SEEDS OF OPPORTUNITY:
Climate Change Challenges and Solutions

Prepared for the Civil Society Institute

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EXECUTIVE SUMMARY

It has been said that within every problem lie the seeds of opportunity. Global warming is no exception to that rule. Global warming threatens us with huge economic dislocations, more powerful storms, diseases, catastrophic droughts, dwindling food supplies, unprecedented floods, and vanishing coastal areas. Nonetheless, it does not make sense to look at global warming only as a *risk* … it also presents an *opportunity* for private sector firms and government to find cost-effective ways to mitigate the damage likely to be caused by climate change. There is the potential for earning substantial profits and creating large numbers of productive jobs by focusing on climate change solutions.

There is widespread consensus among the scientific community — and growing recognition by political and business leaders as well — that global warming poses real and increasingly documented risks. For example, the EPA calculates that a one-meter rise in sea level due to global warming could drown 25-80 percent of the U.S. coastal wetlands and inundate 5,000-10,000 square miles of dry land if shores are not protected. By the year 2050, the total worldwide economic costs of global climate change are expected to reach $300 billion per year. According to a UN Environmental Program (UNEP) report published in 2002, "Worldwide economic losses due to natural disasters [including climate-related hurricanes, floods, and droughts] appear to be doubling every ten years, and have reached almost $1 trillion over the past 15 years…. Each year now brings four times as many weather related disasters as 40 years ago…. If current trends persist, the annual loss amount will, within the next decade, come close to $150 billion…"

The opportunities presented by global warming have received less attention and study to date, but there is already evidence that there are major opportunities for business profits and job creation in meeting the rising demand for solutions to global warming. At the high end, it has been estimated that the annual cost of reducing greenhouse gas emissions (GHG) emissions in the U.S. to 3 percent below 1990 levels is as much as $280 billion per year (in 1992 dollars). However, the Intergovernmental Panel on Climate Change estimates that reducing equivalent GHG emissions by about 15 percent of current levels could be achieved by 2010 and 30 percent by 2020 by taking measures that would save enough energy to actually produce *net economic benefits, rather than costs*. For example, UNEP projects that global sales in the market for all forms of renewable energy will reach $234 billion to $625 billion by 2010, and as much as $1.9 trillion by 2020. The market in the U.S. alone is expected to grow 34 percent by 2020. Using renewable energy to meet just 20 percent of U.S. electricity demand would by itself create nearly a quarter of a million jobs in this country by 2020.

Whether or not the United States takes strong action to deal with the problem, many other nations are already in the process of doing so. This report considers five sensible, robust and flexible policy approaches, which can be used individually or in combination to effectively address the problem of global warming in ways that hold costs down and/or increase the return on our investment:

- ✓ "cap and trade" emission reductions;
- ✓ programs to conserve energy while maintaining or improving our standard of living;
- ✓ increased use and further development of renewable ecologically benign energy sources;
- ✓ enhanced greenhouse gas sequestration (storage); and

- ✓ programs that use positive and negative incentives to induce the progress of technologies useful to climate change mitigation.

When it comes to global warming, there is reason to be optimistic. We certainly cannot afford to be complacent, but there is no need to panic. We still have the time to take a measured approach, to roll up our sleeves and build the political will to take sensible, pragmatic actions that will make global warming a problem of the past, rather than a threat to our future.

SEEDS OF OPPORTUNITY
CLIMATE CHANGE: BETWEEN COMPLACENCY AND PANIC

"I recognize that the surface of the Earth is warmer and that an increase in greenhouse gases caused by humans is contributing to the problem."
President George W. Bush (July 2005)

As Hurricane Katrina approached New Orleans on August 29, 2005, it seemed that the catastrophe about which experts had been warning for years was just about to happen. Having narrowly escaped Hurricane George in 1998 and Hurricane Lili in 2002, it looked very much like the city's luck had finally run out. After passing over Florida as a much weaker storm, Katrina drew energy from the warm waters of the Gulf, growing into a monster Category 5 storm with winds of 160 mph, able to lift sea level nearly 30 feet — enough to overwhelm the surrounding levees and inundate the city with 15-20 feet of water.

Suddenly, Katrina veered east toward Mississippi, weakened slightly and slammed into the Gulf Coast at daybreak with winds of 145 mph. Even though New Orleans was spared the full fury of the storm, it was pounded with 100 mph winds and surges of up to fifteen feet of water. Dozens of buildings were toppled and two of the levees were breached, flooding major parts of the city. By that evening, Hurricane Katrina had weakened into a tropical storm, but not before it had devastated the city of New Orleans and demolished much of the Mississippi gulf coast. Hundreds of thousands of people were left homeless, and the death toll was expected to number in the thousands. More than a million people in three states had no electricity, and sections of highways were flooded up to hundreds of miles from the storm's center.

Of the more than $60 billion in weather-related disasters in the U.S. since 1980,[1] Katrina is expected to be at or near the top of the list. Early estimates were that damage from the storm would range from $9 billion to $16 billion dollars; later estimates were far higher. It is now expected that the damage done by Hurricane Katrina will easily surpass even the $21 billion in insured losses that resulted from Hurricane Andrew in 1992.

There is little convincing evidence linking the frequency of killer storms like Hurricane Katrina to human-induced global warming, but more evidence that global warming (and other human environmental impacts) is linked to the growing severity of such storms.[2] The troubling question is, "Was Katrina an aberration or just an early glimpse of things to come?"

UNDERSTANDING THE CLIMATE CHANGE CHALLENGE

Weather vs. Climate. Since it is notoriously difficult to accurately predict the weather in many parts of the world even a week in advance, it is reasonable to ask how it is possible to make plausible predictions about climate change over a span of decades. The answer is that climate is a kind of "average weather", and it is generally much easier to predict averages than the individual numbers from which averages are derived. Insurance companies, for example, have little trouble developing actuarial tables that can dependably predict the average number of eighty year olds who will die within the next twelve months. But it is an entirely different and much more difficult problem to predict which particular eighty year olds will die on which day of the coming year. Although they are short term and closer to the present, weather forecasts are more difficult because they try to predict specific magnitude and timing of temperature, humidity, rainfall, wind direction and strength, etc. Even though climate forecasts are made over much longer periods of time, they are only trying to predict general average temperatures, humidity, rainfall and the like. That is not especially easy to do, but it is easier than forecasting the details of weather.

Climate Change. Climate change occurs when longer term and broader trends cause a shift in the average weather — places that were usually cool become warmer, places that were usually dry get more rain, the intensity and track of storms change, and so on. The atmospheric, terrestrial and oceanic systems that drive the weather, and over the long term the climate, are complex in themselves, and their many-sided interactions with each other only add to this complexity. A levelheaded, objective assessment would recognize that we do now understand these systems far better than we did 100 (or even 50) years ago, but there is still much that we do not completely understand and are unlikely to understand for many years to come. There is thus an unavoidable degree of uncertainty attached to any detailed prediction we try to make about patterns or even trends in climate change.

From a policy point of view, it would be better if we could have complete confidence our predictions as to what will happen and why. But while it would be ideal, we rarely have that degree of certainty in any policy arena. There is still much debate, for example, about how children learn and what teaching techniques and institutional settings work best to educate them. Yet we know we cannot afford to throw up our hands and wait for complete understanding before we try to make policies to improve the quality of their education. We cannot predict with any real degree of certainty when and where the next major terrorist attack will occur, but we all know that we cannot wait until we understand this particularly reprehensible form of aberrant behavior well enough to make such predictions before we take action.

Perhaps it is because the issue of climate change is surrounded by the aura of science that we even think we can nail down all the details and settle this debate before we have to decide what action to take, if any. We have every reason to have confidence in the ability of science to extend the boundaries of our knowledge, but the reality is, it rarely gives us complete answers with perfect accuracy. While scientific research answers some of our questions, it almost invariably raises new ones. And the processes of serious science take time. So we must always ask, can we afford to wait until every detail is settled and everyone is convinced before we take action? Or is a preponderance of evidence good enough?

There is, in fact, a broad scientific consensus on human-induced climate change behind the quote from President Bush at the beginning of this report. The Intergovernmental Panel on Climate Change (IPCC), created by the World Meteorological Association and the UN Environmental Program in 1988, for example, has written, " Human activities… are modifying the concentration of atmospheric constituents… that absorb or scatter radiant energy. …most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations."[3] The National Academy of Sciences clearly agrees, "Greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise."[4] The National Academy's report then goes on to declare, "The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue."[5]

This conclusion is further strengthened by an analysis of 928 abstracts in relevant refereed scientific journals with the key words "climate change" reported in an essay in Science magazine. The survey revealed that 75% of the papers either implicitly or explicitly accepted the consensus view that climate change is at least partly human-induced, and the remaining 25% took no position at all on the issue. Not a single paper disagreed.[6] The real scientific debate is over how much and how fast global warming will increase as a result of human activity, not whether human activity contributes to global warming.

Global Warming and Climate Change. The terms "global warming" and "climate change" are often used interchangeably, but they are not actually the same thing. Global warming refers to the rise in average global temperature. Climate change refers to changes in the long-term average weather patterns. It includes changes in either the regional or global patterns of temperature, humidity, precipitation, wind, and so on. Global warming is a narrower concept than climate change, but the two are organically connected. Global warming provides more energy to the processes that drive the wind patterns and ocean currents, key forces that determine the long-term weather.

Higher ocean temperatures, for example, are more conducive to hurricane formation than lower temperatures. Warmer temperatures tend to fuel the winds and increase the rains (and therefore the flooding) associated with these storms. More generally, atmospheric temperature differences (which are influenced by the amount of heat rising from the surface of the land or water, as well as by solar radiation) create pressure differences that affect wind patterns, and wind patterns are very important in determining where rain falls and where it does not.[7]

Why Is Climate Change a Problem? Current average global temperatures are now about 0.8°C (1.4° F) above what they were in pre-industrial times. The 2001 IPCC projections of the rise in average temperature likely by the end of this century (2100) range from 1.4°C (2.5°F) to 5.8°C (10.4°F).[8] If this meant that every place on earth would be only a few degrees warmer every day than it is now, this slight change in climate (especially at the low end of these estimates) wouldn't make such a big difference. The problem is that this small average global increase does not represent a slight uniform change everywhere, but much greater changes in individual temperatures and their variation from place to place and over time that average to what looks like a small number. For example, a year that was only a few degrees warmer than usual might be a year with many more extremely hot summer days, along with some winter days than were much colder than normal. Especially when we are averaging temperatures across the whole Earth, averages can hide a substantial amount of variability from place to place and time to time.

Because of this, even small average changes in climate can have dramatic effects on the physical environment (e.g. wind patterns, rainfall, storms) that in turn have powerful impacts on the biological environment — the change in global average temperature between the peak of the last ice age 25,000 years ago and today was only on the order of 5°C (9°F).[9]

Since it is so central to their business, insurance companies can usually be counted on for a sober assessment of risk. A recent study by the Association of British Insurers concluded that there did seem to be a link between climate change and the intensity of extreme weather patterns that have been so costly to the industry lately. They argued that if this trend continued, it could well raise the costs of providers of hurricane insurance in the U.S. to $100-$150 billion by 2080, a 75 percent increase.[10]

The ecology of the planet consists of a complex web of interdependent physical and biological systems. It is a matter of fact, not opinion, that our lives literally depend directly and indirectly on these systems. When climate changes, the balance of these systems is disrupted. Although it is difficult to predict all of the detailed implications of this disruption, it cannot help but have powerful effects on us. Later in this paper, we will lay out in general terms the nature of the impacts that significant ecological change provoked by changing climate is likely to have on our lives.

