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Case Closed: The Debate about Global Warming is Over

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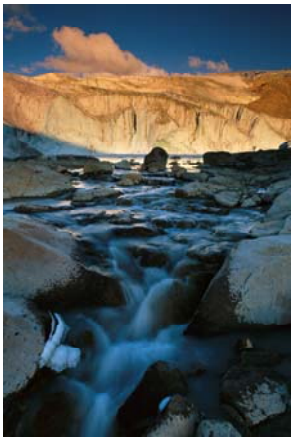
EXECUTIVE SUMMARY

Here's the short version of everything you need to know about global warming. First, the consensus of the scientific community has shifted from skepticism to near-unanimous acceptance of the evidence of an artificial greenhouse effect. Second, while artificial climate change may have some beneficial effects, the odds are we're not going to like it. Third, reducing emissions of greenhouse gases may turn out to be much more practical and affordable than currently assumed.

This brief will address the three points above and, in an appendix, offer non-jargon explanations of the most important recent findings of greenhouse science. But the pressing point of this briefing is not so much scientific as it is practical—that action against artificial global warming may not prove nearly as expensive or daunting as commonly believed. Greenhouse gases are an air pollution problem, and *all* air pollution problems of the past have cost significantly less to fix than projected, while declining faster than expected. This gives cause to hope that artificial greenhouse gases[1] can be controlled reasonably cheaply and without wrenching sacrifices to the global economy. And if there is a chance of an economical approach to greenhouse-gas reduction, then what are we waiting for? Let's start now.



(Peter Essick/Getty Images)

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[1] The natural greenhouse cycle, mediated mainly by water vapor, traps far more heat than artificially emitted greenhouse gases; without natural global warming, there would be no life on "artificial global warming" and "artificial greenhouse gases" when talking about the effects caused by human action.

The Scientific Verdict Is In

When global-warming concerns became widespread, many argued that more scientific research was needed before any policy decisions. This was hardly just the contention of oil-company executives. "There is no evidence yet" of dangerous climate change, the National Academy of Sciences declared in 1991. A 1992 survey of members of the American Geophysical Union and American Meteorological Society, two professional groups of climatologists, found only 17 percent believed there was a sufficient ground to declare an artificial greenhouse effect in progress. In 1993 Thomas Karl, director of the National Climatic Data Center, said there exists "a great range of uncertainty" regarding whether the world is warming. My own contrarian 1995 book about environmental issues, *A Moment on the Earth,* spent 39 pages reviewing the nascent state of climate science and concluded that rising temperatures "might be an omen or might mean nothing." Like others, I called for more research.

That research is now in, and the scientific uncertainty that once justified skepticism has been replaced by near-unanimity among credentialed researchers that an artificially warming world is a real phenomenon posing real danger. The American Geophysical Union and American Meteorological Society, skeptical in 1992, in 2003 both issued statements calling signs of global warming compelling. In 2004 the American Association for the Advancement of Science declared in its technical journal *Science* that there is no longer any "substantive disagreement in the scientific community" that artificial global warming is happening and could become dangerous. In 2005, the National Academy of Sciences joined the science academies of the United Kingdom, Japan, Germany, China and other nations in a joint statement saying, "There is now strong evidence that Data Center said research now supports "a substantial human impact on global temperature increases." And this month the Climate Change Science Program, the George W. Bush Administration's coordinating agency for global-warming research, declared it had found "clear evidence of human influences on the climate system."

Case closed.

In roughly the last decade, the evidence of artificial global warming has gone from sketchy to overpowering. That does not mean that substantial uncertainties don't remain. All researchers agree that knowledge of Earth's climate is rudimentary. (For instance, would a warming world be wetter or drier? Your guess is as good as the next Ph.D. climatologist's.) And considering that the most sophisticated meteorological computer models cannot predict the weather next week, computer predictions of future temperatures are expensive guesswork at best. But incomplete knowledge does not diminish the seriousness of climate change. Some continue to argue, "Because there are significant uncertainties, science cannot issue meaningful warnings about the greenhouse effect." This reasoning is akin to putting a live round in a revolver, spinning the chamber and saying, "Because there are significant uncertainties regarding the location of the bullet, firearms experts cannot issue meaningful warnings about whether to place the gun to your head." Warnings can be imperative even when much remains unknown.

