean. The abrupt temperature drop in 2300 is a result of eliminating all CO_2 emissions and non-CO_2 forcing factors. (IPCC)

To help simplify this picture, many researchers and policy makers have begun focusing on the **cumulative carbon** that's put into the atmosphere, rather than the year-by-year emissions. There's quite a wide range of estimates on how much total carbon we can afford to emit, but surprisingly, the ultimate temperature jump doesn't appear to hinge on the timing of emissions—just on the total amount. As such, no matter what temperature rise we're prepared to risk, the longer we wait to start cutting emissions, the more stringent the later cuts will need to be.

In its 2013 assessment, the IPCC considered this type of global carbon budgeting in new detail. The panel tallied how much CO_2 we could burn and still keep the temperature rise at no more than 2°C over preindustrial levels (using the average temperature in the period 1861–1880 as the preindustrial benchmark). If we agree that a two-out-of-three chance (66%) of staying within the 2°C margin is an acceptable margin of risk, then humanity's total carbon emissions from CO_2—past, present, and future—must stay below about 1000 metric gigatons (and that's not even considering the added impact of other greenhouse gases, such as methane). However, as of 2011, we've already emitted roughly 515 metric gigatons of carbon in the form of CO_2. Thus, to retain that desired 66% chance of not exceeding the 2°C target, we'd need to keep our entire future emissions less than our total past ones—which would be truly a Herculean task, given the relentless upward trend so far.

Selecting a target

The IPCC's use of the 2°C benchmark raises a critical question: how much global warming would be truly dangerous? There's no single bright line that separates mild effects from serious threats, but researchers have done their best to identify points beyond which particular risks become more likely. Many studies suggest that a rise of 3°C (5.4°F) relative to preindustrial levels would be well past the edge of the comfort zone. It may be enough to trigger unstoppable melting of the Greenland ice sheet, for example, or a net drop in world food production. Any further warming could jeopardize parts of the Antarctic ice sheet and cause other dire consequences.

With these and many other factors in mind, the most commonly cited temperature target for climate stabilization is the familiar **2°C (3.6°F)** benchmark above preindustrial levels, or around 1.2°C (2.0°F) above the global temperature of the early 2010s. This value was agreed to by the European Union as far back as 1996. It's also shared by many researchers and activist groups. As German analyst Oliver Geden noted in 2013, "Despite the many uncertainties inherent in it, 2°C has been able to prevail as the global temperature threshold. It functions as the central point of reference in the climate debate, and as the one concrete objective on which key actors from policy, media, and research have been able to reach at least interim agreement."

Some parties have called for more ambitious goals. At the Copenhagen meeting in 2009, a group of more than 40 small island nations and like-minded activists pushed for a target of **1.5°C (2.7°F)**. The idea was to minimize the risk that rising sea levels could swamp low-lying countries. The accord that emerged from Copenhagen included the standard 2.0°C target, but it also called for an assessment (under way in the mid-2010s) to determine whether or not to strengthen the target to 1.5°C.

Even more stringent was the goal proposed by the grassroots effort **350.org**, which has organized more than 10,000 demonstrations and events since 2009. The group's name comes from its central goal of bringing global CO_2 concentrations down from their current values of around 400 ppm to **350 ppm**, which is deemed by the group (and by NASA's James Hansen, among others) to be the value consistent with a reasonable shot of keeping the eventual global temperature rise to 1.5°C. Reaching the 350 target is "a non-negotiable demand from the planet itself," says author and 350.org founder Bill McKibben. Even if it were ultimately unachievable, the 350-ppm goal serves as an icon of urgency and the need for action, as well as a reminder that we're already on a path toward much higher concentrations.

2°C—or beyond?