Greenhouse Gases (GHGs) and Global Warming. Radiant energy in the form of sunlight easily passes through the glass of a conventional greenhouse. When it hits the floor, the plants, the soil, etc. inside the greenhouse, part of it is reflected as light, which passes easily back through the glass. But part of the sunlight's energy is also absorbed and re-emitted as heat. While the glass ceiling and walls of the greenhouse are transparent to light, they are not nearly as "transparent" to heat.

Much of the heat therefore remains trapped, raising the temperature inside the greenhouse.

As so-called "greenhouse gases" (GHGs) accumulate in the atmosphere, they have an effect similar to the glass of the greenhouse, allowing light to pass easily through but trapping heat. The heat that they trap is partly heat that has been produced by the sunlight's warming of the earth's surface, and partly heat that has been generated by other activities within the biological and physical environment of the earth — including heat produced by human activity.

There is nothing unnatural about this process. In fact, it is vital. If it were not for the greenhouse effect of the Earth's atmosphere, the average temperature of the earth would be -18° C (0°F), rather than the current average temperature of +15° C (+ 59° F), and life as we know it could not exist on this planet.[11] The problem is that when too much of these gases accumulates in the atmosphere, there is too much trapping of heat. This causes global warming, which in turn changes the climate with all the problems that implies.

Natural and Human GHG Sources and Sinks. Most greenhouse gases are produced even in the absence of human intervention. The main naturally occurring GHGs are:

- water vapor, the natural result of the evaporation phase of the hydrological (water) cycle that is vital to life on this planet

- carbon dioxide (CO_2), the natural waste product of plant and animal respiration, and a crucial input to photosynthesis, the foundation of the food chain

- methane (CH_4), emitted as the result of the decomposition of dead organisms and organic waste

- nitrous oxide (N_2O), emitted from the microbial breakdown of animal and human waste

Other GHGs include perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6), all of which are the results of various industrial processes.[12]

Even the naturally occurring GHGs are also produced as the result of human activity: carbon dioxide is a major byproduct of the combustion of oil, coal and natural gas, the so-called "fossil fuels"; methane is emitted in the production and transport of fossil fuels, as well as by agricultural processes; and nitrous oxide is produced by both agricultural and industrial activities.

Although most greenhouse gases occur naturally, before the Industrial Revolution, there was a relative balance between the huge amount of carbon dioxide emitted from natural sources and the amount absorbed by natural "sinks" (systems or processes that prevent its release to or remove the gas from the atmosphere). Since that time, human activity has put something on the order of twice as much CO_2 into the atmosphere (chiefly by burning wood and fossil fuels) as remaining natural sinks have been easily able to remove. By some estimates, atmospheric levels of CO_2 are now the highest they have been in 420,000 years.[13]

The forests and other land and sea-based photosynthetic plant ecosystems are very large and important carbon sinks. That is one of the reasons why global deforestation and pollution of the oceans is a matter of real significance for the problem of global warming. There is, in fact, a large carbon sink within the contiguous U.S. that is very much affected, among other things, by processes of land use (such as land clearing and logging) and fire management. Projecting the future of the U.S. carbon sink, a study published by the National Academy of Sciences concluded, "without dramatic increases in the area of forests, without substantial positive changes in land-use practices, [etc.]… the U.S. carbon sink will decrease substantially over the 21st century. … Total U.S. fossil fuel emissions would need to be reduced by an additional 7%-30% to compensate for the declining sink" The study went further, arguing that if fire suppression efforts were a complete failure, the land-based ecosystems of the U.S. would turn into a source of carbon to the atmosphere, rather than a sink, during the whole 21st century because of "extensive burning from large-scale fires".[14]

Climate Change as a Problem

By the year 2050, according to the Worldwatch Institute, the total worldwide economic costs of global climate change are expected to be $300 billion per year.[15] But using models developed by both the Goddard Institute for Space Studies and the Princeton Geophysical Fluid Dynamics Laboratory, James Titus of the U.S. EPA estimated that the costs of a doubling of carbon dioxide levels to the United States alone, would be from $37 billion to $351 billion per year by 2060, depending on the model used and the scenario followed.[16] This illustrates two important points: first, that climate change is likely to impose very substantial economic costs on the U.S. and the wider world; and second, that there is considerable uncertainty as to exactly how large those costs will be. There is, however, much more agreement on the pathways through which costs, economic and otherwise, will be transmitted. We look at the more important of these pathways in turn.

Health Impacts. Climate change can directly affect human health by increasing the rate of heat and cold-related illnesses and death, and increasing the frequency and/or intensity of violent storms and other extreme weather events (such as floods and drought). It can also affect human health indirectly, through its impact on food supply and patterns of disease. In the U.S. and beyond, all of these effects are likely to fall more heavily on the poor, who live in more difficult conditions and have less of a buffer against adversity (as we have seen with great clarity in the aftermath of Hurricane Katrina). But it would be foolish to see the potential health impacts of climate change only as a problem of poverty.

It is not surprising that the number of heat-related deaths is more sensitive to weather changes than is cold-related mortality. Clothing and some form of heating system are cheaper and easier to come by than air conditioning. Although twice as many people die from hot weather as from cold weather each year in the U.S,[17] it is a relatively minor cause of death (about 2000 people per year).[18] Unless the seasonal temperature variations caused by global warming become very extreme, this situation is not likely to change radically.

More troubling is the potential health impact of the spread of infectious disease that is likely to result from unmitigated climate change. The World Health Organization has argued that among the first climate change-related impacts on human health will be changes in the geographical range and seasonality of certain infectious diseases. This includes both illnesses borne by vectors (organisms that carry disease-causing microorganisms from one host to another) such as malaria and dengue fever, and food-borne illnesses such as salmonellosis, both of which tend to be more common in the warmer seasons.[19] Although the effect on the populations of countries with less well-developed systems of public health is likely to be greater, these problems will certainly not bypass the U.S., with potentially large effects on public health costs.

The principal vector-borne diseases that currently threaten people living in the U.S. are transmitted by mosquitoes (e.g. West Nile virus), ticks (e.g. Lyme disease) and fleas (e.g. plague). Studies have shown that climate is important in the life cycle, survival and behavior of these hosts that is vital to the development and transmission of the disease-causing microorganisms they carry. Global warming is expected to increase the likelihood that infectious diseases, as well as diseases that are primarily transmitted by insects such as mosquitoes, will increasingly be experienced in more northern locations of the hemisphere.[20] Together with temperature changes, changes in rainfall amounts may contribute to increases in insect and even rodent populations that will in turn enhance the prevalence and spread of water and food-borne diseases.[21]

Even if we do all the right things to protect the U.S. population, the reality is there is so much movement of people and goods in this globalizing world that disease can spread almost before we know what has happened. The SARS virus, for example, contracted in China in 2003 became, with alarming speed, a threat to the health of people living in Europe and North America. According to the World Health Organization, more than 30 new diseases have emerged since the mid-1970s, along with new drug-resistant forms of old diseases such as tuberculosis we once thought we had completely under control.[22]

On the other hand, it is also possible, that some of the changes in climate will actually help to suppress some forms of disease or the vectors that transmit them, at least in some parts of the country. And if there is sufficient investment in public health, the U.S. should be able to avert the worst health consequences of global warming. But, although it is difficult to estimate the precise cost of the investment required to protect even the most vulnerable, it will certainly not be cheap.

Finally, some of the greenhouse gases that contribute to global warming are also air pollutants that have negative effects on health.. Nitrogen oxides, for example, are not only heat-trapping gases, they are key ingredients of smog.[23] Furthermore, in the lower atmosphere, sunlight breaks molecules of nitrogen dioxide (from automobile exhaust and industrial pollution) into nitric oxide gas and single atoms of oxygen that combine with free oxygen in the air to create ozone. Volatile organic compounds (also from automobile exhaust and industrial pollution) convert nitric oxide back into nitrogen dioxide, which sunlight then breaks apart again, generating still more ozone.[24] While ozone high in the atmosphere (stratospheric ozone) protects the Earth against dangerous ultraviolet light from the sun, ozone that is near enough to the ground to be breathed can damage lung tissue, increase sensitivity to other irritants, and reduce lung function (especially troubling for asthmatics), causing chest pain, congestion and coughing.

Impacts on Agriculture. Agricultural productivity is especially sensitive to a number of the changes that are projected to result from global warming. Crops are generally more sensitive than animals. Variations in temperature, especially unseasonable variations — for example, unusually cold days during critical parts of the normally warm growing season — can substantially reduce crop yields. Plants are more affected by higher concentrations of CO_2 in the atmosphere as well, though in this case the effect seems to be positive: their growth is actually stimulated by it. In the absence of irrigation systems, barring extreme weather events, crops are also especially sensitive to precipitation. Because a warm air can carry more water, the IPCC's 1996 report projected that the global warming that would be expected from a doubling of CO_2 would increase precipitation by 10%-15%, on average.[25] Since global warming shifts wind and rainfall patterns, it is not difficult to predict that it will also change where (and when) the precipitation falls — a critical matter for agriculture.

Grain is a particularly important part of the world's food supply, accounting for more than half of all the food calories consumed. The IPCC report estimated the effect of climate change on grain production using a number of different computer models of global climate change. Even taking the fertilization effect of increased CO_2 into account, not just temperature and precipitation changes, the IPCC estimated that world grain production would still fall slightly (between 1%-8%) by 2100. However, because the warming effect would extend growing seasons in more temperate latitudes but not in the tropics, grain production in the more economically developed countries (which are mainly in the temperate zone) could increase by as much as 11%, while output in the developing countries (which are mainly in the tropics) could fall by as much as 13%.[26]

This is especially striking, because more than 90% of the increased demand for food is likely to come from the less economically developed countries (where population growth is still high) in the next three to four decades.[27] When IPCC models also took account of possible "ambitious adaptation" by farmers to climate change, they forecast a gain of up to 14% for developed countries, but still projected a significant though smaller decline of up to 7% for the developing world.[28]

Working with the UN's Food and Agricultural Organization (FAO), the International Institute of Applied Systems Analysis (IIASA) came to essentially the same conclusions. "[O]n average, industrialized countries stand to make substantial gains in production potential, while developing countries are expected to lose. In the developing world, climate change would lead to an increase in lands that are arid and lands experiencing moisture stress… [leading to] an 11% decrease in cultivable rainfed land, with consequent decline in cereal production."[29] These results were not uniform throughout the developing world. For example, although India was projected to experience an 18% decline in rain fed cereal output, China was projected to gain 15%. In Africa, a continent that has had more than its share of food security problems, some 29 countries would lose about 35 million tons of cereal production.[30]

Aside from humanitarian concerns, there are at least three reasons why U.S. agriculture should not celebrate these results. The first is that these projections do not take into account the potential spread of animal and plant diseases and pests, which is likely to be provoked by global warming for the same reasons given in the discussion of human health. Temperature increases can speed up the growth rates of insects and plant pests, decreasing their mortality in winter at the same time they are affecting the crops themselves in ways that leave them more vulnerable.[31] We need to be concerned about the effect of the spread of animal diseases on agriculture as well. Losses to agriculture resulting from foot and mouth disease, mad cow disease, swine flu and more recently, bird flu have been in the billions of dollars — and they were most certainly not confined to the less developed countries. Some diseases of farm animals have also shown a disturbing tendency to jump species and infect people. Mad cow disease has been implicated in producing Jakob-Creutzfeldt disease in humans, and the virus that causes virulent bird flu has also infected people.

