# MEMORANDUM TO THE PRESIDENT

**From:** **John P. Holdren**

**Subject:** **The Energy-Climate Challenge**

## PROBLEM

More than a quarter of a century ago, two immensely important understandings about the contemporary human condition pushed themselves, almost simultaneously, into public and political consciousness. One of these understandings—reflected in the occasion of the first Earth Day in 1970, the publication of the report of the MIT-hosted international Study of Critical Environmental Problems that same year, and the convening of the first UN Conference on the Environment in Stockholm in 1972—was that the environmental conditions and processes increasingly under siege from the expansion of human activities were too important to human well-being to continue to be neglected, as they often had been, in the pell-mell pursuit of increased material prosperity. People began to realize that ways would need to be found—and could be found—to meet economic aspirations while adequately protecting the environmental underpinnings of well-being. The other understanding, which was thrust on the world by the Arab Organization of Petroleum Exporting Countries-induced oil-price shocks of the 1970s and the global economic recession that followed, was that a reliable and affordable supply of energy is absolutely critical to maintaining and expanding economic prosperity where such prosperity already exists and to creating it where it does not.

Today, these two understandings have long since become part of conventional knowledge. Essentially everybody recognizes the importance of energy for economic prosperity and the importance, for human well-being, of protecting the environment. But far less widely appreciated is the close connection between these two imperatives—and the immense challenge arising from it—in the form of the central role played by civilization's principal energy sources in generating the most dangerous and difficult environmental problems facing the planet. Energy supply is the source of most of human exposure to air pollution, most of acid precipitation, much of the toxic contamination of ground water, most of the burden of long-lived radioactive wastes, and most of the anthropogenic alteration of global climate. Moreover, the constraints imposed by these problems on the composition and expandability of energy supply are becoming the most important determinants of energy strategy and, increasingly, of energy's monetary costs. In short, energy is the most difficult part of the environment problem, and environment is the most difficult part of the energy problem. The core of the challenge of expanding and sustaining economic prosperity is the challenge of limiting, at affordable cost, the environmental impacts of an expanding energy supply.

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The most demanding part of this energy/environment/prosperity challenge is the challenge posed by anthropogenic climate change. In terms of the current scale of damage to health, property, ecosystems, and quality of life, climate change is not yet comparable to air pollution, water pollution, or land transformation. But, over the next several decades, it will come to be understood as the most dangerous and the most intractable of the environmental impacts of human activity.

Climate change is the most dangerous part of the energy/environment challenge because climate constitutes the envelope within which all other environmental conditions and processes operate and because, once it has been set in motion, the degree of irreversibility of human-induced climate change is very high. Substantial disruption of the climatic "envelope" places at risk the full array of "service" functions of the environment: the formation, fertilization, and retention of soils; the detoxification of pollutants; the provision of fresh water; the distribution of warmth and nutrients by ocean currents; the natural controls on human and plant pathogens and pests; the bounding, within mostly tolerable limits, of extreme temperatures, precipitation, and storminess; and much more.[1]

As discussed below, the evidence that human-induced climate change is on a trajectory to create major damage to these services within the current century is becoming overwhelming. The complacent notion that society is clever enough and rich enough to fully replace these contributions of the natural environment to human well-being with engineered substitutes is folly—although insofar as a substantial degree of disruption of global climate is already inevitable, we shall have to try.

Climate change is the most intractable of all environmental impacts to address because its primary cause—increasing carbon dioxide ($CO_2$) emissions—is deeply embedded in the character of civilization's current energy-supply system in ways that would be both time consuming and potentially very costly to change. More than 75 percent of the world's energy supply (and more than 85 percent of that of the United States) currently comes from burning oil, coal, and natural gas.[2] The rich countries of the industrialized world achieved their enviable prosperity based on a huge expansion of the use of these versatile and relatively inexpensive fuels, and the "business-as-usual" energy future would have the developing countries doing the same. Today's fossil-fuel-dominated world energy system (worth some $10 trillion at replacement cost and characterized by equipment-turnover times of 20 to 50 years) could not be rapidly replaced with non-$CO_2$-emitting alternatives even if these were no more expensive than conventional fossil-fuel technologies have been (and today, the non-$CO_2$ options are considerably more expensive); nor is the voluminous $CO_2$ combustion product (some 3 tons of $CO_2$ per ton of coal or oil) easy to capture with add-on pollution-control equipment for existing engines, furnaces, and power plants.

That the impacts of global climate disruption may not become the dominant sources of environmental harm to humans for yet a few more decades cannot be a great consolation, given that the time needed to change the energy system enough to avoid this outcome is also on the order of a few decades. It is going to be a very tight race. The challenge can be met, but only by employing a strategy that embodies all six of the following components:

- expanded research on climate-change science, geotechnical engineering adaptation to climate change, and increased investments to exploit the resulting understandings;

- increased national and international support for measures that address the motivations and the means for reducing family size;

- incentives for reducing the greenhouse-gas emissions of firms and consumers;

- accelerated research, development, and demonstration of advanced energy-supply and end-use technologies;
- increased international cooperation to ensure the application of these advances in all countries; and
- development of a global framework of commitments to long-term restraints on greenhouse-gas emissions.

Each of these components will be discussed later.