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Emissions of artificial greenhouse gases continue to rise at a brisk pace worldwide.

Emissions of artificial greenhouse gases continue to rise at a brisk pace worldwide. Even if reforms are enacted, it seems cast in stone that sometime during the 21st century, atmospheric concentrations of carbon dioxide—the primary greenhouse gas emitted by human activity—will reach double their preindustrial level. This makes a warming world a near certainty for the next few generations.

Would Artificial Global Warming Be Bad?

Bearing in mind that projections are speculation, the current scientific consensus estimate is that if carbon dioxide in the atmosphere doubles, global temperatures will increase by 4 to 6 degrees Fahrenheit during this century. Everything from pop-culture presentations of global warming to political and pundit commentary has assumed that such a warming world would be a place of horrors. The big-studio 2004 movie *The Day After Tomorrow* depicted an artificial greenhouse effect wiping out much of Western society in mere days. No effects remotely resembling what happened in *The Day After Tomorrow* have ever been observed in nature, and scientists viewed the movie as little more than two hours of pretentious drivel. While the sort of "instant doomsday" scenarios favored by global warming alarmists cannot be ruled out, they are highly unlikely.

Nor should it be assumed that a warming world would, in itself, be cause for concern. Consensus science shows the world has warmed about 1 degree Fahrenheit during the last century: that warming moderated global energy demand and lengthened growing seasons, both of which are positives. Some researchers think the warming of the 20th century extended the range of equatorial diseases. But even if this was so, the initial phase of artificial global warming appears to have had a net benefit.

Further warming would likely confer some additional benefits. A vast area of the former Soviet Union might open to agricultural production, while large permafrost regions in Russia and Canada might open to petroleum exploration or even residential development. (For the purposes of this briefing, we are contemplating only impacts on human society, skipping whether such possibilities as melting the permafrost may be good or bad in the abstract ecological sense.) Extended global warming might make Antarctica habitable again—before ice ages began, it was lush—thus adding an entire continent to the part of the world useful to people. And global warming might make my hometown of Buffalo, New York, a vacation paradise where Hollywood celebrities compete to snatch up prime lakefront real estate.

But though there could be benefits to a warming world, the bad is likely to outweigh the good. Here are the main dangers:

- **Significant extension of the range of equatorial diseases.** The equator is the world's most disease-prone region. If global temperatures rise by several degrees Fahrenheit, the equatorial disease zone may extend much farther north and south, further afflicting impoverished nations and increasing the odds that air travelers bring equatorial diseases with them to the northern

Continued global warming may cause more and stronger hurricanes in the Atlantic and typhoons in the Pacific.

and southern nations that today have low rates of most communicable illnesses.

- **Sea-level rise.** The 2005 statement by the National Academy of Sciences endorsed an estimate that artificial global warming will cause sea levels to rise from 4 to 35 inches in the coming century. The low end of that range would flood parts of Micronesia; the midpoint would inundate much of Bangladesh, and make the survival of New Orleans in any future hurricane problematic; the high end would flood coastal cities worldwide. Coastal cities could be abandoned and new cities built inland, but the cost would be breathtaking—and almost surely exceed the cost of reforms to slow greenhouse emissions in the first place.
- **Melting ice.** Melting glaciers and ice sheets may alter the primary Atlantic Ocean current that warms Europe, causing European Union nations to become significantly colder even as global average temperatures rise. Studies suggest that some Atlantic Ocean currents are already changing.
- **Altering the biology of the sea.** Major shifts of ocean currents have occurred in the past, and in the geologic record, are associated with mass extinctions of marine organisms. This suggests that greenhouse-induced changes in the oceans might harm fish stocks. While it is also possible that greenhouse-induced ocean current changes would be beneficial to fish stocks, the gamble is a major one, as much of the seas is already overfished and much of the developing world relies on fish for dietary protein.
- **Misery in poor nations.** Developing nations might be impacted by global warming much more than wealthy nations. Setting aside Antarctica, the largest chunks of the world's cold land mass are in Alaska, Canada, Greenland and Russia. Extended global warming might make these areas significantly more valuable, while rendering low-latitude poor nations close to uninhabitable. Summer temperatures of 110 degrees Fahrenheit are already common in Pakistan, where most of the population has no access to air conditioning and only sporadic electric power for fans. Imagine the human suffering if 115 degree days became common.

