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EDITOR'S COMMENTS

Among the great science-based issues currently pressing upon American society, automotive efficiency, safety, and pollution, climate, energy, environment, nuclear power, and scientific secrecy are certainly at the forefront. We hope that the necessary public discussion of these issues will be informed by input from the professional physicist members of the **Forum on Physics and Society.** It is the task of this newsletter to help keep these members up-to-date on the science and policy matters necessary for them to be major productive components of the public debate.

In this October, 2001 issue of **Physics and Society**, Richard Benedick — the American diplomat largely responsible for the successful negotiations attempting to deal with the diminishing of the Ozone Layer — recounts his experiences with these negotiations and tries to draw useful lessons for future climate negotiations. Steven Smith helps to fill in the background with a discussion of "climate forcing".

The physicist Amory Lovins tries to use purely economic arguments to show that the expected revival of nuclear power is just a chimera. (I'm always suspicious of "impossibility" arguments which depend upon price rather than the laws of physics; price seems so open to seemingly arbitrary change.) Given the present sad state of the nuclear power industry, much hope rests upon the next generation of nuclear reactors. Edwin Lyman describes and discusses the safety of a major new reactor concept - the "pebble bed" reactor. Another concern, when considering nuclear power, is the proliferation of nuclear weapons; this is discussed by William Sailor. Any discussion of nuclear power hinges upon the effects of low-level radiation upon the public health. John Cameron provides a new perspective on this question.

Nuclear power must fit into the overall energy picture, which is sketched, for this issue, by Albert Bartlett. Aviva Brecher, our former chair, looks at the impact of our chosen mode of transportation — the car — upon the core of our civilization, our cities. Finally, Irving Lerch again raises the issue of the impact of governmental secrecy and security concerns upon the health of the science that is so necessary for the health of our general society.

We expect to continue our discussions of these vital issues in the next issue — the January Elections issue — with expected articles on automobile safety and efficiency as well as further examinations of the proposed next-generation nuclear reactor. The Editors are always open for new material for this journal. We strongly urge readers to submit relevant articles, commentaries, letters, and reviews —preferably via e-mail. Certainly the events of Sept. 11 should reinforce the view that we must all work together, as citizens and as physicists, to meet the international and domestic challenges ahead.

A.M.S.

IN THIS ISSUE

Physics and Society is the quarterly of the Forum on Physics and Society, a division of the American Physical Society. It presents letters, commentary, book reviews and reviewed articles on the relations of physics and the physics community to government and society. It also carries news of the Forum and provides a medium for Forum members to exchange ideas. Opinions expressed are those of the authors alone and do not necessarily reflect the views of the APS or of the Forum. Contributed articles (up to 2500 words, technicalities are encouraged), letters (500 words), commentary (1000 words), reviews (1000 words) and brief news articles are welcome. Send them to the relevant editor by e-mail (preferred) or regular mail.

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Statement From the Chair

I am writing to express to FPS members and the broad physics community my deepest sense of sorrow and stunned outrage for the events that shook our nation on September 11. By the nature of our work, many of us were all too close to the terror, either directly or indirectly. I am quite certain that there are many among us who are reeling from the loss of a relative, friend, or colleague. I grieve for all who have perished, who continue to suffer, and for all whose hearts were irreparably broken.

Physics is an international community built on shared knowledge, mutual respect, and networks and friendships that transcend national boundaries, religion, and political beliefs. The trans-nationalism of our community can be a positive force now, as it has been in the past. We must strive for resolution and justice while not singling out whole groups of people for hatred or retribution.

Within FPS, we have colleagues whose life work is dedicated to applying the abstractions of our science to solving real-world problems, particularly those of the geopolitical kind that occurred on September 11. As we recover from the shock and work through our grief and anger, we must renew our shared commitment to apply physics for the benefit of all humanity.

In grief and hope for the future,

Bo

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ARTICLES

Science, Policy, and Environment in the 21st Century

Richard E. Benedick

This article is adapted from an address to the American Physical Society in April 2001, and draws from "The Indispensable Element in the Montreal Ozone Protocol," Columbia University Earth Institute, Earth Matters, Fall 1999.

Humanity in the twenty-first century faces a new generation of environmental challenges. These differ significantly from past environmental problems that were familiar local accompaniments to the industrialization process. In the mid-1970s, the first truly global threat to the planet – depletion of the stratospheric protective ozone layer – was theorized, derided, hotly debated, and ultimately proven true, later earning for its discoverers the Nobel Prize. In the years following, scientists across a broad range of disciplines began to sound alarms about other portentous environmental changes caused by human activities: the greenhouse effect and climate change, the mass extinction of species and loss of biological diversity, the worldwide destruction of forests and habitat, the diffusion of persistent organic pollutants, the spread of desertification and land erosion, the pollution of oceans and coastal waters, and the growing pressures on fresh water.

These new environmental issues share several common features. They are global in scope, transcending national boundaries and affecting all, or substantial portions of, the world's population. They are slow in developing and long-term in their consequences; they may be irreversible over generations, or even forever, once their impacts become entrenched. Addressing these threats requires an unprecedented degree of international cooperation, involving governments, intergovernmental bodies, the private sector, and, indeed, all of society. And, significantly, the problems are characterized by considerable scientific uncertainties concerning their causes, impacts, feedbacks, and the interrelationships among complex natural and social parameters.

It is, therefore, fair to say that the scientific community bears, in this new century, a special responsibility both to identify and assess risks, and to devise solutions to complex and often interrelated threats to the planet's natural cycles – a responsibility upon which the future of human welfare may well depend. At the same time, political and economic decision makers have a concomitant responsibility to take heed of the messages of science, as well as to encourage scientific curiosity and provide adequate research funding.

From this perspective of the indispensable future interaction between science and policy, I would like to analyze the experience of the most successful global environmental agreement to date, the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer -- a treaty that has been characterized by the heads of the World Meteorological Organization (WMO) and the United Nations Environment

Programme (UNEP) "as one of the great international achievements of the century." [1]

Given the threats to life on Earth that have been averted through this landmark treaty, few would challenge their statement as hyperbole. Ozone, whose existence was unknown until 1839, has been characterized as "the single most important chemically active trace gas in the earth's atmosphere." [2] Absent the protection of the thin and constantly varying stratospheric ozone layer, life as it currently exists could not have evolved on this planet.

The Montreal Protocol, by phasing out certain chemicals, preserved the integrity of the stratospheric ozone layer that absorbs harmful ultraviolet radiation from the sun. Depletion of this thin gaseous shield – which, if compressed to the planet's surface, would be no thicker than gauze -- would have incalculable impacts on human, animal, and plant cells, as well as on climate and ecological systems. Research has indicated that if anthropogenic ozone-depleting substances had continued their rapid accumulation in the upper atmosphere, there would have been a "runaway increase" in skin cancer within decades. [3]

And yet, even while the Montreal Protocol was being negotiated during 1986 and 1987, few observers believed that it would be possible for governments to agree on any strong international controls over the production and consumption of the suspected ozone depleting chemicals. The scientific, economic, technological and political factors underlying the negotiations were staggeringly complex.

The science itself remained speculative, relying upon projections from evolving computer models of imperfectly understood atmospheric processes – models that had yielded differing, often contradictory predictions each time that they were refined. Moreover, actual measurements revealed neither the theorized mid-latitude depletion of ozone nor any of the predicted harmful effects. [4]

Chlorofluorocarbons (CFCs) and related substances were virtually synonymous with modern standards of living. Indeed, they had seemed to be the perfect chemicals: nonflammable, nontoxic, and noncorrosive – and easy and inexpensive to manufacture. During the 1980's, entrepreneurs found new applications for CFCs in thousands of products and processes across dozens of industries, from electronics, refrigeration, insulation, and plastics, to telecommunications, aerospace, pharmaceuticals, and transportation. Powerful political and economic interests thus became aligned to oppose meaningful controls.

Nevertheless, the Montreal Protocol was signed in September 1987 and entered into force in January 1989. Within three years it had been ratified by more than 100 countries and had undergone two major revisions. Unexpectedly, the "smoking gun" of CFC complicity in the Antarctic ozone hole was proven in March 1988, and governments then moved rapidly to strengthen the treaty. The list of controlled substances was increased from 8 to over 90, and the timetables for reduction and phase-out of the dangerous chemicals were significantly strengthened.

Within a few more years, a total of nearly 170 nations had joined the protocol. [5] A veritable technological revolution was unleashed that transformed entire industries. The protocol created the first-ever global environmental fund to assist developing nations, and promoted an unprecedented North-South cooperation in research and diffusion of innovative technologies that have now made ozone-depleting substances obsolete.

Even so, it was not inevitable. For decades after their discovery in the 1930's, no one suspected that these "wonder-chemicals" could cause any harm – much less to the critical ozone layer. And, because the CFCs and their cousins have such long atmospheric lifetimes, their deleterious impacts will still be felt for decades, even after new emissions cease.

Unquestionably, science and scientists were the indispensable element in the success of the Montreal Protocol. Without the courage of a handful of curious researchers in the mid-1970's, the world would have learned too late of the deadly, hidden dangers associated with rapidly expanding use of CFCs. The now legendary hypotheses of Sherwood Rowland and Mario Molina at the University of California-Irvine in 1973 initially unleashed a firestorm of criticism and controversy. Together with Paul Crutzen of the Netherlands, they were vindicated by the 1995 Nobel Prize in Chemistry, but it is worth noting that the first popular book on this subject, published in 1978, was entitled *The Ozone War.* [6]

The complexity of the research effort was noteworthy. Ozone amounts to considerably less than one part per million of the total atmosphere, and 90 percent of it is found above six miles in altitude. The intrinsically unstable ozone molecules were continually being created and destroyed by dimly understood natural forces involving solar radiation and interactions with even more minute quantities of trace gases. To complicate matters, stratospheric ozone concentrations fluctuate considerably on a daily, seasonal, and solar-cyclical basis; there are also sizeable geographical and altitudinal variations.

Amidst all these fluxes, scientists faced a formidable challenge in predicting, and then detecting, the minuscule "signal" of a downturn in stratospheric ozone concentrations, not to mention linking such a development to CFCs. This necessitated the development of ever more sophisticated computer models to simulate the stratospheric interplay among radiative, chemical, and dynamic processes such as wind and temperature -- and projecting this for decades or centuries into the future. Intricate miniaturized measuring devices were created and fitted onto aircraft, satellites, and rockets in order to monitor remote gases in quantities as minute as parts per trillion.

To understand the implications of a fading ozone layer, scientists had to venture far beyond atmospheric chemistry: they had to examine our planet as a system of interrelated physical, chemical and biological processes on land, in water, and in the atmosphere – processes that are themselves influenced by economic, political, and social forces. The Montreal Protocol became a truly multi- and interdisciplinary effort. Over the years, researching the dangers and solutions involved, not just chemists and physicists, but also meteorologists, oceanographers, biologists, oncologists, economists, soil scientists, toxicologists, agronomists, pharmacologists, electrical, chemical, automotive and materials engineers, botanists, entomologists, and more.

It was not sufficient, moreover, for scientists merely to publish their findings. In order for the theories to be taken seriously and lead to concrete countermeasures, scientists had to interact with diplomatic negotiators and government policy makers. This meant that they occasionally had to leave the familiar atmosphere of their laboratories and assume an unaccustomed shared responsibility for the policy implications of their research. The history of the Montreal Protocol is replete with instances of scientists being called upon to analyze and report on the implications of alternative remedial strategies and policy measures.

International scientific consensus was also a crucial element. The development of an accepted common body of data and analysis was the prerequisite for a political solution among nations whose opening negotiating positions were essentially incompatible. In 1984, a remarkable international research cooperation was spearheaded by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), together with the WMO, UNEP, the Federal Aviation Administration, the German Ministry for Research and Technology, and the Commission of the European Communities.

The Montreal Protocol later institutionalized this concept by establishing international expert panels to periodically assess scientific, technological, economic, and environmental knowledge, and thereby guide the negotiators in the further evolution of the treaty. Over the years hundreds of scientific experts from dozens of countries participated in the drive to learn more about the risks as well as the possible technological solutions. This proved to be a central element in the protocol's success, facilitating agreement by negotiators on additional, ever stronger measures to protect the ozone layer. In effect, the Montreal Protocol was deliberately designed as a dynamic process of narrowing the ranges of uncertainties, rather than a static solution based on the status quo.

The role of scientists in the ozone history provided some important lessons for climate change. During the 1980's, a few assessments on climate change had been issued under the aegis of WMO and UNEP, developed by a small group of mainly self-selected scientists called the Advisory Group on Greenhouse Gases. While preparing for the final ozone negotiation in Montreal, I recommended in the summer of 1987 that the US government take an initiative to establish a formal international assessment body on climate change, similar to what we were doing on the ozone issue. My belief was that findings would be more credible if they came from a larger and more diverse group of scientists under intergovernmental auspices.

This proposal attracted some unexpected allies and opponents. Anti-environmentalist officials within the Reagan Administration – who only a few short months earlier had tried to replace me as chief US negotiator on ozone -- endorsed the idea, hoping that it would give governments more control over the science. In contrast, some environmentalists feared that the process would become distorted by politics. My own feeling, grounded in the ozone experience, was that the vast majority of scientists would be unlikely to allow themselves to be diverted by political or commercial interests, and that governments would sooner be co-opted by the science than vice versa.

The subsequent experience of the Intergovernmental Panel on Climate Change, founded in 1988, confirmed my expectation concerning the independence of the participating scientists. However, it should be noted that there is at present a critical difference between the science underlying the negotiations on the ozone layer and the science of climate change. In both cases, the theory was robust. In the case of climate change, there is no dispute that an indefinite accumulation of greenhouse gas concentrations would lead to potentially calamitous alterations in the climate system. But it is not yet possible to predict how far into the future serious effects would occur. There is still considerable uncertainty about the probability, timing, location, and severity of the potential harmful impacts of climate change, which include flood, drought, rising sea levels, the spread of tropical diseases, extinction of species, and increased extreme weather events. In contrast, the probable consequences of ozone layer depletion were strikingly clear for the negotiators: the impacts would be global and fatal, and within a time-span of decades.

Another useful lesson from the Montreal Protocol's success is the importance of public education: interpreting the continually evolving and sometimes confusing data, and communicating the science intelligibly, yet without exaggeration, to the general public and the media. This information flow mobilized public opinion on the potential dangers of a diminishing ozone layer, and thereby fostered political consensus for both policy measures and for funding research. The proponents of strong actions to protect the ozone layer generally did not sensationalize their conclusions merely in order to capture media and public attention. In this way, they maintained their credibility and, importantly, they did not inadvertently provide gratuitous ammunition to those interests that sought to downplay the danger of ozone layer depletion.

Here again, the currently ongoing climate negotiations present a contrast to the Montreal Protocol. Perhaps frustrated by initial public indifference to the indefinite and future dangers of climate change, some advocate organizations, especially in Europe, became tempted to exaggerate the threats and immediacy of climate catastrophe ("Klimakatastrophe"). The particularly hot summer of 1988 encouraged some groups to foment a sense of panic; popular publications (also in the US) featured cover stories with the Empire State Building or Eiffel Tower partially submerged by raging tides. When the following summers were more normal, public interest waned, even though some activists (not scientists) continued to label every serious hurricane or flood as evidence of climate change. Damage had been done, and not only to credibility. The exaggerations tended to polarize the debate and to harden the position of industries and others who were reluctant to admit the legitimacy of the problem.

