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PHYSICS & SOCIETY

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EDITOR'S COMMENTS

This issue of *Physics & Society* has some unusual, and to my mind enjoyable, features. We present an article by Gerald Marsh in which he argues, among other things, that all of the anthropogenic carbon dioxide that has been poured into atmosphere during the past few centuries is not nearly enough to stave off massive glaciation from the next Ice Age, a greater danger to civilization (in his view) than global warming. David Hafemeister gives us an exciting memoir of how he bribed himself out of the Soviet Union during the time of its collapse. This editor (JJM) has the pleasure of presenting a thank you note to the organizers and speakers of this Forum's conference on sustainable energy research, held at University of California at Berkeley on March 1-2, 2008. As this issue of P&S goes "to press" the pdf versions of the speakers' powerpoint presentations are expected be available at the UC Berkeley, Energy Resources Group's Renewable and Appropriate Energy Laboratory (RAEL) site: http://rael.berkeley.edu/. By this summer, the pdf versions of the 2008 AIP Conference Proceedings chapters are expected to be available at http://proceedings.aip.org/proceedings/cpreissue.jsp.

We continue our series of articles entitled "What are nuclear weapons for?," the first two articles of which were published in our October 2007 issue. We look forward to continued contributions to, and debate within, the pages of this newsletter concerning the issues of the day. We also include a letter concerning CO_2 emission control and two book reviews. Thank you to all of our contributors.

NEWS

Welcome New Forum Officers

The following members were recently elected to the Forum's executive body. They assume their respective roles at the APS April annual meeting. A brief introduction to each is provided.

Charles D. Ferguson (Vice-Chair):

Dr. Ferguson is a Fellow for Science and Technology at the Council on Foreign Relations, an Adjunct faculty in the Security Studies Program at Georgetown University and in the Homeland Security Certificate Program at the Johns Hopkins University. He is an expert on public policy issues related to nuclear nonproliferation, nuclear and radiological terrorism prevention, nuclear safety, energy security, and missile defense. He has authored or co-authored reports and books on nuclear policy issues and advises the U.S. government on radioactive materials security. He served as a Member-at-Large

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News of the Forum continued from page 1

on the Forum's Executive Committee during 2001-04. Dr. Ferguson would like to help the Forum bring the larger academic physics community into working on the societal issues and doing a better job in educating policymakers about the contributions a non-politicized science can make to improve people's lives as well as on national and international security.

Philip Hammer (Councilor):

Dr. Hammer is vice president for The Franklin Center at The Franklin Institute Science Museum in Philadelphia. He has served as an APS Congressional Science Fellow on the staff of the Subcommittee on Science in the US House of Representatives. He has advised the APS in its efforts to engage Congress through grassroots political involvement. He has worked at the American Institute of Physics as Director of the Society of Physics Students / Sigma Pi Sigma, and of the AIP Corporate Associates Program and has initiated programs to meet professional development needs of physics students, and the technical and workforce needs of industry and communities. Dr. Hammer was Chair of the APS Forum on Physics and Society in 2002. He is currently on the APS Executive Board and chairs the APS Committee on Informing the Public. As the returning Forum Councilor, Dr. Hammer would like to continue working to sustain the output of timely, relevant, and targeted APS studies, such as those in the areas of energy and nuclear weapons. He would also work on advocating strategic approaches to create and keep a healthy flow of students into bachelor's degree programs to meet the pressing national needs in the areas of K-12 teaching, energy, and innovation.

Brian Schwartz (Member-at-Large):

Dr. Brian Schwartz is Vice President for Research and Sponsored Programs and Professor at the Graduate Center of the City University of New York. His scientific career has focused on the communication of science. He has served as Associate Executive Officer of the American Physical Society and Editor of APS News and has managed outreach programs for the APS including the Committees on Education, Minorities, and Women. He helped establish the APS Congressional Fellowship program, and along with a colleague initiated the formation of the Forum on Physics and Society and other APS forums. Dr. Schwartz served as the national director of the centennial celebration of the APS in Atlanta in 1999. He has organized public programs at the interface between science and theater, art, music and dance. He would like the Forum to continue to study and publicize arms control and ethical issues in science and technology. He would work to promote more programming and strategies aimed at the general public and students.

Mark Goodman (Member-at-Large):

Dr. Goodman is a Physical Scientist in the Office of Multilateral Nuclear and Security Affairs at the Department of State, now on an assignment as a senior advisor at the Office of Nonproliferation and International Security at the Department of Energy (DOE). He has worked on nuclear nonproliferation, safeguards, nuclear weapons policy, energy, environment and defense issues. He has worked with many organizations such as the DOE, the Arms Control and Disarmament Agency and with the International Atomic Energy Agency. He has served as an AIP Congressional Science Fellow. Dr. Goodman believes that issues we face regarding energy, climate and international security demand sound decisions based on sound advice. Dr. Goodman's chief priority, during his second term on the executive committee, will be to help the Forum fill in the role of providing sound advice on these issues and restoring a strong and effective institutional relationship between science and policy.

LETTERS

Dear Dr. Saperstein, Editor Physics & Society:

Art Hobson's commentary on "Winning the Climate Race" (Physics & Society, January 2008) reminded me of the predictions of some versions of string theory that an almost-infinite number of parallel universes may in some sense exist, because the commentary seems to be written for a parallel universe where uranium and plutonium do not fission and hydrogen isotopes do not fuse. That is, there is not a single mention of the role nuclear power can and must play if the climate change problem is to be addressed -- a truly remarkable omission for a publication of the American Physical Society!