The private sector will clearly need to play an immense role in much of this agenda. In addition, because the problem involves externalities, common property resources, public benefits, and binding agreements among states, government policies must also play a major role. The government of the United States—a country with one-quarter of the world's fossil-fuel use and $CO_2$ emissions, the world's strongest economy, and the world's most capable scientific and technological establishments—ought to be leading, not following, in this effort that is so crucial to the prospects for a sustainable prosperity for all.

The remainder of this memorandum elaborates on three important aspects of this argument: what the current state of climate-change science allows one to say about the implications of energy business-as-usual (BAU); the extent of the deflection from BAU likely to be required to bring the degree of energy-linked disruption of global climate in this century within manageable bounds; and the content and prospects of the six-point strategy summarized earlier for achieving this deflection.

## BACKGROUND

### *Business-as-Usual and Its Climate Change Implications*

It is illuminating to disaggregate carbon emissions to the atmosphere into four multiplicative factors: the size of the human population, the per-capital level of economic activity (measured in purchasing-power-parity-corrected dollars of gross domestic product (GDP) per person), the energy intensity of economic activity (measured in gigajoules per thousand dollars of GDP), and the carbon-emission intensity of energy supply (measured in kilograms of carbon contained in $CO_2$ emitted to the atmosphere per gigajoule of energy supply). The "business-as-usual" assumption is not that these factors remain constant but rather that their trajectories of change follow recent trends that are adjusted for expected patterns of development. In a typical BAU global energy future:[3]

- World population increases from 6.1 billion in 2000 to 8.5 billion in 2030 and 9.8 billion in 2050, stabilizing by 2100 at about 11 billion. Almost all of this growth occurs in developing countries.

- Per-capita economic growth is higher in developing countries than in industrialized ones but declines gradually over the century in both. Aggregate economic growth (reflecting the combined effect of growth in population and in per-capita GDP) averages 2.9 percent per year from 2000 to 2020 and 2.3 percent per year over the whole century in real terms. As a result, world economic product (corrected for purchasing power parity) grows from about $38 trillion in 2000 to $87 trillion in 2030, $140 trillion in 2050, and $360 trillion in 2100 (all in 1995 U.S. dollars).

- Energy intensity of economic activity falls at the long-term historical rate of 1 percent per year in industrialized and developing countries alike for the entire century. With the indicated economic growth, this produces a doubling of world energy use between 2000 and 2040, a tripling by 2070, and a quadrupling by 2100 (by which time the figure is about 1,800 exajoules (EJ) per year, compared with about 450 EJ per year in 2000).

- Carbon intensity of energy supply falls at a rate of 0.2 percent per year in all countries for the entire century. With the indicated energy growth, this causes carbon emissions from fossil-fuel combustion to triple during the century, going from a bit more than 6 billion tons of carbon per year in 2000 to some 20 billion tons per year in 2100.

Historically, the atmospheric concentration of $CO_2$ rose from a pre-industrial level of about 280 parts per million by volume (ppm) in 1750 to about 370 ppm in 2000—an increase of 32 percent—driven in the first part of this 250-year period mainly by deforestation and in the latter part mainly by fossil-fuel combustion. Under the indicated BAU scenario for emissions from fossil fuels (and assuming no further contribution from net deforestation), the atmospheric concentration would be expected to reach 500 ppm by 2050 and more than 700 ppm by 2100. Moreover, if this BAU scenario persisted until 2100, there would be almost no possibility that the continuing run-up of the atmospheric $CO_2$ concentration thereafter could be stopped below 1,100 ppm (a quadrupling of the pre-industrial value).

In addition to the $CO_2$ increase, atmospheric concentrations of a number of other greenhouse gases—mainly methane, nitrous oxide, tropospheric ozone, and halocarbons—have also increased since pre-industrial times. The warming effect of all of these increases together, as of the mid-1990s, was estimated as roughly equal to that of the $CO_2$ increase; but this warming contribution of the non-$CO_2$ greenhouse gases was estimated to be approximately offset by the net cooling effect of increased atmospheric concentrations of particulate matter also caused by human activities.[4] Under the indicated BAU scenario, the concentrations of the non-$CO_2$ greenhouse gases increase more slowly during the 21st century than the $CO_2$ concentration does, while concentrations of atmospheric particulates slowly decline. By 2100, the net warming effect of all the greenhouse gases together—less the cooling from particulates—is just slightly larger (about 10 percent) than the warming that would be caused by the increased $CO_2$ alone. Therefore, one can simplify the discussion of future possibilities, without much loss of accuracy, by associating these possibilities with $CO_2$ concentrations alone—leaving out the offsetting complexities of non-$CO_2$ greenhouse gases and particulate matter.[5]

Today the debate about whether the effects of rising $CO_2$ concentrations on global climate are already apparent is essentially over—resolved in the affirmative.[6] In 1995, when the atmospheric $CO_2$ concentration was 360 ppm, the Intergovernmental Panel on Climate Change (IPCC) wrote in its *Second Assessment of the Science of Climate Change* that "the balance of evidence suggests a discernible human influence on global climate." This report noted that global mean surface air temperature had increased by 0.3 to 0.6 degrees C since the late 19th century, that this had

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been accompanied by an increase in global sea level by 10–25 centimeters, and that the patterns of change (in relation to day-night temperature differences, vertical temperature distribution, latitudinal differences, patterns of precipitation, and more) match with quite striking fidelity the patterns predicted, by basic climate science and elaborate computer models alike, to result from the observed increases in greenhouse-gas concentrations, adjusted for the effects of atmospheric particulate matter and the known variability of the sun's output. These patterns are often described as the "fingerprint" of greenhouse gas-induced climate change, and no one has postulated a culprit other than greenhouse gases that would have the same fingerprint.[7] Since the completion of the IPCC second assessment, the evidence has only grown stronger.