Information, and particularly sober and accurate information, is thus a critical factor in the linkage between science and policy. The power of the media – and the consumer – should never be underestimated. Between 1976 and 1978, US media interest in the fate of the ozone layer, promoted and nurtured by scientists, legislators, and environmental organizations, stimulated decisions made by millions of individual consumers that led to the collapse of the domestic market for CFC aerosol sprays -- even before there was any government regulation. Later, UNEP and WMO played prominent roles, using workshops, publications, and electronic media, in disseminating relevant information, including the availability of new technologies, to officials, businesses, and the general public throughout the world.

The success of the Montreal Protocol also underscored the necessity of providing adequate funding for all levels of science, from curiosity-driven basic research to applied engineering solutions. While most ozone research funding originally came from governments, for example NASA and NOAA in connection with their space-related research, this was not always the case. In 1985, at a time when the U.K. Government was still opposed to strong controls over CFCs, it ceased financing British scientists in Antarctica who were coming up with disturbing evidence of stratospheric ozone losses. Interestingly, the gap was filled by the US Chemical Manufacturers Association, which, although also not in favor of controls, was nevertheless even more concerned that the uncertainties finally be resolved -- one way or the other – so that they could plan for the future.

Research investments by the private sector later proved crucial in developing substitutes for the ubiquitous CFC family of chemicals. Unusual public-private partnerships found ozonefriendly solutions for products and processes where it had never been thought possible. In one case, Greenpeace teamed up with a former East German company to develop CFC-free refrigerators, which subsequently were adopted in European markets and then promoted in China and India by the German and Swiss aid programs. The technological revolution had many novel aspects, ranging from cooperation by AT&T and a Florida citrus grower in developing new solvents for electronic circuit boards, to China's indigenous approach to replacing styrofoam with a biodegradable product of grass and straw. Scientists and engineers again played a central role in solving the problems of replacing the harmful chemicals.

*   *   *

"Politics," stated Lord Kennet during ozone debates in the House of Lords, "is the art of taking good decisions on insufficient evidence." [7] The memorable success of the Montreal Protocol stands as a beacon for how science can guide decision makers to overcome conflicting political and commercial interests and reach desirable outcomes. The ozone history demonstrates that, even in the real world of ambiguity and imperfect knowledge, the international community -- with the strong assistance of science -- is capable of undertaking difficult and foresighted actions for the common good.

Ambassador Benedick, formerly Deputy Assistant Secretary of State for environmental affairs, is now a Deputy Director of Pacific Northwest National Laboratory at Battelle, Washington DC. Concurrently he is Visiting Fellow in the Wissenschaftszentrum Berlin (Social Science Research Center Berlin), as well as President of the National Council for Science and the Environment. He was chief US negotiator and a principal architect of the historic 1987 Montreal Protocol on protecting the ozone layer, and later served as Special Advisor to Secretaries- General of both the 1992 UN Conference on Environment and Development (Rio de Janeiro) and the 1994 International Conference on Population and Development (Cairo). He has authored over 90 publications on environment, population, and science policy, including the acclaimed ***Ozone Diplomacy*** *(Harvard, 1991, rev. ed. 1998, Japanese ed. 1999).*

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1 P. Obasi and E. Dowdeswell, Foreword to R. Bojkow, *The Changing Ozone Layer* (Geneva: WMO/UNEP, 1995).

2 D. Albritton et. al., *Stratospheric Ozone: The State of the Science and NOAA's Current and Future Research* (Washington, D.C.: National Oceanic and Atmospheric Administration, 1987), p.1.

3 H. Slaper et. al., "Estimates of Ozone Depletion and Skin Cancer Incidence to Examine the Vienna Convention Achievements," *Nature* 384 (November 21, 1996):256.

4 At the time, the Antarctic "ozone hole" was considered by most scientists as an anomaly, since it did not conform to theoretical ozone depletion models and could possibly have had other than anthropogenic causes. See e.g., Albritton et. al., S*tratospheric Ozone*, p. 9; WMO, *Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change* (Geneva, 1986), chap. 14.

5 R. Benedick, *Ozone Diplomacy: New Directions in Safeguarding the Planet* (Cambridge, MA. and London: Harvard University Press, rev. ed. 1998), provides a history and analysis of the ozone issue and the Montreal Protocol negotiations.

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Past and Future Climate Forcing

Steven J. Smith

Climate change is again in the news. First the failure of the COP6[1] meeting to agree on terms for the Kyoto Protocol and now the apparent rejection of the protocol by President Bush leaves the future of climate policy uncertain. To move forward it is important understand the drivers of climate change in order to inform discussions of where mitigation efforts need to be focused. This paper will present a quantitative overview of the physical drivers of past and future climate changes. The paper will first address attribution of past climate changes, then the radiatively important substances that will drive future climate change, and, finally, the mitigation of climate change in the context of the recent Hansen *et al.* "alternative scenario".[2]

Forcing and Climate Sensitivity

This discussion will be framed in terms of radiative forcing. Radiative forcing is the energy imbalance caused by a change in the climate system and is defined as the change in radiative flux at the top of the troposphere after allowing for stratospheric adjustment.[3] Since radiative forcing refers to a change, this quantity must always be given relative to some reference date or concentration level.

Radiative forcing is measured in units of Watts per square meter. A doubling of carbon dioxide concentrations, for example, will cause an imbalance of approximately 3.7 W/m^2.[4] The total forcing from all anthropogenic greenhouse gases, as compared to pre-industrial times, is presently (~ year 2000) about 2.7 W/m^2, with an offset of perhaps half this amount from aerosol cooling (see below).[5] The radiative forcing caused by carbon dioxide is known to within about 1%. Uncertainties for the other important greenhouse gases are 5-10%, with higher uncertainties for some halocarbons.[4,6]

An important property of the climate system is that the source of the radiative forcing appears to be relatively unimportant. To first order, the *global* system is thought to respond to one radiative forcing much as any other— making radiative forcing a useful tool for analysis.[7] We can, therefore, use radiative forcing to compare the relative importance of different driving forces (*e.g.*, GHG emissions, aerosols, solar luminosity variations).

What is not known with nearly as much certainty is how the climate system will respond to a given radiative forcing. The most general measure of this response is the *climate sensitivity*. The climate sensitivity is often defined as the equilibrium global-mean surface warming that would occur if carbon dioxide concentrations were doubled. The uncertainty range used by the IPCC in its 1990 through 1996 assessments is 1.5–4.5 °C per CO_2 doubling. This large range in climate sensitivity reflects uncertainty about feedbacks within the climate system.[8]

Attribution of Recent Changes

Our ability to explain past changes in climate is an obvious test of our understanding of the climate system. The following review of the causes of past climate change will demonstrate that there is considerable uncertainty in the causes of *past* climate change. The next section, however, will show that these uncertainties are largely irrelevant to the issue of what will drive *future* climate change.

There is broad agreement that global surface temperatures have warmed over the last century (Figure 1). The primary driving forces of these changes are thought to be variations in: greenhouse gas concentrations, aerosol particles, and solar flux. Attribution of historical changes is complicated by the intrinsic variability of the climate system apparent in Figure 1. While plausible combinations of the above components can reproduce the historical record, a deterministic reconstruction of the climate of the 20th century is not yet possible.

Some apportionment of causality could be accomplished if the radiative forcing due to each of the above components were known. While the forcing change due to greenhouse gases is quite well known, this is not the case for either solar irradiance or aerosols.

First consider solar irradiance, which is known to change slightly over a solar cycle. Changes over longer timescales, however, remain a matter of much speculation. A number of irradiance "re-constructions" have been calculated, where a solar irradiance time series is produced by using proxy variables such as sunspot number or solar cycle length.[10] The difficulty is that, even if such a correlation exists, the proportionality between such proxies and irradiance is not known for our sun over century time scales. Research to better constrain past solar irradiance changes continues.

Measured changes in total solar irradiance are small when compared to historical greenhouse gas forcing changes. Consider a 0.2% change in solar irradiance, which is about twice the variation seen over one solar cycle and only slightly less than some estimates of the solar irradiance change since the Maunder minimum. This change translates into a 0.5 W/m^2 change in radiative forcing. This is several times smaller than the historical increase in greenhouse gas forcing over the last century (§ 1). It is possible that the effect of these irradiance changes are magnified in some way, such as through chemical changes in the atmosphere due to the much larger change seen in solar UV emissions.[11]

Aerosol particles, which derive both from direct particle emissions and from chemical reactions in the atmosphere, have a number of climate effects. Light-colored particles, such as sulfate aerosols, reflect sunlight and cause a cooling. Black carbon particles (*i.e.*, soot) absorb sunlight and cause a warming. Aerosol particles can also act as cloud condensation nuclei, thus changing the number density and lifetimes of clouds. Other effects are also possible.[2] Injection of aerosol particles into the stratosphere by volcanic activity can also cause a transient cooling, an effect seen after the Mount Pinatubo eruption in 1991.[12]

From a climate perspective the dominant aerosol precursor compound at present is thought to be sulfur dioxide. Also the primary cause of acid rain, sulfur dioxide is emitted when coal and oil products are burned and subsequently forms sulfate aerosols in the atmosphere. The net result is thought to be a cooling effect on the climate of perhaps -1.4 W/m^2, although the uncertainty range on this figure is very large.[3,13] The radiative forcing associated with black carbon aerosols, which are emitted due to incomplete combustion of fossil fuels, is even more uncertain. An additional source of both types of aerosol is biomass burning.

The overall forcing picture for past climate change is that greenhouse gases and anthropogenic aerosols are likely to be have been the dominant forcing agents over the last few decades. Solar variability and other forcings (such as changes in average volcanic activity) may have played more important roles earlier in the 20th century. The largest uncertainty is in the forcing effect of aerosols. The combination of uncertainty in aerosol forcing, uncertainty in climate sensitivity, and the presence of unforced climate variability means that the anthropogenic contribution to past climate change cannot be determined with great accuracy.

This also means that historical data cannot be used to determine the climate sensitivity unless these uncertainties are substantially reduced. Since definitive attribution of past climate is not likely to be achieved for some time, policies will need to be based on a wide range of data and theoretical knowledge that can be used to project possible future changes.

The Drivers of Future Climate Change

Future anthropogenic forcing will depend on emissions of greenhouse gases and the precursor compounds of aerosols and tropospheric ozone. Future emissions of greenhouse gases can never be predicted in a deterministic sense because emissions of these substances depend on future socio-economic developments. Instead of a deterministic prediction, scenario analysis offers a method of establishing reasonable bounds on the magnitude of future emissions.

The most recent international effort along these lines is the IPCC Special Report on Emission Scenarios (SRES), which presents 40 scenarios of future emissions of greenhouse gases in

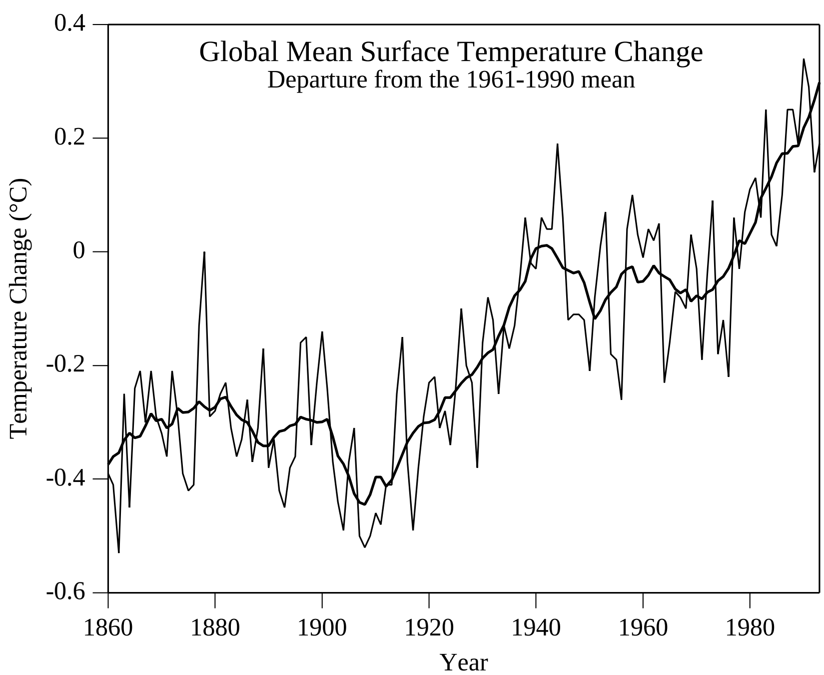

Figure 1 — Global average surface temperature (Thin line: monthly values, thick line: 11-year running average).[9]

the absence of additional climate policies.[14] These scenarios represent a wide range of possible economic, social, technological, and demographic developments. In some scenarios greenhouse gas forcing increases throughout this century while in others greenhouse gas forcing stabilizes by the end of the century — although it remains to be determined if those stabilization levels would be sufficient to avoid "dangerous anthropogenic interference with the climate system", the goal of the FCCC.

Using these emission scenarios, a conservative estimate of the range of additional radiative forcing over the next 100 years is 2.3 to 6.8 W/m^2.[15] This is in addition to the 2.7 W/m^2 of current greenhouse forcing minus any current aerosol cooling offset. These figures are illustrative and different model parameters (*e.g.*, carbon cycle parameters, sulfate aerosol forcing strength, inclusion of tropospheric ozone chemistry, etc.) would lead to somewhat different values.

Even given these uncertainties, we can predict with a high degree of confidence that neither solar nor volcanic influences are likely to exceed the magnitude of the forcing changes expected from anthropogenically-driven increases in greenhouse gas concentrations.

Now consider the future role of aerosol particles. Emissions of soot particles and sulfur dioxide have decreased substantially in Japan, Western Europe, and the United States. These decreases are due to concerns over acid rain, human health effects, and visibility issues. In the long term, global emissions of both of these compounds are expected to decrease further as increasing affluence drives ever more concern with "quality of life" issues. Eventual reductions in sulfur dioxide emissions are a key finding of the SRES.

These considerations indicate that the future will be simpler than the past, at least with respect to radiative forcing. Instead of a multiplicity of possible anthropogenic and natural forcing agents, greenhouse gases and aerosols will likely be the dominant climate forcing agents over the next several decades. By the end of the century, increases in greenhouse gas concentrations and probable decreases in aerosol emissions will leave greenhouse gases as the dominant radiative forcing agents. Note that, while the cause of future climate changes will be more certain, the amount of climate change remains uncertain due to the unknown climate sensitivity and the wide range of possible future emissions.

Climate Mitigation and the "Hansen, *et al.*" paper

The previous discussion leads to the conclusion that limiting the amount of future climate change (mitigation) in the long term will require limiting concentrations of greenhouse gases. Over shorter time horizons the situation is less clear. The recent paper by Hansen *et al.*[2] created some controversy over which substances were the appropriate targets for mitigation action. Hansen *et al.* sketch an "alternative scenario" under which the additional radiative forcing from carbon dioxide over the period 2000-2050 is kept to 1 W/m^2 (the period beyond 2050 is not addressed). Their mitigation scheme then calls for no net increase in forcing from the combination of non-CO_2 greenhouse gases and aerosols. Limiting forcing change to only 1 W/m^2 over the next 50 years is quite ambitious. This would represent limiting additional climate forcing over this time to considerably less than in any of the "no climate policy" SRES scenarios.[16]

The controversy engendered by the Hansen et al. paper was largely due to the perception that they had argued that little needed to be done to reduce carbon dioxide emissions and that, instead, efforts should focus on non-CO_2 forcing agents. The lead author of the paper, however, in an open letter to the community has stated that "we expect that equal emphasis is needed on non-CO_2 and CO_2 forcings to keep the net forcing [increase] at 1 Watt" over the next 50 years.