The second reason is, while general climate change projections are reasonable sound, it is extremely difficult to predict the details of exactly where and when the extra rain that is projected to help U.S. crops grow will actually fall within the country. If the forecasts are a bit off and the change results in a lot more rain along the Boston-Washington corridor and a lot less in Kansas and Nebraska, the same total U.S. rainfall will have very different implications for American agriculture.

Finally, some of the most important "ambitious adaptations" in agriculture that are needed to adjust to global warming could be quite expensive. Yes, changing planting time and harvest time to adjust to a longer growing season will not cost much, but the investment in research required to understand all the downsides of global warming for agriculture and develop technologies (e.g. new pest control techniques) to deal with them may not come cheap. And some of the equipment and supplies needed to make the necessary changes in agricultural practices may not only be expensive, but may have costly environmental implications. In the end, these adjustments may prove to be more or less costly. Still, this adds yet another element of uncertainty to thinking realistically about climate change.

Impacts on Severe Weather. According to a UN Environmental Program (UNEP) report published in 2002, "Worldwide economic losses due to natural disasters appear to be doubling every ten years, and have reached almost $1 trillion over the past 15 years…. Each year now brings four times as many weather related disasters as 40 years ago…. If current trends persist, the annual loss amount will, within the next decade, come close to $150 billion…"[32]

There is no doubt that human-induced global warming affects weather patterns, and little doubt that it plays some role in the patterns and severity of drought and floods, since it clearly does affect rainfall. But there is still an unsettled and ongoing scientific debate as to just what effect it has in generating the most severe and violent storms, hurricanes and tornadoes.

For example, a paper accepted in late August 2005 for publication in the Bulletin of the American Meteorological Society concludes, "the significance of any connection of human-caused climate change to hurricane impacts necessarily has been and will continue to be exceedingly small". But Kerry Emanuel, a noted atmospheric physicist from MIT who had helped write that paper, withdrew his name from it and instead published the results of a new study he had done that came to essentially the opposite conclusion in Nature that same month. Emanuel found that the power output of storms in the Atlantic and western North Pacific cycled up and down over the decades since 1930, but shot upward 30 years ago. Although he cannot be sure, he now believes global warming may very well be the reason why.[33]

In mid-September 2005, meteorologist Peter Webster of Georgia Tech and his colleagues reported the results of their study of satellite records of tropical storms around the world from 1970-2004. They found no long-term trend in the number of storms, but a dramatic increase of nearly 80% in the number of category 4 and 5 hurricanes. In this same 35 year period, global warming had raised sea surface temperatures worldwide 0.5°C (0.9°F).[34] Of course, correlation is not the same as causation. The fact that sea surface temperatures rose due to global warming at the same time that storm intensities increased certainly does not prove that global warming has caused hurricanes to become more powerful. But this pattern is consistent with that predicted by recent climate model simulations (and with the pattern Emanuel observed). So it is quite possible that global warming may be the culprit.

In the 25 years between 1980 and 2004, there were 62 weather-related disasters in the U.S. that did at least $1 billion worth of damage. These events included hurricanes (and tropical storms), tornadoes, snow and ice storms, wild fires, floods, and droughts. Hurricanes were far and away the most frequent, accounting for about 30% of the disasters. But the most damaging of these events by far was not a hurricane; it wasn't even a storm. It was the killer drought and heat wave that gripped the central and eastern U.S. in the summer of 1988, doing nearly $62 billion worth of damage and taking the lives of 5,000-10,000 people. Hurricane Andrew (1992) did the second most damage, almost $36 billion, and took 61 lives. The third most damaging event was the Midwest flooding due to persistent heavy rains in the summer of 1993 — close to $27 billion of damage and 48 deaths. (Some 17% of all the urban land in the U.S. lies within the 100-year flood plain).[35] The total money-valued loss from these 62 major disasters was more than $390 billion.[36]

The Association of British Insurers (ABI) concluded recently that climate change was probably helping to intensify the extreme weather patterns that in the past few years have produced heavy insured losses. In June 2005, ABI issued a report on the financial risks associated with climate change. Based on IPCC's scenarios, the report indicated that by 2080, insured losses from hurricanes in the U.S. could increase by as much as 75% ($62 billion) over present losses. Under the high emissions scenario (CO_2 levels double), insurer's capital requirements could increase by more than 90%. If emissions were controlled enough to match the low emissions scenario, increased losses from U.S. hurricanes would be 80% lower than under the high emissions scenario, saving $35-$50 billion per year — the equivalent of avoiding one to one-and-a-half Hurricane Andrews per season.[37]

Impacts on Water Resources and Sea Level Rise. Global warming affects many aspects of the global water cycle: cloud characteristics, rainfall, soil moisture, patterns of snowfall and snowmelt, the rate at which water evaporates from the Earth's surface, and the rate at which it is released to the atmosphere by plants (transpiration). Transpiration rates are also increased by the higher CO_2 levels that contribute to warming, because they increase plant growth. About a third of the 25 billion metric tons of carbon dioxide released into the air by burning fossil fuels each year is absorbed by the ocean, according to a report by Britain's leading scientific organization (the Royal Society). It is turning ocean water more acidic, damaging plankton, and disrupting the food chain.[38]

Many of the expected changes in the water cycle will affect U.S. water resources directly by altering total availability, and more importantly, by changing the quantity and quality of water available to different regions of the country. In general, the northern U.S. is likely to have more precipitation and runoff, while the southern U.S. is expected to have less. Changes in seasonal patterns within regions are also likely. For example, areas where snow falls, such as the Rockies and the Sierra Nevada, are expected to have greater runoff in winter and early spring, and less in late spring and summer. Changes in the amount and timing of runoff affect not only water supply, but also river navigation, hydropower and aquatic ecosystems. The semi-arid and arid western parts of the U.S. might see greater drying of soils during the growing season and perhaps more variability in water supply. But there is also a risk that other changes due to global warming, such as the expected rise in sea level, will indirectly affect regional water supply by increasing the intrusion of saltwater into freshwater aquifers along the coasts, in places like Cape Cod, Long Island, central coastal California, Hawaii, and Florida.[39]

It has been estimated that additional costs imposed by climate change on the water industry alone could reach $47 billion per year by 2050.[40] But there is considerable uncertainty in such estimates, because the details are hard to predict and the details make a very big difference to projections of economic costs. For example, using the least-cost management scenario, the Canadian climate change model projects much higher annual costs of meeting water demands in the contiguous U.S. — $105 billion. On the other hand, the so-called Hadley2 model projects that climate change will actually cause these costs to be $5 billion lower than they would be without climate change.[41]

It is by now well accepted that higher global temperatures will cause increased melting of glaciers that will lead to a rise in sea level.[42] This is already happening. In Antarctica, for example, warmer temperatures seem to be causing melt water to penetrate deeper into ice crevices, weakening enormous ice formations that have been built up over thousands of years. Huge glaciers in various parts of the continent are thinning and ice shelves "the size of American states" are either falling apart or retreating.[43]

In 1995, the Larsen A ice shelf collapsed; in 1998, the Wilkinson ice shelf also disintegrated. In a period of about a month in early 2002, the Larsen B ice shelf lost more than 25% of its total mass, launching thousands of icebergs into the Weddell Sea.[44] But global warming is also causing additional snowfall in the East Antarctic icecap, an area in which it was previously too cold to snow. The snow is causing the ice sheet to grow about enough to offset the roughly 45 billion tons of water flowing into the ocean each year as a result of the melting Greenland icecap.[45]

When the ice in land-based glaciers (or their melt water) flows into the sea, it increases the volume of water. Unless this flow is offset by another process (such as increased evaporation) that is removing as much or more water, the sea level naturally rises). An EPA sponsored study suggests that there is a 50% chance that global warming will cause as much as a 20-inch rise in the sea level at Miami Beach, a 25-inch rise in Charleston, South Carolina, and a 55-inch rise for Grand Isle, Louisiana (about 50 miles south of New Orleans).[46]

Not only does sea level rise increase intrusion of saltwater into low-lying coastal freshwater supplies, it puts people living in low-lying coastal areas at greater risk from storm surge. The third IPCC assessment projected that storm surge flooding will affect double or triple the number of people in the next century.[47] It also changes the critical saltwater-freshwater mix of estuaries. In some coastal areas of the country, the species on which commercial fishing depend inhabit these on estuaries, and more than 90% of these species are very sensitive to this mix.[48]

According to the EPA, global warming could cause sea level to rise by 0.5 meters (20 inches) to 2 meters (6.5 feet) by 2100. A 1-meter rise could drown 25%-80% of the U.S. coastal wetlands and inundate 5,000-10,000 square miles of dry land if shores were not protected. The capital costs of protecting developed areas at risk against such inundation and erosion by building bulkheads and levees, pumping sand and raising barrier islands could be $73-$111 billion by the year 2100. The EPA estimates that the Southeast U.S. would most likely suffer 90% of the land loss and bear 66% of shore protection costs.[49]

Ecological Impacts. The first of the four major findings of the recent Millennium Ecosystem Assessment Report is that "Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable time in human history."[50] The report goes on to say, "Humans are fundamentally, and to a significant extent irreversibly, changing the diversity of life on earth, and most of these changes represent a loss of biodiversity."[51] A 2002 report of the National Research Council points out (citing earlier biodiversity studies), "[R]ecent research suggests that the rate of species extinctions is on the order of 100 to 1000 times higher than before humans were dominant.... For example, over the last two millennia, one-fourth of all bird species are believed to have gone extinct as a result of human activities".[52]

Clearly, people have impacted the ecosystem in many different ways; global warming is only one of them. Nevertheless, part of the human impact on the global environment is a result of greenhouse gas (GHG) emissions and, as the Millennium Ecosystem Assessment Report points out, about 60% of the increase in atmospheric CO_2 since 1750 has occurred within the past 50 years.[53]

It is difficult to separate out the ecological effects of the increase in CO_2 and other greenhouse gases from those of other sources of human-induced ecological change, since the ecology is, almost by definition, a complex intensely interconnected system. Still, it is clear that global warming works with these other sources of change to alter the environment. For example, heavy commercial fishing is no doubt the most important factor in driving some aquatic species to the edge of extinction. But a recent study of Europe's heavily fished North Sea concluded that the warming of its waters over the past 25 years has driven indigenous fish populations northward and to greater depths. As a result, the North Sea's ecosystem is changing in ways whose effects on commercial fishing are difficult to predict.[54]

The effect of rapid climate change on biodiversity is a major concern, although various plant and animal species have shown a greater ability to adapt to past climate changes than was at first thought likely. Ice core records extracted from Greenland and Antarctica in the 1990s showed considerable variability in climate over the past 200,000 years. "Yet biodiversity has survived these past rapid changes largely intact. There is no reliable record of mass extinctions in the Pleistocene."[55] Range shifts (movement to habitats in new places), rather than genetic changes, seem to have been the main mechanism for surviving dramatic changes in climate over very long periods of time.

The migration of plant and animal species to new areas is now hampered by human activities that have destroyed or fragmented new habitats and/or blocked the routes that might have made these habitats more accessible in the very distant past. The fragmentation or outright destruction of habitats has also reduced the number of individuals, making the species less viable. According to Thomas Lovejoy and Hannah Lee, "…the potential for rapid response is greatly constrained by habitat loss… both rapid genetic response and range shifts are jeopardized…. In human dominated landscapes, natural habitat may remain as small fragments, implying small populations of resident species which lose genetic diversity"[56]. It is extraordinarily difficult to isolate the effects of climate change on biodiversity. Its effects are therefore best understood in combination with those of other human-induced stresses, such as habitat destruction and environmental pollution.