Given physical and political realities, the world may not be able to avoid 1.5°C at this point. After all, as we saw back in chapter 1, Earth has warmed by more than 0.8°C (1.4°F) thus far, and there's an additional 0.5°C (0.9°F) to come as the planet adjusts to emissions already in the atmosphere. Together, these bring us uncomfortably close to 1.5°C. Scenarios that would likely keep us below this target are so sparse (and perhaps so implausible now) that none have been examined thoroughly by multiple models, as the IPCC noted in its 2014 report on mitigation.

At least in theory, we might still have a chance of staying below 2°C, but the odds of reaching that goal are diminishing quickly. Global emissions have soared more than 50% since the **UN Framework Convention on Climate Change (UNFCCC)** process began in 1990, with increases of several percent notched in every year outside of the occasional minor drop during recessions (see below). Every so often there's a glimmer of hope, such as the news from the Netherlands Environmental Assessment Agency that global emissions in 2012 increased by a relatively modest 1.1%, even as the global economy grew by more than double that percentage. Experts took this as a sign that economic growth isn't necessarily yoked to emissions growth, as so many have argued in the past. Even so, the split between developed and developing economies that ultimately hobbled the Kyoto Protocol remains a huge obstacle, one that's proven extremely difficult to address (as evidenced by the schisms on display during the 2013 UN climate meetings in Warsaw). Given the labored pace of UN negotiations over the last few years, it's possible that any binding agreement to reduce emissions wouldn't take effect until well into the 2020s, if even then. Some analysts have already begun to explore the implications of revising or even abandoning the 2°C target should developments over the next few years prove it to be out of reach. Such a move would be tremendously risky, since it could lead to cynicism and fatalism about the global effort to keep greenhouse gases in check. This puts even more emphasis on the need for national, regional, and local initiatives—plus action by companies and individuals—to help stem the tide of emission growth.

All this effort could be for naught unless the act of burning carbon carries a price tag that's valid in some form or fashion around the entire world. Otherwise, there's a major risk of what's been dubbed **carbon leakage**. Should one nation reduce its emissions voluntarily, the supply of unburned fuel will rise and its price on the open market will go down, all else being equal. In turn, that would open the door for some other entity to purchase and burn the fuel that was conserved in the name of climate. For example, the United States moved from coal to natural gas in the early 2010s, which helped the nation to achieve unexpected emission reductions—but much of that coal ended up being burned elsewhere, as U.S. coal exports jumped to a record high.

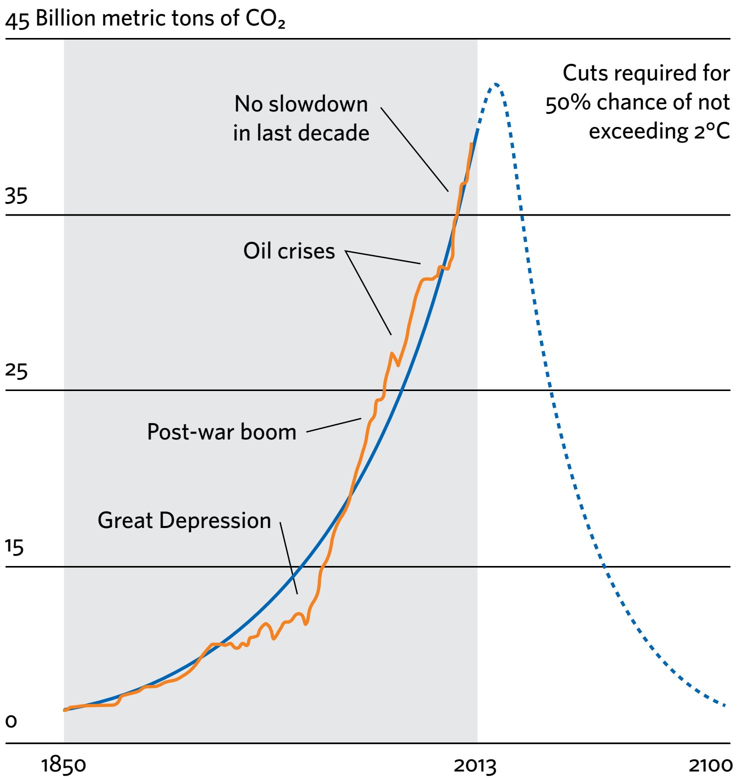
A similarly thorny problem is **rebound effects**, which occur when the benefits of increased efficiency are directed into activities that burn more energy. Paradoxically, the result can sometimes be *more* carbon emission rather than less. For example, a family might decide to save money on utilities by insulating their home, but then spend that newfound cash on an extra plane trip each year—thus expanding their carbon footprint even more than they'd reduced it by sealing their drafty house.