Beyond these concerns is the great danger of artificial global warming—namely, climate change. Global warming and climate change sound like the same thing, but are different. If the world became warmer while climate remained the same, the change would be manageable. In that scenario, the benefits might outweigh the harm. Significant climate change, by contrast, could cause awful problems.

The first danger of climate change involves storms and wind. Tropical storm activity is currently in an up cycle. Whether this is caused by artificial global warming or by natural variability is not known, but the weight of evidence points toward artificial greenhouse gases. Continued global warming may cause more and stronger hurricanes in the Atlantic and typhoons in the Pacific. More frequent or powerful tropical storms might not just wreak havoc with America's Gulf Coast cities; they could bring regular

Huge numbers of people might die of malnourishment while... armies of desperate refugees came to the borders of the wealthy nations.

misery to coastal areas of Central America, Indonesia, Malaysia, Bangladesh and other nations. North and south of the tropical-storm band, tornadoes, strong thunderstorms and torrential rains might increase. (There are already indications that rainfall in much of North America is becoming less frequent but more intense.) If jet streams or other major winds increase, air travel and air cargo could be impacted or even become impractical during some parts of the year, and the globalized economy increasingly depends on air travel and air cargo.

The second danger of climate change lies in activating the unknown. We live in an "interglacial," a warm period between ice ages; our interglacial is called the Holocene. Ice-core readings from the interglacial period that preceded ours, called the Eemian, suggest that it was common then for global temperatures to shift from warm to cool and back again, with climate havoc ensuing. Why these shifts occurred is unknown. But during our era, Earth's climate has been magnificently stable—almost strangely so. For roughly the last 8,000 years, coinciding with the advent of the controlled agriculture on which civilization is based, global temperatures, ocean currents, rainfall patterns and the timing of the seasons have varied by only small amounts. Scientists don't know why the climate has been so stable during the last 8,000 years. We do know that stable climate is associated with civilization, while climate change is associated with mass extinctions. We would be fools to tempt that equation.

The third and gravest danger of climate change is disruption of global agriculture. The predicted Malthusian calamities of the postwar era have not occurred. For instance, none of the mass starvations predicted by Paul Ehrlich have happened, though the world population has doubled since Ehrlich said mass famines were just around the corner. The reason Malthusian calamities have not occurred is that global agricultural yields have increased faster than population growth. But the world's agricultural system is perilously poised, barely covering global needs. Suppose climate change shifted precipitation away from the breadbasket regions of the six food-producing continents, sending rain clouds instead to the world's deserts. Over the generations, society will adjust. But years or decades of global food shortages might stand between significant climate shifts and agricultural adjustment. Huge numbers of people might die of malnourishment, while chaos rendered impossible social progress in many developing nations and armies of desperate refugees came to the borders of the wealthy nations.

In 2005, the United Nations Food and Agriculture Organization reported that "chronic hunger is on the decline." Despite rising global population, malnourishment is now believed to be at the lowest level in human history. Because food is in oversupply in the West and malnutrition is declining generally, commentators have begun to take food supply for granted. Climate change that disrupts the agricultural system on which the global economy is based—and almost all successful nations are agricultural nations—could spark a worldwide calamity. Do we really want to stick a bullet into a revolver, spin the chamber and see what happens with global food production?

Are There Cheap Solutions?

If you think the Kyoto Protocol on greenhouse gas emissions can save the world from artificial global warming, think again.

If you think the Kyoto Protocol on greenhouse gas emissions can save the world from artificial global warming, think again. The United States has withdrawn from the Kyoto mechanism—and advocating a reversal of that decision seems a waste of everyone's time, since there is no chance the Senate will ever ratify a treaty that grants the United Nations authority over U.S. domestic policymaking. The United States would ignore any attempt by the United Nations to exercise such authority, of course—but then why bother with an empty treaty? Most nations that have ratified the Kyoto treaty are merrily ignoring it. Canada, for example, frequently hectors the United States about being an environmental offender, yet its greenhouse gas emissions are currently 24 percent above the level mandated by Kyoto—and Ottawa has no meaningful program to change that. Canada's greenhouse gas emissions are also rising faster than greenhouse gas emissions in the United States. Even Japan, which staked much of its international prestige on an agreement signed in its glorious ancient capital city, is turning a blind eye to treaty's requirements: Japan's emissions of greenhouse gases are 9 percent above promised level.