Even today, after decades of neglect, nuclear power provides 20% of America's electricity needs with carbon dioxide emissions savings equivalent to taking tens of millions of automobiles off the road. France gets 80% of its electricity from nuclear power using decades-old technology, and does so as a result of decisions made for purely economic and energy security reasons, before climate change was even an issue. Of course, a similar American contribution from nuclear power would require a much greater effort than required in France because of our much greater electricity needs, but resources available for this effort are correspondingly greater. It is hardly credible to claim that, with today's more advanced nuclear technology, America cannot do what France was able to do decades ago.

Uranium supply limitations have been advanced as an argument against expanding nuclear power, but upon closer examination this limitation turns out to be largely illusory. Known uranium reserves would support a substantial increase in nuclear power. Furthermore, rock-bottom uranium prices until recent years meant there was little interest in prospecting for new uranium sources until the recent revival of interest in nuclear power, and it is virtually certain that large additional uranium reserves remain to be discovered. In addition, "recoverable reserves" are a very steep function of uranium price; for example, the Energy Information Administration estimates that known American reserves recoverable at a price of $30/lb are about 133,000 tons U3O8 but increase to 445,000 tons at $50/lb. Since nuclear fuel is only a few percent of the cost of nuclear power, very much larger increases in uranium price would be required to substantially impact the economics of nuclear power. Finally, in the long run, nuclear "breeder" reactors offer the potential to make nuclear power an essentially unlimited energy source. Although large-scale application of breeder reactors on the year 2030 timescale considered by Hobson is neither necessary nor feasible, their potential does offer an invaluable hedge against the very real possibility that renewable energy sources never live up to the claims made for them by their enthusiastic advocates.

Nuclear waste disposal has, of course, been the favorite bugaboo of anti-nuclear forces. However, numerous technical assessments, including those of the National Academy of Sciences, have concluded that the waste disposal problem is more political than technical, and "political will is a renewable resource," as Al Gore likes to say. Furthermore, partial fuel reprocessing with recycle of the actinide fraction through fast-neutron-spectrum "burner" reactors, as proposed in President Bush's Global Nuclear Energy Partnership (GNEP), offers reductions in the waste disposal problem by at least one to two orders of magnitude. In the GNEP plan, weapons-usable plutonium is never separated from other actinides and it is destroyed in the burner reactors, which are collocated with the reprocessing facilities on sites subject to international inspection, greatly reducing any weapons proliferation risks.

Hobson asserts that developed nations ("rich countries") must cut emissions 90% by 2030 and advocates draconian and grossly unrealistic measures to achieve this; e.g., virtually eliminating or severely restricting everything from automobile travel to long-distance air travel. Such recommendations far exceed what even the most ardent global-warming politicians are considering and could not possibly be imposed in a democracy. To some extent, the extreme recommendations are necessitated by his ignoring the potential contributions of nuclear power, but a more important reason is ideological: his assertion that the "fair pathway" towards emissions reductions demands equal per-capita emissions worldwide, which leads to his conclusion that the "rich" nations must reduce emissions by 90% to meet his overall goal of a 60% world-wide reduction by 2030.

The pages of Physics & Society may not be the best place to debate ideological "fairness" issues, but it should at least be acknowledged that it should be much more feasible for developing nations to develop using nonfossil energy sources than it is for the "rich" nations to discard and replace their vast fossil fuel infrastructure on a crash basis. This is especially true if the developing nations are given technological assistance from the developed world, something that would cost a tiny fraction of what Hobson's 90% reductions would cost.

It may conflict with certain ideological concepts of "fairness", but the fact is that concentrating on the developing world has to be the top priority if climate change is to be addressed. China already equals the United States as the world's leading source of greenhouse gas emissions and its emissions are increasing far more rapidly; India and other developing nations are on similarly rapid growth curves in their emissions. China alone is adding one or more coal-fired power plants every week and, once on line, each of those plants will emit millions of tons of carbon dioxide into the atmosphere every year for the next forty years or so. If the breakneck expansion of greenhouse gas emissions in the developing nations is not drastically altered, it does not matter greatly what the developed nations do.

As physicists we have no special expertise to contribute in ideological debates about "fairness," but we do have much expertise to contribute in advising the public and their political leaders on the scientific and technological issues of global warming and possible contributions to its mitigation. Nuclear power has to be high on that list. Few would claim that nuclear power can slay the global warming dragon all by itself, yet it is obvious nuclear does have a great potential to contribute to the solution. Neglecting that potential can only make an already very difficult problem far more intractable or even impossible.

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(Until his retirement in 1997, Dr. David C. Williams was a Distinguished Member of the Technical Staff at Sandia National Laboratories in Albuquerque, New Mexico. He worked extensively on a variety of nuclear power plant safety issues, with most of this work being funded by the Nuclear Regulatory Commission.)

Dear Sir,

While there is a widespread view that "something must be done" about carbon dioxide emissions, there is extraordinarily little thought of when and how. There are many technologies for supplying energy for society, such as those suggested by Art Hobson, but all will cost somewhat more than the present fuels. Some action is necessary to force expenditure by society of the extra money. Almost all political proposals are for regulating downstream, e.g., egulating Miles per Gallon, or taxing (some) CO2 emissions. Yet for carbon it is possible to regulate upstream at the coal mine, the oil well, the gas field, and for a country control, port of entry. I argue this is far preferable. The control points are limited in number, are easy to monitor and most already are. This is in contrast to the hundreds of thousands of CO2 emitters. Once carbon is brought to the surface it will be CO2 within a year. The government would only have to take one set of actions. It could insist on carbon permits for bringing carbon to the surface and reducing the number of permits until the desired CO2 concentration is achieved. Carbon sequestration could be encouraged by a certificate of sequestration which is the opposite of a permit. The free market could then do what it does best decide on the preferred allocation of the carbon between the various societal uses.