Biodiversity as such is not the only relevant ecological issue. According to UNEP, not only could about 3°C - 4°C (5.4°F – 7.2°F) worth of global warming eliminate 85% of all remaining wetlands, it could cause the permafrost in arctic habitats to thaw, releasing vast stores of additional GHGs trapped in the soil. By this route, the global warming could make itself worse.[57] Researchers studying western Siberia have found that an area of permafrost the size of France and Germany combined has already begun to melt — for the first time in 11,000 years. The entire sub-Arctic region of western Siberia is one gigantic peat bog, and as it thaws it could release billions of metric tons of methane into the atmosphere. Methane, produced as a result of the decomposition of organisms and organic waste, is a much more potent GHG than carbon dioxide. It would most likely take many decades for the Siberian permafrost to thaw, and therefore for all that methane to be released. But climate scientist Stephen Sitch and his colleagues have calculated that even if it took 100 years, it would still add 700 metric tons of carbon to the atmosphere per year. That's about as much carbon as is released each year from all the world's wetlands and agriculture. By itself, this could increase global warming by 10%-25%.[58]

Siberia is not alone in this. According to a 2004 report prepared for the Pew Center on Global Climate Change, "The Alaskan tundra has already experienced much stronger warming trends than the rest of the United States. At some point, as deeper layers remain above freezing, the rate of decomposition of dead matter will exceed the rate of plant growth, and the tundra will turn from a net sink to a net source of CO_2. … [D]uring 1983-1987 and 1990, the tundra across the North Slope of Alaska was acting as a source of CO_2 to the atmosphere, instead of the sink it had been."[59]

CLIMATE CHANGE AS AN OPPORTUNITY

It has been said that within every problem lie the seeds of opportunity. That is certainly true of climate change. There are opportunities for building international cooperation and goodwill by addressing this global concern, both of which are very helpful in dealing with a variety of U.S. concerns around the world. But there are also enormously profitable opportunities for business and for job creation in meeting the rising demand for solutions to global warming.

At the high end, estimates of the annual cost of reducing GHG emissions in the U.S. to 3% below 1990 levels have been as much as $280 billion per year (in 1992 dollars). Estimates this high are typically the result of worst-case assumptions, such as limited use of non-carbon fuels and the absence of any mechanism for emissions permit trading. More importantly, they often do not offset against the cost of mitigation, the cost of the damage caused by doing nothing.[60]

More realistically, a U.S. Department of Energy study in 2001 showed that a combination of measures, such as increased research and development, wider use of cogeneration and greater use of renewable energy, could reduce carbon emissions to 13%-17% below "business as usual" scenarios by 2010 *without any net cost* to the U.S. economy.[61] That same year the IPCC estimated that reductions in equivalent GHG emissions of about 15% of current levels could be achieved by 2010 and 30% by 2020 by taking measures that would save enough energy to actually produce *net economic benefits, rather than costs*.[62]

There are basically three key strategies for dealing with the climate change problem without compromising standards of living: 1) shift to environmentally benign energy sources; 2) conserve energy; and 3) increase carbon sinks. Each one of these approaches opens the door to enormous potential profits and very large amounts of job creation in developing effective new technologies, and producing, installing and maintaining the equipment needed to put them into use. Growing numbers of American venture capital firms, many of them in California, are just beginning to respond to these opportunities. Ira Ehrenpreis, a hard-nosed venture capitalist and co-chair of the Cleantech Venture Network advisory board put it this way, "The reason we're allocating dollars to this sector is we think we can deliver attractive returns. It's not because we want to do great things for the environment or great things for the world."[63]

Venture capitalists know that getting in the game early is the key to getting a high rate of return. But venture capitalists are used to taking higher than normal risks, and any new business based mainly on long-term projections rather than ongoing experience must be considered inherently risky. Without attempting to eliminate normal business risk, the right kinds of government policies could play an important facilitative role here, helping to create the conditions that would encourage the private sector to use its ingenuity to overcome the inevitable obstacles and go after these potentially profitable new business opportunities worldwide.

Government Action and Market Expansion. Many national governments are committed by treaty to achieving agreed targets for reducing GHG emissions. (For example, more than 150 countries have signed the Kyoto agreement.) Late last spring the government of Japan introduced new measures to urge its citizens to buy hybrid vehicles and still more energy efficient appliances. In Germany, a new law aimed at saving energy set housing design standards intended to reduce home heating fuel consumption to one-third the amount consumed by a typical house built in the early 1970s.[64]

Led by rapid growth in India and China, the developing countries as a whole are going to need a great deal of investment in infrastructure, not the least of which will be energy-related. The UNEP study projects that, taken together, the developing nations will need between $1.7 trillion and $4 trillion worth of capital investment for new power generation by 2020. To achieve its goal of satisfying half of its energy needs with renewables, Europe will also need to undertake an estimated $90 billion -$135 billion worth of capital investment by 2050.[65] All this represents an enormous opportunity for American business.

In the U.S., state and local governments have increasingly taken the lead in introducing policies aimed at addressing the problem of global warming in general and GHG emissions in particular, within their limited political jurisdictions. For example, power plants and motor vehicles are among the most important human-based sources of greenhouse gases. In September 2004, the State of California adopted regulations which would require a roughly 30% reduction in automotive emissions of CO_2 and other GHGs by the model year 2016. By late November 2005, ten other states (including New York, New Jersey, Massachusetts and Pennsylvania) — representing about one-third of the nation's auto sales — had either adopted or were in the process of adopting the California rules.[66] On December 20, 2005, after two years of negotiations, seven states in the Northeastern U.S. (New York, New Jersey, Connecticut, Delaware, Maine, New Hampshire and Vermont) came to an agreement to freeze power plant emissions within their region now, and reduce them 10% by 2020. California, Washington and Oregon were exploring a similar regional agreement.[67] A few months earlier, Republican and Democratic mayors, representing 29 million Americans from 132 cities around the U.S. (including New York City, Los Angeles, Seattle, San Francisco, Salt Lake City and New Orleans), pledged to meet the Kyoto Protocol's requirement to reduce emissions of GHGs by 2012 to 7% below 1990 levels.[68]

Seeing a solid economic development opportunity with considerable growth potential, state and local governments have also taken action to encourage the expansion of industries whose products are critical to mitigating human-induced climate change. There have been a variety of types of initiatives, the two most popular being so-called "public benefits funds"(PBFs) and "renewable portfolio standards"(RPSs).

Public benefits funds are pools of money accumulated from small charges added to customer's electricity bills. As of 2003, 15 states had some form of PBF, fourteen of them relying on mandatory charges, and one (Maine) allowing only voluntary contributions. There is, of course, some variability in just how these moneys are used, but they typically pay for rebates on renewable energy systems, promotion of renewable energy or energy efficiency initiatives, support programs for low income energy users and, perhaps most importantly, funding of renewable energy research and development. Considered something of a model, California's program created a $540 million fund, 45% of which was used to support existing renewables projects in the state, 30% for bringing on line new renewable technology projects, 10% for encouraging emerging technologies (such as fuel cells) and 15% for rebates to consumers buying "green power".[69]

Renewable portfolio standards are regulatory mandates, requiring that at least a specified fraction of an electric utility's capacity or sales come from renewable sources. The RPS may apply to the utility's total capacity or sales, or only to new capacity or sales. Here Texas is considered something of a model. Established by law signed in December 1999 by then-Governor George Bush, the Texas RPS established renewable energy purchase requirements for all suppliers of electricity in the state, and a renewable energy credits trading program that provided incentives (similar to those created by emissions trading) for further renewable power generation. The RPS has been successful largely because it made the requirements high enough and the penalties for noncompliance great enough that the market for renewable energy grew considerably, creating profitable opportunities that attracted renewable energy suppliers[70].

Through both positive incentives, such as those provided by PBFs, and regulatory pressures, such as those created by fuel economy standards and RPSs, government can stimulate technological development with the potential for giving American business a competitive edge in the rapidly growing global market for climate change mitigation processes and products. Technological development has historically been a key driver of economic growth in the U.S., and government has been an important facilitator of technological development. As a joint report of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine pointed out in 1992,
"the U.S. government played an important role in facilitating investment, stimulating R&D and technology generation, and promoting technology adoption in sectors [of the civilian economy] such as commercial aerospace, agriculture, energy, and health care.... Indeed, in aircraft, high-performance computers, and agriculture, the federal government had a direct role in the creation of industries that today dominate world commerce and generate export surpluses for the United States."[71] There is every reason to believe that government encouragement of climate change-related technological development will fit neatly into this historical pattern.

In addition to directly funding key research and applying regulatory pressure, government can also facilitate the development and deployment of new growth stimulating technologies by simply providing a "seed market", a market that gives private sector producers a place to ease into an important, potentially profitable new market that might otherwise seem too risky to enter. A seed market can also gives risk-averse customers a chance to see how well the new product works in practice, so that they feel comfortable entering the market as buyers. As Alic, Mowery, and Rubin remind us, "Government procurement during World War I transformed an infant aircraft industry that had produced a cumulative total of only a few hundred planes; by the war's end, U.S. firms had manufactured some 14,000 planes, with much concomitant learning".[72]

Federal procurement, as well as R&D support, was also critical to the creation and extended predominance of the U.S. computer and semiconductor industries. According to the 1992 report of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine: "In the 1950s and early 1960s, government military purchases of semiconductors… aided the development of the U.S. semiconductor industry. Through R&D and procurement programs, federal assistance to private R&D projects helped to lower production costs through subsidization of manufacturing test and production facilities…. The federal government [also] played an important, direct role in the commercial development of the computer industry. Clearly, much of the success of this involvement can be attributed to government procurement practices, which helped insure a market for products…"[73]

As of 2003, 16 states had some form of "green purchasing" program at the state or local level. These programs typically require that government buildings buy (or generate) a certain percentage of the electric power they use from renewable sources.[74] They can also include requirements for more energy efficient and/or environmentally benign design of the facilities and equipment they purchase. This is an area where city governments can easily get into the act as well. The city of Portland, Oregon, for example, has held GHG emissions in 2004 to a level only slightly above those in 1990, despite rapid economic and population growth, by encouraging a series of public and private initiatives. These include purchasing more than 10% of the electricity used by the city government from renewable sources, adding two major light rail lines, achieving a 54% recycling rate, constructing almost 40 high-performance "green buildings", and planting over 750,000 trees and shrubs since 1996.[75] Local governments can also boost the market for renewable energy by using "green power" for streetlights, water pumping stations and the like.

Considering past successes in providing seed markets and the magnitude of current federal civilian procurement, a federal government equivalent of these state and local green purchasing programs could be expected to boost U.S. industrial competitiveness in climate change mitigation. It would create a market large enough to encourage the private sector R&D and investment necessary to achieve the scale of operations and experience that would help make American made climate change mitigation products attractive in price and quality to ordinary non-government customers. That is the classic economic role of a government seed market. It would also give American business a competitive edge in satisfying the large and growing foreign demand for climate change related technologies. Such an approach therefore makes economic sense independent of prevailing federal attitudes as to appropriate American policy on global warming.