As has been noted elsewhere, the Hansen et al. CO_2 forcing target would likely require quite a strong climate policy.[16] In the set of SRES scenarios, for example, the increase in carbon dioxide forcing over this period ranges from 1.1–2.7 W/m^2. Under the most optimistic set of assumptions the 1 W/m^2 CO_2 target could be met with minimal action. Under most of the SRES scenarios, however, achieving this target would require significant action.

While action to limit carbon dioxide emissions is a part of most mitigation scenarios, an integral part of the Hansen *et al.* mitigation scheme is to reduce emissions of black carbon (soot) particles, which is a new suggestion for climate mitigation. Such a reduction would, indeed, tend to reduce climate forcing. But the net change in aerosol effect depends on emissions of other precursor compounds, particularly sulfur dioxide. The synergistic effects of further pollution controls and a stringent carbon dioxide constraint are most likely, however, to result in a net forcing increase due to a decrease in total aerosol cooling.[16] Producing a net increase in aerosol cooling, or probably even a constant level of aerosol cooling, is inconsistent with a strong carbon dioxide emissions constraint.

Hansen *et al.* also propose to achieve a net decrease by 2050 of 0.1 W/m^2 in tropospheric ozone forcing. Control of tropospheric ozone levels in urban areas in developed regions has proved to be a difficult task. These efforts are, however, underway and a global decrease of tropospheric ozone due to such efforts by 2050 cannot be ruled out.

They also propose a 0.2 W/m^2 decrease in methane forcing over this period. The proposed decrease in methane forcing compares to an estimated increase of 0.1-0.4 W/m^2 in methane forcing with no climate policy, although projections of methane concentrations are particularly uncertain. The potential for methane emissions reductions (i.e., mitigation) is area of active research.[17] Methane emissions grow from 2000 to 2050 in all of the SRES scenarios. This growth is driven, in large part, by emissions from increased agricultural production (particularly ruminant animals and rice) driven, in turn, by both increasing population[18] and increasing incomes. A net reduction in emissions seems possible, although implementing the necessary changes in developing countries poses a challenge (as is also the case for reductions in carbon dioxide emissions).

Our examination of this "alternative scenario" indicates that the likely gains from decreasing the levels of conventional pollutants such as soot and ozone are not sufficient to remove the main focus of any climate policy from carbon dioxide and the other greenhouse gases.[16]

Conclusion

As the century progresses, the effect of greenhouse gases as a climate forcing agent will increasingly dominate other possible forcings. While the radiative effects of greenhouse gases at present are likely to be partially offset due to aerosols, the likely continuation of reductions in "conventional" pollutant emissions in the future will "unmask" the full effect of increasing greenhouse gas concentrations. Among the greenhouse gases, carbon dioxide is still the "800 pound gorilla" of climate change.[16] This is, in large part, because carbon dioxide is unique among greenhouse gases in that it is not destroyed in the atmosphere. Some portion, therefore, of any fossil-fuel emission will make an essentially permanent contribution to atmospheric concentrations.[19]

As a final note, addressing future climate change will likely require a combination of emission reductions (*i.e.*, mitigation) and adaptation to climate changes that are not or cannot be mitigated. How this should be done, how much, and by what time, are difficult questions. In part their answers are not determined by science, but on values. The value placed on natural systems, for example, and the acceptable level of risk tolerance play important roles in determining the answers to these questions.[20]

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1 Sixth meeting of the Conference of the Parties (COP) to the Framework Convention on Climate Change (FCCC)

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3 Shine, K.P., Forster, P.M. de F. "The effect of human activity on radiative forcing of climate change: a review of recent developments" *Global and Planetary Change* **20**, 205–225 (1999).

4 Myhre, G., Highwood, E.J., Shine, K. P., Stordal, F. "New estimates of radiative forcing due to well mixed greenhouse gases" *GRL* **25**, 2715-2718 (1998).

5 This forcing figure includes carbon dioxide, methane, nitrous oxide, halocarbon, tropospheric ozone. An offsetting negative forcing due to stratospheric ozone depletion by CFC's has been applied.

6 Jain, A. K., B. P. Briegleb, K. Minschwaner, D. J. Wuebbles. Radiative forcings and global warming potentials of thirty-nine greenhouse gases, J. Geophys. Res. **105**, 20,773-20,790 (2000).

7 The response difference is likely to be largest for substances with non-uniform spatial distributions. Even here, any difference seems to be within about 20% (L.D.D. Harvey *Global Warming: The Hard Science*, Prentice Hall, NY, 2000, pp. 48–51), which is an order of magnitude smaller than the currently accepted uncertainty range for the climate sensitivity.

8 The current consensus is that, overall, climate feedbacks are positive. Therefore, the effect of any given forcing is amplified. For example, a warmer troposphere will tend to hold more water vapor, which is itself a greenhouse gas, thus causing more warming. Warmer temperatures will also tend to melt snow and ice, reducing surface reflectivity. The largest uncertainty concerns clouds, which can act to both cool and warm the surface.

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13 IPCC Working Group I Summary for Policymakers, Third Assessment Report (2001). http://www.ipcc.ch/

14 Nakicenovic, N. et al. *Special Report on Emissions Scenarios* (Cambridge, U.K., Cambridge University Press, 2000).

15 S. J. Smith, N. Nakicenovic and T.M.L. Wigley "Radiative Forcing in the IPCC SRES scenarios" (unpublished). The reason this estimate is conservative is that possible changes in atmospheric chemistry, particularly increases in tropospheric ozone, were not considered. Consideration of these compounds increases the overall range, although there are reasons to believe that these increases may not be realistic (Smith *et al. in preparation*).

16 Steven J. Smith, Tom M.L. Wigley, and Jae Edmonds "A new route toward limiting climate change?" (perspective) *Science* **290** 1109 (2000).

17 U.S. EPA *U.S. Methane Emissions 1990-2020: Inventories, Projections, and Opportunities for Reductions* (Washington, DC, 1999).

18 Note that the SRES scenarios assume that increasing income levels lead, overall, to decreasing fertility levels. World population in 2050 in two of the four SRES scenario families peaks at slightly under 9 billion near 2050 and declines thereafter, which is lower than many past projections.

19 "Permanent" on time scales of at least several thousand years.

20 The author would like to thank Hugh Pitcher for helpful comments on the manuscript.

Why Nuclear Power's Failure in the Marketplace Is Irreversible

(Fortunately for Nonproliferation and Climate Protection)

Amory B. Lovins

AP: Would the introduction of more nuclear power plants -- something the vice president has said the country needs to meet future electricity demand -- weaken Enron's natural gas trading business?

Jeff Skilling (former CEO of Enron): I will personally eat every new nuclear power plant built in this country for the next 100 years. I don't think we are going to see any new plants built. We've just got a fundamental problem in that nuclear plants make a lot of waste and there is no solution to that problem right now. So they can talk all they want about nuclear power. I don't believe it.

Associated Press Interview – August 14, 2001

Nuclear power has suffered the greatest collapse of any enterprise in the industrial history of the world. The twentieth century ended with installed nuclear capacity less than 10%, and an ordering rate less than 1%, of the lowest IAEA forecasts made a quarter-century ago. No vendor has made money by selling reactors, though some have made it up on repairs. Worldwide, nuclear power is stuck at 11% of total generating capacity, providing 6.3% of 1998 primary energy output, *vs.* 8.8% for renewables without, or about 20.3% with, traditional biofuels. In the U.S., nuclear investments exceeding a trillion dollars are delivering little more energy than biofuels; nuclear power's primary energy output and installed capacity are roughly the same as renewables', though its electric output is about four-fifths higher due to nuclear plants' recently improved capacity factors.

The basic reason for this market disappointment is not public concern but unfavorable economics. As *The Economist*'s 19 May 2001 cover story concludes, nuclear power has gone from too cheap to meter to too costly to matter, especially in an increasingly competitive marketplace. A nuclear plant with zero capital cost is now cheaper to write off (and give away equivalent electricity-saving equipment instead) than to operate. Nuclear power's unpleasant capital- and repair-cost escalation and technical surprises are worldwide phenomena, independent of politics. Even France's nuclear program was outpaced twofold by energy efficiency, bankrupted its operator in all but name, and is unlikely to be replaced by more reactors. During 1990–99, global capacity growth averaged only 1%/y for nuclear power (to 354 GW), *vs.* 17%/y for photovoltaics (PVs) and 24%/y for windpower. That's no longer simply rapid growth from a tiny base: in the 1990s, nuclear power averaged global additions of 3.1 GW/y, yet in 2000–01, windpower is adding 3.5–5 GW/y, and by the end of 2001 should reach 22 GW.

Nuclear power's main if not sole competitor was originally presumed to be giant coal plants. These are now equally obsolete on the margin: many competitors work better and cost less than either. That's why central thermal plants are seldom ordered nowadays except by a handful of centrally planned energy systems. Nuclear salesmen scour the world for a single order, while vendors of combined-cycle gas plants, microturbines, wind turbines, PVs, and energy efficiency strive to meet bulging order books.

If no existing nuclear plant suffers an accidental or malicious radioactive release serious enough to compel their early shutdown, they'll probably operate until they're too costly to maintain. In theory, they must also compete in economic dispatch (lowest short-run marginal cost of operation), but in fact, many U.S. reactors have won "must-run" status entitling them to run whenever available even if uneconomic, which ~20–25% of them already are against market-clearing prices. (In Sweden, Sydkraft unsuccessfully sought compensation for *not* continuing to lose money by running Barsebäck at an operating cost roughly twice the price of imported power.) The U.S. short-run marginal cost of nuclear electricity at the busbar is typically reckoned at ~$0.015–0.039/kWh; the average in 2000, under the industry's restrictive definition of costs, was about $0.018. (This article uses constant year-2000 U.S. dollars throughout. Net capital additions—major repairs that are really hidden operating costs—increase the industry's declared operating costs, as would fully internalized waste, decommissioning, and major-accident costs, now typically socialized.)

In any event, the cost of *delivering* the power to the customer must also be added for fair comparison with onsite options that require no delivery. Delivering the average U.S. kWh costs roughly $0.025/kWh for the capital and operating costs and the losses embedded in the existing grid; residential delivery costs, or costs of marginal delivery capacity (new transmission and distribution capacity), are often several-fold higher, but let's use the historic average figure as a conservatism. Nuclear power's typical short-run marginal cost, delivered to the customer, is then about $0.045/kWh using the industry's narrow cost definition. But its long-run marginal delivered cost (including *building* a new nuclear plant) is at least $0.10–0.15/kWh. (Enthusiasts claim that building and running a hypothetical South African pebble-bed design might cost perhaps $0.05/kWh delivered, but given historic experience with paper *vs.* real reactors, twice that would be more plausible.) Existing coal plants often run at or below $0.02 and hence deliver at about $0.045/kWh for existing plants; cleaner new ones would raise that to roughly $0.06–0.08/kWh, almost certainly cheaper than new nuclear plants. What else costs less to build and run than nuclear power?

The most potent competitor, many-fold cheaper than just *running* existing nuclear plants anywhere in the world, is end-use efficiency—a resource that's also many-fold larger. Its average historic U.S. cost, including many poorly designed and chiefly residential programs, is only $0.02 per saved kW-h, already delivered to the customer's premises. Well-designed retrofits, however, can save most of the electricity now used at empirical costs typically ~$0.005/kWh in the business sectors (a 16-month payback at a 5-cent tariff)—even less than zero in new buildings and factories. (My own 90% saving in household electricity had a 10-month payback in 1984; today's technologies are far better and cheaper.) Saved energy is currently the United States' largest single source of energy services, delivering two-fifths of their total. Reduced primary energy intensity during 1975–2000 is now an energy "source" over five times as big as domestic oil output, over twice total U.S. oil imports, over 12 times Persian Gulf imports, and 7.7 times primary nuclear energy output. Oil productivity has indeed doubled since 1975.

Electrical productivity is far less mature, having improved only 8% during 1975–2000—partly because electricity has been heavily subsidized and promoted, has typically been priced at average cost rather than on the margin, and is distributed by utilities that in 49 states are rewarded for selling more energy and penalized for cutting customers' bills. Nonetheless, electrical productivity since 1997 has sustained its steadiest gains in history, averaging 1.6% per year—half as fast as the aggregate drop in primary energy intensity. One-fourth of the national electrical saving has come from California, even after its demand-side efforts were derailed in the mid-1990s. California has held its per-capita use of electricity nearly flat for the past quarter-century, saving 25 average GW compared with the intensity prevailing in the rest of the U.S., and boosting its economic output by investing more productively the billions of dollars thereby saved. Analogously, the Electric Power Research Institute, at its 2001 summer seminar, presented an "enhanced productivity" scenario envisaging 3%/y gains in electrical productivity (a 45% drop in intensity) during 2000–20.

EPRI's 1991 conventional wisdom was that over half of U.S. electricity could be saved at an average cost around $0.03/kWh. RMI's far more detailed analyses in the late 1980s, using empirical cost and performance data for more than 1,000 technologies, found potential retrofittable savings around 75% at an average cost around $0.0085/kWh. The potential today is undoubtedly larger and cheaper, because better technologies and delivery methods have more than kept pace with "depletion" of the efficiency resource. Indeed, new integrative design methods (www.natcap.org) can often make very large energy savings cost *less* than small or no savings—"tunneling through the cost barrier." Moreover, ancillary improvements in service quality, such as a ~6–16% gain in labor productivity in efficient offices, are often an order of magnitude more valuable than the saved energy. Proven methods (www.rmi.org/images/other/C-ClimateMSMM.pdf) can also convert the scores of implementation obstacles into lucrative business opportunities. "Negawatts" can be marketed so quickly that during 1983–85, the ten million people served by Southern California Edison company cut the ten-years-ahead forecast of peak demand by more than 8% *per year*, at about 1% the cost of new supply. And in developing countries, efficiency investments can cut marginal capital needs by four orders of magnitude, making the power sector—now a black hole for one-fourth of development capital—a net exporter of capital to fund other development needs.

After end-use efficiency, typically the next cheapest competitors are three kinds of new generators:

1. combined-cycle gas turbines (often ~$0.05–0.06 per delivered kWh at 1999 prices, including 30-year fixed-price gas contracts, or about a penny more at 2001 prices due to temporary turbine and gas shortages),
2. some renewables (notably, well-sited windpower costs ~$0.055–0.06 per delivered kWh and will soon drop to or below $0.05, minus a $0.015 subsidy in the U.S.), and
3. onsite and hence requiring no delivery, industrial and commercial co- and trigeneration from larger units or from microturbines, again using 30-year constant-price gas contracts (~$0.005–0.05, often ~$0.01–0.02, per delivered kWh net of thermal credit).

In short, *any* of three abundant and readily purchasable resources—efficient end-use, efficiently used gas (especially when thermally integrated), and windpower—can easily beat new and can even beat most old nuclear plants on private internal cost. Any one of these three competitive resources would make nuclear power unnecessary and uneconomic. Two of them are climate-safe, and the third has very low climate impact. Even though cogeneration is typically gas-fired, full practical and profitable conversion to it would cut U.S. CO_2 emissions by about 23%.