I dislike the thought of the "Command and Control" mechanisms now being discussed. Each of them is for an individual sector. Who is to make the decisions sector by sector? Lawyers for environmental groups? Politicians? Starry eyed academics? I prefer the allocation to be by the free market. Any modification for helping the poor and developing countries should be specifically noted as such.

Richard Wilson
Harvard University

ARTICLES

Climate Stability and Policy

Gerald E. Marsh

Starting in the 1980s and culminating in the Kyoto accords of 1997, followed by the awarding of the 2007 Nobel Peace Prize to Al Gore and the United Nation's International Panel on Climate Change, international attention has been focused on the dangers of global warming owing to anthropogenic carbon dioxide emissions. In this essay, however, I will argue that humanity faces a much greater danger from the glaciation associated with the next Ice Age, and that the carbon dioxide increases that we have seen during the past two hundred years are not sufficient to avert such glaciation and its associated disruptions to the biosphere and civilization as we know it. Such conflicting considerations have obvious implications for the formulation of public policy regarding human attempts to manage climate changes.

During most of the Phanerozoic eon, which began about a half-billion years ago, there were few glacial intervals until the late Pliocene 2.75 million years ago. Beginning at that time, the Earth's climate entered a period of instability with the onset of cyclical ice ages. At first these had a 41,000 year cycle, and about 1 million years ago the period lengthened to 100,000 years, which has continued to the present. Over this period of instability the climate has been extraordinarily sensitive to small forcings,* whether due to Milankovitch

As can be seen from the figure, interglacial intervals are generally considerably shorter than the glacial ones. On the whole, the Earth for the last 5 million years has been colder than at any time in the last 550 million years, except for a glacial period 300 million years ago. This is despite the increasing luminosity of the Sun over the whole of the Phanerozoic.

The first part of this paper deals with some policy considerations raised by the current interglacial nearing its likely end. This is followed by a discussion of climate stability to changes in solar irradiance, and a probabilistic exploration of whether a decrease in solar activity comparable to the Maunder minimum of the late 17th century (the Little Ice Age) or the Dalton minimum of around 1805 could initiate a new ice age.

Policy Issues

It is known that the carbon dioxide geochemical cycle coupled with the evolution of both the Sun and biota over the Phanerozoic has led to the exceptionally low value of atmospheric carbon dioxide concentration that characterizes modern times [2]. These low levels have in turn resulted in the Earth entering a period of instability characterized by the cyclical ice ages of the past 2.75 million years. The present extraordinary sensitivity of climate to small changes in forcing, whether due

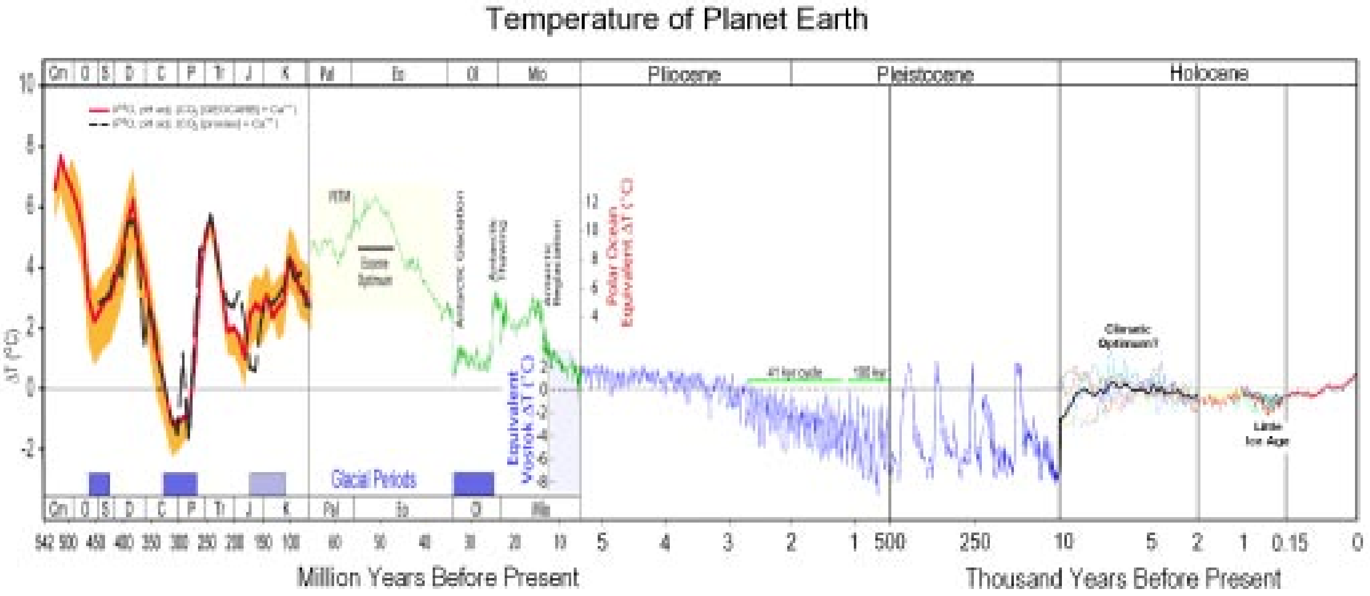

Figure 1: Temperature of the Earth over the Phanerozoic eon. Figure from Wikipedia [1].

to Milankovitch cycles affecting insolation, solar variations as occurred during the Little Ice Age, variation in stratospheric aerosols, or cosmic ray driven albedo variations, is a result of the low carbon dioxide concentrations that have remained generally below 500 ppmv beginning some 20 million years ago. Although proxy data show concentrations of this gas occasionally falling below this level previous to 20 million years ago, the average was above [3]. The glacial period centered around 300 Myr in the past was perhaps an exception.