Creating American Jobs and Stimulating the U.S. Economy. As state, local and national governments here and around the world put pressure on and create incentives for businesses and consumers to take actions that result in lowered GHG emissions, they will help build very large and profitable markets for clean energy technologies and equipment. Nowhere is this combination of environmental benefit and economic potential clearer than in the area of renewable energy. Wind power generation, for example, has been the fastest growing power source, growing by some 20% per year (through 2003). Given the energy market share projected for wind power by 2020, it should be producing sales of $150 billion to $400 billion worldwide by then, according to a study prepared for UNEP. The same study projects that global sales in the market for all forms of renewable energy will reach $234 billion to $625 billion by 2010, and as much as $1.9 trillion by 2020. The market in the U.S. alone is expected to grow 34% by 2020.[76]

After thoroughly analyzing thirteen independent reports and studies on the economic and employment impacts of clean energy in the U.S. and Europe (and developing their own model), Kammen, Kapadia and Fripp of the University of California conclude, “The renewable energy sector generates more jobs per megawatt of power installed, per unit of energy produced, and per dollar of investment than the fossil fuel-based energy sector.” The differences are not small. Comparing a scenario using renewable energy to meet 20% of U.S. electricity demand with a “fossil fuels only” scenario, they estimate that renewables would create between two and three times as many jobs by 2020 — close to a quarter million jobs.[77]

The 2004 Apollo Jobs Project investigated the impact of federal support for renewable energy as part of a more comprehensive 10-year federal program to encourage energy diversity and promote high performance buildings, among other investments. The renewable energy component alone was projected to create nearly half a million jobs.[78]

Interestingly, many of the jobs that would be created by a vigorous renewable energy industry are in sectors of the economy that have had significant unemployment problems in recent years. Chief among these is the nation’s manufacturing base, which has shrunk substantially over the last few decades. Renewable energy tends to create more jobs in manufacturing than in services or operations and maintenance. The construction industry would also be boosted by movement toward creating a more renewables-oriented energy infrastructure, as would agriculture. The flow of benefits to agriculture would be particularly strong to the extent that biomass became a more important energy source.[79] But wind farms can also help to reinvigorate rural communities. As the Council of State

Governments pointed out in 2003, "For a 250-acre farm, with income from wind at about $55 an acre, the annual income from a wind lease would be $14,000, with no more than two to three acres removed from production…. Wind farms may extend over a large geographic area, but their actual 'footprint' covers only a very small portion of the land, making wind development an ideal way for farmers to earn additional income."[80]

The model with which Kammen, Kapadia and Fripp estimated these rather sizable job gains did not even include the jobs that would be generated by exporting renewable energy systems. This means that their impressive figures could actually turn out to be substantial underestimates. By way of gauging the potential of this export market for job creation, a 2003 report by Heavner and Del Chiaro estimated that the international market could generate more than sixteen times as much employment for the state of California as would the in-state market alone.[81] Although the U.S. is currently a leading manufacturer of renewable energy systems exported to the developing nations, it is important to do what is necessary to position American industry to capture the considerable economic benefits that will derive from servicing an international market that will be growing by leaps and bounds. The market for solar power, for example, is expected to be nearly eight times as great in 2012 as it was in 2002.[82]

As things currently stand, rather than gaining great net advantages from energy export markets, the nation's increasingly heavy dependence on foreign suppliers of energy leaves the U.S. economy more and more vulnerable to foreign disruption. According to the Department of Energy, some 54% of our oil supplies came from foreign sources in 2003, up from 34% prior to the OPEC oil embargo that shook the U.S. in 1973.[83]

Trying to estimate the full economic impacts of any kind of spending requires taking into account the economic multiplier or "ripple effect". When money is spent, that money is then available to be spent by those who received it on the goods and services they want to buy (and then spent again by those who received that money, etc.), so the ultimate total economic effect of that spending is larger than the original (direct) amount spent. Some types of spending generate larger economic "ripples" than others. There is some evidence that spending on renewable energy has a greater economic multiplier than equivalent spending on fossil fuels. Estimates for Nebraska, for example, indicate that a dollar spent on fossil fuels generates $1.48 of economic activity in the state economy, while a dollar spent on renewables generates $2.32. Applying an approach that includes this multiplier effect, a 2003 study by the Regional Economics Applications Laboratory in Chicago estimated that for the ten-state Midwest region, renewable energy development would create about $6.7 billion in additional economic output *each year* by 2020.[84]

According to the U.S. Department of Energy, foreign countries will be spending between $25-$40 billion on geothermal energy development alone by 2020.[85] It has been estimated that the global market for photovoltaic cells will reach more than $23 billion by 2010.[86] Projections of the size of the wind power installation market worldwide over the next decade are on the order of $75 billion.[87] Our ability to capture a substantial fraction of these and other markets related to climate change mitigation constitutes an economic opportunity that we would be unwise to ignore.

The economic benefits of stimulating the renewable energy industry would not be the preserve of only a few states. Because all states have some form of renewable energy resources that can be developed, the benefits would spread across the entire country. It is estimated that 46 of the 50 states, for example, have some sort of developable wind resources.[88] The Midwest in particular has a great deal of wind power potential. North Dakota alone is estimated to have enough developable wind energy to generate almost one-third as much electricity as the country as a whole consumed in 2002.[89] The Northeast also has considerable wind power potential, though much of it is offshore. Winds off the shores of Long Island, New York, for example, have been estimated to have sufficient force to generate more than three-quarters of Long Island's electricity needs.[90] Wind farms in west Texas are already feeding considerable electric power into the state's electricity grid.

Grassy biomass, usable as an energy source, can be grown in the Midwest; energy crops can be produced in the upper Midwest, lower Great Lakes area and the Mississippi Delta; and forest biomass is concentrated in the Pacific Northwest, the Southeast, and parts of the Great Lakes region.[91] Geothermal resources are greatest in the western U.S., including California, Nevada, Utah and Hawaii.[92] Solar energy is generally most abundant in the Southwest, but a large area of the U.S. receives an average of 3.5 kilowatt-hours (kWh) or more of solar energy per square meter per day. Since a typical U.S. home uses an average about 25kWh per day, a living room-sized solar collector operating at 30% efficiency should be enough to provide sufficient power.[93] States in the Sunbelt, however, are clearly best able to generate electricity to satisfy their own needs and to export through the use of solar power.

Emissions Trading. Economists have long advocated a "cap and trade" approach to reducing greenhouse gases (explained in more detail in the section on cost-effective policies). Putting an overall cap on the total amount of GHG emissions permitted, issuing permits for that amount of emissions, and allowing firms to trade these "rights to pollute" with each other will give rise to a large international market in GHG emission credits. This will create a substantial business opportunity for the financial industry in brokering these trades, transferring the rights and tracking the transfers. Estimates of the size of the GHG emissions trading market range from $10 billion today to more than $2 trillion by 2012 (the end of the first commitment period of the Kyoto treaty).[94]

CHARACTERISTICS OF THE CLIMATE CHANGE CHALLENGE

The problem posed by climate change is particularly challenging because it is a high stakes game that combines a serious degree of uncertainty with the need to intervene in a system that is very inertial and yet capable of very abrupt change. In order to understand how to make sensible, practical and effective policy under these difficult conditions, it is first worth considering the nature and implications of each of these characteristics of the climate change problem in turn.

Uncertainty. It is certain that global warming is occurring, and it is clear that human activity is one of the causes. But there is great uncertainty as to exactly how much human activity is contributing to each of the drivers of global climate change, how much each of the drivers is individually contributing to the overall problem, and precisely how these drivers are interacting with each other. The strongest evidence for this is that there is such a wide range of estimate for the projected value of almost every physical and economic dimension of the impact of global climate change among the many studies that have been done.

For example, consider the most basic physical estimate, the rise in global temperatures expected by the end of this century (2100). The upper limit of the 2001 IPCC projections (5.8°C) is more than four times as large as the lower limit (1.4°C). On the economic side, the upper estimate of the costs that would be imposed on the U.S. by 2060 as a result of doubling carbon dioxide levels given in the study by James Titus of the EPA cited earlier ($351 billion) is more than nine times the size of the lower end estimate ($37 billion). Such wide ranges of estimate are in part due to different model structures and assumptions, as well as varying scenarios that include differences in the human response to the problem, a notoriously difficult factor to predict. But, apart from the human factor, there would not be such a wide variation in these structures, assumptions and scenarios if we knew better how all the factors that affect climate actually work and interact.

It is worth pointing out that the situation we face here is one of true uncertainty, not just risk. We are dealing with "risk" when we cannot predict what will happen, but we know all the possible outcomes, along with how likely each of these outcomes is to actually happen. For example, when we roll a pair of dice, we know all the numbers that could possibly come up, and if the dice have not been loaded, we can easily calculate the chance of each of these numbers occurring. "Uncertainty" means we are missing some of this information — either we do not know all of the outcomes that are possible, or we do not know how likely some of the possible outcomes are, or both.

An honest, objective assessment of the present state of knowledge about climate change is that while we do know quite a lot, we cannot be sure that we are aware of everything that could possibly happen, given the complexity of the planet's meteorological system and ecology. We cannot even be certain of our ability to unambiguously calculate the chances that the outcomes we do know about. When it comes down to it, much that we would like to know to understand the details of the climate change problem more precisely is still beyond the boundary of what we now do know. As Leonard Smith of the London School of Economics has put it, "At best, our models hold only in certain circumstances…. All results at the boundaries of our understanding must be treated as fundamentally uncertain."[95]

For example, in July 2004, an international conference of more than 70 climate change researchers came more or less to the consensus that the amount of global warming most likely to result from a doubling of CO_2 was 3°C, with a change of either less than 1.5°C or more than 6°C - 7°C very unlikely.[96] Then, in January 2005, climate modeler David Stainforth of Oxford University and 15 of his colleagues published the results of a series of simulations, the most extreme of which showed a climate change as large as 11°C, at least 2°C higher than any previous study had shown possible. How likely is such an extreme response? Even Stainforth admits, "We can't yet give a probability for our results".[97]

The natural impulse in such a situation is to do more research to try to clear up enough of the uncertainty so that we can work out the best approach to solving the problem. That is a healthy impulse; it has been the impulse behind much of our intellectual progress, especially in science and engineering. I think any sensible person would agree that doing more research on climate change is a good idea. But the problem is, since climate change is happening here and now, the longer we wait to act, the more painful and extreme the action needed to solve the problem may turn out to be. As a result, there is likely to be a great advantage to acting sooner rather than later.

The Possibility of Abrupt Change. We know from our experience with complex, interacting systems (including the ecology) that for a while, slow, bit-by-bit changes in the context within which they are operating may produce only slow, predictable, incremental change in the system's behavior, if any. But when a threshold or "tipping point" is reached then crossed, these systems can suddenly undergo major changes in behavior that may be very difficult or impossible to predict or to undo.

For example, when increased sensitivity caused by highly interactive computerized program trading helped push the stock market across a critical threshold in 1987, the value of stocks on the New York exchange plunged precipitously. For that matter, an even more spectacular example occurred when low margin requirements and that era's version of "irrational exuberance" combined to push the stock market of the 1920s over the edge, leading to the crash of 1929 that ushered in the Great Depression.

