

The Science and Ethics of Global warming

Global warming has become one of the central political and scientific issues of our time. It holds a fascination for scientists because of the tremendous complexity of the physical processes that govern global climate and the far reaching potential ecological impacts. It is equally compelling to students of public policy because the measures proposed to mitigate its effects reach into nearly all aspects of the human economy. Beyond the intellectual interest, the conversation about global warming has taken on an urgent tone, since the costs of both action and inaction are high. In this short space I will outline the physical aspects of the phenomenon, and then discuss some of the considerations that might govern our response to global warming, including a discussion of some new developments that may put a solution to the problem within reach.

The basic facts of the global warming problem are now well established (those seeking further information might start by reading the 2001 summary report of the intergovernmental panel on climate change, at www.ipcc.ch). Over the past two hundred years, humanity, by burning fossil fuels, has put the carbon cycle of the atmosphere, land and ocean out of equilibrium. The carbon dioxide (CO₂) concentration of the atmosphere has increased from about 280 parts per million (a level that had been nearly constant for about ten thousand years) to 380 parts per million. About half of this increase has been accomplished since 1974. The current concentration corresponds to a mass of 760 Petagrams (Pg) carbon (1 Pg equals a trillion kilograms). Burning of fossil fuels adds 6.5 Pg carbon each year, of which about 3 Pg carbon accumulates in the atmosphere, accounting for the observed increase in concentration. The extra 3.5 Pg carbon has been

taken up by plants in parts of the world where forests are growing, and dissolved into the oceans. Photosynthetic organisms (plants, algae and bacteria) take in about 120 Pg each year, while all living things breathe out a little less than this (accounting for the storage of carbon in growing things). Our understanding of ocean carbon chemistry yields a prediction that, if all emissions of carbon dioxide by people were halted today, carbon dioxide concentrations in the atmosphere would return to their previous levels with a half-life of about 100 years—so in 2100, the carbon dioxide concentration would be about 330 parts per million, the level observed in 1974. If emissions continue at the present level, by the end of the century the concentration of carbon dioxide in the atmosphere will have approximately doubled from its pre-industrial level.

Carbon dioxide has the ability to absorb and emit infrared radiation, while nitrogen and oxygen, which make up most of the atmosphere, are essentially transparent to infrared radiation. Thus, the effect of increasing the carbon dioxide concentration of the atmosphere is to reduce the efficiency with which the earth's surface radiates away the energy it absorbs from the sun. This is called the "greenhouse effect." It causes the surface temperature to rise, until enough energy is lost from the surface by radiation or convection to overcome the effect of the added carbon dioxide. This equilibration process takes at least several decades, so that even if CO₂ were held fixed at today's level, computer models show warming continuing for the next 50 years or so. If CO₂ continues to rise to twice the pre-industrial level (which would happen in 2090 at the current rate of increase), models and data analysis predict warming of 2⁰C to 4.5⁰C (about 4 to 8 degrees in the Fahrenheit scale), once the climate reached equilibrium.

In two important respects, my discussion so far has been conservative: I assumed that emissions will not increase further, although human energy needs and use are widely expected to grow substantially in the coming century, and I assumed that the uptake of CO₂ by the biosphere will remain constant, although the capacity for such uptake may in fact be limited.

Greenhouse warming is expected to be larger than average over mid-latitude land masses, and especially near the north pole, possibly eliminating summertime sea ice cover in the Arctic Ocean by the end of the century. Global warming causes thermal expansion of sea water, and melting of mountain glaciers, yielding a sea level rise of about half a meter, assuming that warming does not dramatically weaken either the Greenland or West Antarctic ice sheets. Accompanying the temperature effects, we expect shifts in precipitation patterns, so that some regions become substantially drier and some moister.

Many of these forecasted effects of increasing carbon dioxide have already been substantiated to one degree or another by observed trends: global temperatures are indeed rising; temperatures are rising more in the north polar regions than at the equator; arctic sea-ice cover has thinned substantially; mountain glaciers are melting; global sea temperature and sea level are increasing; precipitation patterns are shifting from frequent light rains to infrequent heavy rains. Beyond these well-established effects are many possible effects. Absorption of carbon dioxide by the oceans will certainly raise ocean acidity. This increase may be enough to cause global wasting of coral reefs, with attendant consequences for the rich ecosystems they foster. Hurricane energy seems to increase with global ocean temperatures, so although we cannot yet reliably predict

hurricane statistics using global climate models, the observed relationship between temperature and hurricane energy would predict a strong increase in the future. There is some evidence that in past warm periods, slightly warmer than today's climate, the entire West Antarctic ice sheet has broken off its continental base and melted. If this were to happen (perhaps over a period of a few centuries), sea level could rise by 6 meters.