These three formidable competitors to nuclear power are being joined by another that's just entering volume production. A winning dark horse, ~60%-efficient proton-exchange-membrane fuel cells, is poised to capture most of the power market in buildings, which use two-thirds of U.S. electricity. Its ~$800/kW initial cost will drop rapidly, ultimately to <$50/kW. The transition to a climatically benign hydrogen economy, profitably at each step starting now (www.rmi.org/images/other/HC-StrategyHCTrans.pdf), is starting to be rapidly implemented by major firms. One of its consequences—wellhead reforming of natural gas with CO_2 reinjection—would make the world's two centuries' worth of known gas profitably usable without climatic harm. (Contrary to the impression of some nonexperts on natural gas, this is a rather ubiquitous and abundant resource, which is partly why the Department of Energy projects U.S. combined-cycle gas capacity to surpass nuclear capacity later in this decade: 126 GW in 2010, *vs.* 97 GW for nuclear power in 2000.) Professor R.H. Williams at Princeton University even makes a plausible case that hydrogen may ultimately be more cheaply made from coal than from natural gas, with carbon sequestration in both cases.

As IIASA first showed for inefficient solar trough systems two decades ago, renewable power generation is no more land-intensive than the full nuclear or coal fuel cycle. Denmark, now 16% wind-powered, is on target for 50% by 2030, without issues of land-use or intermittence (an old canard long since resolved by wind diversity on a mesoscale). A fifth of U.S. electricity could be made by modern wind turbines occupying 5% of four Montana counties, or 0.6% of the Lower 48 states; or all of U.S. annual electricity could come from ordinary PVs occupying half of a square 160 km on a side (though one would actually site them in distributed fashion, chiefly on buildings). In either case, the land-use can be shared, much as farmers and ranchers do now, earning valuable revenues from the wind that blows above their herds and crops. Modern renewable sources repay their energy investments in months to a few years: illustrating their materials-frugality, 1 kg of silicon in thin-film PVs can produce more electricity than 1 kg of uranium in a pressurized-water reactor. Further PV breakthroughs continue (*e.g.*, *Science* **293**:1119–1122 (2001)).

Meanwhile, the next revolution—distributed utilities—is gaining momentum. As *The Economist* remarked (17 May 2001, online ed.), "In fact, the trend since the mid-1970s has been towards smaller plants. It is micropower, not megapower, that the market favours, thanks to the far smaller financial risk involved." My forthcoming book *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* shows how roughly 125 "distributed benefits" of decentralized electricity sources can typically increase their economic value by roughly tenfold, making even PVs cost-effective today in most applications. Even more valuable than familiar electrical engineering attributes—lower grid costs and losses, higher reliability and power quality, dispatchable reactive power, near-infinite ramp rates, etc.—are the lower financial risks of small, short-lead-time modules. For example, a 10-kW resource installable overnight could cost 2.7 times as much per kW as a 50-MW resource installable in two years, yet yield identical financial performance. In the new arena now emerging, discount rates are project-specific and risk-adjusted, new market actors understand financial economics, and competition increasingly embraces all options. Continuing nuclear ownership consolidation may improve operations more than it concentrates risks, but the firesale prices realized at used-reactor sales in the late 1990s confirm a market perception of low or even negative long-run asset value.

Nuclear waste accumulates, and neutron fluence raises decommissioning costs, proportionally to nuclear power generation. Moreover, nuclear power's having died of an incurable attack of market forces—plus the end of the Cold War—offers a unique opportunity to inhibit proliferation as fissile materials, skills, and equipment become no longer ordinary items of commerce (except for minor and readily safeguarded medical and industrial uses). This would make such bomb-kit ingredients harder to get, more conspicuous to try to get, and politically far costlier to be caught trying to get or supply, because for the first time, the reason for wanting them would be unambiguously military. This exposure of illicit transactions—now hidden in and rationalized by a vast flow of supposedly innocent civilian nuclear commerce—would not make nuclear bomb proliferation impossible, but would make it far more difficult, and would focus its resource flows into narrower, more readily monitored channels. This potential for an internally consistent nonproliferation policy was summarized in *Foreign Affairs* in Summer 1980 and in the 1979 book *Energy/War: Breaking the Nuclear Link*; today, its preconditions, somewhat visionary at that time, have been realized, and the logic is as tight as ever.

A word about California's current electricity crisis may be necessary because so many myths have been propagated about its causes (www.rmi.org/URLTOCOME). The published official data clearly show that California did not suffer soaring electricity demand, least of all from the Internet; that the state added in the 1990s more new generating capacity than its 4.3-GW nuclear capacity (but the additions were distributed and nonutility, therefore seemingly invisible); and that the state was not short of oil, which anyhow generates <1% of its electricity. The actual causes were many and complex. Fundamentally, the most important cause was botched restructuring and concentrated market power: seven firms control two-thirds of the bidding space, so each can move the market. Each therefore earned far more profit by selling less electricity at a higher price rather than more at a lower price. Until June 2001, 10–15 GW was apparently being withheld from the market, not all legitimately; that's why the same system that met a 53-GW peak load in summer 1999 suffered rolling blackouts at 29 GW in January 2001. It's not obvious that new capacity built by the same firms that already exercise excessive market power will solve this problem, since those firms will then have even more capacity to withhold and no less incentive to do so.

Nuclear power is unrelated to this problem save in the fundamental sense that its high "stranded asset" costs helped trigger the dreadful restructuring, and in the minor sense that a 1.1-GW outage at San Onofre contributed to the problem. More nuclear power certainly wouldn't help timely (or economically) even it could be financed and sited. In fact, as *Barron's* 6 August 2001 cover story noted, the U.S. is already building more power plants than it might plausibly need. Such overshoot, last seen in the mid-1980s, occurs when slow-to-build central power plants collide head-on with quickly captured efficiency. In the first six months of 2001, for example, even before price hikes hit, Californians' electric savings undid the previous 5–10 years' demand growth, helping to stabilize the market and frustrate the ticket-scalpers' ambitions.

Some advocates hope an oil shock will restore nuclear power's market credibility. Oil shocks may well recur, though the world is far better prepared for them—the Gulf War triggered no oil shortages. Yet the rational response would be not the slowest, costliest option—and the one whose output, electricity, is least fungible for oil—but rather efficiency, distributed thermal and thermoelectric systems, natural gas, and biofuels. Anyhow, oil problems will fade away as superefficient cars (www.hypercar.com) save as much oil as OPEC now sells, helping to make oil uncompetitive even at low prices before it becomes unavailable even at high prices. Moreover, each fuel-cell Hypercar[SM] will be a 20–40-kW_e mobile power plant. When parked, ~96% of the time, it can be plugged into the hydrogen appliance in a nearby building and into the grid, electricity sales to which should repay up to half the car's lease cost. Such a fleet will ultimately have ~6–12 times as much generating capacity as all power companies now own—yet another nail in the nuclear coffin.

Nuclear advocates' last hope is that climate concerns will revitalize their option. Alas, they've overlooked opportunity cost—the impossibility of spending the same money on two different things at the same time. If saving a kW-h cost (pessimistically) as much as three cents, while delivering a kW-h of new nuclear electricity cost (very optimistically) as little as six cents, then the six cents spent for each new nuclear kW-h could instead have bought *two* kW-h worth of efficiency. The nuclear purchase therefore displaced one *less* kW-h of coal-fired electricity than the same money could have done by buying the cheaper (efficiency) option instead. That's why the order of economic priority must also be the order of environmental priority; why it's irrelevant whether nuclear power can beat coal power as long as any other option costs still less; and why nuclear power makes global warming worse.

Nuclear power is a future technology whose time has passed. Its economic problems are so ineluctable that it would still fail even if it had no political, environmental, safety, or security problems. And as the retirement of the older, higher-quality nuclear pioneers continues the worrisome trend predicted by Nobel physicist Hannes Alfvén—that the enterprise will "pass into ever less competent hands"—each dollar spent to address the unsolved problems will buy ever less solution.

Looking after nuclear power's legacy will be a business with a long future; but the operation of today's nuclear fleet will not. Despite immense investments, devoted efforts, and dedicated careers, those plants will long stand as a monument to what happens when a technology avoids market and political accountability for long enough to make really big mistakes, and when its advocates develop a reputation for mendacity. Its epitaph could be: "Here lies a technology that failed because it did not take its discipline from the marketplace, its values from its customers, and its design from nature." Its seemingly great promise was betrayed by tragic flaws.

Nuclear power has been called "a fit technology for a wise, farseeing, and incorruptible people." A pity we haven't more of them. But its best legacy would be not to make the same mistake again; and the best way to do that is to take economics seriously. The Bush Administration's claims that nuclear power is safe, but needs an extension of its unique statutory cap on liability for major accidents, and is economic, but needs another $1.5 billion in tax breaks, is perplexing to advocates of free markets, and hardly seems a propitious start at acknowledging and respecting market outcomes.

Shorn of distracting details, the nuclear power issue is simple. The technology has failed in the marketplace—a tragic misallocation of talent, work, hope, and investment that deserved better and that continues to distort public choices. However, accepting the verdict of the marketplace will yield the right energy policy conclusion and will also simplify the politics of finding the least unsatisfactory place to put nuclear waste. An orderly terminal phase should be designed for this unfortunate mistake—but can't be, so long as nuclear theology dominates policy. If recognized, however, the commercial collapse of nuclear power, and the rise of better energy alternatives, could be turned into the long-awaited missing step toward effective nonproliferation.

Amory Lovins, a MacArthur Fellow and originally a consultant experimer physicist, is a frequent advisor to utilities and other industries, and cofounder and co-CEO of the independent nonprofit applied research cer Rocky Mountain Institute (www.rmi.org). Published in 27 books c hundreds of papers, his work has been recognized by the "Alternat Nobel," Onassis, Nissan, Shingo, and Mitchell Prizes, the Happold Mec and the Heinz, Lindbergh, Hero for the Planet, and World Technolc Awards. Portions of this article are adapted from one invited for November 1999 British newsletter Power Economics, *and from the open address to the Nuclear Control Institute's 9 April 2001 symposium "Nucl Power and Nuclear Weapons: Can We Have One Without the Other (www.nci.org/conf/lovins/index.htm).*

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Expanding Nuclear Power Worldwide Without Proliferation

Of the countries that are party to UN Framework Convention on Climate Change (UNFCCC), the two with the lowest emissions of carbon dioxide per unit of gross domestic product are Japan and France, the two countries with the greatest commitments to nuclear energy. If the UNFCCC were ultimately successful it would mean that atmospheric CO2 concentrations would not double the current level of about 370 ppm. If the world's easily-recovered uranium reserves are fissioned in reactors, about 5300 ppm of atmospheric CO2 emissions could be avoided. Other reserves could stretch the contribution by orders of magnitude. Thus, nuclear energy potentially has a large role to play in meeting the goals of the UNFCCC, especially if other technologies do not live up to their promises.

Rather than allowing nuclear energy to place a central role in the UNFCCC, the parties recently agreed not to allow nuclear energy into its Clean Development Mechanism (CDM). The representatives from the European Union, especially, think it is easier to leave nuclear energy out of the mechanism than address problems with nuclear proliferation and reactor safety. Some also claim that nuclear energy is not sustainable, although, as shown above, it is difficult to support this argument on the basis of resource depletion.

Without nuclear energy, there is no reason to believe that carbon-free technologies will be adequate to meet future energy demand, especially in the developing world, unless the goals of the UNFCCC are abandoned. Simply stated, burning fossil fuel (without sequestering the CO2) is now the most economical option for most of the developing world. This will not change unless there are dramatic developments in carbon abatement technology, or nuclear power is allowed back into the CDM. If nuclear power is put into the CDM, much additional care and thought must be added as well.

The most serious objection to nuclear power -- some would say the only serious objection -- is the possibility that it might foster nuclear weapon proliferation. Therefore, it is important that there be mechanisms to address this concern.

The Carbon-Control Framework

The details of the nuclear aspects of a future agreement are difficult to envision without first discussing the current framework for greenhouse-gas-emission mitigation. It is assumed that some sort of workable but realistic framework will survive into the future with most of the industrial countries participating. It is also assumed that the CDM will survive, allowing the industrial countries to export carbon-free power technology to non-participating countries to collect credits.

The agreement to reduce carbon emissions encourages national governments to create economic incentives for constructing and using carbon-free power plants. Alternatively, they would create economic disincentives or taxes on carbon dioxide emissions. Either way, the fundamental metric for this incentive is the "carbon value" expressed in units of $ per ton of carbon avoided. This value may be determined by fiat or by market or by a combination. In general, the more stringent the emission-reduction goal, the higher the carbon value. If there is greater international participation and trading allowed, the carbon value will tend to be lower for a given amount of carbon reduction[1].

Suppose a power plant generating a thousand megawatts of electrical power needs to be built, and there are two choices for the fuel; one is coal and the other is a carbon-free fuel. Suppose further that (in the absence of added incentives) it costs more to build and operate the carbon-free plant than the conventional fossil fuel power plant. The owner of the plant must get some financial compensation or avoid some financial penalty for not emitting CO2 in order that it be persuaded to select the carbon-free plant. Suppose that the power plant owner is required to obtain a permit to emit carbon dioxide into the atmosphere every month, and that the permit costs $100 per ton of carbon. Under these circumstances, a carbon-free power plant would avoid paying hundreds of millions of dollars every year for permits.

From a policy viewpoint, this type of mechanism is a good way to balance environmental and economic objectives. For corporate and other decision-makers, they will be able to make business decisions based on the information available in this marketplace. The only requirement for this mechanism to work smoothly is that investors be fairly sure that they cannot otherwise avoid the need for the permits. This mechanism could work even if dollar amount of the emission permit were dictated by governmental fiat. However, if there is a market mechanism that determines the value of the carbon dioxide permits, information about carbon values will be continually updated depending on world economic conditions. It is therefore preferable to use a system based on tradable carbon-emission permits and allow there to be a world market in permit trading.

The nation where a power plant was built would then simply show the UN body charged with climate-change treaty compliance that it is enforcing its permit laws. National governments would have no other obligations theoretically, if there were a free world market on the permits.

No nation has yet seriously adopted this type of strategy, and as a result there has been essentially no abatement of greenhouse-gas emissions in the world other than for reasons of economic downturn. In the future, if this changes, each country will try to follow its target emissions quota for each year. Control of total global carbon dioxide emissions would occur simply by limiting the number of permits issued worldwide.

Enforcement of compliance could raise some very serious political problems at the international level, which would tend to make the regime unstable. Suppose a country has an economic recession but still needs to spend large amounts of money on controlling carbon emissions. There would be strong motives for that nation's government to either stop enforcing the emissions-permit process or to withdraw from the treaty completely. This problem would nearly disappear if there were a zero-cost way of avoiding fossil fuel use. However, at the present time there are no avoidance technologies that are widely applicable, especially in the transportation sector, that have zero or negative cost. The motivation to stay within the regime becomes greater if the economic costs of staying in the regime are lower. If costs are too high, the regime will collapse.

Developing countries do not, in general, want to join the agreement. Countries such as India and China intend to expand their economies significantly over the next 50 years, want an exemption because their fossil fuel use per-capita is only a tiny fraction of the average for the developed world. Therefore targeting their allocation to a previous year's emissions seems unfair to them. Some compromise could be worked out, where developing nations were not asked to fully join the international regime until their per-capita income level reaches a certain fraction of the developed world average. All of this is a current subject for debate at the international level and, for the time being, the agreement does not require that the developing nations control their emissions of greenhouse gases.

The distribution of permits within a country (by its government) is properly the internal affair of each nation. For example, France may simply distribute some permits to its large, state-owned industries and require private industry to pay a fixed fee for each allocation of carbon dioxide emission. In another country there may be an auction. In any case, each government can raise revenue by selling the permits; this revenue stream can pay for the costs of enforcement.