This isn't to denigrate the importance of personal as well as national emission reductions, both of which are absolutely crucial in any effort to keep our planet from overheating. It's simply to recognize that our global economic system is hard-wired to consume whatever energy is available on the free market. If the cost to our global commons isn't somehow factored in, then achieving major emissions cuts will be a truly daunting effort. The true scope of this challenge was highlighted in 2012 through a hugely popular *Rolling Stone* article by Bill McKibben entitled "Do the Math," accompanied by a standing-room-only lecture tour. McKibben pointed out that, according to the Carbon Tracker Initiative, the world's proven reserves of fossil fuel in 2011—the oil, gas, and coal held by the planet's private and state-owned energy firms—represent a staggering 2795 billion metric tons of carbon. That's more than five times the total that can be burned from this point onward while still retaining a two-thirds chance of meeting the 2°C target, on the basis of the IPCC calculations noted above. It's difficult to imagine the world's big energy firms, which are among the largest and most profitable companies on the planet, voluntarily writing off more than 80% of their holdings (trillions of dollars' worth) and leaving them in the ground. Yet if even half of those proven reserves are burned, the chance of avoiding what the IPCC terms "dangerous interference with the climate system" will become slender indeed.

Overall, this looks like quite the discouraging picture. However, we have little choice but to face the predicament head on. That includes working in a variety of ways to ensure that any eventual multifaceted solution can benefit as much as possible from progress achieved on many fronts. As we'll see in the next two chapters, policy experts are looking at new ways to approach the carbon problem from an international standpoint, and plenty of new technologies are on tap to help reduce emissions substantially wherever there's an incentive for doing so. See the subsequent section (chapters 17–21) for tips on what you can do on a personal level.

When one considers greenhouse gases other than CO_2, the picture brightens just a bit. Most of those gases are less prevalent and shorter-lived than CO_2, but far more powerful. Together, they account for more than 30% of the global warming impact from gases we're adding to the atmosphere each year. The good news is that some of them could be reduced more easily and affordably than CO_2, and political agreements that can smooth the way are already in place, such as the Montreal Protocol and regional air pollution laws. In the EU, for instance, the nitrogen oxides emitted from

"The choice we face is between taking unimaginable risks with the planet and leaving vastly valuable fossil fuels in the ground." —*Mike Berners-Lee and Duncan Clark, The Burning Question*



CO_2 emissions since 1850 (orange), exponential growth (blue), and cuts to hit climate target (dashed). (Duncan Clark/*The Burning Question*)

diesel-powered cars and light trucks sold after 2009 were cut by roughly 20%; they're being reduced more than 50% beyond that new limit starting in 2014. There is some hope among policy experts and climate scientists that a two-step approach—cutting the emission rates of non-CO_2 greenhouse gases right away, plus reducing CO_2 over a somewhat longer time frame—might prove fruitful. New approaches to keeping carbon in Earth's ecosystem, including stronger **deforestation** limits, could also have a big impact relatively quickly.