By the end of 1999, for example, it was clear that 15 of the 16 warmest years worldwide, in the 140 years since the global network of thermometer records became adequate to define a global average surface temperature, have occurred since 1980. The seven warmest years in the 140-year instrumental record all occurred in the 1990s, notwithstanding the cooling effects of the Philippine's Mount Pinatubo volcanic eruption at the beginning of that decade. Based on evidence from ice cores and other paleoclimatological data, it is likely that 1998 was the warmest year in the last thousand, and the last 50 years appear to have been the warmest half-century in six thousand years. A National Academy of Sciences report that appeared in January 2000, reviewing modest discrepancies between the surface thermometer records and satellite measurements made over the preceding 20 years, concluded that "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real."[8] And a comprehensive survey of ocean-temperature measurements, published in *Science* in March 2000, showed widespread warming of the oceans during the past 40 years.[9] With rather high confidence, then, one can now say that global warming is being experienced and that greenhouse gas increases from human activities are its primary cause.[10]

What is to be expected from continuation of business-as-usual? Because of the large thermal inertia of the oceans, the attainment of the equilibrium temperature increase associated with a given $CO_2$ concentration lags by some decades the attainment of that concentration. Thus, although the BAU emissions future described above yields a doubling of the pre-industrial $CO_2$ concentration by 2070, the best estimate temperature increase over the pre-industrial value is only about 1.8 degrees C by 2070, reaching 2.5 degrees C in 2100.[11] On the other hand, these estimates are global land and ocean averages; in general, the increases on land will be higher, and those on land at high latitudes higher still. Sophisticated climate models capable of tracing the time evolution of these changes typically show mid-continent U.S. temperatures in the range of 2.5 to 4 degrees C higher than today's for the middle of the century under the business-as-usual scenario.

The IPCC's 1995 assessment concluded, for the indicated BAU scenario, that sea level would rise by 2100 to a best estimate of 50 centimeters above today's value (and would continue to rise for centuries thereafter) and that other characteristics of the warmed climate would be likely to include increases in floods and droughts in some regions,[12] increased variability of precipitation in the tropics, and a decrease in the strength of the North Atlantic circulation that warms the southeastern United States and western Europe in winter. (A warmer climate overall can make it colder in some places at some times.) The assessment found that the expected climate change "is likely to have wide-ranging and mostly adverse effects on human health" (with the increased damage from heat stress, aggravation of the effects of air pollution, and expanded range of tropical diseases more than offsetting the reduced health impacts from cold winters); that northern forests "are likely to undergo irregular and large-scale losses of living trees;" and that agricultural productivity would "increase in some areas and decrease in others, especially the tropics and subtropics" (where malnutrition is already most prevalent).[13]

The 1995 assessment also emphasized, as all competent reviews of climate-change science do, that many uncertainties about the character, timing, and geographic distribution of the impacts of climate change remain, and that the nonlinear nature of the climate system (in which small causes can have big effects) implies the possibility of surprises that current models cannot capture at all. Such possibilities include increases in the frequency and intensity of destructive storms (which a few models do suggest), larger and more-rapid-than-expected sea-level rise (from, for

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example, slumping of the West Antarctic Ice Sheet), and a "runaway" warming effect from the release of large quantities of the potent greenhouse gas, methane, immense amounts of which are currently locked in icy-like solids called clathrates beneath permafrost and on the ocean floor. These examples illustrate that "uncertainty" does not necessarily mean, as the public and policy makers sometimes suppose, that when we learn more, it will all turn not to be as bad as was feared. It can easily turn out to be worse than the best estimates.

Although there is room for debate about whether the impacts of doubling the pre-industrial $CO_2$ concentration would be unmanageable, any basis for optimism shrinks when the postulated $CO_2$ level moves to a tripling or a quadrupling.[14] Under the IPCC's assumptions, a quadrupling of pre-industrial $CO_2$ would yield an equilibrium mean global surface temperature increase of 3 to 9 degrees C with a best estimate of 5 degrees C. Studies by Princeton's Geophysical Fluid Dynamics Laboratory—one of the few groups to analyze this case—found equilibrium average temperature increases of 7–10degrees C (13–18 degrees F) for the mid-continental United States after a quadrupling, drops of June–August soil moisture by 40 to 60 percent over most of the country, and a July heat index for the southeastern United States reaching 43 degrees C (109 degrees F) compared with the prewarming value of 30 degrees C (86 degrees F).[15] The Princeton calculation also showed the North Atlantic thermohaline circulation (which drives the Gulf Stream) shutting down almost completely under a quadrupling of pre-industrial $CO_2$, accompanied by a rise in sea level at about twice the rate expected for a $CO_2$ doubling.[16]

Although there are of course uncertainties associated with the projections of this particular study—as for all others—it would be foolish to suppose that the impacts of the degree of climate disruption that any model will show for a quadrupling of atmospheric $CO_2$ would entail anything other than immense human costs.