At current rates only Russia, Germany and the United Kingdom are close to complying with the Kyoto mandates, and most of the compliance by Russia and Germany is the result of backdated credits for the closing of Warsaw Pact-era power plants and factories that had already been shuttered before the Kyoto agreement was initialed in 1997. Meanwhile, developing nations especially India and China are increasing their greenhouse gas emissions at prodigious rates—so much so that in the short term developing nations will swamp any reductions achieved by the West. Since 1990, India has increased its emissions of greenhouse gases by 70 percent and China by 49 percent, versus an 18 percent increase by the United States. China is on track to pass the United States as the leading emitter of artificial greenhouse gases. If current trends continue, the developing world will emit more greenhouse gases than the West by around 2025. And here's the real kicker: even if all the provisions of the Kyoto Protocol were enforced to perfection, atmospheric concentrations of greenhouse gases in the year 2050 would be only about 1 percent less than without the treaty.

These can sound like reasons to despair about combating artificial global warming, but they are not. Rather, they are reasons to shifts gears from the overly ponderous Kyoto approach to a market-driven, innovation-based approach. The latter approach may not only work much better than Kyoto but be relatively cheap. This is the Big Thought that's missing from the global warming debate: there may be an optimistic path that involves affordable reforms that do not stifle prosperity. Greenhouse gases are an air pollution problem[2], and *all* previous air pollution problems have been addressed much faster than

[2] It can be argued that carbon dioxide is not a pollutant because plants, rain and rocks participate in a natural carbon dioxide cycle much greater in scope than artificial emissions of this gas. The point is not merely theoretical: that carbon dioxide is emitted naturally in large quantities probably means carbon dioxide does not fall under the aegis of the Clean Air Act, which regulates only "pollutants." Probably any binding federal program of greenhouse gas reduction will require new legislation from Congress, not merely an interpretation of the Clean Air Act. But for the sake of

expected, at much lower cost than projected.

True, previous air pollution problems have been national or regional in character; greenhouse gases are a global issue whose resolution must involve all nations. But this does not mean greenhouse gases cannot be overcome using the same tools that have worked against other air pollution problems. In the last 30 years, the United States has substantially reduced air pollution—during the same period the United States population and economy have both boomed. If air pollution can be reduced even as a national economy grows, there is good reason to hope that greenhouse gases can be reduced even as the global economy grows.

Nor do developing nations need an "era of pollution" in order to industrialize. In the 19th century, it was true that air pollution and industrialization were inexorably linked: then, the unregulated smokestack was essential to manufacturing advancement. Today power plants and factories are being built that emit only a fraction of the air pollution of their predecessors—and efficient, low-polluting facilities tend to have the highest rates of return. Already China to a great extent and India to a lesser extent are switching to low-pollution approaches to power production and manufacturing, observing that low-polluting industry not only is good for the environment but for the bottom line. Fifteen years ago, smog was rising at dangerous rates in Mexico City. Mexico adopted anti-pollution technology and now Mexico City smog is in decline, even as the city booms economically and its population grows. Such examples suggest that the air pollution controls that have worked so well in the United States can be expanded to the world. And if the whole world can act against air pollution, maybe the whole world can act against greenhouse gas.

Consider that a little more than three decades ago in the United States rising urban smog from automobiles was widely viewed as an unsolvable problem, just as artificial global warming is widely described as unsolvable today. During the early 1970s, Los Angeles averaged more than 100 Stage One smog alerts annually, while automakers declared that building low-emission cars would raise the price of an automobile by $10,000 or more (in current dollars), if not be technically impossible. In 1970, Congress created an ambitious national smog-reduction goal and gave automakers a strong incentive to comply—devise anti-smog technology if you want to keep selling cars. Engineers turned their attention to the task and in less than a decade a cheap and effective anti-smog device—the catalytic converter—was perfected.