Until the levees built around New Orleans were pounded by storm forces that exceeded the strength of their weakest points, or were faced with water levels higher than the levees themselves, they could protect the city. But when Hurricane Katrina and (a few weeks later) Hurricane Rita took the levees over those critical thresholds, the city was quickly flooded. Something similar had happened years earlier in Grand Forks, North Dakota. Grand Forks had been successfully protected against flood since the 19th century, despite frequent threats from river surges up to a stage of 49 feet. But in 1997, the river crested just 10% higher than before (54 feet), and the result was catastrophic damage.[98]

We know that such thresholds exist within the environment and that crossing them can trigger major ecological damage, but we often do not know where these "ecotriggers" are, or how they work. This is especially true with respect to climate change.

According to the National Research Council of the U.S., "The quintessential abrupt climate change was... about 11,500 years ago, when... climate shifted dramatically in many regions by about one-third to one-half the difference between ice age and modern conditions, with much of the change occurring over a few years."[99] We know that abrupt regional climate change has had a powerful impact on human societies, from time to time. Sudden but persistent droughts seriously disrupted the highly advanced Mayan culture. Abrupt climate change was also an important factor in the collapse of Mesopotamian civilization.[100]

The recent discovery that a million square miles of permafrost in western Siberia is now melting (mentioned earlier in the section on ecological impacts) raises the possibility that billions of metric tons methane, a potent greenhouse gas, will be released to the atmosphere. Sergei Kirpotin, one of the two discoverers of this phenomenon, said that the thaw, which had probably begun only a few years ago, was an "ecological landslide that is probably irreversible and is undoubtedly connected to climatic warming." Reacting to Kirpotin's discovery, British climate researcher David Viner said, "When you start messing around with these natural systems, you can end up in situations where it's unstoppable. There are no brakes you can apply".[101]

Summarizing the results of its analysis of abrupt climate change, the National Research Council points out, "Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events. The abrupt changes of the past are not fully explained yet, and climate models typically underestimate the size, speed, and extent of those changes. Hence, *future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected*."(emphasis added).[102]

Inertia. It is not unusual for time lags to be built into the structure of large, complex, interactive systems. These delays tend to make the system sluggish in responding to changes in the external forces that drive it. As a result, after a change is made, it can take some time for the system to respond at all, and considerably longer for the change to work its way completely through the system.

There are many examples of systems with this kind of inertia. In the demographic system, for example, a precipitous drop in the birth rate in the U.S. would take about five years to have any effect on grade school enrollment, and about 13 years more to have any major effect on the number of new entrants to the labor force. Further along in the life cycle, it is predictably taking about 65 years for population bulge created by the post-war baby boom to work its way through to retirement, with all that implies for social security and other pension systems.

The Earth's ecology is also a large, complex interactive system with considerable inertia. It took more than a decade after the peak use of the pesticide DDT for peak levels of DDT to be detected in fish. The Montreal Protocol on Substances that Deplete the Ozone Layer was created in 1987, and ultimately signed by more than 180 nations. Eighteen years later, it has been noted that the amount of chlorofluorocarbons (CFC's) in the lower atmosphere has finally started to decline. But it is expected to take decades before the stratospheric ozone layer is restored to pre-1970 levels.[103]

The climate system too is inertial. Many greenhouse gases (GHG's) are long-lived in the atmosphere, and they are continuing to accumulate because of current GHG emission levels. But even if the amount of GHG's in the atmosphere were stabilized today, average global temperature would continue to rise. So would sea level, because the oceans take a long time to heat up. According to Gerald A. Meehl of the National Center for Atmospheric Research and his colleagues, "…even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000, we are already committed to further global warming of about another half degree and an additional 320% sea level rise caused by thermal expansion by the end of the 21st century… At any given point in time, even if concentrations are stabilized, there is a commitment to future climate changes that will be greater than those we have already observed."[104]

Looking farther into the future, T.M.L. Wigley (also of the National Center for Atmospheric Research) estimated that the average global temperature could rise by more than 1°C (1.8°F) and sea level could rise by 40 centimeters (1.3 feet) by 2400, due to the inertia in the climate system. According to Wigley, "Ocean thermal inertia causes climate change to lag…. Because of this lag…, and because of the changes in atmospheric composition [and changes in the buildup of heat]… that have already occurred, the climate system will continue to change for many decades (centuries for sea level) even in the absence of future changes in atmospheric composition".[105]

Inertial systems put a premium on starting now rather than later to make a change when a change is needed. Anticipation becomes crucial. Just as someone at the helm of an oil supertanker must begin to turn the ship much earlier than someone at the helm of a small speedboat, there is so much inertia in the climate system that we must start "turning the ship" now, if we are to successfully turn toward a more viable course. There is no need to panic, but we cannot afford to wait until global temperatures and sea level have risen to dangerous levels before we begin to take some corrective action.

High Stakes. According to British Petroleum (BP), world energy consumption rose 4.3% in 2004, the biggest percentage rise in twenty years and the largest absolute increase ever. The company's annual statistical review also indicated that the increased burning of fossil fuels last year resulted in the biggest absolute increase ever in carbon emissions, boosting the atmosphere's burden of greenhouse gases. The fast-growing Asian economies were responsible for an important part of the rise in GHG's: energy consumption in China increased by 15.1%; in India, the increase was 7.2%.[106]

As long as the developing economies continue to grow — and that has long been not only their dream, but ours — we are likely to see more of the same. Yet neither their continued growth nor ours can be sustained without finding a way to disconnect economic progress from the voracious consumption of nonrenewable, environmentally damaging energy resources. Otherwise, we will find ourselves in increasing competition for a dwindling stock of nonrenewable resources, a competition that has already caused a more than its share of conflict costly in both money and blood. And we will find ourselves burdened by higher and higher cost as a result of the environmental and climatic forces we are unleashing. Nothing less than the quality of our common — and individual — economic futures is at stake.

As we have seen, the direct economic costs of climate change are high, estimated to reach as much as $351 billion per year in the U.S. alone by 2060. They have the potential to become much higher. Whether or not the United States takes strong action to deal with the problem, many other nations are in the process of doing so. As a result, as we have also seen, global markets for technologies and devices designed to reduce greenhouse emissions are large today and will grow over time. UNEP projects that sales in the market for renewable energy will reach $234 billion to $625 billion worldwide within a few years (2010), and as high as $1.9 trillion by 2020.

Because business people cannot pay attention to everything at once, even profitable opportunities will sometimes slip by them when their attention is focused elsewhere. U.S. companies may be disadvantaged in the competition for these profitable markets if strong leadership is not taken to push them to pay attention to climate change. If it is not, we will eventually wind up buying the equipment and technology needed to address climate change from other nations, rather than selling it to them.

The stakes are high, both in terms of the costs likely to be imposed on us by climate change, and the economic opportunities now being created by global action to mitigate climate change.

PRACTICAL STRATEGIES FOR ADDRESSING THE PROBLEM

Climate change presents us with a high stakes problem characterized by great uncertainty, system inertia and the likelihood that crossing thresholds we cannot even foresee may cause sudden escalation that is very difficult to predict or control. What is the most sensible strategy to follow in this kind of challenging situation?

We could wait until the scientific community is able to gain enough knowledge to understand all the details of the problem, so that we can be sure we know what the best solution is. But while climate change research should be encouraged, it is likely to be a long time before we understand the situation even close to that well. In the meantime, business-as-usual could easily carry us across one of those unseen escalation thresholds — or even just build up enough momentum that by the time we know what the best approach would have been, the inertia of the climate system will have rendered it unworkable.

Alternatively, we could wait until the worst that is going to happen actually does start happening before taking action, and then try to deal with the problems after the fact, say a few decades from now. But if anything near the worst-case scenario does happen, dealing with the problem after the fact could absorb so much of the nation's available resources that we won't be able to do anything else.

On the other hand, if we act strongly enough now to even significantly reduce the scope of the problem, we can preserve the nation's ability to take care of the population's educational and health care needs, to provide a strong national defense — and to maintain the flexibility that will allow us to successfully deal with and overcome other unforeseen (and perhaps unforeseeable) problems. Just as the events of 9/11/01 (and more recently, Hurricane Katrina) suddenly called upon the nation to take strong and expensive action we did not expect to have to take, there is no way to be sure future events will not once again hand us an expensive "bad surprise". Preserving our fiscal flexibility is critical to keeping the nation and its people secure.

Although on the surface it seems like a more conservative strategy to wait before taking action, when it comes to climate change, it is actually a far safer, more conservative strategy to take reasonable but bold action sooner rather than later.

Some Key Characteristics of Sensible Strategies. We know that many meaningful actions we can take to deal with climate change involve bearing significant costs now. Since strong action taken in the presence of considerable uncertainty could turn out to be more than was strictly necessary to deal with the problem, it makes sense to look for ways of minimizing the cost of taking effective action. Even better, if we can find effective programs that actually have the promise of generating future returns, we can turn the costs we have to bear now into an investment, rather than an expenditure.

Cost Minimizing. The first step toward minimizing the cost of mitigating climate change is to take advantage of whatever effective costless or even "negative cost" (money saving) options are available. While it is not so difficult to believe that consumers or government agencies might be overlooking such possibilities, it is harder to understand how they could be overlooked by the private sector as well. After all, since we normally think of private sector firms as being focused on minimizing costs as a means to maximizing profits (that's certainly the way it is in standard economic theory), it is surprising that firms could actually be ignoring significant money saving opportunities. But let's remember that attention is also a limited resource: the managements of real world firms cannot pay attention to everything at once. If their attention is focused elsewhere, it is easy for costless or even money saving options for reducing global warming to slip by them.

For example, energy has been so cheap for so long in the United States that we have not worried very much about how to conserve it. When energy prices skyrocketed in the mid-1970s, it suddenly seemed to make sense to pay more attention to how much energy we were consuming. Once our attention was focused on the issue, we began to see changes we could make some of which would have saved us a significant amount of money even before energy prices took off.

In a book I wrote on energy conservation nearly 30 years ago, I cited the example of an office building designed for Toledo Edison. The architects discovered that by using specially coated double-glazed windows to save energy, they could reduce the size of the building's heating, ventilating and air conditioning (HVAC) system. The space needed for the air ducts could then be reduced, shrinking the size of the building without reducing the amount of useable interior space. It turned out that the money saved by using a smaller HVAC system and making the building smaller was greater than the extra cost of the more expensive energy-conserving windows. In other words, the newly designed building actually cost less to build, in addition to saving tens of thousands of dollars a year in energy costs. It would therefore have made sense to build it that way even before energy became so expensive. But would the architects or their clients have even thought of that until changed economic realities refocused their attention?[107]

As Lawrence Goulder of Stanford University points out, "Several studies indicate that, in many circumstances, firms fail to minimize their private costs by overlooking *pre-existing* zero or negative cost opportunities for emissions reductions.... A public policy intervention can stimulate "discovery" of costless emissions reduction opportunities that, in a sense, were already there for the taking."[108] Though it is unlikely to be enough, we should always go after such "low-hanging fruit" first.

As we introduce policies that are more costly, it is important to work out ways of implementing them that are as cost effective as possible. The key to doing that is to create incentives that are sensitive to differences in both the technical difficulty and the financial cost to those targeted of implementing climate change mitigation policies. This is one of the great advantages of a properly designed "cap and trade" approach (discussed below).

Return Maximizing. Since we can be reasonably sure that there will be a large and growing market worldwide for technologies and equipment useful in addressing the problem of climate change, one obvious approach to turning climate change mitigation from an expense into an opportunity to earn a healthy return is to encourage research and development (R&D) aimed at finding those technologies and developing that equipment.