### *How Big a Departure from Business-as-Usual is Required?*

Stabilizing $CO_2$ emissions at or near current levels would not lead to stabilizing the atmospheric $CO_2$ concentration. Constant emissions at the mid-1990s rate would lead, instead, to a more or less steady increase of about 1.5 ppm per year in the concentration, leading to a value of about 520 ppm by 2100 if the constant emissions rate were maintained throughout this century. Stabilizing the atmospheric concentration at any level of possible interest—even at a quadrupling of the pre-industrial level—would require that global emissions drop eventually to a small fraction of the current 6 billion tons of contained carbon (GtC ) per year. However, it is consistent with ultimate stabilization of the atmospheric concentration that emissions rise for a time—as they are destined to do given the momentum in the current fossil-fuel-dominated energy system—as long as they peak eventually and then fall to levels well below today's.

For example, to stabilize the atmospheric concentration at 550 ppm—about twice the pre-industrial value—the BAU trajectory could be followed until about 2020, and the concentration would need to peak at not more than 11 GtC/yr around 2030 and begin falling by 2035, reaching 5 GtC per year by 2100 and 2.5 GtC per year by 2200. A somewhat different emissions trajectory that would still be compatible with stabilizing the atmospheric $CO_2$ concentration at 550 ppm would depart from business-as-usual sooner (essentially immediately), peak lower (at 8–9 GtC per year) and later (around 2050), and then fall more gradually, becoming coincident with the more sharply peaked 550 ppm trajectory between 2150 and 2200.

In addition to the details of their shapes, emissions trajectories that lead to stabilization of the atmospheric $CO_2$ concentration at various levels can be characterized by the cumulative emissions they entail between 2000 and 2100. Trajectories compatible with stabilization at 550 ppm would have cumulative emissions in the range of 800 to 900 GtC in this century. Trajectories corresponding to stabilization at 750 ppm would have 21st century cumulative emissions in the range of 1,100 to 1,200 GtC. For comparison, cumulative 21st century emissions on the BAU trajectory would be about 1,400 GtC.

Under the UN Framework Convention on Climate Change (UNFCCC), which was enacted at the Earth Summit in Rio de Janeiro in 1992 and subsequently ratified by the United States and more than 170 other nations, the parties agreed to pursue "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." There has been no formal or even informal agreement, up until now, on the stabilized concentration that would be considered low enough to meet this criterion. But it is difficult to believe, given the evidence that global climate change is already doing damage, that any level equivalent to more than a doubling of the pre-industrial $CO_2$ concentration could possibly be considered compliant with the convention. Were it not for concerns about the practicality of meeting a lower target—or, stated another way, concerns that the cost of compliance might exceed the benefits—it seems likely that a level at or below today's concentration would be chosen. If the target were a compromise of 450 ppm (a bit closer to today's 370 ppm than to a doubling at 560 ppm), then cumulative carbon emissions over the 21st century would have to be kept below 600 GtC—a figure 2.5 times smaller than that for business-as-usual.

The magnitude of the challenge represented by a target this low can be illustrated by considering what would be required to meet it by emissions reductions alone—that is, without reductions below BAU population growth or per-capita economic growth. With the population and per-capita GDP trajectories at their BAU values, a doubling of the century-average rate of decline of energy intensity (energy divided by GDP), from 1.0 to 2.0 percent per year, and a doubling of the rate of decline of carbon intensity (carbon emissions divided by energy), from 0.2 to 0.4 percent per year, would reduce the 21st century emissions to about 700 GtC, establishing a trajectory that could stabilize the atmospheric concentration at about 500 ppm. If, in this variant, the century-average rate of reduction of carbon intensity were boosted to 0.6 percent per year—three times as fast as business-as-usual—the result would be a trajectory consistent with stabilization at 450 ppm.[17]

Attaining such a trajectory would not be easy, but neither would it be impossible. Higher reduction rates in these intensities than are needed have been achieved in some places and times in the past (although never for as long or as universally as would be required to meet the challenge described here). For example, between 1973 and 1986, in response to the 1973–74 and 1979 world oil-price shocks, energy intensity in the United States fell at an average of 2.5 percent per year. In France in about the same period (1973–91), when that country was rapidly nuclearizing its electricity-generation sector, the carbon intensity of energy supply in the French economy fell at an average rate of 2.7 percent per year. Among global scenarios for energy in the 21st century constructed by IPCC, the joint Global Energy Futures study of the World Energy Council and the International Institute for Applied Systems Analysis, and other reputable efforts, there are high-technological-innovation variants with long-term world-average rates of improvement averaging 1.5 to 2.5 percent per year in energy intensity and 0.6 to 1.2 percent per year in carbon intensity.