Today, any make or model new car purchased in the United States emits about 1 percent of the amount of smog-forming compounds per mile as a car of 1970, and the cost of the anti-smog technology is less than $100 per vehicle. Air pollution in Los Angeles, as in most other American cities, has declined spectacularly fast, at unexpectedly low cost. Nationally, smog-forming emissions have declined by almost half since 1970, even though Americans now drive their vehicles more than twice as many miles annually. In

shorthand, carbon dioxide can be called "air pollution" because artificial greenhouse gases act like pollution, by causing environmental problems.

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the last five years combined, Los Angeles has experienced just one Stage One smog alert.

Now consider acid rain, which is caused mainly by the emission of sulfur compounds by coal-fired power plants. In the 1980s, it was said that acid rain would cause a "new silent spring" for the Appalachians, which are downwind from the coal-fired generating stations of the Midwest. Supposedly, by now, the Appalachians would be a dead zone. In 1991, Congress enacted a program that allowed power plants to trade acid-rain emissions permits, without government involvement. The permits annually decline in value, forcing reductions. Any power plant that cut its emissions below a legal maximum could sell its extra credits on the open market. Given a profit incentive, power-plant engineers and managers rapidly found ways to "overcontrol," cutting emissions more than the law required. Since 1990, acid rain emissions have declined by 36 percent, even as the amount of coal burned for power has risen. When the permit-trading program was enacted, reducing acid rain was expected to cost about $2,000 a ton (in current dollars). Instead most permits of the 1990s sold for about $200 a ton, meaning acid rain control cost only about 10 percent as much as predicted. The reason the phrase "acid rain" has largely vanished from American politics is that acid rain is no longer a problem in the United States—and the Appalachian forests are currently in their best health since Europeans first laid eyes on them. Big cuts in acid rain, considered impossible just two decades ago, happened faster and at a much lower price than anyone would have guessed, and without any harm at all to the economy.

Today the problem of an artificial greenhouse effect may seem unsolvable, but today no one can make money by controlling greenhouse gases. Create a profit incentive for greenhouse gas reduction, and human ingenuity will rapidly be applied to the problem. Nearly all analysts who have pondered the problem of how to create a profit incentive to reduce greenhouse gases have come to the same recommendation: a market-based system of auctioned or traded greenhouse gas permits, modeled on the acid-rain trading program. Details of a possible greenhouse-gas trading program are in the *Brookings Review* article by Warwick J. McKibbin and Peter J. Wilcoxen. A bill that drew 43 votes in the Senate in 2003, the McCain-Lieberman Act, would have created a binding greenhouse gas trading system at low initial cost per permit, so that the system could be tried with very little risk to the economy. Because this bill came reasonably close to passage, it or a similar program is expected to be considered by Congress again. More about potential greenhouse gas restriction ideas can be learned from Resources for the Future, the nonpartisan think tank that specializes in market-based environmental solutions and which designed the successful acid-rain trading system.

If market-based greenhouse gas restrictions create a profit incentive to reduce greenhouse emissions, many good things should happen:

- **New techniques for generating electricity will come into use.** Do you think some multibillion-dollar government crash program is needed to develop coal-fired power plants that emit no greenhouse gases? General Electric has already perfected this technology and is already offering it to utility companies. Many utility companies are merely waiting for a federal

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greenhouse gas reduction program to be decided upon, and then will start building zero-greenhouse coal-burning power plants using technology that *already exists.*

- **Green motor fuels will become more widely used.** Advanced, affordable ethanol made from grasses or genetically engineered dwarf trees, rather than from corn, will be greenhouse-neutral because the plants, when growing, will subtract from the air as much carbon dioxide as the ethanol gives off when burned.
- **New fuels will be invented.** Carbohydrates and hydrocarbons are similar. If a microorganism can be devised that uses sunlight to make hydrocarbons instead of carbohydrates, the entire global transportation industry potentially could become greenhouse-neutral.
- **Energy-efficient technology will rise in popularity.** The new "clean diesel" engines—which run exactly like gasoline engines, but use far less petroleum per mile—will become popular in cars.
- **Wind, solar and nuclear power—all zero-greenhouse sources of energy—will rise in popularity.** All nuclear power reactors in use in the United States are at least 30 years old and rely on complex active safety systems. New "passively safe" reactors are much simpler, have far fewer moving parts and are designed so that if safety systems fail, the chain reaction cannot be sustained.
- **Somebody will make the big breakthrough.** Some engineer, tinkering on some work bench, will invent some device that strips carbon dioxide from combustion exhaust as cheaply and efficiently as the catalytic converter strips smog from car tailpipes. Then, suddenly global warming won't look unstoppable.