Governments, of course, also have the right to create and enforce all sorts of laws and regulations regarding the technologies that are allowed for energy production. For instance, local governments may ban certain energy technologies they deem to be inappropriate, possibly including nuclear power. Export of carbon-free power plants could occur under the same treaty, without additional protocols, if both the exporter and the importer were treaty members. The corporate exporter and the importer would divide the costs and profits according to their own, separate agreement.

A separate mechanism, the CDM, is required to account for construction in developing nations that are not party to the treaty. If a developed nation exports a carbon-free power plant to a developing nation, it could receive an allowance for the avoidance of an appropriate amount of greenhouse gases.

Nuclear Exports

A high-visibility template for proliferation-resistant nuclear power export is the Agreed Framework (AF) between the US and North Korea (DPRK). The effort to halt the DPRK's nuclear research assumes great importance in the present context because it holds powerful implications for the evolution of the international non-proliferation regime. If agreements that are as good or better can be made, more countries can be brought into the center of the regime. The parties to the UNFCCC should borrow from the AF to include nuclear energy in the CDM.

Under the AF, the government of DPRK has agreed to freeze and ultimately abandon its nuclear weapon program in exchange for support from foreign governments in constructing two state-of-the-art nuclear power plants in North Korea. The power plants, built under modern safety standards, using a proliferation-resistant fuel and reactor design, will be safeguarded by the International Atomic Energy Agency (IAEA). The swap, which is verifiable, is a good deal for all the parties involved. In this particular case, the money is provided by the governments of Japan and South Korea, who have an interest in stability and peace in the region.

Integrating nuclear power into the CDM would require the nations to work closely with the IAEA to set standards for reactor safety, waste disposal and nuclear safeguards. Credits would not be made available unless the recipient nation is in good standing in the NPT and dismantled any nuclear weapon infrastructure and reprocessing facilities. The countries that are already within the regime but have not accepted the current (INFCIRC/540) safeguards standards from IAEA would have to accept the new standard. The recipient nation would also provide its initial declaration of materials and facilities, and have that declaration verified by the IAEA. This whole process could take as long as a few years and could cost the IAEA considerably in terms of resources. Therefore, the exporter and importer nation would be required to be in good standing with respect to their IAEA monetary obligations.

There would be special "transitioning" provisions for a weapon state such as India who wishes to receive the nuclear power plants. It would be obligated to join the NPT and agree to the INFCIRC/540 safeguard protocol. It would immediately shut down and begin dismantlement of any plutonium-production reactors that are not also used to produce electricity. Power-producing reactors and dual-use reactors would continue to operate unless replacement capacity is provided on a temporary basis by the exporter country through, e.g., small gas turbines. It would store all its separated fissile material in cans or canisters. Seals would be put in place on the frozen materials while the new power reactors are under construction. It would cease production of highly enriched uranium, but not low-enrichment uranium. During the period of time when the new power reactors are being built, the IAEA will verify the accuracy of the initial declaration of materials and facilities. The nuclear components of the new reactors would not be delivered unless the IAEA verification process was complete. When the installed capacity of the new power reactors exceeds the capacity of the old infrastructure, dismantlement of the old power reactors would begin.

The subsidized power reactor exports could only add stability to the non-proliferation regime because it would provide incentive to join and stay within the regime. The NPT would not have to be amended; the process of accepting the power plants along with the enhanced safeguards would be voluntary and non-discriminatory. Low-enrichment uranium fuel will be supplied to the recipient nation under long-term contract. Reprocessing or re-enrichment of fuel would be disallowed. The spent power reactor fuel can be monitored on the site or moved to another location, such as an international or regional facility. Under the monitoring, the burnup and the history of every fuel assembly will be known and catalogued.

The new plants would come with a limited-term maintenance agreement and an initial, interim work force. During this start-up period, the recipient nation will have to learn how to perform maintenance, repairs and refueling. There will be a period where the interim work force will be training the permanent work force through an apprenticeship program.

The plant owners will not receive the subsidy unless the plant is built and operated according to international (IAEA) safety standards. If the recipient nation is not capable of running their own plants in a safe manner, the safety standards must be imported with the power plant. A workforce will be trained in the safe operation and maintenance of the plants. These nuclear workers will be trained how to run plants safely, how to maintain plants safely, and after a few years will have come up to the level of training which will qualify them in apprenticeship roles. A regulatory force will be trained for those countries that do not have an independent regulatory commission that regulates the nuclear industry. The regulatory force itself will have to comply with international standards.

The recipient nation would relinquish any ownership rights over the spent fuel and agree to the transfer of the spent fuel out of its territory as soon as technically possible after the fuel is discharged. Dry spent fuel storage technology is not out of the question for many sites around the world. A typical storage cask is made out of reinforced concrete, and each one weighs about 100 tons. The fuel cannot be removed unless one has a special lifting device to actually lift the entire cask and take it to a facility that disassembles it. The casks would be stored where the spacing is several meters and resolution typical of optical cameras from a low orbit satellite is about one meter, so individual casks can be easily resolved in satellite imagery.

Commercial photography in the visible and infrared range may be used for verification.

Conclusion

Nuclear energy may have a significant role to play in preventing dangerous climatic changes, especially if there are troubles expanding other forms of carbon-free energy. But nuclear energy has been blocked from admission into the UNFCCC's CDM because of the argument that it is not "sustainable," and also because of concerns about nuclear proliferation and reactor safety. Yet the resources of fissionable material, especially if uranium from seawater is included, are essentially inexhaustible. Legitimate concerns about nuclear proliferation and reactor safety can be addressed by using the CDM as a means to bring the nuclear programs of the world up to the best international standards. In fact, if done carefully, an expansion of nuclear energy under the CDM could actually reduce worldwide nuclear proliferation and reactor safety concerns.

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Is Radiation an Essential Trace Energy?

John Cameron

Introduction

Radiation protection policy in the United States and in most of the world is based on the assumption that the risk of a radiation induced fatal cancer is linearly proportional to the dose. This is known as the linear, no-threshold (LNT) model of radiation risk. There are no human data to support this assumption for a short-term dose below 0.2 Gy--the equivalent of about two centuries of exposure to natural gamma radiation. If there is a threshold at 0.2 Gy (and much larger for low dose rate radiation) or benefits from the low dose rate radiation received by many workers, billions of tax dollars can be saved annually in the U.S.

I describe two little known peer reviewed human radiation studies, which strongly support the hypothesis that ionizing radiation stimulates the immune system. The U.S. National Council for Radiation Protection and Measurements (NCRP), has ignored these data in providing guidance on health effects of radiation to the U.S. Congress. These data suggest the need for research on radiation benefits. Currently, radiation research concentrates on the known cancer risk at large doses.

The U.S. Gulf States have a high cancer death rate compared to the mountain states although background radiation is much lower in the Gulf States. I suggest they are suffering from radiation deficiency. I will propose a double blind study using increased radiation to stimulate the immune systems of senior citizens in the U.S. Gulf States. The idea that radiation is beneficial is not new. For centuries, millions of people have visited health spas with high radiation levels. There is an extensive literature on radiation benefits. (Luckey 1980; 1991)

The nuclear shipyard worker study (NSWS)

Nuclear ships have been built and maintained in seven US shipyards for over 40 years. In 1980, the US Department of Energy (DOE) gave a contract to the School of Public Health at Johns Hopkins University to study radiation risks to nuclear shipyard workers. This study, which extended for more than a decade, cost the taxpayers $10 million. This was the World's best epidemiological study of nuclear workers. The study has yet to be published more than 12 years after its completion in early 1988. The final report of the study has been available since 1991 (Matanoski 1991)

Although the nuclear shipyard worker data have not been published, the study had excellent peer review during its eight-year duration. The DOE contract provided for peer review twice a year by a panel of eight scientists with expertise relevant to the research. Appendix 2 of the final NSWS report states: "The Technical Advisory Panel (TAP) was formed in 1980 as a standing committee of experts who would provide objective advice to the project staff on a continuing basis. In selecting its members, it was important for each [TAP member] to have had personal research experience with some of the problems related to the Shipyard Study. Disciplines which we believed to be important and which were included in the group are: radiation biology and radiation physics, medicine, genetics, industrial hygiene, epidemiology and biostatistics." The scientists who served as members of TAP were Dr. Arthur Upton, (chair); Gilbert Beebe, John Cameron (the author of this article), Carter Dennison (who resigned in 1983), Merril Eisenbud, Philip Enterline, Philip Sartwell and Roy Shore. TAP met twice a year to review data, question the scientific staff and make suggestions. Early in 1988, TAP approved the draft of the final report.

The summary in the final NSWS report (p. 393) states: "The shipyard nuclear worker population represents a large number of individuals exposed to low documented [doses] of radiation. They receive this radiation almost exclusively from gamma rays due to the decay of cobalt-60. Within the [shipyard] population there are comparable groups of workers exposed to negligible or no radiation at their shipyard jobs but who engage in similar work. Therefore this is an ideal population in which to examine the risks of ionizing radiation in which confounding variables can be controlled. *"

Note that the study was to examine "risks" rather than "health effects" or "health benefits". The final report concludes, "The [exposed] population does not show any risk which can be clearly associated with radiation exposure in the current analysis." Since the study was looking for risks, the final report does not mention the significant health benefits of radiation to the nuclear workers. No article has been published on the results of the NSWS. After waiting for over a decade, I feel it is appropriate to call the results of this important study to the attention of other scientists

The nuclear shipyard worker study consisted of three groups: nuclear workers with cumulative doses greater than 0.5 rem dose effective (NW0.5); (A dose of 0.5 rem is roughly five years of background radiation, excluding contributions of radon progeny to the lungs.); nuclear workers with cumulative doses less than 0.5 rem (NW<0.5); and non-nuclear workers (NNW) of similar ages and jobs as the nuclear workers The numbers in each group

Table 1

Deaths from All Causes, Person-years and Death Rates* for high dose nuclear workers (NW0.5)); low dose nuclear workers (NW<0.5); and non-nuclear workers (NNW) (after Matanoski 1991 p. 333)

	High dose	Low dose	Zero dose
Workers in subset	27,872	10,348	32,510
Person-years	356,091	139,746	425,070
Deaths	2,215	973	3,745
Death Rates per 1000**	6.4	7.1	9
Death Rates (SMR)***	0.76	0.81	1
95% C.L.****	(0.73,0.79)	(0.76,0.86)	(0.97,1.03)

* Rates calculated per 1000 person-years. ** Adjusted for deaths excluded from analysis due to unknown date of death. *** Using age-calendar time specific rates for U.S. white males. **** C.1. = 95% Confidence intervals.

are given in Table 1. The total study group consisted of nearly 71,000 workers with a total of over 922,000 person-years.

Although the study involved radiation, no summary is given of the cumulative dose in "rem-years". An estimate can be made from Table 3.1.C1 in the final report. Doses to the NW0.5 group were divided into four dose categories. A worker may contribute to each of the four groups. A rough estimate from that table suggests that the NW0.5 group, had average doses 5 to 10 times their cumulative dose from background (excluding radon progeny.) Their occupational dose was comparable to background doses received by people living in mountain states.

When the study started, the statistical power of the shipyard worker study was known to be inadequate to show an increase in cancer. The final NSWS report (p. 379) states "The shipyard worker study has less than a 20 percent chance of detecting an excess of leukemia at the level of the BEIR III report estimates." Rather than showing increased cancer, the cancer death rate of the NW0.5 group was over four std. dev. lower than the NNW control group. This good news is not mentioned but the data are available in the final report.

The important finding from the NSWS is support of the hypothesis that a moderate dose rate of radiation is beneficial to the health. The NW0.5 group had a death rate from all causes 24% lower than the control group. That is, their death rate was 16-std. dev. lower than the controls (p< 10-16). . If the study aim had been to look for health benefits of ionizing radiation, it would have been a huge success. As a study to find radiation risks, it was an abysmal failure. This may explain the reason the study has yet to be published. I published a brief summary of the results in 1992, shortly after the final report was submitted. (Cameron 1992) I know of no other publication or reference to this important study.

The British radiologists study (1900-1980)

The reader may think that the nuclear shipyard study is contradicted by other human studies. I know of no contradictory studies. One other radiation worker study--the British radiologists study. (Smith and Doll 1981)-- also looked at the death rate from all causes. It gives results consistent with NSWS. (Table 2.) Radiologists in the study were divided into two groups--those who joined a radiological society before 1921 and those who joined such a society after 1920. The dividing date was chosen because the British x-ray safety committee became active about 1920. There was a need for the committee as data in Table 2 indicate. The large radiation exposures to early radiologists significantly increased their cancer death rate compared to three control groups of men in England and Wales.

Despite the large occupational exposure to the early radiologists, their death rate from other causes decreased. That is, there was no statistical evidence of a decrease in longevity compared to the three control groups. This suggests that radiation stimulation of their immune systems canceled the radiation induced cancer deaths.

There can be little doubt that the British x-ray safety committee did its work well. Note the great decrease in cancer death rate after 1920. More importantly, the study provides strong support for radiation stimulation of the immune system. Note the statistically significant decrease in deaths from all causes. The probability of this health improvement being accidental is generally lower that 0.001.

Table 2

Mortality of British Radiologists 1900 to 1980

Deaths of British radiologists were compared to three groups:

A---All men in England and Wales; B---All men in social class I; C---All male medical practitioners. A total of 1338 radiologists were divided into two groups: "Before 1921" All British physicians who joined the British Institute of Radiology or the Royal College of Radiologists before 1921 and "After 1920" All British physicians who joined either society after 1920 (From Smith PG, Doll R. 1981)

O/E = OBSERVED/EXPECTED

		BEFORE 1921		AFTER 1920	
		OBSERVED	O/E	OBSERVED	O/E
DEATH FROM ALL CAUSES	A		0.95		0.76***
	B	319	1.04	411	0.89*
	C		0.97		0.87**
DEATH FROM ALL CANCERS	A		1.26*		0.63***
	B	62	1.44**	72	0.79*
	C		1.75***		1.05
DEATH FROM OTHER CAUSES	A		0.95*		0.79***
	B	257	0.97	339	0.92
	C		0.88*		0.84**

Short-term (acute) radiation doses may also be beneficial

Short bursts of radiation appear to stimulate the immune system. The article by Feinendegen et al (1998) suggests that a short-term (acute) dose of 0.1 Gy to animals --about 100 years of background dose, excluding radon progeny--is about optimum.

A proposed human study of radiation stimulation of the immune system.

When there are controversies in science, it indicates inadequate data. The present controversy over the health effects of low dose rate radiation calls for a prospective double blind human study. The DOE has set aside research funds to study risks of low dose rate radiation but no funds to study benefits, such as demonstrated in the British radiology and the nuclear shipyard worker studies.

I propose a prospective double blind human study to see if increased radiation stimulates the immune system. If the results are positive, additional studies will be needed to determine the Recommended Annual Dose Rate. Such a study of the immune system should be relatively short compared to a cancer induction study, which might require years. For example, they are still seeing a few radiation induced cancer deaths among the a-bomb survivors from over 50 years ago.

I suggest that people in the Gulf States are suffering from radiation deficiency. (Jagger 1998) Evidence is the 25% higher cancer death rate in three U.S. Gulf States (LO, MS & AL) compared to three mountain states (ID, CO & NM)--which have a much higher background level. In studying any deficiency disease it is logical to choose the group most likely to benefit from an increase of the essential factor. Increased background radiation can be easily and safely produced by containers of weak radioactive sources under the beds of the study cohort. The sources would increase the radiation level to the background level found in the mountains. Similar containers without radioactivity would be placed under the beds of the controls. Neither the participants nor their medical caregivers would know which participants were receiving supplemental radiation. It would be useful to record infectious diseases and their duration as a measure of the function of the immune system. The most important data will be a comparison of the longevity of the two groups. The study would involve routine inspections to monitor the radiation sources and the similar containers under the controls. The study could be done in large retirement homes where many subjects would be readily available to participate in the study. Replacement participants would be added from time to time. The study would be inexpensive, as it would not require additional medical care, medication or expensive laboratory studies. I am sure many senior citizens will be willing to participate in the study since it would not involve taking medication or receiving injections. The possibility that more radiation will prolong their life will appeal to many. It will be much cheaper than for them to move to the mountains or visit a radiation health spa.