The current inter-glacial period has lasted for some ten thousand years, comparable to the length of past inter-glacials. While policy considerations over the last couple of decades have concentrated on potential effects of rising temperatures—due, it is believed by many, to the increase in carbon dioxide concentrations from anthropogenic sources—these concentrations are quite low relative to those during times of climate stability that include most of the Phanerozoic. Even if all the temperature increase over the last century is attributable to human activities, a doubtful proposition at best, the rise has been a relatively modest 0.7 ^{o}C, a value within natural variations over the last few millennia. During the Holocene Maximum extending from some 7,000 years before the present (BP) until 4,000 Yr BP, the temperature was about 1.3 ^{o}C warmer than the 20th century; during the Medieval Maximum, that lasted from 1000 AD to 1400 AD, the temperature was 0.6-0.7 ^{o}C warmer than the 20th century. Thus, while an enduring temperature rise of similar magnitude over the next century would cause humanity to face some changes that would undoubtedly be within our spectrum of adaptability (we have done so in the past), entering a new ice age would be catastrophic for the preservation of modern civilization. One has only to look at maps showing the extent of the glaciation during the last ice age to understand what a return to ice age conditions would mean. Even if the transition took centuries, the historical records of the Little Ice Age of the late 17th century make it clear that life would become increasingly difficult even in the early stages [4].

Over the near term, NASA maintains that Solar Cycle 25, peaking around 2022, could be one of the weakest in the last three centuries [5]. The sunspot minima around this time will be comparable to the Dalton Minima around 1805, and could cause a very significant cooling (see Fig. 2 and compare this period to that of The Little Ice Age of the late 17th century).

There has been much speculation in both the scientific and popular literature that increased warming as a consequence of anthropogenic carbon dioxide emissions could lead to an increased flow of fresh water into the north Atlantic that would shut down the thermohaline circulation, known alternately as the meridional overturning circulation or the Atlantic heat conveyor [6]. This in turn, it is argued, could initiate a new ice age in Europe. There are two major misconceptions behind such speculation: First, the Gulf Stream is not responsible for the transport of most of the heat that gives Europe its mild climate [7]; and while the shut down of the thermohaline circulation does appear to play an important role in the dramatic drop in temperature due to Heinrich and Dansgaard-Oeschger events [8], such shutdowns can only occur during an ice age. Indeed, Broecker [9], who first linked the thermohaline circulation to the ice ages, now discounts the fear that a shutdown of the thermohaline circulation could trigger an ice age. He has pointed out that for that scenario to work feedback amplification from extensive sea ice is required [10]. The possibility that global warming could trigger an ice age through shutdown of the thermohaline circulation may therefore be discounted.

Given that the real danger facing humanity is a return to a new ice age, it makes sense to ask what concentration of carbon dioxide would be adequate to stabilize climate so as to extend the current inter-glacial indefinitely. Some idea of the range of concentrations needed can be had from the work of Royer [3] who found that over the Phanerozoic consistent levels of carbon dioxide below 500 ppmv are associated with the two glaciations of greatest duration—those that occurred during the Permo-Carboniferous some 300 Myr ago and the Cenozoic, within which we are now living. Cool climates were found to be associated with carbon dioxide concentrations below 1000 ppmv, while no cool periods were associated with concentrations above 1000 ppmv.

Some support for the idea that moderately increased carbon dioxide concentrations could extend the current interglacial period comes from the work of Berger and Lautre [11]. Working with projections of June insolation at 65 ^{o}N as affected by Milankovitch variations over the coming 130 kyr, they used a 2-dimensional climate model to show that moderately increased carbon dioxide concentrations, coupled with the small amplitude of future variations in insolation, could extend the current interglacial by some 50 kyr. The insolation variations expected over the next 50 kyr are exceptionally small and occur only infrequently, the last time being some 400 kyr in the past. They also found that a carbon dioxide concentration of 750 ppmv would *not* extend the interglacial beyond the next 50 kyr. In addition, concentrations of less than 220 ppmv would terminate the current interglacial.

One should not, however, take these carbon dioxide concentrations as the last word. The sensitivity of the climate to a doubling of carbon dioxide concentration could be in error. The change in forcing due to a change in carbon dioxide concentration is given by

$$\Delta F = \alpha \ln(C/C_0) \text{ w/m}^2,$$

where C_0 and C are the initial and final carbon dioxide concentrations. Since 1990, the estimate by the Intergovernmental Panel on Climate Change (IPCC) of the coefficient α changed by 15% ($\Delta\alpha/\alpha = 0.15$) and "implicitly include[s] the radiative effects of global mean cloud cover" [12], and estimates of the radiative effect of clouds are quite uncertain. If the actual sensitivity is significantly lower than current estimates, that would elevate the concentration of carbon dioxide needed to extend the current interglacial.

IPCC projections for carbon dioxide concentrations by the year 2100 depend on projections of social and industrial development in countries with large populations that currently consume small amounts of energy per capita. The highest concentrations projected are about 1100 ppmv. This projection could be exceeded, however, if development in China and India accelerates and if other underdeveloped nations are able to overcome current impediments to modernization.