What world leaders most urgently need to know today about global warming is not what computer models say the temperature will be, say, in Paraguay in 2063 or any similar conjecture. Rather, they need to know if a program of mandatory greenhouse gas reduction via market-based trading will work without harming the global economy. If the answer is "yes," then an artificial greenhouse effect is not destiny. The only way to find out if the answer is yes is to start greenhouse trading programs that include mandatory reductions.

A significant fraction of corporate America already assumes that mandatory greenhouse reductions are inevitable and is simply waiting for Washington to say a single word: "Go." Leader companies such as DuPont, General Electric, 3M and others have already instituted corporate-wide greenhouse gas reduction programs and are running them without loss of profits—and cutting greenhouse emissions even as their manufacturing output increases.

The Kyoto Protocol might not have been right for the United States, but a mandatory program of greenhouse gas reduction is. For decades, the United States has led the world in technology development, economic vision and pollution control. Right now the

The United States needs to start now with mandatory greenhouse gas reductions not out of guilt or shame, but because it is a fight we can win.

catalytic converter and "reformulated" gasoline, anti-smog technology invented here, are beginning to spread broadly throughout developing nations. If America were to impose greenhouse gas reductions on a solely domestic basis—keep the United Nations out of this—it is likely that the United States would soon develop the technology that would light the way for the rest of the world on reducing global warming. The United States was the first country to overcome smog (ahead of the European Union by years), the first to overcome acid rain, and we should be first to overcome global warming. Once we have shown the world that greenhouse gas emissions can be reduced without economic harm, other nations will follow our lead voluntarily. The United States needs to start now with mandatory greenhouse gas reductions not out of guilt or shame, but because it is a fight we can win.

Three Bonus Optimistic Thoughts

Maybe you're thinking—yes, but China and India will never go along with global warming reforms. In fact they will, for their own reasons. Gross air pollution, nearly conquered in the West, is at emergency levels in much of the developing world. The inefficient burning of coal without smokestack filters today casts a choking pall of air pollution across the eastern coast of China, much of India and Pakistan, parts of Africa and Indonesia. Suppose legislation allows U.S. industry to achieve greenhouse-gas reduction credits by cutting greenhouse gases in the developing world. What will happen is that American companies will begin to invest in cleaning up the power plants of India and China. American companies will look to the developing world because the bang-for-the-buck of greenhouse control will be 10 times greater there. Governments in Beijing and New Delhi will embrace such reform for public-health reasons, because better power plants will reduce gross air pollution in their countries. That better power plants will also reduce greenhouse gases will be, to developing country governments, strictly a bonus. Public health, not greenhouse effect theory, will give developing countries a major incentive to cooperate if the United States becomes serious about global warming reform.

Next, carbon dioxide is the most important greenhouse gas, but hardly the only one. Recent research by the Goddard Institute of Space Studies, a NASA affiliate, has shown that methane and industrial soot are leading greenhouse malefactors: methane traps heat far more potently than greenhouse gases, while industrial soot, being dark, absorbs sunlight that might otherwise be reflected back into space. Unlike fossil fuel combustion, methane and soot emissions by industry have no economic utility; in theory both could be eliminated. Calculations by the Goddard Institute suggest that a major effort against methane and soot emissions might slow artificial global warming by two decades or so, granting the world a reprieve during which to develop carbon-reduction technology and new non-fossil fuels.

So what are we waiting for? Industrial soot today is emitted almost exclusively by

developing country industries, which need Western help in achieving clean manufacturing and power production. Methane reduction, meanwhile, is already being advanced by a 2003 multinational agreement initiated by the Bush administration. In fact, President Bush's methane reduction agreement—bet you didn't even know it existed—may do more to slow global warming than perfect compliance with the Kyoto treaty. But methane reduction could become an even higher international priority—buying the world time to deal with other greenhouse gases.