Whether any particular temperature, emission, or concentration goal can be met depends on other factors as well, such as how fast **new technology** is developed and adopted and how seriously we take **energy efficiency**, which in turn depends partly on the political will to prioritize climate change. Another important factor is the state of the world **economy**. Global emissions of CO_2 from fossil fuels actually fell more than 4% between 1980 and 1983, a period of high oil prices and widespread recession, and they dropped by about 2% in 1992 and 1999, when the economies of eastern Europe and Russia were struggling. Despite the intensity of the worldwide downturn of 2009, global CO_2 emissions fell by only a little more than 1% that year, and in the following year (2010) they soared by more than 4%.

Naturally, all these factors are interrelated in complex ways. For example, high oil prices can simultaneously dampen economic growth, encourage efficiency, and stimulate investment in alternative energy sources—all of which are likely to reduce emissions. But if the economy suffers too much, governments may feel pressure from voters to prioritize short-term growth over long-term environmental issues. Despite all these complications, it seems at least theoretically possible that we could manage long-term net global emission cuts of a few percent within a decade or two, assuming there are incentives for reducing carbon use that carry weight in the global marketplace. And, though implementing such deep cuts would be liable to cause short-term fiscal pain (perhaps significant in some quarters), the long-term economic and environmental gains from energy efficiency and renewable energy could be enormous and widespread.

The wedge strategy

Since almost all human activity contributes to greenhouse gas emissions on some level, the task of reducing global emissions can seem somewhat overwhelming. What if we thought of it as a series of simultaneous smaller goals? That's the philosophy behind Stephen Pacala and Robert Socolow's "wedge" approach to climate protection. The two Princeton University scientists brought the wedge concept to a wide audience through a 2004 article in *Science*. The idea is to break down the enormous carbon reductions needed by midcentury into more manageable bits, or wedges, each of which can be assigned to a particular technology or strategy.

When it was introduced, the wedge concept triggered widespread interest and excitement, in part because Pacala and Socolow claimed that the needed emission cuts through 2050 could be handled entirely through existing technologies. The concept has proven hugely influential, and it's a handy way to compare and contrast various pieces of the overall emission-reduction puzzle.

The wedge concept originates from Pacala and Socolow's projection of historical CO_2 emissions into the future, starting from 2004, the year their paper was published (see diagram, p. 305). Let's assume it is 2004 right now, and let's also assume that emissions can be instantly stabilized—in other words, the yearly increases in CO_2 all go to zero right now—and remain that way until at least the 2050s. This is represented by the flat black line on the diagram. Pacala and Socolow argued that this would correspond to an eventual CO_2 concentration of about 500 ppm. Such a route falls somewhere between the two most optimistic emissions pathways (RCP2.6 and RCP4.5) in the 2013 IPCC report. This would provide us with a good chance of staying below 3°C by century's end, and at least a shot of remaining below 2°C, depending on how sensitive the climate is to CO_2 (see chapter 12). However, if emissions continue to increase as they have in the last several decades, at more than 1% per year—the red line on the diagram—then by 2054 we'd be adding twice as much CO_2 to the atmosphere each year (see the red "business as usual" line on the diagram). The result would be a warming far more severe than 2°C, in line with the most pessimistic of the IPCC pathways.

The triangle between the black and red lines shows the difference between the desired path of steady emissions and the dangerous uphill path. To get rid of the triangle, we'd need to come up with at least seven wedges, each of which would eliminate a billion metric tons (a metric gigaton) of annual carbon emission by 2054. Further wedges would probably be needed after 2054 to stay below the 2°C target.

Pacala and Socolow identified 15 examples of potential wedges (see descriptions beside graphic), each of which was already being implemented on a reasonably large scale somewhere in the world. They maintained that a 50-year goal was easier to grasp than a century-long one. Among other things, it's comparable to the length of a career or the lifetime of a coal-based power plant. As they put it, "Humanity can solve the carbon and climate problem in the first half of this century simply by scaling up what we already know how to do."

