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Putting Science to Work in Developing a Climate Policy

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In this contribution four principal points are discussed: (1) greenhouse gases and radiative forcing, (2) energy and CO_2 from fossil fuels—large challenges, (3) goals and constraints on energy pathways, and (4) science and technology must create and guide the choices.

By way of introduction, it is important to state that although climate change is a major issue to be taken into account in formulating a national energy policy, climate change is not the sole goal for which energy policy must be developed. For example, the means to safe and secure sources of energy must be achieved simultaneously. To meet all of the major goals, I am convinced that more must be expected from science and technology than from changes in human behavior.

One can see evidence of the operation of the greenhouse effect by calculating the steady-state temperature of the planet by assuming radiative energy balance. In such a calculation, one equates the amount of energy absorbed by the Earth's surface and atmosphere from the Sun, to the amount radiated back to space by the Earth. The former energy is visible light and the latter is infrared. Assuming steady state, one can solve the equation for temperature, and one finds a sub-freezing temperature for Earth; clearly not correct. It is only by including the absorption capacities of air and clouds in such a calculation that one can find a reasonable answer. A similar calculation for Mars yields a correct answer because the Martian atmosphere is so thin. For Venus, one grossly underestimates temperature unless one includes a very strong greenhouse effect from Venus' thick, CO_2-rich atmosphere.

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A variety of greenhouse gases (generally long-lived polyatomic gases that absorb wavelengths between 6 and 16 micrometers) such as CO_2, CH_4, and N_2O are increasing in concentration in Earth's atmosphere owing to human activities.

Several such gases have much greater global warming potential (GWP) than CO_2; examples of chemicals with infrared characteristics and enough chemical inertness so that their GWP value exceeds that of CO_2 are sulfur hexafluoride and many chlorofluorohydrocarbons and perfluorinated hydrocarbons.

However, the emissions of CO_2 are so much greater than those of any of the other gases that it dominates the human-enhanced greenhouse effect. The combined effect of these human-activity-derived greenhouse gases yields an anthropogenic radiative forcing of approximately 2.6 watts per square meter, effectively increasing the solar constant by 1.1%. In contrast, over 25 years the measured oscillatory change in solar irradiance or output power is only 0.1% as big as the human-enhanced greenhouse effect, and it is oscillatory rather than increasing steadily with time like the effect of the greenhouse gases.

Thus, the increased greenhouse effect owing to the changing chemical composition of Earth's atmosphere is seen, from empirical evidence, to be a significant force and one which is persistent and growing.

The total release of CO_2 resulting from the burning of fossil fuels worldwide is about 8 billion tons of carbon per year. Just a few years ago it was 6 billion tons of carbon per year. Although less certain quantitatively, a further net release of about 2 billion tons of carbon per year results from both the burning of biomass and the oxidation and volatilization of the carbon in the exposed soil, minus the uptake of CO_2 by Earth's terrestrial biota.

CO_2 emissions have now reached about 10 billion tons carbon per year. Of this annual amount, 60% shows up in annual increases of CO_2 in the atmosphere. Most of the remaining CO_2 goes into the oceans and somewhat less is taken up by the terrestrial biota. The global reach of the problem is highlighted by looking at the energy demand of the world, 85% of which is based on fossil fuels and thus a global source of CO_2. We are now at a point at which transitional and emerging economies are overtaking mature market economies in terms of energy demands. Considering the respective energy growth rates, perhaps in as little as 20 years the emerging economies will be responsible for consuming two-thirds of the world's energy and will thereby contribute most of the CO_2 emissions. International discussions of climate change therefore must recognize the fact that the industrialized nations have been the historical source of most of the excess CO_2 that now resides in the atmosphere, but future amounts are likely to be dominated by developing countries.