Even if development continues along its current trajectory, carbon dioxide concentrations are almost certain to fall in the range of 500-1000 ppmv over the next century. This is because there are very good reasons to be pessimistic about current approaches to limiting carbon dioxide emissions—they are simply not realistic, instead being the result of political rather than scientific considerations. This is an observation, not a criticism, since the current approach may be the best that is possible given existing international relationships and law, along with other aspects of political reality.

Two examples regarding fossil fuels may suffice to illustrate realistic constraints on curtailment of their use. First consider oil. Its use in industry is widespread for a variety of purposes in addition to energy production, but it will be irreplaceable in the transportation sector for decades. Apart from niche applications for other fuels, there are simply no good alternatives that are economically and politically viable. Some may be tempted to believe that the use of oil will be self-limiting, forcing the use of alternative fuels. This point of view is based on the claims of "peak oil" theorists. Such claims, however, show a misunderstanding of the meaning of "oil reserves". These reserves depend on price and are not a direct measure of the amount of oil physically available in the ground. There is plenty of oil, perhaps as much as the 7200 billion barrels estimated by ExxonMobil, but these reserves cannot be brought to market as cheaply as oil from the Persian Gulf, and the economics of oil dictates that cheaper oil will be used first. Moreover, these sources cannot begin production immediately; there is a ramp up period of years. If the phasing-in of such reserves does not match the decline of current oilfields, rising prices and conflict over resources are inevitable. In the end the oil will become available.

The argument that biofuels could replace oil is worth discussing. While the substitution of biofuels in the transportation sector appears at first blush promising, it has the severe handicap of competing with food production. Extensive development without careful planning is likely to raise the cost of food and other agricultural products much more than it already has. Nor is it clear how planning could be done without interfering with the market mechanisms needed for efficient production—existing subsidies have already had this effect.

There are other problems. One attractive choice for biodiesel fuel is rapeseed oil, but to produce enough biodiesel from this source to fuel the country would require some 1.4 *billion* acres. For comparison, the U.S. now has only 400 million acres under cultivation. In addition, there is the fresh water, already in short supply, and the fertilizer needed for this increased cultivation. Even if cellulose can be used as a feedstock, biofuels based on agriculture are unlikely to replace oil any time soon.

Another example is electricity. In the United States, about 40% of the carbon dioxide emissions are from the burning of fossil fuels to generate electricity. Projections by the International Energy Agency and the Energy Information Administration indicate that alternative sources of electricity such as solar and wind have no possibility of being able to displace this use of fossil fuels any time soon, if ever. The choice is between coal and nuclear, and the latter, while currently undergoing a limited renaissance, is beset by political obstacles, one of which is the prevalent concern about waste disposal. This concern, however, is also political [13].

Nevertheless, there is only one practical way known today to stabilize carbon dioxide concentrations over the next few centuries: nuclear power coupled with the long-term development of a hydrogen economy based on nuclear energy. A hydrogen economy does not necessarily mean that nuclear generated hydrogen is burned directly; the hydrogen may be used in the production of liquid fuels, should it turn out that such fuels are the most efficient and economical means for storage and distribution. But other than the current feeble attempts to implement a Global Nuclear Energy Partnership, this is not even on the international agenda.

Unless the international approach to stabilizing carbon dioxide concentrations changes dramatically, the world will continue to depend on fossil fuels for generations to come, and the burning of such vast quantities of fossil fuels is bound to have a serious environmental impact. The developed world cannot legislate how the developing world will use these fuels, and history has shown that commercialization will likely be at the lowest cost to the producer with the concomitant release of vast quantities of pollutants as well as carbon dioxide. China is a perfect contemporary example. Yet if the grinding poverty that most people in the developing world must live under today is to end through development along the Western model—and no alternative model has been shown to be viable—the required energy has to come from somewhere.

Resolving these issues is far beyond the purview of the IPCC. But that United Nations organization could have an important role in the future. The IPCC and the climatology community in general should devote far more effort to determining the optimal range of carbon dioxide concentrations that will stabilize the climate and extend the current interglacial period indefinitely.

Climate sensitivity

A measure of climate sensitivity is the predicted rise in temperature due to a doubling of the carbon dioxide concentration. Climate models give broad probability distributions in temperature for such a doubling, with small but finite probabilities of large increases. Roe and Baker [14] have shown that the breadth of these distributions is due to the nature of the climate system. They also showed that the probability distributions associated with such projections are relatively