## RECOMMENDATIONS

### *Ingredients of Strategy*

A sensible strategy to overcoming the energy climate challenge would seek to stabilize the atmospheric $CO_2$ concentration below 500 ppm while taking additional steps to try to reduce the harm to human well-being that disruptions of climate, even at this level of greenhouse-gas increase, would tend to cause. In principle, there are just four possible approaches to the overall problem from which the ingredients of such a strategy can be assembled, and they can be enumerated as follows:

- reduce greenhouse gas emissions to less than what they would otherwise be;
- remove from the atmosphere greenhouse gases that have previously been added to it;
- intervene to reduce the effects of greenhouse gas increases on climatic variables; and
- adapt to reduce the human impact of the degree of climate change that cannot be avoided.

Working up from the bottom of this list, it is plain that a considerable amount of adaptation will be needed, inasmuch as climate change and adverse impacts from it are already apparent. Adjustments in agriculture, forestry, fisheries, water storage, flood control, public-health measures, transportation management[18] and protection of coastal settlements, among other activities, will be required. Some of this is already under way. But a strategy that relies too heavily on adaptation or not enough on avoidance is likely to be costly, not to mention much less effective in resource- and infrastructure-poor developing countries than in industrialized ones.

Interventions to reduce the effects of greenhouse gas increases on climatic variables constitute what is often termed "geotechnical engineering." An example would be the insertion of reflecting materials into orbit to reduce the sunlight reaching the Earth and thereby offset greenhouse warming. Although such ideas are intriguing, they suffer too much from insufficient understanding of the intricacies of the planet's climatic machinery for us to be confident of achieving the desired effects (or, to be confident of doing more good than harm). Humans are powerful enough to disrupt the climate and smart enough to notice we are doing it, but we are not yet competent enough to fine-tune the complex machinery of climate to our tastes. The possibilities—and the climate system itself—need much more study.

The best means currently known for removing $CO_2$ from the atmosphere is growing trees. The trick is to increase the inventory of carbon embedded in plant material, of which the most enduring form is wood: Just as net deforestation reduces that inventory and adds $CO_2$ to the atmosphere (as has happened on a global-average basis during much of the past few centuries), so does net afforestation increase the inventory and remove $CO_2$ from the atmosphere. Expanding the forested area of the planet is feasible (although not as easy to achieve and to sustain as is sometimes supposed), as is increasing the carbon storage on existing forested land. But given the amount of continuing deforestation in the tropics, it would be a considerable accomplishment just to stay even on a global-average basis during the next century. The best imaginable performance at rapidly ending current deforestation and improving other land-management practices that generate greenhouse-gas emissions,[19] combined with aggressive reforestation and afforestation efforts (including widespread, costly restoration of degraded land), might achieve 20 or 25 percent of what is required for a transition, in this century, from the BAU trajectory to a trajectory consistent with stabilizing atmospheric $CO_2$ at 500 ppm. Far more study and effort than are happening today will be required to achieve even this much.[20]

### *The Six-Point Action Program*

The foregoing considerations about the adaptation, geotechnical engineering, and greenhouse gas-removal options motivate the first element in this six-point program, namely:

> *(1) expanded research on the science of climate change, climate-change impacts, enhancement of the uptake of carbon sinks in terrestrial ecosystems and in the oceans, geotechnical engineering to offset the effects of greenhouse gas increases in the atmosphere, and means of adaptation to the degree of climate change that proves unavoidable; and increased investments to exploit the opportunities that this research uncovers.*[21]

The same considerations make it plain that no matter how much ultimately proves to be achievable under these headings, prudence also requires pushing forward aggressively on the option of reducing greenhouse gas emissions to below what they would otherwise be. This necessary preoccupation leads back to the determinants of the most important anthropogenic greenhouse gas emissions—those of $CO_2$—in the form of population, GDP per person, energy use per unit of GDP, and carbon emissions per unit of energy. Although the trajectories of these four factors alone are sufficient to specify the trajectory of total carbon emissions, each of the four is influenced in turn by an array of interacting technical, economic, social, and political factors, wherein reside the leverage points for policy.

The range of plausible world population sizes in 2100 extends at least from 7 billion to 14 billion. The difference between these two figures in terms of ease or difficulty of achieving a low-carbon-emission energy future (as well as for a great many other aspects of the human condition) is immense. We should be striving for a result near the low end of these possibilities.

The principal manipulable determinants of human fertility, and hence of population growth, are the prospective parents' knowledge of reproductive biology, their motivation affecting desired number and spacing of offspring, and the effectiveness and availability of technologies of fertility limitation. Knowledge of reproductive biology is a matter of education—of women even more importantly than of men—which is in turn a matter of development. Motivation about number and spacing of offspring has been shown to depend most directly on the status and education and employment opportunities of women, the survival prospects of offspring, and the availability of a social security system—again, all matters closely related to the process of development itself—as well as government incentives for small families and other factors influencing perceptions about the individual and social costs of large ones. Fertility-limiting technologies (the means of contraception and abortion) are already quite good; the key factor is access to them on satisfactory terms.