How do the wedges of 2004 hold up in the 2010s? Apart from occasional economy-produced dips, global emissions have been rising a bit faster than the 1.5% annual increase assumed in the Pacala and Socolow graph. In 2011, seven years after the breakthrough paper he coauthored, Socolow took a fresh look at the wedge strategy and concluded that, given the unabated emissions up to that point, we now needed nine rather than seven wedges. That's with the concentration goal now bumped up to 550 ppm, which adds perhaps 0.5°C to the eventual temperature peak and makes reaching the 2.0°C goal far more problematic. Taking into account the stark realities of our current path as well as the latest science, researchers led by Steven

Davis (University of California, Irvine) mapped out a far more ambitious variation in a 2013 paper called "Rethinking wedges." They propose a total of 19 wedges, each as large as those in the original 2004 set, that could bring CO_2 emissions close to zero within 50 years. Doing so, they hasten to add, would require "an integrated and aggressive set of policies and programs . . . to support energy technology innovation across all stages of research, development, demonstration, and commercialization. No matter the number required, wedges can still simplify and quantify the challenge. But the problem was never easy."

Indeed, while the wedge strategy is a helpful way to assess which directions we might want to go in, it certainly doesn't make the job a cakewalk, as Pacala and Socolow acknowledged from the start. "Each of these wedges represents a staggering amount of effort from the public and private sector," noted Joseph Romm in a 2008 *Nature* analysis. It's obvious that some proposed wedges are far more practical and/or politically palatable than others. At least one of the original wedges—the ramp-up of ethanol—has been fraught with problems that weren't fully foreseen a decade ago. Even if alternatives are deployed, there's no guarantee that they will supplant traditional fuels. And if the history of energy development is any guide, the economies of scale tend to push each sector toward a strongly preferred fuel type: gasoline for vehicles, coal for electric power plants, and so on. This would work against, say, the parallel large-scale growth of electricity generation from wind power, nuclear power, and cleaner types of coal. Moreover, key interest groups—whether it be fossil fuel companies or hard-green activists—are often hesitant to relax long-held positions that end up favoring only a small number of wedges rather than the full smorgasbord. There's also the obvious fact that we can't stabilize emissions today or tomorrow as if we were flipping a switch. Even using current technologies, such massive change would take years to implement. This is why many scenarios constructed by the IPCC and others include a ramp-up phase of continued growth, followed by substantial cuts in emissions—ultimately bringing us well below today's emission levels—in contrast to the flat-line "stabilization trajectory" shown on the above graph. One other concern: bolstering the clean-energy wedges may not reduce the global use of dirty energy if there aren't economic incentives that transcend national boundaries, as noted above.

Looming in the background, and not considered directly in the wedges, is the inexorable rise in global **population**, which threatens to swamp the emission cuts made in efficiency and technology. Because the idea of stabilizing global population has proven to be such a political minefield, it's

The wedges (expressed in terms of the year 2054 versus 2004):

Doubling vehicle fuel economy and **cutting the distance driven per car in half** (one wedge each). Fuel economy is on the rise in many wealthy nations, including the United States, but auto use is also increasing rapidly in the developed world.

Installing lights and appliances with state-of-the-art energy efficiency in all new and existing residential and commercial buildings, thus reducing emissions by about 25%. There's been incremental progress in recent years, especially with the advent of compact fluorescent (CFL) and LED lighting.

Improving the efficiency of coal-fired power plants from 40% to 60%, plus cutting in half the energy lost when fossil fuels are extracted, processed, and delivered to those plants. Progress has been relatively slow in this area.

A 50-fold expansion in wind energy, replacing coal. As of 2012, the global total of installed wind-power capacity was more than five times the 2004 value. A second wedge could be obtained by adding another four million turbines to generate hydrogen for fuel-cell vehicles.

A 700-fold expansion of photovoltaic (PV) solar energy, again replacing coal. This would require enough panels to blanket every inch of an area the size of New Jersey. However, many of the panels could be mounted on roofs and walls. The total capacity of solar PV panels installed around the world grew roughly 20-fold from 2004 to 2012, with no end in sight to the rapid growth.