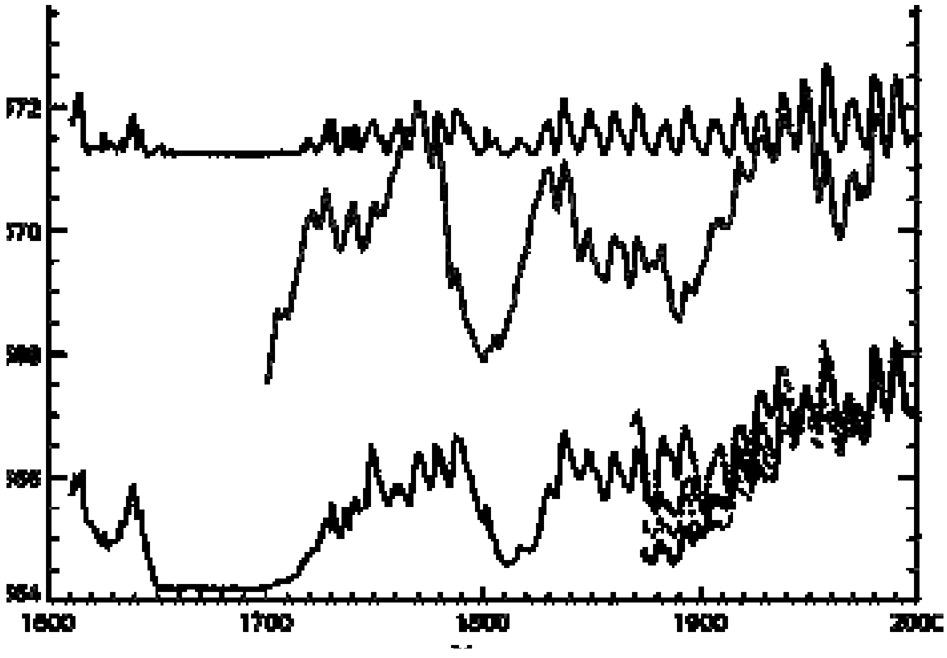

Figure 2: Reconstructions of total solar irradiance (TSI) by Lean et al. (1995, solid red curve), Hoyt and Schatten (1993, data updated by the authors to 1999, solid black curve), Solanki and Fligge (1998, dotted blue curves), and Lockwood and Stamper (1999, heavy dash-dot green curve); the grey curve shows group sunspot numbers (Hoyt and Schatten, 1998) scaled to Nimbus-7 observations for 1979 to 1993. [Fig. 6.5 and caption from Climate Change 2001: The Scientific Basis] (Color on-line)

insensitive to decreases in the uncertainties associated with the underlying climate processes. The approach they used was the standard feedback analysis employed for many purposes including electronic feedback-amplifier theory.

Their approach is also applicable to other perturbations of the climate system besides changes in carbon dioxide concentration. The same methodology will be used here to look at the response of climate to a decrease in solar irradiance comparable to that of the Little Ice Age (LIA). In this case one also finds that there is a small probability of a large decrease in temperature that could initiate another Ice Age. The results are best summarized in the figure shown at the end of this section.

For a change in radiative forcing, the equilibrium change in global temperature, ΔT, is $\Delta T = \lambda \Delta R_f$, where λ is the climate sensitivity and R_f is the change in radiative forcing, which—for the case being considered here—could be due to a change in solar irradiance or the Earth's albedo. In the absence of feedback processes, it is generally assumed that the reference climate sensitivity is $\lambda0 = 0.3\ ^{o}\mathrm{C}\mathrm{w}^{-1}\mathrm{m}^{2}$.

The best data available on total solar irradiance from 1600 to 2000 were given in 2001 by the IPCC in Fig. 6.5 of their report *Climate Change 2001: The Scientific Basis*. They gave the change in solar irradiance between the LIA and around the year 1850 (after the LIA) as about 1.75 $\mathrm{w/m^2}$. The 2007 IPCC report rescaled this data by a factor of 0.27 based on the work of Yang, et al. [15]. The figure from the 2001 IPCC report is shown here.

The updated estimate by Yang, et al., gives a model-dependent average increase in total solar irradiance from the Maunder minimum (the time of the LIA) to an average around 1850 as being about 0.7 w/m2. Using this value in the methodology developed below, however, yields unreasonable values for the total climate feedback in response to a change of solar irradiance. For this reason, an intermediate value of 1 w/m2 will be used here. This more conservative approach reduces the sensitivity of climate to changes in solar forcing. A decrease in solar irradiance of 1 $\mathrm{w/m^2}$ corresponds to a decrease in solar forcing of 0.178 $\mathrm{w/m^2}$.

The equilibrium change in temperature, ΔT_0, due to a change in solar irradiance of 1 $\mathrm{w/m^2}$ is then $\Delta T_0 = \lambda_0 \Delta R_f = (0.3\ ^{o}\mathrm{C}\mathrm{w}^{-1}\mathrm{m}^{2})\ \mathrm{X}\ (0.178\ \mathrm{w/m^2}) = 0.053\ ^{o}\mathrm{C}$. This is without any feedbacks from the climate system. Such feedbacks will affect the forcing, which in turn modifies ΔT. Along with Roe and Baker, it is assumed here that the functional relation is $\Delta T = \lambda_0(\Delta R_f + c\ \Delta T)$, where c is a constant. Let the total feedback factor, including feedbacks from multiple underlying climate processes, be defined as $f = \lambda_0 c$. Then one may express the latter functional relation as

$$\lambda = \frac{\Delta T}{\Delta R_f} = \frac{\lambda_0}{1-f}.$$

A model-independent estimate of the climate sensitivity, including all feedbacks, to a change in solar irradiance can be calculated from data from the LIA. This in turn allows the feedback factor *f* to be calculated from the above formula.

The average global reduction in temperature during the LIA is generally accepted to be about 0.4 °C. If the reduction in solar irradiance for the LIA is 1 $\mathrm{w/m^2}$, the change in forcing as given above is 0.178 $\mathrm{w/m^2}$, and therefore the climate sensitivity, including all feedbacks, is

$$\frac{\Delta T}{\Delta R_f} = \frac{0.4\ ^{o}\mathrm{C}}{0.178\ \frac{w}{m^2}} = 2.25\ ^{o}\mathrm{C}w^{-1}m^{2}.$$

Using the previous equation, this gives a value for *f* of $f = 0.867$. If the rescaled change in solar irradiance of 0.7 $\mathrm{w/m^2}$ were used, the result would be $f = 0.9$; alternatively, if the original un-rescaled data were used from Fig. 2, corresponding to a change in solar irradiance of 1.75 $\mathrm{w/m^2}$ for the period of interest, the resulting feedback would be 0.77. These are large feedback values compared to the mean value for carbon dioxide given by Roe and Baker as 0.65 ($0.42 \leq f \leq 0.73$). Such a large feedback factor goes a long way towards explaining the extraordinary sensitivity of the climate system to small changes in forcing due to changes in solar irradiance, albedo, or insolation changes caused by Milankovitch cycles.