Although a few of these fertility-reducing factors have been or could be politically sensitive, nearly all of them are things that most of the world's people want for their own immediate well-being. That achieving them would also bring a large societal gain in the form of reduced population growth and the benefits of that for addressing the energy/climate challenge (and a great many other resource, environmental, and social problems of the 21st century) means that there can be even less excuse than otherwise for failing to push ahead with the second element in the six-point program:

> *(2) increased national and international support for the education, development, social-welfare, and family-planning measures known to be most effective in reducing population growth.*

The GDP-per-person factor in carbon emissions can be dispensed more quickly, at least in respect to policy leverage for reducing those emissions. Much can be said, of course, about how GDP is influenced by the productivity of labor (which in turn is influenced by health, education, training, organization, technology, and natural resources), but policy is rightly focused on how to increase all this, not on decreasing it as a way to reduce environmental harm. In the long run, GDP per person also depends on the allocation of time between economic and noneconomic activities, influenced in turn by conceptions about the relative importance of economic and noneconomic contributions to well-being. However, as much as some might like to see a reorientation of human wants away from economic consumption, advocating this explicitly is not likely to become a part of a major political party's platform for some time to come. It may happen, nonetheless, that bringing more of the external costs of economic growth into the balance sheets of producers and consumers—as overall economic efficiency requires—will raise the price of growth enough that people will not buy so much of it. But the appropriate policy instruments relate to internalizing the external costs—not to suppressing economic growth per se.

This leads to the two more technical determinants of emissions, namely the energy intensity of GDP and the carbon intensity of energy supply. The energy intensity of GDP relates both to "technical efficiency" (the energy requirement to produce a given good or service) and to the composition of economic output (the mix, in the economy, of more and less energy-intensive types of goods and services). The carbon intensity of energy supply depends on the characteristics of fossil-fueled energy technologies (specifically, how much carbon they emit per unit of end-use energy they supply to the economy) and the mix of fossil-fueled and nonfossil-fueled energy technologies in the energy system as a whole. The two elements of the six-point program that relate directly to the evolution of these factors in the United States are

> *(3) incentives and other help for firms and consumers to make low- and no-$CO_2$ choices from the menu of energy-supply and energy-end-use-efficiency options available at any given time; and*
>
> *(4) accelerated research, development, and demonstration of advanced energy-supply and end-use technologies, to steadily expand and improve the menu from which choices are made.*

The range of policy measures that can be considered under the third component is wide, including analysis and education of firms and individual consumers about the available options, correction of perverse incentives embedded in existing policies, lowering of bureaucratic barriers to adoption of otherwise desirable options, performance standards (relating, for example, to energy efficiency and to emissions), portfolio standards (relating to the proportion of low- and no-carbon options in the energy-supply mix), preferential financing, tax breaks, and other subsidies for demonstration and widespread deployment of targeted options, overall emissions caps implemented through tradable permits, and carbon taxes.[22]

**. . .the most potent and economically efficient means to encourage low-carbon and no-carbon choices from the menu of available options and to encourage research and development of better choices of these kinds, would be a tax on carbon emissions.**

Although there is room for innovation and expanded activity on many of these fronts, most economists will argue that the most potent and economically efficient means to encourage low-carbon and no-carbon choices from the menu of available options and to encourage research and development of better choices of these kinds, would be a tax on carbon emissions. They are right. Taxing a widely practiced activity that society has reason to want to discourage has a long and successful history. Taxing "bads" (such as pollution) is preferable to taxing "goods" (such as income and capital investment) for a variety of reasons, and the revenue stream from taxing the "bads" can be used to reduce the taxes on "goods,"[23] to reduce the burdens on hard-hit subpopulations (such as coal workers), and to finance research, development, and demonstration of better low-emission technologies. The money does not disappear into a black hole.

Serious advocacy of a carbon tax has been anathema in U.S. political discourse, but it is far from obvious that the persuasive power of the presidency would not be enough to sell such a tax to the public. One does not have to leap to the levels of $100 or $200 per ton of emitted carbon that feature in scare stories about how damaging this approach would be to the fossil-fuel industries; getting our toes wet with a tax of $20 per ton, as a beginning, would generate a healthy set of incentives for energy firms and individual energy users to start making more climate-friendly choices, and it would raise about $30 billion per year initially in the United States—of which, perhaps, one-tenth could be used to alleviate resulting burdens on the groups hardest hit, one-tenth could be used for additional targeted incentives for the adoption of low-carbon energy options from the existing mix, one-tenth could be used for more than doubling federal support for research, development, and demonstration of improved low-carbon options, and the remaining seven-tenths ($21 billion) would still be left for reducing other taxes.[24]

As economists frequently point out, an effect on the energy marketplace substantially identical to that of a carbon tax can be obtained through the use of an emissions cap implemented through tradable emissions permits. It is often supposed that this approach would be less problematic politically than a carbon tax, and this may be right. But a cap-and-trade system is harder to design, harder to calibrate, and harder to implement than a tax. For the United States, initially, a carbon tax would be more effective. However, ultimately, an international cap-and-trade scheme may be the best negotiable approach for constraining carbon emissions worldwide in an equitable way.