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The Pebble-Bed Modular Reactor (PBMR): Safety and Non-Proliferation Issues?

Edwin S. Lyman

Introduction

The Bush Administration has made the expansion of nuclear power generation a centerpiece of its domestic energy policy. However, the White House has not addressed the practical issue of how to overcome the nearly three-decade-long aversion among U.S. electric utilities to investing in new nuclear plants. In today's deregulating market, utilities will not build new nuclear power plants unless they are clearly competitive with fossil fuel plants (or receive substantial government subsidies). Compounding the difficulty are the nagging questions that continue to inhibit public acceptance of nuclear power: severe accident risk, non-proliferation, vulnerability to sabotage and nuclear waste disposal. To solve all these problems simultaneously will be a considerable challenge --- one unlikely to be met by the current generation of light-water reactors (LWRs), the only reactor type now used for power generation in the U.S.

Given this context, it should come as no surprise that the U.S. nuclear industry is hanging its hopes on a radically different type of plant known as the pebble-bed modular reactor (PBMR). The mega-utility Exelon has invested in a project of the South African state utility Eskom to develop and commercialize the PBMR, and is now engaged in detailed discussions with the U.S. Nuclear Regulatory Commission (NRC), in anticipation of submitting a license application for construction of ten 110 MWe PBMR modules in December 2002. Once construction approval is granted, Exelon hopes to build the first module in only 20 months.

Advocates of the helium-cooled, graphite-moderated PBMR argue that it is significantly safer than LWRs and should be exempted from a number of regulatory requirements that apply to the current generation of nuclear plants. If the NRC were to waive these regulations, these advocates claim that a PBMR could be developed with many of the characteristics that make gas turbines economically attractive: low capital cost, short construction time, high conversion efficiency and feasibility of modular production and distribution. Without these exemptions, however, the prospect of a commercially viable PBMR would become much less certain.

The nuclear industry has a long history of proposing new nuclear plant designs that sound great in theory but disappoint in practice, and the PBMR may be no exception. Some technical features of the PBMR are clearly improvements over LWRs, but others raise new safety concerns. Unlike LWRs, the PBMR does not have the benefit of thousands of reactor-years' worth of operating experience. Only a handful of high-temperature gas-cooled reactors (HTGRs) have operated in the past, and the results have been decidedly mixed. Moreover, none of these reactors had employed the unique power conversion system proposed for the PBMR, in which the reactor coolant is used as the working fluid of a gas turbine to directly generate electricity.

Definitive resolution of the numerous open technical issues is likely to take quite some time. This is time that Exelon --- which hopes to obtain a license from NRC in only two-and-a-half years --- is not inclined to expend. The increased flexibility that utilities need to compete in a deregulated market limits their timelines for decision-making, and may well be incompatible with the caution and rigor that advanced nuclear reactor development requires.

PBMR Design and Safety Features

Although the general outlines of the PBMR are known, the design that Exelon plans to submit to the NRC has not been finalized, so the following description is subject to change. The reactor consists of an annular core surrounded by graphite blocks. The core consists of 330,000 "pebbles": softball-sized graphite spheres, each containing 15,000 fuel microspheres, and 110,000 graphite spheres containing no fuel. Each fuel microsphere is composed of a uranium dioxide pellet (enriched to 8% U-235), enclosed in a three-layer coating consisting of a layer of silicon carbide sandwiched by two layers of pyrolytic carbon. This so-called TRISO fuel has exhibited good fission product retention in German tests up to temperatures of about 1600 C. Fuel pebbles are continuously loaded at the top of the core, flow downward, and are discharged at the bottom. Because the PBMR is fueled while operating, shutdowns would be required only for maintenance purposes and would take place every six years. (In contrast, LWRs must be shut down for fuel reloading; currently this is done about every eighteen months.) Fuel burnups are intended to go as high as 80,000 MWD/MT, whereas NRC limits the maximum burnup of LWR fuel pins to 62,000 MWD/MT. (MWD/MT= megawatt-days per metric ton, a measure of the total amount of heat extracted from a fuel element.)

The temperature resistance of the fuel and the use of a single-phase, gaseous coolant enables the reactor to operate at a coolant temperature of about 900 C, considerably higher than the operating temperature of LWRs. The higher temperature alone allows the reactor to achieve a conversion efficiency of 39%. Use of the coolant in a direct gas turbine cycle (known as the Brayton cycle) further increases the efficiency to about 43%.

Because the PBMR is continuously refueled, the excess reactivity can be kept low. Also, the design has a more negative fuel temperature coefficient than LWRs, as the Doppler feedback is greater for the less-thermal neutron spectrum associated with a graphite moderator.* These features reduce the risk of reactivity accidents for most scenarios (but increases the risk for accidents involving core overcooling).

A major component of the PBMR safety basis is a low power density (an order of magnitude below that of an LWR) and large thermal capacity (as a result of the large mass of graphite in the core), together with the high-temperature resistance of the fuel. The maximum power rating of each module (265 MWth) and the high surface-to-volume ratio of the core were chosen so that in the event of a loss of coolant from the primary system, adequate cooling would be provided without the need for forced convection. PBMR designers claim that in the event of a total loss of primary coolant and no operator intervention, the core heatup rate would be slow and the maximum fuel temperature would not exceed 1600 C. Thus the design does not include conventional emergency core cooling systems, which are required for LWRs to provide emergency water sources in the event of a loss-of-coolant accident.

PBMR advocates are so confident in the safety of the reactor (some even call it "meltdown-proof") that they have proposed a drastic weakening of a number of safety requirements that apply to the current generation of U.S. nuclear plants. These proposals include (1) use of a filtered, vented confinement building instead of a robust containment capable of preventing a large release of radioactive materials in the event of severe core damage; (2) a reduction of the size of the emergency planning zone (EPZ) from 16 kilometers to 400 meters; (3) a reduction in the number of staff, including operators and security personnel; and (4) a reduction in the number of systems whose components must meet the most stringent quality assurance standards.

However, there is insufficient technical justification for these measures. The presence of a pressure-resistant, leak-tight containment and the maintenance of comprehensive emergency planning are both prudent "defense-in-depth" measures that could mitigate the impact of a severe accident with core damage. Defense-in-depth is the requirement that nuclear reactors should have multiple, independent barriers in place to prevent injuries to the public and damage to the environment. The presence of multiple barriers is a hedge against uncertainty and an acknowledgement that the understanding of the performance of any one barrier is incomplete.

PBMR promoters claim that a robust containment is unnecessary because the design-basis depressurization accident cannot cause damage to the PBMR fuel severe enough to result in a large radiological release. They argue further that such a containment would actually be detrimental to safety because it would inhibit heat transfer and interfere with the passive mechanism needed to cool the core in the event of a loss-of-coolant accident. However, a containment is needed not only to inhibit the relatively minor releases that would occur during the design-basis accident, but also to mitigate the consequences of a more severe accident. Containments can also help to protect the reactor core from a sabotage attack utilizing truck bombs or hand-held rocket launchers --- an ominous possibility that should not be discounted.

If one could predict with confidence that severe accidents or sabotage attacks were so unlikely as to be incredible, then protection against them might not be justified. However, in the case of the PBMR, significant uncertainties remain, both in the likelihoods of potential severe accidents and in the identification of every potential accident sequence. The PBMR designers have not yet carried out a probabilistic risk assessment (PRA) and do not even have estimates of the risks of more severe accidents.

Among the largest sources of uncertainty for the PBMR are the potential for and consequences of a graphite fire. The large mass of graphite in the PBMR core must be kept isolated from ingress of air or water. Graphite can oxidize at temperatures above 400 C, and the reaction becomes self-sustaining at 550 C (the maximum operating temperature of the fuel pebbles is 1250 C)[1]. Graphite also reacts when exposed to water vapor. These reactions could lead to generation of carbon monoxide and hydrogen, both highly combustible gases.

If a pipe break were to occur, leading to a depressurization of the primary system, it has been shown that flow stratification through the break can cause air inflow and the potential for

* Doppler broadening is a temperature feedback mechanism in which the absorption resonances of U-238 in the 6-100 eV range broaden as the temperature increases, resulting in greater resonant neutron absorption. As more neutrons are captured by U-238 atoms, fewer are available for U-235 fission at thermal energies (i.e. around 1/40 eV), reducing the reactivity. Since neutrons must undergo more collisions with carbon than with hydrogen to reach thermal energies, there are more neutrons in the resonant absorption range for graphite-moderated homogeneous systems than for water-moderated homogeneous systems, so the graphite system would feel the Doppler effect more strongly.

graphite ignition[2]. While the PBMR designers claim that the geometry of the primary circuit will inhibit air inflow and hence limit oxidation, this has not yet been conclusively shown.

The consequences of an extensive graphite fire could be severe, undermining the argument that a conventional containment is not needed. Radiological releases from the Chernobyl accident were prolonged as a result of the burning of graphite, which continued long after other fires were extinguished[3]. Even though the temperature of a graphite fire might not be high enough to severely damage the fuel microspheres, the burning graphite itself would be radioactive as a result of neutron activation of impurities and contamination with "tramp" uranium released from defective microspheres. An even worse consequence would be combustion of carbon monoxide, which could damage and disperse the core while at the same time destroying the reactor building, which is not being designed to withstand high pressure. In contrast, the large-volume concrete containments utilized at most pressurized-water reactors can withstand explosive pressures of about 9 atmospheres.

Another important source of uncertainty comes from the complexity of the PBMR core, which is constantly in motion. A PBMR operator must be able to accurately compute the pebble flow, neutron flux and core temperature distributions without the benefit of in-core instrumentation (since there are no structures to support such instrumentation). Previous experience with the AVR test reactor in Germany, a precursor to the PBMR, indicates cause for concern. Experiments measuring the He coolant temperature in the AVR found numerous "hot spots" in the coolant that exceeded 1280 C, whereas the maximum predicted temperature was only 1150 C[4]. After NRC staff highlighted these findings, Exelon raised the design maximum fuel temperature limit during PBMR normal operation from 1060 C to 1250 C. This is of concern because above 1250 C the SiC layer of the TRISO fuel coating will degrade as a result of attack by palladium isotopes produced during fission[5]. It also calls into question the accuracy of the current generation of computer codes for PBMR core analysis.

PBMR Fuel Performance

The safety case for the PBMR places great emphasis on the ability of the fuel pebbles to contain radionuclides under design-basis accident conditions. In order to provide assurance that the fuel will perform as expected, several levels of confirmation are required.

First, the fundamental fuel behavior must be sufficiently well understood that a complete set of technical specifications for the fuel can be derived. It appears that this is not yet the case. There are numerous instances in which TRISO microspheres manufactured to identical specifications and irradiated under identical conditions exhibited drastically different fission product release behavior that could not be attributed to observed physical defects like cracking of the SiC layer[6]. This indicates that there are technical factors affecting TRISO performance that have not yet been identified.

Second, when a complete set of technical specifications is finally at hand, the PBMR fuel manufacturing process will have to be reliable enough to ensure that the specifications are met. Because PBMR fuel is credited to a greater degree than LWR fuel for maintaining safety under accident conditions, and is less tolerant than LWR fuel to defects, PBMR fuel will have to be subjected to more stringent quality control. However, even if the requirements were no more stringent for PBMR fuel than for LWR fuel, inspecting the enormous microsphere flow with a high enough sampling rate to ensure an adequately low defect level would be a considerable challenge. The number of TRISO microspheres manufactured annually to support ten PBMR modules (1150 MWe total) would be on the order of ten billion, three orders of magnitude greater than the number of uranium fuel pellets needed to supply an LWR of the same capacity.

Finally, even if the above two criteria are satisfied, there must be assurance that the behavior of the fuel will not be significantly worse than expected if conditions in the core deviate from predictions --- that is, the fuel should "fail gracefully." It is on this count that the current TRISO fuel technology is clearly a loser. While past experiments have shown that the SiC layer of TRISO fuel limits the release of highly hazardous radionuclides like Cs-137 to below 0.01% of inventory up to 1600 C, the retention capability is rapidly lost as the temperature continues to increase. At 1800 C, releases of 10% of the Cs-137 inventory have been observed, which is on the order of the release expected during a LWR core-melt accident[7]. Without a leak-tight containment present, the release into the environment would be comparable to the release from the fuel.

Thus in order to justify the absence of a leak-tight containment, Exelon needs to demonstrate that the PBMR maximum fuel temperature will not exceed 1600 C during the design-basis depressurization accident, and that more severe accidents that could cause higher fuel temperatures are so improbable that they do not need to be considered. However, given the uncertainties discussed in the previous section --- like a discrepancy between calculated and measured maximum temperatures of at least 130 C --- there are serious grounds for skepticism.

Nuclear Waste Disposal

PBMR proponents do not normally bring up the issue of final disposal of the reactor's spent fuel. There is a reason for this: the volume of the spent fuel produced by a PBMR is significantly greater than that of the spent fuel produced by a conventional LWR, per unit of electricity generated. This is because the uranium in the fuel spheres is diluted in a large mass of graphite.

One can estimate the volume of spent pebbles discharged per unit of electricity generated for the Eskom PBMR as follows. Each pebble has a radius of 3 cm and a volume of 113 cm^3. Eskom calculates that operating a 110 MWe unit continuously at full power for 40 years will require 13.8 full fuel loads. Since each fuel load contains 330,000 pebbles (not counting the pure graphite spheres), this means that 4.55 million will be required over the plant lifetime. The amount of electricity generated during this period is 1.61 million MWD, so the total volume of spent fuel produced is 320 cm^3/MWD.

A typical 1150 MWe PWR operating on an 18-month cycle will discharge about 84 fuel assemblies per outage, with each assembly having a volume of about 186,000 cm^3. The amount of electricity generated is 630,000 MWD. Therefore, the volume of spent fuel produced is 25 cm^3/MWD, a factor of 13 less than for the PBMR.

Conclusion

The greatest amount of experience worldwide with nuclear reactor technology has been with the LWR. Even so, many outstanding technical and safety issues with LWR technology remain unresolved, and new surprises in well-established areas, like metallurgy, continue to arise. The development needed to take a new and unproven technology like the PBMR to a point where one can have confidence in the workability of the design will be substantial. Fundamental issues associated with the relationship between fuel quality control and fuel behavior under normal and accident conditions will have to be resolved, probably through extensive testing. While it is hard to estimate the amount of time and effort that would be required to do a satisfactory job, it is clear that the schedule that has been proposed by Exelon is inadequate for the task.

To get over the high hurdle of public acceptance, new nuclear plants should be clearly safer than existing ones. This is not the case with the PBMR. This problem is compounded by Exelon's desire to reduce safety margins required for current plants. In the aftermath of Chernobyl, the U.S. nuclear industry tried to reassure the public that such an accident could not happen here because U.S. reactors were equipped with robust containments, unlike Chernobyl. This argument will make it more difficult for Exelon to justify its choice of PBMR containment to the public.