There are many uncertainties in the various feedbacks that make up the total feedback factor *f*. The effects of these uncertainties, following Roe and Baker, will be assumed to result in a normal distribution for *f*. Its average value will be assumed here to be $f = 0.867$ as determined above, and the standard deviation of *f* will be chosen to be $\sigma f = 0.13$, typical—according to Roe and Baker—of feedback studies using global climate models.

The change in temperature as a function of *f*, given the equilibrium change in temperature, $\Delta T_0 = 0.053\ ^{o}\mathrm{C}$ due to a change in solar irradiance of 1 $\mathrm{w/m^2}$, is then

$$\Delta T(f) = \frac{\Delta T_0}{1-f}.$$

As $f \rightarrow 1$, the system approaches an unstable regime. For a decrease in forcing, ΔT_0 is negative, and consequently so is ΔT. Because ΔT is not a linear function of *f*, the distribution for ΔT which, using Roe and Baker's notation is $h_T(\Delta T)$, is not normal but is obtained in the following way.

The normal distribution for *f* is given by

$$h_f(f) = \frac{1}{\sigma_f \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{f-\bar{f}}{\sigma_f}\right)^2\right].$$

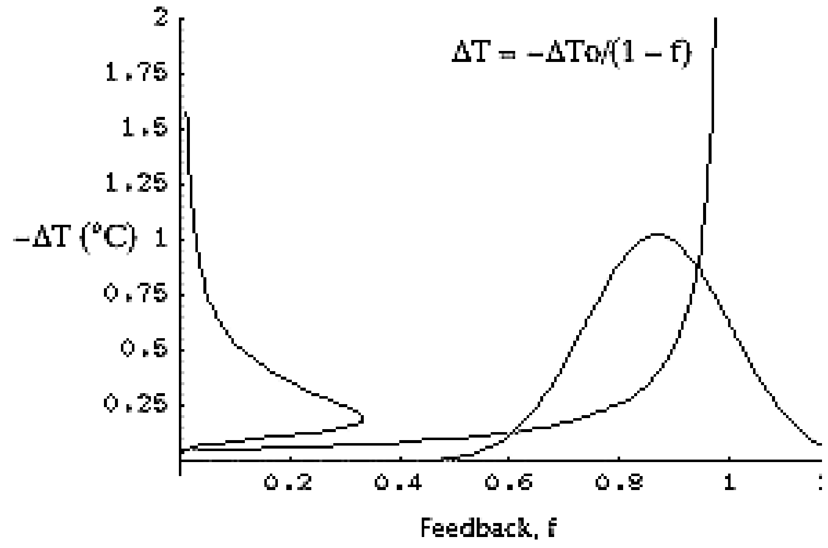

Figure 3. The normal distribution hf(f) is shown on the right of the figure, while the distribution hT(ΔT) is on the left. The ordinate, showing temperature, is to be associated with the distribution hT(ΔT), while the abscissa, showing the feedback factor f, with hf(f). The third curve shows ΔT as a function of f. The temperature difference −ΔT0, excludes all feedbacks and corresponds to a decrease in temperature of 0.053 oC due to a drop in solar forcing comparable to the Little Ice Age. The average feedback f = 0.867 intersects the curve for ΔT(f) at a temperature of 0.398 oC. Note that even a 1σ positive deviation from the mean in f gives a feedback very close to unity.

Now f can be viewed as a function of ΔT, that is, $f = f(\Delta T)$. Taking the derivative of the expression above for ΔT, and multiplying the resulting equation by $h_f(f)$ allows one to write

$$h_f(f(\Delta T))\,\frac{\mathrm{d}f(\Delta T)}{\mathrm{d}(\Delta T)} = h_f(f(\Delta T))\,\frac{\Delta T_0}{(\Delta T)^2} = h_T(\Delta T).$$

$h_T(\Delta T)$ is defined by the quantity on its left. Note that $h_T(\Delta T)$ as defined has the property that as $f \to 0$ or 1, $h_T(\Delta T) \to 0$. Since, from the above,

$$f(\Delta T) = 1 - \frac{\Delta T_0}{\Delta T},$$

the distribution $h_T(\Delta T)$ can be written

$$h_T(\Delta T) = h_f\left(1 - \frac{\Delta T_0}{\Delta T}\right)\frac{\Delta T_0}{(\Delta T)^2}.$$

$$h_T(\Delta T) = \frac{1}{\sigma_f\sqrt{2\pi}}\,\frac{\Delta T_0}{(\Delta T)^2}\,\exp\left[-\frac{1}{2}\left(\frac{\left(1 - \frac{\Delta T_0}{\Delta T}\right) - \bar{f}}{\sigma_f}\right)^2\right].$$

The distributions and their relationships are shown below in Figure 3. Note that the probable error for the feedback factor, P.E.—defined such that 50% of the data falls between $\bar{f}$ ± P.E., is given by P.E. = 0.6745 σf = 0.0877. Added to $\bar{f}$ this gives 0.95, perilously close to unity.