The consequence of these climate changes for human and other life are much less certain, and in many cases will not be known until after the fact. The ranges of tropical animals and plants will likely expand poleward (this has given rise to concerns over the spread of tropical disease-bearing insects into presently temperate regions). Since heat stress kills far more people than cold, warming climates are expected to increase summertime death rates more than they reduce wintertime cold-related deaths. The rising sea level will inundate low-lying areas, with particularly bad consequences for island and low-lying nations, and cities like New Orleans.

There are a number of possible responses to these forecasts. We could do nothing in particular about them. We could decide to continue emitting carbon dioxide, but to study its effects closely, planning to take some action if effects begin to look dangerous. We could decide that some change in the global mean state is acceptable, and limit carbon dioxide emissions to an amount that we think will prevent change in excess of the acceptable limit. We could decide that no human-caused change in the mean climate is acceptable, and aim to live our lives with zero net carbon emissions. Finally, we could attempt to manage multiple aspects of the earth's climate system in an attempt to globally optimize climate.

Decisions, of course, are not matters of science, but of ethics. To decide, we consider the harms and benefits of our actions, understanding in this case that our actions will constrain the choices of our descendants: carbon dioxide lasts a long time in the atmosphere, climate change takes a long time to occur, and loss of species diversity is permanent on human time scales. In the particular case of climate change, the international community has committed itself, through the Framework Convention on Climate Change (signed in Rio in 1994 and ratified by 150 nations, including the United States), to “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [human-caused] interference with the climate system.” Since “danger” in the context of the treaty includes danger to ecosystems, the climate change science community would say that we are at or above that level of greenhouse gas concentrations now. The question remaining before us is, will it be so expensive to reduce carbon dioxide emissions or concentrations that we will fail to live up to the Framework convention?

The problem is challenging because the rapid industrialization of China and India means that we must reduce emissions rapidly, even while the total number of serious emitters grows rapidly. However, there is reason to be optimistic. Some point to possible compensatory actions that would cool the earth, countering the warming effects of carbon dioxide. These solutions have appealing and unappealing aspects. Shooting sulfur dioxide into the stratosphere would be cheap and effective (volcanic eruptions cool the earth by this mechanism), but might cause unacceptable damage to the ozone layer. Orbiting mirrors could cleanly deflect sunlight away from the earth’s surface. However, such temperature-control systems would not protect the oceans from acidification by the

carbon dioxide they absorb, and they would leave the earth vulnerable to a dramatic warming should some economic downturn prevent maintenance of the climate-control systems.

Fortunately, another class of solutions exists. Although the *natural* lifetime of carbon dioxide in the atmosphere is long, there are very plausible artificial ways to remove the gas from the atmosphere. Large structures, similar to cooling towers, could be built that would draw in air, and spray it with sodium hydroxide solution. The solution would then be processed to remove the carbon dioxide, and the carbon dioxide stored underground. This procedure would cost about \$500 per metric ton of carbon, or \$1.25 per gallon of gasoline burned. In combination with the development of biomass fuels, the total additional cost of driving a car without emitting any net carbon dioxide could be reduced to about \$0.50 per gallon.* These prices are actually rather high: on the European carbon trading market, established under Kyoto, prices are around \$32/ton, meaning that for \$32, a utility company (for example), is willing to reduce its emissions of CO₂ by one metric ton. However, it is expected that prices on these exchanges would rise if controls on emissions become stricter, while the estimates for carbon drawdown listed above are made assuming a very high volume.

The present U.S. administration has argued that we should spend our resources on the development of technologies that will help to reduce carbon dioxide emissions in the future, but avoid the cost of reducing emissions now. The costs and benefits of such an approach may result in a short-term net positive economic outcome for the United States. The ethical problem with this approach is that it gambles on our ability to solve all the problems required for full scale manipulation of the earth's carbon budget in advance of

actually doing so, and so imposes the risk of long-lasting impacts of global warming on our descendants, without giving them any voice in the matter. It may turn out in fact that many of the technological problems involved in carbon sequestration will only be *encountered*, let alone solved, at the very large scales necessary to halt or reverse global warming. Thus, mechanisms that assign a cost to the emission of carbon dioxide (and a prize for its capture), and so encourage early implementation and market-driven innovation of emission reduction should be implemented immediately, if we are to avoid dangerous anthropogenic interference with the climate system

* See David Keith's article at <http://www.ucalgary.ca/~keith/AirCapture.html>.