Realizing that natural uptake capacity of Earth for CO_2 is only about 3 billion tons carbon per year, one sees that in order to hold the CO_2 level constant in the atmosphere CO_2 emissions must be trimmed by 60–70%, that is, ca. 5 to 7 billion tons carbon per year. A useful illustration of both scale and what actions might be needed to manage this reduction makes use of carbon "wedges," formulated by Socolow and Pacala in 2004. In their illustration, a wedge corresponds to the reduction of carbon emissions by 1 $GtC\,a^{-1}$. They argue that if the goal were to stabilize the CO_2 concentration in the atmosphere at the level of 500 ppm, emissions must be cut by ca. 7 $GtC\,a^{-1}$ by 2050. Each GtC corresponds to one wedge. One wedge could then be obtained, for example, if the energy use of every building on Earth were to be cut by 20–25%. Alternatively, 2 billion cars getting 60 miles per gallon rather than 30 miles per gallon would also realize this goal of one wedge. The capture of CO_2 from 800 1 GW power plants, replacing 700 coal-fired power plants with nuclear plants, 1 million 2 MW peak power wind turbines, or 2000 1 GW (peak) photovoltaic plants would each result in one wedge of CO_2 reduction.

The need to stabilize climate is not the only constraint with respect to energy and consumption. Other principal factors are energy security, domestic energy supplies, financial costs, the many environmental factors other than climate, and nuclear safety both in terms of waste storage and proliferation. Thus there are multiple goals for policy and they may be complementary or they may be competitive. If the goal is to assure the national energy supply, the preferred solutions might include domestic coal and oil, wind/solar energy, nonagricultural biofuels, and nuclear power. If the main goal for energy policy is to reduce CO_2 emissions to mitigate climate change and to reduce the acidification of the oceans, then one must minimize the use of coal and oil and employ instead renewable sources, nuclear power, and carbon capture, and sequestration for coal burning becomes imperative.

Major strategic challenges include the reduction of oil used for transportation and the reduction of CO_2 from coal-fired power plants. To replace petroleum for transportation would require a transportation fleet of electric-drive vehicles. Of course, more efficient internal combustion engines with high-energy-content convenient liquid fuel could be a partial solution if the fuels were derived from noncrop plants through advances in molecular biology and genetics. Decreased dependence on coal to produce electricity, or the capturing of CO_2 from coal burning, is also imperative as it is very likely that we will make use of our vast resources of coal because of the need for secure domestic supplies and domestic political considerations.

Immediate actions with multiple benefits are available today. Energy efficiency, as defined by technology, would decrease dependence on foreign oil, improve national security, decrease trade deficits, decrease local air pollution, increase national competitiveness, encourage development of new products, and decrease household energy costs all as it would slow down the increases of CO_2 and CH_4. Why is not more being done? A principal reason is that there are barriers between people who need energy efficiency and those who can supply it. Many more energy service providers are needed to fill the niches to bring existing technologies into place.

One example of what can be done with science and technology is illustrated by the environmental consequences of the number of vehicle miles traveled per year in California. That number of miles increased by more than 50% over the period 1987–2006. Yet pollution by particulate matter, ozone, and CO was reduced by ca. 25%, ca. 45%, and ca. 50%, respectively. Despite an increase in the driving population in the state, technological advances decreased California's air pollution. This was due to cleaner fuels, better engines, and emission control devices—all the result of science and technology, not changes in human behavior.

A good example of what needs to be done is exemplified by the Dreyfus symposium: we must continue to educate ourselves and take information back to our institutions to educate students, colleagues, and fellow citizens. The issues that need to be faced are long-term and will require enormous public resolve. Constructive, successful efforts have to be led by the educated public, whether they are business leaders, government officials, nongovernmental organizations, or private individuals. Scientists must actively participate in the education of the public in these matters.

From a scientific point of view, in order to facilitate change, scientists must become more effective at identifying and analyzing options, and comparing them quantitatively with respect to what the various energy pathways can lead to. And we must do more than analyze and quantify problems. Research is still needed for the variety of aspects of climate and energy, including plant biology and microbiology; energy storage; capturing, storing, and distributing solar and wind energy; and several challenges in using and deploying nuclear energy.

The US Congress is much more aware of all of these issues today than ever before. Also, there is increasing awareness of the details of energy challenges in Congress, and of the fact that there is no single "silver bullet" to these complex problems.

Enormous business incentives may also drive some of the solutions. But scientists will have to guide the formation of all of the options, to quantify them, figure out the inadvertent side effects, including those of geo-engineering, and guide policy development at every stage continuously while also educating the current and future generations. It is an enormous challenge but we can and must succeed.