Politically easier than carbon taxes or emissions caps are the increases in research, development, and demonstration of advanced energy-supply and energy-end-use technologies recommended as the fourth part of this six-part program. But even this proved problematic in the last administration. The 1997 report of the President's Committee of Advisors on Science and Technology (PCAST) on *Federal Energy Research and Development for the Challenges of the Twenty-First Century* concluded that the federal energy-technology research and development programs then in place were "not commensurate in scope and scale with the energy challenges and opportunities that the twenty-first century will present," taking into account "the contributions to energy [research and development] that can reasonably be expected to be made by the private sector under market conditions similar to today's."[25] The panel recommended modifications to U.S. Department of Energy's (DOE) applied energy-technology (fossil, nuclear, renewable, efficiency) research and development programs that would increase funding in these categories from their fiscal year (FY) 1997 and FY1998 level of $1.3 billion per year to $1.8 billion in FY1999 and $2.4 billion in FY2003.[26]

The administration embodied a considerable fraction of this advice in its FY1999 budget request (which contained a total increment about two-thirds of what PCAST recommended for that year) and Congress appropriated a considerable fraction of that (about 60 percent of the increment requested by the administration). The net result was an increment about 40 percent as large as PCAST recommended for FY1999. In subsequent budgets, the gap between the PCAST recommendations and what the administration was willing to recommend widened steadily, and Congress continued to appropriate only a fraction of what the administration recommended. This should not have been so hard. As PCAST pointed out, its proposed increases in federal energy research and development would not only have positioned the country to respond more cost effectively to the need to reduce greenhouse-gas emissions when and if a national decision were made to do this; it would also lower the

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monetary costs of energy and energy services below what they would otherwise be, increasing the productivity and competitiveness of U.S. manufacturing, reducing U.S. overdependence on oil imports, and reducing emissions of air pollutants directly hazardous to human health and ecosystems, among other benefits. In addition, it would only have restored federal spending on applied-energy-technology research and development, by FY2003, to its level in the FY1991 and FY1992 Bush administration budgets (the annual total for which could be raised by an increase of 2.5 cents per gallon in the federal gasoline tax).

Another PCAST study, this one completed in June 1999,[27] fleshed out the arguments for and ingredients of the fifth element of the six-point program recommended here:

> *(5) increased international cooperation to facilitate the application of the results of first, third, and fourth components in developed and developing countries.*

The report from that PCAST study, entitled *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*, noted that enhanced U.S. participation in such cooperation would improve the access of U.S. firms to the immense foreign market for energy technologies,[28] lower the cost of energy-technology innovation for U.S. domestic application, and help other countries participate effectively in the solution of global energy problems that the United States cannot solve by itself. The energy technologies that other countries deploy will largely determine not only the pace of global climate disruption by fossil-fuel-derived greenhouse gases[29] but also the extent of world dependence on imported oil and the potential for conflict over access to it, the performance of nuclear-energy systems on whose proliferation resistance and safety the whole world depends, and the prospects for trade-enhancing and security-building sustainable economic development in regions where, otherwise, economic deprivation will be a continuing source of conflict.

This 1999 PCAST study estimated that federal spending on international cooperation in energy research, development, demonstration, and deployment (ERD$^3$) amounted in FY1997 to about $250 million per year, and it recommended that this figure be increased to about $500 million in the FY2001 budget and to $750 million by FY2005. The increments were for specific initiatives to strengthen the foundations of energy-technology innovation and international cooperation relating to it (including capacity building, energy-sector reform, and mechanisms for demonstration, cost-buy-down, and financing of advanced technologies); for increased cooperation on $ERD^3$ of technologies governing the efficiency of energy use in buildings, energy-intensive industries, and small vehicles and buses, as well as of cogeneration of heat and power; and for increased cooperation on $ERD^3$ of fossil-fuels-decarbonization and carbon-sequestration technologies, biomass-energy and other renewable-energy technologies, and nuclear fission and fusion. The administration's FY2001 budget request included an increment of $100 million for these initiatives (as opposed to the $250 million increment proposed by PCAST). At this writing, the fate of this increment in an election-year Congress controlled by the other party is unclear.

Addressing the energy/climate challenge should not be a partisan issue. The values at stake—economic prosperity, environmental quality, and international security—are held dear by both parties. The UN Framework Convention on Climate Change was signed by a Republican president. That convention, which, unlike the Kyoto Protocol, has long since been ratified by the U.S. Senate and is therefore the law of the land, already commits the United States to most of the climate-related actions that climate-change skeptics in the 106th Congress have mistakenly associated with the Kyoto Protocol and noisily opposed. For example, Article 4 of UNFCCC commits the parties to "formulate, implement, publish, and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change," and to "promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices, and processes that control, reduce, or prevent anthropogenic emissions of greenhouse gases. . . ."[30] This covers a lot of ground—and provides a lot of cover for doing what is required.

The 1992 UNFCCC and the unratified 1997 Kyoto Protocol represent early, halting, imperfect steps in the effort to achieve the sixth element of this six-part program of action on the energy/climate challenge, namely:

> *(6) development of a global framework of commitments to long-term restraints on greenhouse-gas emissions designed for sufficiency, equity, and feasibility.*

UNFCCC correctly recognized the asymmetries built into the energy/climate challenge—notably that it has been industrialized countries who mostly consumed, in the course of their economic development, the capacity of the atmosphere to hold anthropogenic $CO_2$ without entraining intolerable changes in climate; that industrial countries are far better positioned financially and technologically to undertake early corrective action; and that no approach to planetary emissions limits that closed off the path to development for three-quarters of the Earth's population would be acceptable. Article 3 explicitly affirms, accordingly, that "the developed country Parties should take the lead in combating climate change and the adverse effects thereof." This is only sensible.