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COMMENTARY

Restrictions on Travel: No International Exchange, No Science

Irving A. Lerch

The most oft-quoted pro-science declaration of 2001 is Allan Bromley's March 9 ***New York Times*** Op-Ed which concludes with, "No science, no surplus…" The assumption on which Allan's statement stands is that funding is needed to nourish a well-lubricated machine to convert intellectual capital into new science and which, in turn, transforms technological innovation into economic expansion. The problem is that ill-considered legislation and State Department policies and procedures threaten to throttle the international intellectual exchange on which our scientific and economic prosperity depend.

The US domestic science enterprise is part of a global machine whose bells and whistles bear the many labels of widely varying national origins. Thirty-five percent of all doctorates granted by US institutions in the natural sciences and engineering go to foreign scholars and this is roughly the same as the percentage of foreign scientists resident in US research universities. Cut off this source of erudite input and the machine grinds to a halt. This may be happening now.

In the immediate post-war era, roughly 70% of the world's research productivity in the natural sciences originated in the US. This was the result of the fact that the world's scientific talent gathered in this country to exploit the largest and most unique research facilities available in a planet devastated by war. Today, when 70% of the articles published in ***The Physical Reviews*** are proffered by foreign authors, US submissions have become a declining minority presence in a formerly largely domestic publication once dominated by US physicists.

Of course this is not quite true. It is not possible to portray domestic US science as a purely nationalist venture. As a nation of immigrants, our academic community has benefited from the talents and educational systems of many nations. This constant renewal is largely responsible for the wealth and power of the US. In sum, the capacity of US science is directly related to its efficiency at integrating new talent and in its participation in the worldwide intellectual commerce. Does this mean that we cannot develop native-born scientists? Have we arrived at the point in our national lives that we have to import scientists along with farm workers and day laborers?

The fact is that science has done a dismal job in nurturing and exploiting the talents of native-born minorities and women. And we've done little better in recruiting young people generally, owing to a failing educational system. While recruitment in some of the natural sciences has increased the training of women–especially in biology and medicine, we have not cleared the obstructions preventing the elevation of the most senior and talented to positions of authority. Even if we succeeded in training more minorities and women as scientists, would that solve the problem?

No. We may be able to increase domestic recruitment by a few percent, but in the absence of an overhaul of the nation's education system, we could never hope to match the large numbers of scientists who come to this country to receive advanced education, do research and develop new ideas. Does this mean that we must engage in predatory recruitment of intellectuals and denude developing and re-developing countries of their talent, thereby diminishing their prospects for economic improvement? No. We must fashion a world where global intellectual transactions–like monetary and commercial arrangements (at least as they now exist among the industrialized nations)–benefit all participants. We must have an international system where scientists may freely work with colleagues anywhere for universal profit.

Problems with visas

The process of acquiring visas is the valve regulating the flow of scientific talent into the US. In the past, the single most important hurdle to the granting of visas has been economic and the fear of illegal immigration as defined in various subsections of paragraph 214 of the Immigration and Naturalization Act.

However, a complex array of provisions affixed to the INA has sought to reduce the flow of industrial and defense technologies to competitors by restricting scientific exchange. Many of these provisions require scientific and technical expertise to account for the fact that both our economic and defense technologies are dependent on foreign exchange—that to impede such information flow is to do injury to our own economy and security. The law and it administration do not have mechanisms or expertise to weigh risks in the national interest. The reasons are easy to enumerate:

- Consular officers in our embassies and consulates abroad usually do not have the background to judge scientific credentials or the value of a scientific visit. Scientists seeking entry to the US are treated in the same manner as all visitors—business, tourist or job applicant.

- There is ambiguity and confusion concerning the guidelines for enforcing provisions of the INA. Many US universities and national laboratories employ expert staff to deal with visa problems. But their interactions with consular officials are punctuated with inconsistencies in interpretation of regulations and law. And since consular officials are held accountable, it is safer and easier for them to deny an application than to examine the facts and to adjudicate on the basis of merit.

- The advent of the "sensitive countries list," (countries assumed to be engaged in activities counter to US interests) the "entities list," (the list of institutions deemed to have violated US non-proliferation statutes), export control regulations (to include such vague concepts as "deemed exports" and "sensitive but unclassified information") have given the Department of State an impossible task: to monitor and prevent the flow of scientific and technical information deemed critical to the economic and defense interests of the US. Not only do these contradictory and obscure provisions lead to delays and obstacles impeding scientific exchange, they often impose the ludicrous circumstance of impairing the exchange of information developed by foreign colleagues–information essential to the progress of science. The task of processing requests for entry visas often falls to an interagency task force, which imposes an additional bureaucratic layer on the evaluation mechanism without adding any illumination.

These problems have created difficult conditions for our national labs. There has been an ongoing effort to convince foreign governments and institutions to make substantial investments in large programs. The US has then made it difficult for foreign colleague to participate in on-site experiments because of restrictions in our visa laws, which make no provision for open-ended scientific visits. The labs have often faced the ludicrous situation where a scholar representing a foreign university is denied admission to participate in an experiment funded by that university!

There are other obstacles: high fees for some visas in retaliation for charges imposed by other governments ("Reciprocity Schedule" reprisals) and severe restrictions preventing host institutions from reimbursing visiting scholars (primarily those participating in research programs at government laboratories who incur travel and subsistence expenses associated with their work in the US).

Among the more important factors contributing to the success of US science has been the recruitment of foreign graduate students. Large numbers of Chinese students have been a vital factor in invigorating physics programs around the nation. In recent months, however, visas have been routinely denied because these students are unable to demonstrate binding ties to their country. This means that they do not have an academic or research appointment in advance of their completion of graduate studies!

The international standard of free exchange

The International Council for Science is a global structure of disciplinary scientific unions such as the International Union of Pure and Applied Physics, Chemistry, Crystallography, etc. In the period between the world wars, before the advent of the International Council, adherence to many of the international disciplinary unions was vested in the Department of State. However, the system was wrested from government patronage and now resides with the Academies of Science in each member state. Thus, with the exception of China, Cuba and a number of authoritarian states, adherence to the international system is non-governmental. Nonetheless, each country must uphold the international standard for the free circulation of scientists–something almost impossible to achieve when the government restricts entry to foreign scientists. Failure to adhere to this standard is grounds for the international union to withdraw sponsorship from a scientific meeting.

For international union-sponsored meetings in the US, the National Academy of Sciences usually communicates with the Bureau for Consular Affairs requesting that our consular officers abroad be apprized that an international meeting is being organized and requesting the Department to expedite visa applications regardless of origin. For the most part this system has worked well. However, there are increasing signs that this arrangement may be weakening.

Treasury and Commerce embargoes

US scientists are routinely denied permission by the Treasury Department to travel to Cuba unless an international meeting is organized by an entity to which the US is a member but which is not headquartered in the US. While social scientists, anthropologists, climatologists and some others have been able to travel to Cuba with increasing frequency, many physical scientists have been denied licenses on often inconsistent and contradictory grounds. The US community views such restrictions with grave concern since it directly affects the freedom of citizens to participate in important cultural exchange of benefit to both Cuba and the US.

Applications for license are often complex and time-consuming with little feedback after submission. Attempts to track the progress of applications are often rebuffed. Rarely do government employees respond to inquiries or provide meaningful information.

Remedial actions

Last year, in response to language added to the State Department appropriations bill, a Science and Technology Advisor was added to the staff. The position is currently held by a senior scientist who has the trust and confidence of the US scientific community: Dr. Norman Neureiter. It is urgent that this office be strengthened and be given the opportunity to coordinate issues affecting entry of scientists into the US.

It is proposed that short and long-term scientific visas be processed under a new category of visa and that the Department S&T advisor work with both the Office of Science and Technology Cooperation in the Bureau of Oceans and International Environmental and Scientific Affairs, and the Bureau of Consular Affairs, to administer a coherent, effective policy to promote scientific exchange.

It is also proposed that the State S&T Advisor assist the Treasury and Commerce departments in dealing with visits of US scientists to embargoed countries. US science has maintained its international leadership by promoting scientific exchange. The unprecedented flow of intellectual talent into our country has continued unabated over the past half-century. This represents a huge contribution to both our domestic science enterprise and to our economy since innovations in science and technology have been shown to have a direct impact on our commercial expansion and development. In addition, some of the most important international scientific meetings are convened in the US and foreign participation in these events contributes to the centrality of US science on the world stage. However, impediments to the granting of visas have burgeoned. Scientist visits have been curtailed and this has jeopardized a variety of programs dependent upon short and long-term visits. Scientists from the former Soviet Union, China, India and many developing countries have found it increasingly difficult to gain entry to the US to continue their research and collaboration with US colleagues. Even scientists from traditional allies such as Germany have been barred for reasons that defy explanation. If this situation continues to worsen, the center of gravity for important research may shift away from the US.

In their 1999 report, *The New Challenge to America's Prosperity: Findings from the Innovation Index*, the Council on Competitiveness issued a warning. "*Finally, the authors note that despite the advances of other nations, the United States is failing to invest in the 'fundamentals' of its own innovation system. Although the past decade has been one of the strongest periods of U.S. macroeconomic growth since World War II, total spending on basic research is flat or heading downward, and the declining numbers of degrees granted in the physical sciences and engineering suggest that reversing this trend will involve concerted public policy changes. These observations suggest that America's current innovation leadership is increasingly rooted in past investment and that the long run basis for our future strength is being eroded—all while other nations are accelerating their own efforts"*

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Our National Energy Situation is a Mess!

Albert A. Bartlett

(Invited oral testimony (limited to 5 minutes) given to the Subcommittee on Energy of the Science Committee of the U.S. House Representatives, May 3, 2001, in Room 2318 of the Rayburn House Office Building in Washington, D.C).

For years we have seen recommendations from the Department of Energy that suggest that the leaders of the Department have little scientific understanding of the problems of energy.

We have seen the President of the United States sending his Secretary of Energy on bended knee to plead with OPEC leaders to increase petroleum production so as to keep our gasoline prices from rising. *For a country that boasts that it is the world's only superpower, this is profoundly humiliating.*

Gasoline prices are rising. California currently has an electrical energy crisis that is likely to spread. Natural gas prices are rising rapidly, which poses real economic hardship for millions of American home owners who depend on natural gas to heat their homes in the winter.

The only energy proposals we see are for short-term fixes, sometimes spread over a few years, that seem to ignore the important real-world realities of resource availability and consumer costs.

For years, scientists have warned that fossil fuels resources are finite and that long-range plans should be made. These plans must recognize that growing rates of consumption of fossil fuels will lead, predictably, to serious shortages that are now starting to appear.

For years we have heard learned opinions from non-scientists that resources are effectively infinite; that the more of a resource that we consume the greater are the reserves of that resource; and that the human intellect is our greatest resource because the human mind can harness science and technology to solve all of our resource shortages.

There seem to be *two cultures; science and non-science*. Each has its own Ph.D. "experts" and "think tanks." Each has its own lobbyists who argue vigorously that their path is the proper path to achieve a sustainable society. So let's compare the two recommended paths.

The centerpiece of the scientific path is conservation; hence it is appropriate to call this path the "Conservative Path." On this path the federal government is called on to provide leadership plus strong and reliable long-term support toward the achievement of the following goals. The U.S. should:

1) Have an energy planning horizon that addresses the problems of sustainability through many future decades.
2) Have programs for the continual and dramatic improvement of the efficiency with which we use energy in all parts of our society. Improved energy efficiency is the lowest cost energy resource we have.
3) Move toward the rapid development and deployment of all manner of renewable energies throughout our entire society.
4) Embark on a program of continual reduction of the annual total consumption of non-renewable energy in the U.S.
5) Recognize that moving quickly to consume the remaining U.S. fossil fuel resources will only speed and enlarge our present serious U.S. dependence on the fossil fuel resources of other nations. This will leave our children vitally vulnerable to supply disruptions that they won't be able to control.
6) Finally, and most important, we must recognize that population growth in the U.S. is a major factor in driving up demand for energy. This calls for recognizing the conclusion of President Nixon's Rockefeller Commission Report (Commission on Population Growth and the American Future, 1972). The Commission concluded that it could find no benefit to the U.S. from further U.S. population growth.

In contrast, the non-scientific path suggests that resources are effectively infinite, so we can be as liberal as we please in their use and consumption. Hence this path is properly called the "Liberal Path." The proponents of the Liberal Path recommend that the U.S. should:

1) Make plans only to meet immediate crises, because all crises are temporary;
2) Not have government promote improvements in energy efficiency because the marketplace will provide the needed improvements.
3) Not have government programs to develop renewable energies because, again, the marketplace can be counted on to take care of all of our needs.
4) Let fossil fuel rates continue to increase because to do otherwise might hurt the economy.
5) Dig and Drill. Consume our remaining fossil fuels as fast as possible because we "need them." Don't worry about our children. They can count on having the advanced technologies they will need to solve the problems that we are creating for them.
6) Claim that population growth is a benefit rather than a problem, because more people equals more brains.

We should not be confused by the conflicting expertise that supports each of these two paths because there is a very fundamental truth:

For every Ph.D. there's an equal and opposite Ph.D.

For our U.S. energy policy, we must choose between the Conservative and the Liberal Paths. The paths are the exact opposites of each other. Each is advocated by academically credentialed experts. On what basis can we make an intelligent choice?

There is a rational way to choose. If the path we choose turns out to be the correct path, then there's no problem. The problems arise in case the path we choose turns out to be the wrong path. It follows then that we must choose the path that leaves us in the less precarious position in case the path we choose turns out to be the wrong one.

So there are two possible wrong choices that we must compare.

If we choose the Conservative Path that assumes finite resources, and our children later find that resources are really infinite, then no great long-term harm has been done.

If we choose the Liberal Path that assumes infinite resources, and our children later find that resources are really finite, then we will have left our descendants in deep trouble.

There can be no question. The Conservative Path is the prudent path to follow.

However, it is the Liberal Path that we are so eagerly taking today.

If resources turn out to be infinite, then we will be OK on the Liberal Path. But if resources turn out to be finite, then today's choice of the Liberal Path will create enormous and critical problems for our children.

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LETTERS AND E-MAILS

Editor's Comments: There have been many responses to my note in the July issue requesting reader reactions to the transition from a quarterly hard-copy "Physics and Society" to the publication of a semi-annual hard copy version plus a semi-annual web version. (The paper issues are always accompanied by a web version and all issues are announced by e-mail - containing a complete table of contents - to all members.) The overwhelming number of responses from readers has been negative; a sample is given below. There has also been some negative reaction from potential authors, saying they would rather have their contributions appear in the hard-copy issues. The gist of these replies is that this journal is read differently than a research journal – it is browsed in relaxing times and places; it is not relaxing to browse from a computer screen. Never-the-less, financial constraints being what they are, it seems unlikely that we will soon go back to a paper quarterly, even though many correspondents volunteered to make an annual contribution to offset the additional costs of the two extra paper issues per year (~$4500 per paper issue). Our Electronic Media Editor, Marc Sher, has gone to great lengths to make it easy to print out each web issue, in parts and totality. I hope the regular members of the Forum will get used to this format, continue and expand their readership, use this journal to enhance their membership in the Forum, indeed extend our membership. (I don't know what our library subscribers will do.)

Reading P&S is Pleasurable But Not High Priority

Your editorial in the July 2001 issue of Physics and Society demonstrates that you have discovered one of the major problems with net publication. That is, that readers are by and large (except for high school web freaks) busy individuals who use their precious time logged in front of a terminal for their highest priority tasks. Reading for pleasure means that one can pick up and put down publications at will as the time permits, in whatever setting is available – in front of the fireplace, on an airplane or train, in the backyard, or in a taxi. Being constrained to a computer, until truly universal wireless remote access is as easy as reading a newspaper in a cab, will not encourage people to read publications such as P&S on the web when they have higher priority tasks at hand.