Finally, the fact that the Bush administration already has an unheralded greenhouse-gas reduction program is an indictment of the U.S. media, which refuse to report the existence of the program because it spoils the preferred narrative of "Bush as Kyoto villain." Otherwise, the methane program is an optimistic sign. President Bush must believe artificial global warming is a real danger or he wouldn't have a methane reduction program. The president must also believe that America can lead the world in fixing the greenhouse effect problem, or he wouldn't have put the United States at the forefront of methane control. With two and a half years remaining in office, President Bush has ample time in which he could speak to history by starting the great project of global warming reform. Who better than a Republican oilman from Texas to propose the first binding controls on U.S. emissions of greenhouse gases? Any serious greenhouse gas program that President Bush proposes is likely to work faster than expected and be cheaper than expected. So what are we waiting for?

Appendix: Key Findings of Greenhouse Science

The following sections provide a simplified explanation of the most important recent findings of greenhouse science:

- Since the early 1990s, there has been a broad scientific consensus that average global temperatures have increased about 1 degree Fahrenheit over the past century. The only significant objection stemmed from satellite data suggesting that while surface temperatures had increased, upper atmospheric temperatures had not. In May 2006, the National Oceanographic and Atmospheric Administration determined that the apparent temperature discrepancies were data flaws, and that ground and atmospheric warmth are rising at approximately the same rate. The global temperature increase might be natural variation, but accumulation of greenhouse gases seems a more likely explanation. In the early 19th century, the atmospheric concentration of carbon dioxide, the primary artificially emitted greenhouse gas, was 280 parts per million (PPM). Today the atmosphere is 380 PPM carbon dioxide, and the fraction continues to rise. If large amounts of heat-trapping gases are released into the atmosphere, and global temperatures then rise, the likelihood is that the gases are responsible.
- Alternatively, if natural variation were causing observed warming, one would have to explain how large amounts of heat-trapping gases could enter the atmosphere and yet have no effect. One proposed explanation was that acid rain

emissions, which reflect sunlight back into space, were cooling the Earth even as greenhouse gases were warming it. But studies have shown that air temperatures are rising at about the same rate in regions with acid rain as in regions without, seeming to discount this explanation.

- The strongest candidate for an explanation of how large amounts of heat-trapping gases might not cause global warming is the possibility that cloud covers serve as a natural self-regulating mechanism for planetary temperatures—as the air warms, more high-altitude clouds form and reflect more sunlight back into space. Indeed, satellite photography shows more high-altitude clouds in recent decades. Studies have found, however, that increases in high-altitude clouds seem to be offset by decreases in low-altitude clouds, netting no apparent regulatory effect.
- Failure of researchers to document any sufficiently powerful "negative feedback," by which the Earth sheds or regulates heat trapped by increased greenhouse gases, stands as the primary reason the scientific consensus now accepts that artificial climate change is happening.
- Because global society continues to burn fossil fuels in huge quantities—80 million barrels of oil are burned per day, along with mountains of coal—the fraction of carbon dioxide in the atmosphere is certain to continue rising. Even the most optimistic scenarios for clean-energy reform will entail decades of rising atmospheric levels of greenhouse gases. At some point during the 21st century, if current trends continue, the level of atmospheric carbon dioxide will reach double the preindustrial level. What this may do to temperatures cannot be forecast with any certainty, but the scientific consensus is that it will raise global temperatures by 4 to 6 degrees Fahrenheit.
- The rate at which carbon dioxide accumulates in the atmosphere may increase owing to fatigue in nature's mechanisms for limiting this gas. Of the carbon dioxide emitted so far by human activity, only about half is present in the atmosphere; most of the other half has been absorbed by the oceans in chemical reactions. ("Industrial forestry" and high-yield agriculture have also absorbed some of the greenhouse gases emitted by fossil-fuel combustion; the faster plants grow, the more carbon dioxide they draw from the air.) Carbon dioxide absorption is beginning to add acidity to the world's seas, a problem in itself. More important, studies suggest the world's oceans are approaching the limit of their ability to soak up carbon dioxide. If the seas lose their ability to absorb a portion of artificial greenhouse gases, a ton of carbon dioxide emissions in the future may have a greater warming effect than a ton emitted in the past.
- Three-quarters of the Earth's surface is water; the top 10 feet of sea surface water has more thermal capacity than Earth's entire atmosphere. The mass of the oceans tends to moderate atmospheric temperature swings—the seas stay cool when the air warms and warm when the air cools. Because the "Little Ice Age" period from roughly the years 1500 to 1700 was relatively cold, the oceans