The Kyoto Protocol negotiation attempted, with insufficient time and insufficient preparation in relation to the complexity of the agenda, both to address a variety of gaps and ambiguities in the UNFCCC's treatment of the coverage and approach of a global framework for limiting anthropogenic climate change and to agree on an initial set of binding numerical targets and timetables for emissions reductions by the industrialized countries. The biggest shortcoming of the negotiation was the degree of preoccupation in the meeting—and in the preparations in individual industrialized-country governments—with these numerical targets and timetables, to the near exclusion of addressing the mechanisms (above all, incentives) that might start to move emissions trajectories in the right direction.

The result was a set of targets and timetables for industrialized countries—expressed in terms of percentage reductions from 1990 levels to be achieved in the 2008–2012 time period—that has been assailed for requiring more than is needed in the short run and for requiring much less than is needed in the long run. It has also been assailed for failing to bind developing countries. The criticisms about too much and too little have some validity, but the bigger failure is that arguments and agreements about targets and timetables are essentially irrelevant in the absence of mechanisms that might cause them to be achieved.

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The idea that developing countries could have been or should have been included in reductions targets of this character (percentage cuts from 1990 levels) was a nonstarter from the outset—inconsistent with the principles of UNFCCC and not taken seriously by most people outside the U.S. Senate. When it is time to bring developing countries into a framework of commitments to reductions (and this will only happen after the industrialized nations have demonstrated a willingness not just to establish targets but to impose mechanisms to make the targets attainable), the formula will need to be based either on carbon intensities (agreement to reduce the ratio of carbon emissions to GDP at a specified rate) or on tradable emissions permits allocated on a per-capita basis.

A satisfactory global framework for emissions restraints might well employ the two approaches just mentioned in successive stages: commitments based initially on specified annual percentage reductions in the carbon intensity of economic activity, transitioning in the longer term to evolving global emissions caps implemented through tradable permits. If "sufficiency" in a framework of emissions restraints were defined in terms of getting the world onto a trajectory that would stabilize the atmospheric $CO_2$ concentration at between 450 and 500 ppm, then the initial commitments for reducing the carbon-to-GDP ratio might start in the range of 1.5 percent per year (not far above the long-term historical average) and ramp up over a decade or so to the range of 2.5 percent per year that would be required, as a century-long worldwide average, to achieve stabilization at the indicated level.

The later phase, employing caps, would be based on the insight that the desired stabilization trajectory cannot have a peak higher than about 10 GtC per year around 2035 and must fall thereafter. If one supposes that world population in 2035 will be 8 billion persons (somewhat below the 8.8 billion projected for 2035 in the BAU scenario), the per-capita allocation in 2035 would need to be about 1.2 tons of carbon per person. This is about three times less than what industrialized nations were averaging at the end of the 1990s, and three times more than what developing countries were averaging then. So, in this strikingly symmetric scheme, the per-capita allowances of industrialized and developing countries would have converged from opposite sides, after 35 years, to the geometric mean of their current per-capita emissions.[31] The emissions cap and the associated per-capita allocations would fall gradually thereafter, tracking the trajectory needed to achieve stabilization at 450–500 ppm.

Such an approach would certainly be equitable. It is more likely to be sufficient than variants aiming for stabilization at 550 ppm or more (although worse-than-expected evolution of climate change over time could still show it to be inadequate). This is a feasible approach, at least from the technical and economic standpoints even if not yet from the political one. But, crucially, it does not need to be politically feasible today, because its most politically problematic ingredient—equal per-capita emissions allocations—would not need to begin being phased in before 2015 or 2020, by which time people's everyday experience of the impacts of climate change is likely to have stretched considerably the scope of what domestic and international politics will allow.

As for the Kyoto Protocol, it is, with all its warts, sufficiently important today as a symbol of the world's commitment to move forward collectively to address the energy/climate challenge that a serious effort must be made to either salvage or supplant it. The most important ambiguities in it—relating, for example, to the treatment of carbon sinks and to the operation of the Clean Development Mechanism—have been in the process of being ironed out in Conferences of the Parties (to UNFCCC) subsequent to the Kyoto meeting. As for the binding targets and timetables, these might be made acceptable by designing a set of agreed penalties for noncompliance that are more constructive than punitive. (Industrialized countries could agree, for example, to increase their investments in ERD$^3$ and international cooperation on low-carbon-emitting energy technologies in proportion to the margin by which they miss their 2008–2012 targets.) If the Kyoto Protocol proves not to be salvageable in these ways, it will be important to have a new and better agreement that the major emitters in the developed and developing worlds alike are prepared to sign at the same meeting when the final demise of the Kyoto agreement is formally acknowledged.

## *Conclusion*

The energy/climate challenge must be met. And it can be met. There is no shortage of persuasive professional knowledge about why doing so is necessary, nor is there any shortage of promising proposals about how to proceed. There is not even a good argument that doing this job would be too expensive: The cost of the needed steps almost certainly would be small compared with the cost of the environmental and economic damages averted, as well as small compared with investments society makes in military forces (in which the degree of certainty about the magnitude of the threat—and about the cost-effectiveness of the proposed investments against it—is actually considerably smaller than in the energy/climate case). What have mainly been missing are simply the public understanding and the political conviction that this is a problem to which the nation and the world must now give high priority. Repairing that deficit is a matter of political leadership, and no one is in as good a position to provide it as the new president of the United States.