Thank you.

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More on Alice Stewart

I am writing in response to the Jan. 2001 issue of P&S review of the book by Gayle Greene on the life of Dr. Alice Stewart. While Dr.Stewarts early work was creditable and important, about 30 years ago she became one of the tiny minority of scientists who diverged sharply from the vast majority of their colleagues and took the position that the mainstream scientific community was grossly under-estimating the cancer risk from low-level radiation. In fact Dr. Stewart has carried her case further by alleging personal improprieties by well respected scientists, motivated by gender-bias.

Gayle Greene is a Professor of Women's Studies and Literature with principal research activities in Shakespeare, women writers, and feminist issues. She has no expertise in science. Her book is based on interviews with Dr. Stewart and others with her anti-Establishment views. In fact the author admits that she didn't spend much time with people on the other side of the controversies. She interviewed only one Establishment scientist. Her "Acknowledgements and Selected Bibliography" include only works by anti-Establishment scientists, and none of the numerous Reports by National Academy of Sciences Committees, United Nations Scientific Committees, International Commission on Radiological Protection, and National Committees on Radiation Protection in U.S., U.K., and other countries, all of which reject Stewart's controversial findings over the past 30 years. Nevertheless, the review in P&S states that the book is well referenced.

Your review states that in the 1970s, she came to the U.S. and saw nuclear workers dying from radiation induced cancers, and that gradually her conclusions were confirmed by other scientists. Actually her methodology and conclusions were heavily criticized and rejected in dozens of published papers (as well as by the Reports mentioned above) including some by women (Ethel Gilbert, Sarah Darby, Valerie Beral, Shirley Fry) whom Greene relegates to the convenient category of honorary men so their work can be ignored. Her conclusions have been rejected by the vast majority of the involved scientific community. Her collaborator in this work, George Kneale, who is called her genius statistician, has not been able to justify his procedures to other statisticians, and they generally reject them. All of the criticisms and rejections of the Stewart-Kneale collaborations are characterized in the book as a conspiracy to hide the truth. The author makes no attempt, other than blaming it on sexist prejudice, to explain why so many prominent scientists have colluded to deceive the public in this way, and why almost all of the subsequent studies of nuclear workers have come out with results that do not agree with Stewart's.

The polemic nature of the book makes it a favorite for those with anti-nuclear political axes to grind, but I find it difficult to understand why P&S would publish this book review. It was reprinted by permission from a non-scientific British journal, without any provision for simultaneous publication of the counter-positions held by the mainstream scientific community.

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Teaching Innovations

I would like to thank Professor Lindenfeld for taking the time to share with us the positive experiences of innovative curriculum at Rutgers University. In turn, I would like to share some attempts I have made to initiate a physics program at a small liberal arts university, with incredibly limited resources. I hope this might help others with similar lack of facilities and perhaps initiate a dialogue on how we as a community might help each other in this regard.

I have every intention of being as brief as possible, but would like to start with a short comment on the aptness of Dr. Lindenfeld's choice of category, - 'missionaries for physics', - for that indeed is what many of us are! (Interestingly, I have been called the "Billy Graham of Physics" by a student in Middle Tennessee and was unsure how to react to the description!)

When I joined Cumberland University four years ago, physics was a service program for some other majors and the general education core. As the only faculty member in the subject, I quickly realized I had no hope of initiating a traditional physics program or of finding any students in the highly improbable situation of getting one going. As a persuasive 'missionary' of physics I increased enrollment in physics and astronomy courses by 150 % in the first year. Thereafter, I was able to initiate a non-conventional physics program, with emphasis in Information Systems or Industry, so that I could utilize mathematics, computer programming and business courses that were taught by other faculty and other programs. I embarked on this path with considerable trepidation, as might be expected. I was going to let loose in the world physics majors, without all of the traditional courses we ourselves survived! However, I was emboldened in my endeavors by encouragement from colleagues in research and teaching and by some of the informative studies and surveys available from AIP.

To cut the long story short, in a school of about 1000 students, (mostly recruited for athletics), we had 10 students enrolled as physics majors last year and three of them graduated in May 2001. The majority of the students have spent successful summers participating in undergraduate research at the National Labs and I expect them to be launched in successful careers, with positive feelings for physics and a generalized overview of what physics is about. I continue to have occasional twinges of doubt, but there probably is no clear demarcation of whether we should try to spread physics as much as at all possible or stop if we cannot provide the perfect program?

It is certainly encouraging to hear the steps taken at Rutgers and other universities to alleviate the problem of dearth of undergraduate physics students and I am sharing mine so that the chain might diversify and expand. I could not have implemented the program without the help of friends and colleagues around the country, particularly those at Oak Ridge National Laboratory, Brookhaven National Laboratory and University of Tennessee, - but I think help does have a way of appearing when the mission is physics!

I think the efforts of faculty trying to institute physics programs at small universities could be vastly aided, if we could come up with resource material or web-based courses that would allow students anywhere in the country to take individualized upper-level courses, depending on their physics and career interests. Occasionally one finds students at a small school who are potential graduate school material but whose faculty lack the resources to steer them to this path. I would be happy to interact with colleagues to help co-ordinate such accessible upper-level undergraduate curricula and make them available at the national level. I feel strongly that such efforts would help lighten the problem of shortfall of graduate students as well as increase the impact and visibility of physics.

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King Canute Rules Again

In a display of arrogance that is becoming all too typical of the Bush administration, communities lining the banks of the Mississippi are being encouraged to build levees to prevent flooding. It is amusing (if you live in Cleveland and not

St. Louis) to perform the back-of-the-envelope calculation that predicts an interesting consequence of this policy.

Annual rainfall in the US averages about 1 m, and the surface area approximates that of a rectangle 5000 km wide and 2000 km tall. Of this 10^{13} m^3 of water, about 40% lands in the Mississippi watershed, from which we might guess that 10% reaches the river, the rest being lost to evaporation. The flow is thus 4 * 10^{11} m^3 per year, or 10^4 m^3 per second. In a river 10 m deep and 300 m wide the water speed is then on average about 3 m/s, or 6 mph - a reasonable number.

The problem arises when we realize that rainfall is not constant, and that a wet month may bring 0.3 m of rain, with evaporation reduced from 90% to 50%. This increases the flow rate by a factor of about 16. What an impressive sight it would be to watch the river rush through Baton Rouge at 96 miles per hour! Professional baseball pitchers could test their fastballs by trying to hit floating objects!

Unfortunately the laws of physics intervene. There is not sufficient gravitational energy in the water to achieve this speed unless the water were made superfluid, a solution that even the Army Corps of Engineers might find difficult to implement. That there will be floods is thus physically unavoidable. Where they will occur will just be a question of who cannot afford to build a levee as high as their neighbor's. What a beautifully free-market solution to an environmental problem!

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Science and Belief

I read your review (in July, 01 P&S) of Wendy Kaminer's book, "Sleeping with Extra-Terrestrials ..." with some interest. I was particularly taken with your statement, "This hold seems irrational since that public has had more formal education in science than any other public, past or present." "That public" in the previous sentence relates to "American public" which is being compared to "any other public". Let me suggest for comparison that you use the Scandinavian or Canadian publics, with which I have some familiarity, and you would find that the prevalence of nonsensical pseudoscience is markedly lower in those countries than in America. I might be so bold as to suggest the reason is that the public education system in those countries is markedly better than in America.

Having been born and raised in America, I am always amazed at the huge disparity in educational excellence by regions which is not nearly so great in other countries. In the suburbs of the large cities the public schools are really quite good. In the inner cities and rural regions it can be dreadful.

Let me offer one further observation. Science is not a belief system. I find that most non-scientists think that it is and recall the time a chemistry colleague made the statement, in a student's oral defense exam,"... we all believe in quantum mechanics." I quickly corrected him but have often reflected on the fact that we don't stress, as often as would be useful, the difference between a belief system and one that is demonstrable. One can be a believer and be a scientist, so long as one keeps clear the separation between religion and natural philosophy. We, as a society, have not kept that distinction clear and I find that many believers think that science is out to destroy their beliefs. I like the vantage of the agnostic and know many good scientists who are people of faith. If we, as scientists, can admit there is much that is outside the world of science, and that which is, is a matter of belief, then many are comforted and are willing to try to recognize that which falls under the umbrella of science. If permitted (by the scientist) to believe in anything they like, their belief in pseudoscience soon wanes, and their belief in the Bible may or may not follow but that is a different matter altogether.

Liked your review.

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Further Comments on Science and Religion

I gather from Howard Richards' Letter in the last issue that he is opposed to my earlier suggestion for a broad in-depth discussion as to whether or not the teaching of religious dogma harms science/math education. I surmise that he is against this because he already "knows" that there is no such harm, only good, and that it is sacrilegious form to even suggest otherwise. I feel that this requires no comment from me, but I am deeply disturbed that he interprets my suggestion as being broadly anti-religious since, for some reason, he seems to believe, erroneously, that all religions are basically alike. I point out that it is the teaching of dogmatism whose harm I question, not the teaching of religion, per se.

For example, while I come from a Germanic-Lutheran background, I have great admiration for Judaism which has produced over 20 percent of all Nobel prizes ever awarded, and has produced an out-of-proportionate number of super-achievers in both the arts and the sciences and in almost all areas of human endeavor. I believe that this is so because Judaism concerns itself primarily with social cohesiveness and customs, not with dogmatic theology. As Alan Dershowitz says: "Jews do not need to believe in God, only in Judaism".

This is highlighted in the 1990 National Jewish Population Survey wherein "Jews by Religion" includes three subcategories: "Born Jews, Religion Judaism," 4.2 million; "Jews by Choice," persons who are currently Jewish but were born non-Jews, 185,000; "Jews Born with No Religion," persons who identify as Jewish but who answer "none," "agnostic," or "atheist" when queried about their religion, 1.1million. Together, these three categories total approximately 5.5million people. Consequently it is seen that approximately 20 percent(1.1 million out of 5.5 million Jews) characterize themselves as being non-religious. I now ask: "How many people who identify themselves as Christians would answer 'none,' 'agnostic,' or 'atheist' when queried about their religion?"

This interesting aspect of Judaism was recently made more personal in a Los Angeles Times obituary for Joseph Weber, a prominent UC Irvine physics professor. Therein his wife, Virginia Trimble, another well-known UC Irvine scientist, an astronomer and author, is quoted as follows:

"We typically never squabbled very much. If we disagreed, it was about scientific issues. He didn't believe the observational evidence for the cosmological constant, and I think it's highly probable. He was raised as an Orthodox Jew and we both attended Temple Beth Emet in Anaheim. He was actually an atheist, who wanted to maintain Jewish traditions. It was another thing we didn't have to disagree about. We both agreed that modern cosmology provided a better picture of the early universe than does the book of Genesis."

This leads me to the question" Would an atheist who evolved out of an evangelical Christian background, or a Roman Catholic background, be accepted by members of his or her former congregation and feel comfortable attending services routinely?"

And now for a couple of comments relative to the last paragraph of Howard Richards' letter. I say: "Hooray for the racial minorities and foreigners who are rapidly becoming the predominant number of graduate students in our university science departments. Why the dearth of American youngsters? Could it be because of their early exposure to, and then continued emphasis on, dogmatic belief?" And further: "A great hooray for the editors of Physics and Society for maintaining a balanced and open editorial policy that invites diverse opinions and interaction."

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REVIEWS

Suburban Nation: The Rise of Sprawl and the Decline of the American Dream

by *Andres Duany*, *Elizabeth Plater-Zyberk* and *Jeff Speck* (North Point Press, 200)

This book was written by three well-known architect-planners, who designed and helped develop over 200 planned communities and revitalized urban centers across the nation. They are cofounders of the Congress for New Urbanism (CNU), an organization dedicated to community-friendly "smart growth." Although, as a transportation professional, I was familiar with the thesis and the arguments made, I found the concrete examples of "good" and "bad" communities and the graphics very instructive. Although the book sometimes reads like a manifesto mirroring the writers' beliefs and biases which culminate in the Charter for New Urbanism in Appendix B, it is written with enthusiasm and conviction and redeemed by the logical organization of chapter topics and subtopics, by numerous graphics illustrating their points, and by copious notes and scholarly references.

In the past decade, "suburban sprawl" has been transformed from the yuppie ideal of single-family homes on large, green lots outside congested urban centers, into a code word with many negative connotations. I found the generalizations in the book unsettling and overdone: "In the sparse universe of sprawl, the elementary particle is the single-family house"… and "Americans have the finest private realm, but our public realm is brutal." The primary adverse impact of urban and suburban sprawl is environmental degradation: although only 5% of the land area in the USA is built-up, recent growth has accelerated the loss of wetlands, wildlife habitats and watersheds, especially in fast growing sun-belt states like Florida and California. Its opposite is "sustainable growth," an agenda for community- and environmentally-friendly development and renewal, espoused by Vice President Gore's initiatives and by the Transportation Efficiency Act for the 21st Century (TEA-21) in 1998. The authors strive to first analyze the plethora of interrelated socio-economic and environmental ills spawned by the spread of suburbia, and then to provide prescriptive "how-to" examples of well thought-out urban and community development, including planned economic growth, transportation, and civic services.

The authors blame "sprawl" and misguided planning by narrow disciplinary specialists for a broad range of societal and environmental ills, from the loss of green fields and environmental degradation, to the "malling" of America and the decay of urban centers. At the core of this Gordian knot is "automobility" in transportation policies and infrastructure subsidies, seen here as a twin of sprawl and a cause of the lack of public transit that should provide both mobility and access to jobs. Poor transportation planning to accommodate low density housing in isolated suburbs, and the lack of people-friendly, walkable neighborhoods, are seen as causing congestion and gridlock, long commutes, air pollution, as well as gobbling up wetlands and agricultural land.

This book is not original in either outlook or substance, but one of dozens written in the past decade by authors such as Jane Holtz Kay (*Asphalt Nation*), J.H. Kunstler (*The Geography of Nowhere: the Rise and Decline of America's Manmade Landscape*; and *Home from Nowhere: Our Everyday World for the Twenty first Century*), and others listed in a lengthy bibliography.

However, what distinguishes this book, in my opinion, is the recognition of the multifaceted and complex fabric of urban and suburban planning and historic transportation and economic (tax, zoning, permitting) policies at federal, state and local levels that underlie the built environment in USA. Ultimately this is a nation of individuals freely making lifestyle choices, and not constrained by either landform, or land and water availability, as is Japan or Europe. I was bothered by the authors' blanket condemnation of government policies and planning at all levels ("In sum: the federal government is distant, local government is myopic and regional government is lacking"), but encouraged that they dared to make explicit state and federal policy recommendations for a citizens' and planners' action platform in Chapter 11.

In advocating mixed-use communities and bottom-up rezoning combined with regional transportation and development planning, the authors make a compelling case for their "TRANSECT" concept, which might be loosely paraphrased as "think globally, act locally, but plan regionally." This concept involves joint planning and coordinated development by multidisciplinary teams and recognizes a full spectrum of "appropriate" planning and design principles ranging from outlying suburbs to downtowns. An excellent short overview of these issues is provided by Donald Chen in his December 2000 *Scientific American* article "The Science of Smart Growth," including a text-box describing the TRANSECT concept by the chief author, Andres Duany.

Ample reference materials on the ills of transportation and socioeconomic and cultural ills rooted in urban sprawl can be found on several websites, including www.sprawlwatch.org/, www.smartgrowth.org/, and www.transact.org/

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