A 50-fold expansion in ethanol, displacing petroleum. Even with plants that yield far more energy per acre than the corn and sugar cane used now for ethanol, these fuel crops would still require a region about the size of India. Biofuels production more than tripled from 2004 to 2010, but the trend then flat-lined over the following two years.

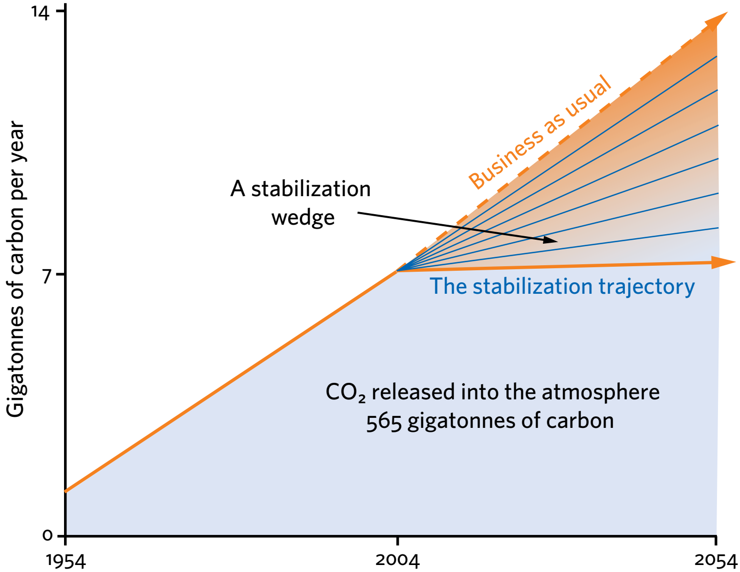
A halting of current deforestation, coupled with plantations on non-forested land, together covering a total area about 40% the size of Australia by 2050. There's been major progress on deforestation, due in part to agreements made at the 2009 Copenhagen summit.

Employing conservation tillage on all cropland, in which farmers avoid plowing and thus reduce the amount of CO_2 escaping from tilled soil. It's now used on only a small fraction of cropland globally, but interest in these techniques is spreading.

Tripling the amount of energy now generated by nuclear sources, adding about 700 one-gigawatt plants as well as maintaining or replacing all nuclear plants now in use. Nuclear power has been on the decline globally in recent years, with global electricity production from nuclear plants dropping more than 3% from 2009 to 2011. It plummeted another 7% in 2012, largely due to the Fukushima disaster and the power-down of other nuclear plants in Japan.

Quadrupling the use of natural gas in power plants, replacing an equal number of coal-fired plants. Electricity production from natural gas grew by more than 10% from 2004 to 2010, though it dipped slightly in 2011.

Sequestration—capturing carbon emitted by large fossil fuel power plants and storing it underground—with one wedge each coming from standard coal or natural-gas plants, synfuel plants (which generate synthetic fuel from coal), and hydrogen plants that draw on coal or natural gas. Although research continues, even experimental deployments have been few and far between.



The original wedge-strategy diagram, as conceived by Stephen Pacala and Robert Socolow.

sometimes omitted from climate change discussions. But there's no getting around the fact that more people on the planet will—all else being equal—lead to more greenhouse emissions.

Despite all these various qualms, the wedge concept remains useful as a rough framework for examining the total emissions picture. Each wedge is technically feasible—it's a matter of society choosing which ones to emphasize. There's been real progress since 2004 on some of the wedges, including wind and solar energy (see chapter 16). Government subsidies or other incentives can further shape this course, and it's possible that different countries will opt for different technologies, thus providing a well-rounded portfolio on the global scale. The wedges also allow one to work backward and set even shorter-term goals, taking into account that some wedges might grow more rapidly at first while others would take a while to get going.

We'll be considering the above options in chapters 16–21, after we explore what governments are doing—and not doing—to speed us along the path to a low-carbon future.