There are basically four types of technologies that should prove to be profitable, if they can be made cost-effective: 1) those that reduce emissions of greenhouse gases; 2) those that conserve energy; 3) those that are useful in artificially sequestering (storing) greenhouse gases; and 4) those that increase the efficiency of alternative, ecologically benign energy sources. Their development involves varying degrees of risk. There may be little need to encourage low-risk projects, since the risks involved are within boundaries that the private sector normally finds acceptable. But some of the projects involving the largest outlays and the highest risks may actually have the greatest social value, as well as the greatest profit potential, should they succeed. Because of the scale required and the risk involved, they might well not be undertaken by the private sector in the absence of additional incentives or support.

Yet another way to achieve a greater return from resources spent on mitigating climate change is to look for strategies that work to solve more than one problem at the same time. That way, if it turns out that we have unintentionally done more than was actually necessary to deal with climate change (because we had to act despite considerable uncertainty), the approach we have taken will still prove to be beneficial, rather than excessively costly. For example, energy conservation done properly would not only reduce greenhouse gas emissions, it would reduce other forms of environmental pollution too. By stretching out the life of existing secure nonrenewable energy sources, it would also buy time for doing the longer term R&D needed to improve more environmentally benign energy sources, and at the same time lower the nation's dependence on energy from troubled (or troublesome) foreign suppliers. Mitigating climate change this way thus brings three additional payoffs: less money spent on energy, additional pollution reduction, and increased national security.

Robustness and Adaptability. If we could be surer of how the processes driving climate change would play out in the real world, it would make sense to look for the single best way of dealing with the problem. But since the characteristics of the climate change problem require us to act while there is still substantial uncertainty, in makes more sense to look for an approach or approaches that are "robust", in that they work reasonably well under a wide range of plausible scenarios. That which is best is often best only under a relatively narrow set of circumstances. Since we have no way of knowing which of the scenarios we believe to be plausible will actually happen, we can hedge our bets in this high stakes gamble by going for robustness, rather than optimality.[109]

The advantages of robustness are complemented by those of adaptability. Both the problems we face and the strategies we choose are processes rather than events. They will take some time to work themselves out. As time passes there will be less uncertainty, particularly if we continue to do more research. We will learn more about the what has actually happened, what is likely to happen next, and how well our approaches to mitigating or at least coping with climate change are working. This puts a premium on choosing approaches now that are flexible enough to allow us to adapt as we see later that a change of plan would be a good idea. Adaptability has much to recommend it. When you think about it, being able to adapt as we learned more about the world has been one of the keys to our success as a biological species. It has proven especially useful in confronting a changeable and uncertain world.

A Cautionary Note. If we are too narrowly focused in our search for approaches that are effective in dealing with climate change, we are liable to fall into a trap. We may take actions that help solve that serious problem, but actually make other serious problems we face worse. This has happened all too frequently in the past.

For example, the Montreal Protocol on Substances that Deplete the Ozone Layer included an agreed phase-out of a number of stratospheric ozone depleting chemicals, among them hydrochlorofluorocarbons (HCFCs). This stimulated the development of other fluorocarbons that were much less of a threat to the ozone layer to replace those being phased-out. Among these were hydrofluorocarbons (HFCs). As it turns out, although HFCs have far less potential for depleting ozone, they are greenhouse gases with a much higher potential for making global warming worse (see the list of GHGs given earlier).[110]

Such is the case with nuclear power. Although no one could reasonably put nuclear power forth as a *cheap* solution to the problem of climate change, many reasonable people have begun to put it forth as an effective solution. There are at least three reasons to be cautious about this approach.

First, while it is true that nuclear power plants generate electricity without emitting greenhouse gases, it is not true that the nuclear fuel cycle is free of such emissions. Substantial amounts of chlorofluorocarbons (CFCs), for example, are emitted during the process of enriching uranium.[111] A 1997 assessment of life cycle GHG emissions per kilowatt-hour (GHG/kw-hr) for a number of methods of generating electricity done by the Öko Institute in Germany estimated that nuclear power generated about 6% more GHG/kw-hr than hydroelectric power and 75% more GHG/kw-hr than wind power (although it was much cleaner than fossil fuel plants).[112] Second, we are still far from having a technically efficient, cost-effective solution to storing and protecting the nuclear waste we have already generated (and are continuing to generate). It doesn't make sense to do anything to make that problem worse. Finally, encouraging large-scale growth of the nuclear power industry here will inevitably encourage its expansion abroad, with all the negative implications that has for nuclear proliferation and hence national security.

Toward Sensible, Cost-Effective Policies that Work

We can find ways to mitigate, if not reverse, human-induced global warming and we can do so without seriously threatening either the present standard of living of those who live in the developed countries or the future prospects of those who live in the developing world. Finding these ways will require mobilizing and coordinating the best efforts of government, the private sector, and the public at large, while playing to the strengths of each.

There is no single change in our behavior or our policies that is likely to solve the problem of global climate change, but there are many changes that together add up to a solution. Although it would be simpler, and it might seem more desirable, to try to find one approach that addresses the problem, we are actually better off looking for a variety of paths to the solution. It allows us to spread our risks. Diversification is nearly always a risk management strategy worth considering, especially when there is a lot at stake.

We consider in turn a handful of policy directions that make sense for mitigating climate change, given the special characteristics of that problem. They are not meant to exclude other possibilities, but rather to illustrate how we can and should take decisive action without not rushing off wildly into the unknown.

"Cap and Trade" Greenhouse Gas Emissions Reduction. It does not make sense for government to micromanage private sector actions to reduce greenhouse gas (GHG) emissions. Companies know the details of their business better than anyone in the government does. They deal with those details every day. They are in a far better position than government to know how to reduce GHG emissions cost effectively. Even if they don't know now, they are in a much better position to know what to do to figure it out.

But it does make sense for government to set lower year-by-year targets for the total amount of GHGs emitted by the private sector as a whole consistent with strong and effective action to deal with global warming, and to create incentives for business to take these targets seriously. The incentive most likely to work in this case is pressure to meet overall emissions standards, enforced by heavy fines levied if the standards are violated.

Different firms face different technical problems and cost situations in reducing GHGs. The private sector as a whole will therefore meet the overall targets at the lowest possible cost if the government issues an amount of GHG emission permits equal to the overall target level of emissions considered acceptable that year, and then allows the firms to trade them with each other. If a firm finds it extremely expensive to reduce GHGs, it can buy additional permits from a firm that

can cheaply and easily reduce GHGs. Because the permits can be traded, firms that can cheaply and easily reduce
GHG emissions will make most of the reductions and earn money selling off some of their permits to companies that find GHG reductions very expensive. The overall target will therefore be met as cheaply as possible.

This approach also has other advantages. It leaves it up to those who know best how to work out the most cost effective way to reduce GHGs released by their operations, the companies themselves. It is completely their call. It also encourages innovation, because all firms have an incentive to find better, cheaper ways of reducing the GHG emissions. Those spending money to buy extra permits can save that money if they find cost effective ways of reducing their emissions; those selling permits will be able to earn more money by selling more of them if they can do the same. Finally, the targets are flexible enough to allow greater year-by-year reductions if it turns out that stronger action is required (or that the cost of reducing GHGs emissions turns out to be lower than expected), and they can be eased if it is proven that the problem is clearing up much faster than expected.

There are three very important cautions in implementing this approach. First, total emissions targets must be set low enough and they must fall quickly enough so that reductions in GHG emissions are consistent with serious climate change mitigation. If they are set too high or reduced too slowly, they can become merely window dressing — the appearance of a meaningful action without the reality. Second, there must be cheap and effective ways to monitor the amount and strength of GHGs released, backed up by serious enforcement that includes fines large enough to cause firms to sit up and take notice. Finally, even though this is a global problem, there may be a need to set emissions targets regionally, as well as nationally, to avoid the local damage that might be caused by concentrating all or most of the emissions in one small geographic area.

Energy Conservation.[113] We have been told again and again that ever expanding energy use is necessary to continued technological progress and an absolute prerequisite to maintaining and improving our standard of living. We have heard it so often that most of us believe it. But it is not true.

A national energy conservation effort, comprehensive enough to bring about a very substantial reduction in energy use (and thus in GHG emissions) while protecting our standard of living, does require basic changes in our approach to the design and operation of energy-using systems. But in many cases, a great deal of energy could be saved without threatening our standard of living by relatively simple and cheap changes in how we do things. In other cases, the procedures are somewhat more complex and expensive, but still both technically feasible and economically viable. It is not possible to discuss the details of the energy conservation strategies that could make such a program work here, but I can lay out a few broad rules of thumb that could take us a considerable part of the way.

Rule 1: Think Simple. When faced with problems that have a heavy technological component, as the energy problem clearly does, we have a tendency to think in terms of complex, highly sophisticated solutions. But often the simplest and most straightforward approaches are the most effective, reliable, and economical. For example, buildings with windows that can be opened and closed and manually adjustable thermostats in each space nearly always use less energy (and often provide a more comfortable internal environment) than buildings with sealed windows and centralized automatic feedback controls for heating, cooling and ventilating systems. One of the early "windowless schools" built in New York City in the 1960s used 2.5 times the energy per square foot of the average of all the thousand buildings in the city's public school system.

Rule 2: Avoid Overdesign. Overdesign is the process by which everything is made bigger, stronger, harder, brighter or more powerful than necessary. Sometimes it is done to insure that whatever system is being designed meets its basic performance requirements with a big enough margin for error to avoid the additional work needed to evaluate more precisely what is really needed to meet the demands the system will actually face. Sometimes it is done because it is easier to use a "brute force" approach than to look for creative, ingenious ways of meeting requirements more efficiently. But whatever the reason, Overdesign nearly always results in systems that waste a lot of energy and/or materials. For example, a plant manufacturing jar lids was using an oversized six-foot tall, seven-foot wide natural gas oven used to cure the sealing compound in lids, which passed on a conveyor belt through the bottom of the oven. Nearly 95% of the heat was being absorbed by the belt and the walls or going up the stack. When the plant replaced this monster oven with a much smaller oven whose heat source was much closer to the lids, more than 90% of the energy used in the process was saved.[114]

Rule 3: Recycle. The basic energy-saving advantage of recycling comes from the fact that the energy needed to manufacture the materials from scrap is often much lower than the energy required to manufacture the same materials from scratch. In recycling, we are in effect recapturing some of the energy already embodied in the scrap. But sometimes it is possible to recycle the energy more directly. For example, brakes slow or stop a car by using friction to remove energy from the turning wheels. The useful energy that turns the wheels is turned into waste heat lost to the air. By one estimate something like 10% of the total work done at the drive wheels is lost this way in suburban driving, and more than 30% in stop-and-go urban traffic. It is perfectly possible to slow or stop the car with "regenerative" brakes that remove energy from the wheels by, for example, converting it into electricity, which can then be stored in a battery and recycled to the wheels when it is time to move again. This approach is particularly compatible with kind of hybrid engines that power some of the most energy-efficient vehicles on the road today.[115]

Development and Use of Renewable Ecologically Benign Energy Sources. Solar energy comes to us directly in the form of sunlight and indirectly in the form of wind power, ocean thermal gradients (temperature difference in seawater) and biomass (energy embodied in, for example, agricultural wastes). Solar energy, together with other forms of renewable energy such as tidal power (gravity-driven) and geothermal power (geologically-based), constitute abundant sources of energy that, for all practical purposes are permanently renewable. Taken together, these forms of energy are much more equitably distributed among the nations of the world than any finite fuel resource. They cannot be as easily restricted, embargoed, or directly monopolized as fossil fuels.