entered the industrial era relatively cool, and their cool mass has been opposing the warming of the air. (This is a phenomenon called "thermal inertia.") Recent studies have shown ocean warming to be in progress, suggesting that oceans will soon stop holding back global warming and instead begin contributing to it. A 2005 study by the federal National Center for Atmospheric Research estimated the "thermal inertia" of the seas is now such that even if artificial emission of greenhouse gases stopped tomorrow, the oceans will cause the world to warm by about 2 degrees Fahrenheit in the coming century. Irreversible in the short term, ocean warming creates a danger that if the seas begin to give off warmth rather than absorb warmth, global warming may suddenly accelerate.

- Evidence suggests that warming has already begun to alter ocean currents. A 2004 study showed the "subpolar gyre," the primary arctic sea current, has in recent decades slowed significantly, and a 2005 study found a moderate reduction in the overturning of the principal Atlantic Ocean current. Though much of Europe lies to the north of Maine, Europe is temperate because the principal Atlantic current carries warm water northward toward the continent. After releasing its warmth in the seas west of Europe, cooled saltwater from the Atlantic current sinks (cool water weighs more per unit of volume than warm water) and flows southward along the sea floor, to warm at the equator and be pumped north again. Rising temperatures are, however, causing land and sea ice to melt in the northern latitudes, especially around Greenland. This in turn means significant volumes of freshwater are entering the North Atlantic. Freshwater disrupts the primary Atlantic current, because freshwater is lighter than saltwater and refuses to sink. Fresh meltwater entering the North Atlantic might slow or even stop the primary Atlantic Ocean current, causing declining temperatures in Europe and perhaps northeastern North America. Geologic studies of the interglacial period between the last two ice ages suggest that freshwater from melting ice can shut down Atlantic currents in as little as 50 years. In 2005, the technical journal Science reported that the rise of freshwater in the far North Atlantic appears similar in pattern to conditions during the last ice age.
- Less is known about Pacific Ocean currents. El Niño and La Niña, the alternating warm and cold water masses of the Pacific, are elaborately tracked but poorly understood. The "trade winds" that govern global weather originate in the Pacific Ocean and may change if Pacific temperatures and salinity change.
- New research shows that both land and sea ice masses are melting much faster than previously estimated. As recently as the late 1990s, most researchers thought large glaciers and the "ice shelves" of Greenland and the Antarctic required thousands of years to thaw, because only the top surface of an ice sheet can warm. Standard thinking was that the Antarctic ice shelf had not changed significantly in four million years. Several studies released in 2005 showed, however, that large ice sheets can thaw from both the top and the bottom, which

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considerably accelerates melting. Most of the world's large glaciers are currently in retreat, while land ice in Greenland appears to be melting much faster than previous estimates. Snowfall has also increased in some high- and low-latitude regions, and specialists are debating the extent to which thawing ice is offset by increasing snow pack. But meltwater sufficient to disrupt ocean currents and raise sea levels now seems likely.

- The month before hurricanes Katrina and Rita hammered the Gulf Coast, the National Center for Atmospheric Research published a study that reached the following conclusion: "Trends associated with human influences are evident in the environment in which hurricanes are forming, and our physical understanding suggests that the intensity of and rainfalls from hurricanes are probably increasing." Another 2005 study showed that tropical storm intensity and frequency are increasing in the vast "blue water" regions of the Pacific, where many typhoons pass unnoted because they never approach land.
- Studies show that spring in North America is now arriving an average about 11 days earlier than 50 years ago. Other studies show that North American rainfall patterns are shifting toward fewer total rainy days but more downpours. Studies of migratory birds are finding many ranging farther north in search of their ideal temperatures. Some migratory birds whose arrival in North America is timed by instinct to the emergence of caterpillars (a food source for migratory birds) are now arriving too late in the caterpillar cycle because the insects, sensing the arrival of spring, are emerging sooner. The ranging areas required by some migratory birds are shifting north much more rapidly than trees and plants can shift north, suggesting some species of migratory birds may soon be imperiled by the need to fly beyond the trees and vegetation they are adapted to. Migratory birds may not themselves be related to human survival, but traditionally have been harbingers.