It is not true that using these resources more fully to meet our energy needs will not contribute at all to environmental pollution, or even to GHG emissions and thus to human-induced climate change. It depends on how they are used — especially what sorts of devices are used to capture them, how those devices are manufactured, and what materials they embody. As in the case of nuclear power, we must consider the whole fuel cycle. But it is clear that they can be used in ways that meet our energy needs with much, much less danger of accident, misuse, damage to the environment or contribution to global warming than fossil fuels or nuclear power.

There are already many practical, cost-effective ways to use these alternative energy sources. Wind power farms in West Texas and elsewhere already feed considerable amounts of electricity into the power grid (including the electricity that powers my house).[116] The school zone traffic signals in the town where I live are routinely powered by solar panels. There is no technical reason why these more ecologically benign forms of energy cannot be much more widely used.

It has often been argued that these energy sources are economically impractical because they are not cost effective; the only way to encourage their widespread use is by subsidizing them, and subsidies violate the spirit and undermine the workings of a rational market economy. There are at least three reasons why this argument is wrong. First, there have been enormous public subsidies of both fossil fuels (e.g. through generous oil depletion allowances) and nuclear power (e.g. as a result of the Price-Anderson Act) in the past. Providing counterbalancing subsidies is completely justifiable in order to offset the market distortions created by these earlier subsidies. This would level the playing field, create free and fair competition among energy sources, and allow the market to work the way it should.

Second, since producers only take into account costs they have to bear, and not the costs they impose on others as a side effect of what they do (so-called "externalities"), markets do not respond directly to the costs that GHG emissions (and other forms of pollution) impose on the public. If all these costs were included in the costs and thus the prices of all forms of energy, solar power and other renewable energy sources would be much cheaper relative to fossil fuels and nuclear power. In other words, if energy sources were actually priced at what they really cost us, renewable energy would look much more attractive than it currently does.

Finally, subsidizing renewable energy by putting money into encouraging additional R&D to bring its costs down is an investment, not an expenditure, and one that has a high probability of producing a substantial rate of return. How do we know that? Since 1977, public and private R&D efforts have reduced the cost of photovoltaic (solar- electric) panels by more than 65% and windpower by close to 90%.[117]

Enhanced Greenhouse Gas Sequestration. If global warming is the result of the accumulation of GHGs in the atmosphere, then finding cost-effective ways of preventing more of the GHGs that are produced from being released to the atmosphere also makes sense as climate mitigation strategy. There are basically two approaches: increase the natural storage/removal of GHGs from the atmosphere; find artificial ways of preventing GHGs from escaping.

Since green plants remove carbon dioxide from the atmosphere (it is needed for photosynthesis), the most obvious way to increase natural sequestration of at least some GHGs is by increasing the amount of green plants. Taking steps to reduce forms of pollution that destroy green plants, such as acid rain and pollution of the seas, is one obvious strategy that has many additional advantages. Even simpler, rebuilding forests by planting trees (afforestation) and reducing the rate at which forests are destroyed by unsustainable practices (deforestation) are also sensible strategies. But are they cost-effective?

In a 1999 analysis partially funded by the U.S.DA Forest Service, Andrew Plantinga and his colleagues argue that earlier studies of afforestation have tended to underestimate carbon sequestration costs.[118] In a study based on a survey of Canadian landowners, G. Cornelius Van Kooten and his colleagues find that the so-called "transactions cost" of getting landowners to convert their land from agriculture to plantation forests may be higher than conventional economic analysis had shown.[119] Nevertheless, Plantinga concludes that "afforestation still appears to be a relatively low-cost approach to reducing CO_2 concentrations".[120]

As to artificial means of capturing and storing GHGs, in the July 2005 issue of Scientific American Robert H. Socolow argues that techniques for artificially sequestering large amounts of carbon dioxide underground are within reach. After 60 years of operation, a 1000-mega-watt coal burning electric power plant would need an underground reservoir capable of storing three billion barrels of CO_2 (in a compressed form nearly as dense as saltwater). If such a plant were built on top of (or near) an old "giant" oil field, Socolow argues that injecting CO_2 at high pressure into the field could help push the remaining crude oil out, at the same time turning the field into an underground storage site capable of sequestering the carbon dioxide generated by the plant. Using the CO_2 that way might even yield a profit. He argues that other less profitable (more costly) storage sites are also possible.[121]

As Socolow admits, there are significant risks associated with this kind of a scheme. Great care would have to be taken to make sure that every underground storage area was geologically stable. If not, an earthquake or other geological event might suddenly release an enormous quantity of CO_2 to the atmosphere. Not only would this quickly undo the global warming advantages of this approach, it could also prove deadly to anyone living in the surrounding area.[122] While this is a sufficiently interesting idea to be worth investigating further, it does not seem a reasonable substitute for policies that either reduce GHG emissions or make use of more natural (and less dangerous) approaches to CO_2 sequestration, such as rebuilding forests.

Encourage R&D. Technological progress can be encouraged by both positive and negative incentives. Positive incentives include providing funding for R&D or offering prizes that carry prestige and/or monetary reward for successful innovation. Negative incentives involve putting pressure on companies or researchers to achieve particular objectives. For example, requiring auto manufacturers to meet increased gas mileage requirements puts pressure on them to look for new technologies that result in more energy efficient cars.

Although positive incentives have generally been more politically popular in the past, it is likely that a combination of both "carrot and stick" policies will be more effective. In 1997, Schneider and Goulder assessed the costs of reducing CO_2 emissions in the U.S. by a modest 15% over the hundred-year period from 1995-2095. They compared the costs of achieving this goal by a subsidy to low carbon energy R&D alone to the costs of using a combination of R&D incentives and a carbon tax. They estimated that the combined approach would be about 90% less expensive.[123]

The "cap and trade" approach to GHG emission reduction is an example of a policy that creates both positive an negative incentives to look for new technologies. Negative incentives are created by a desire to avoid the cost of buying additional emission permits in the market, as well as by the threat of fines for exceeding permitted limits. Positive incentives are created by the prospect of earning money by either selling any new GHG emission reduction technologies developed or by being able to sell more emission permits because they are no longer needed.

While encouraging R&D has a great deal to recommend it, it is important to beware of the "technological fix"mentality. Thinking that we are likely to find new technologies that free us from the need to pay attention to how we are using the world's resources and what we are doing to the global environment on which all of our lives literally depend is foolishness. Technological progress is likely to play a very important part in finding a solution to the problems of human-induced global warming and climate change. But we must avoid the temptation of pouring all our efforts, resources, and attention into chasing after this politically-appealing chimera, the technological "master stroke". More than once we have thought we could find a technological fix to our problems only to find that it either did not work or created as many problems as it cured.[124] Technological progress is very powerful and very important, but it is not magic.

CONCLUSION

Human-induced global warming and the climate change it produces are not phantoms or misinterpretations. They are real. They threaten us with disease, more powerful storms, droughts and floods. They threaten our ecology, our coastal population, our water supplies and the food supply of many of the world's most vulnerable people.

At the same time, the commitment of many local, state and national governments — and a growing number of private sector firms — to finding cost-effective ways to mitigate climate change has created great opportunity. On the one hand, there is the potential for earning substantial profits and creating large numbers of productive jobs by joining the effort. On the other, there is the very real prospect of undoing some of the damage that the image and reputation of the U.S. has suffered in recent years by asserting our willingness to take effective action in finding and implementing solutions to this matter of vital importance to all the world's people, rich and poor.

Climate change presents us with a high stakes problem that is still surrounded by considerable uncertainty. Yet we cannot wait to take bold and decisive action because of sluggishness of the climate system in responding to our efforts, and the ever-present chance that it will cross an unseen threshold that will suddenly accelerate the problem beyond our control. Such a problem is best solved by implementing policies that are robust (effective under a wide range of plausible scenarios) and adaptable (flexible enough to be modified "on the fly" as progress is made and some of the uncertainty clears), while minimizing costs and maximizing returns (by creating profit making opportunities or helping to solve more than one problem at the same time).

We have considered five sensible, robust and flexible policy approaches, which can be used individually or in combination to effectively address the problem of global warming in ways that hold costs down and/or increase the return on our investment: 1) "cap and trade" emission reductions; 2) programs to conserve energy while maintaining or improving our standard of living; 3) increased use and further development of renewable ecologically benign energy sources; 4) enhanced greenhouse gas sequestration (storage); and 5) programs that use positive and negative incentives to induce the progress of technologies useful to climate change mitigation. There may well be others.

Government should not be in the business of telling the private sector how to solve the problem of climate change. But one useful role of government is to get the attention of business aimed in the right direction by, for example, setting energy and environmental performance requirements for energy-using systems (such as cars), and leaving it up to the creativity of private business to work out the details. Another possibly useful role for government is to serve as a proto-market for new technologies and devices, helping American business get a running start at servicing important but financially risky new markets whose products are valuable to society, as well as potentially profitable. The Internet and satellite communications are just two of many examples of markets where the U.S. government played a key role in giving American business a head start.

There is reason to be optimistic. We certainly cannot afford to be complacent, but there is no need to panic. We still have the time to take a measured approach, to roll up our sleeves and build the political will to take sensible, pragmatic actions that will make global warming a problem of the past, rather than a threat to our future.

APPENDIX

Table 1

Global Average Temperature and Carbon Emissions from Fossil Fuel Burning, 1950–2002, and Atmospheric Concentrations of Carbon Dioxide, 1960–2002

Year	Temperature (degrees Celsius)	Emissions(mill.tons of carbon)	Carbon Dioxide parts per mill. By vol.
1950	13.87	1612	n.a.
1955	13.89	2013	n.a.
1960	14.01	2535	316.7
1965	13.9	3087 3	19.9
1970	14.02	3997	325.5
1975	13.94	4518	331
1976	13.86	4776	332
1977	14.11	4910	333.7
1978	14.02	4961	335.3
1979	14.09	5249	336.7
1980	14.16	5177	338.5
1981	14.22	5004	339.8
1982	14.06	4961	341
1983	14.25	4944	342.6
1984	14.07	5116	344.2
1985	14.03	5277	345.7
1986	14.12	5439	347
1987	14.27	5561	348.7
1988	14.29	5774	351.3
1989	14.19	5882	352.7
1990	14.37	5953	354
1991	14.32	6023	355.5
1992	14.14	5907	356.4
1993	14.14	5904	357
1994	14.25	6053	358.9
1995	14.37	6187	360.9
1996	14.23	6326	362.6
1997	14.4	6422	363.8
1998	14.56	6407	366.6
1999	14.32	6239	368.3
2000	14.31	6315	369.4
2001	14.46	6378	370.9
2002(prel)	14.52	6443	372.9

Sources: Goddard Institute for Space Studies, ORNL, BP, IEA, DOE, IGU, LBL, and Scripps Institute of Oceanography.

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[7] The temperature-related processes that drive winds and create storms are considerably more complicated than these simple statements indicate. For example, a natural regional cycle of climate known as the North Atlantic Oscillation that influences ocean temperatures seems to be a major determinant of long-term hurricane frequency. In the part of the cycle where ocean temperatures are higher, hurricanes tend to be more frequent and more severe there. But the warm phases of the short term El Niño Southern Oscillation in the tropical Pacific (known as El Niño events) have the opposite effect, tending to reduce the frequency and severity of hurricanes in the Atlantic. (The Pew Center on Global Climate Change, http://www.pewclimate.org/hurricanes.cfm, August 31, 2005).

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