As pointed out by Roe and Baker, "The basic shape of $h_T(\Delta T)$ is not an artifact of the analyses or choice of model parameters. It is an inevitable consequence of a system in which the net feedbacks are substantially positive." The long tail of the skewed distribution $h_T(\Delta T)$ means that there is a not insignificant probability of large changes in temperature in response to relatively small changes in forcing. Keep in mind that the difference between the LIA and current global temperatures is only about 1.1 oC. Will Solar Cycle 25, mentioned earlier and predicted by NASA to be comparable to the Dalton Minimum, be the trigger for a new Ice Age?

Footnotes

* *Radiative forcing is defined as the change in net downward radiative flux at the tropopause resulting from any process that acts as an external agent to the climate system. It is usually measured in w/m2. See the Global Warming Primer on my website gemarsh.com.*

Endnotes

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[2] *J.F. Kasting and D.H. Grinspoon, The Faint Young Sun Problem, contained in C.P. Sonett, M.S. Giampapa, and M.S. Matthews, editors, The Sun in Time (University of Arizona Press, Tucson 1991), pp. 447-462; D.O.Gough, Solar Interior Structure and Luminosity, Solar Physics 74, 21-34 (1981); R. A. Berner, A. C. Lasaga, and R. M. Garrels, "The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years", Am. J. Sci. 283, 641-683 (1983).*

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What are Nuclear Weapons For?

Ivan Oelrich

After a two decade gestation since the end of the Cold War, the question of what nuclear weapons are for is finally emerging into a wider public debate. If I took the title of this essay literally, this essay would be very brief indeed because I believe the proper role of nuclear weapons is extremely limited. The United States should declare the narrowest possible mission for nuclear weapons, take its weapons off alert, bring all forward-deployed nuclear weapons home, and reduce its total arsenal to a thousand or fewer unilaterally and then engage the other nuclear powers in further reductions, leading eventually to a world free of nuclear weapons.[1] Thus, much of what follows is a discussion of what nuclear weapons are *not* for.

The very question, "What are nuclear weapons for?" steers us toward the wrong answer. Nuclear weapons are immensely powerful and are particularly effective at blowing things up. So if we set off to find some military mission that nuclear weapons can fulfill, we will always find something. If we start, however, from the question of what are the nation's and the world's security challenges and how can those best be met, then following those lines of inquiry will rarely if ever lead to any plausible, much less optimal, solution that includes nuclear weapons.

Setting aside for a moment the substance of the discussion, the current debate's nature and tone alone tell us a great deal about the talismanic power of nuclear weapons. Much of the discussion seems to treat nuclear weaponry as a force of nature, and the question is how we should cope with it. Nuclear weapons exist, true, and cannot be "uninvented" but we must remember that people made them and control them. We must not forget that how nuclear weapons might be used and for what purposes is always someone's decision.

The Cold War still permeates thinking about nuclear weapons in two ways. First, directly: much of the vocabulary and logic of nuclear weapons that is used today was developed specifically to address the challenges of a nuclear Cold War. We must be careful not to apply the shorthand developed then to today's radically transformed world. Second, our thinking is also affected by the physical legacy. Almost all nuclear weapons in existence today are left over from the Cold War. This legacy subtly, but powerfully, shifts the presumptions of the debate about nuclear weapons. Specifically, it shifts the burden of proof onto those who would shatter the status quo. Arguments that would be dismissed out of hand if used to justify building a nuclear arsenal up from zero are good enough to justify keeping the nuclear arsenal we have. A related logical sleight of hand is to make some argument in favor of nuclear weapons and allow it to imply that we should stick more or less with the status quo of thousands of weapons left over from the Cold War, even if the argument really justifies having only a handful of weapons.

Discussion of the purpose of nuclear weapons usually begins and ends with deterrence. Deterrence and nuclear weapons have become thoroughly entangled in our thinking and rhetoric. Much talk of deterrence is breathtakingly vague. "Deterrence" is rarely defined; *how* it is achieved is even more rarely discussed. That deterrence is something we need, and nuclear weapons automatically generate it, is typically simply assumed or asserted. Indeed, sometimes nuclear weapons just become a deterrent as when, for example, the nuclear weapons on missiles in submarines are called the "sea-based deterrent" or nuclear weapons in general are referred to as our "deterrent forces."

Deterrence is, in theory, quite simple. You might be tempted to do something that I do not want you to do; so I must be able to plausibly threaten you with some punishment, to threaten to inflict some pain, such that your action will, on balance, not seem worthwhile.

When discussing the mechanisms of deterrence, advocates for a nuclear deterrent make several logical errors. The first is to carry over the zero-sum, game-theory thinking of the Cold War. If the goal of deterrence is to make your action seem not to be worthwhile, then the *value* of the action has to be taken into account. During the Cold War, two world systems, liberal capitalism and totalitarian communism, felt that they were locked in a struggle both for their own survival and for control of the future of the whole world. If the prize is the whole world, that is, everything, then I must threaten to inflict near infinite pain, total, nation crushing pain, to make seizing that prize seem like a bad deal. Moreover, in a truly global struggle, there is no out-of-bounds, which means outcomes are not measured in absolute terms but in relative terms. Indeed, during the Cold War, our war plans included not just destroying the Soviet Union but making certain that it could not recover faster than we could. This goal, in turn, means that damage to my opponent can seem like a positive to me. Thus, if we suffer ten million dead and the Soviets suffer one hundred million dead, we somehow come out, not ten million down, but ninety million ahead because we are ahead, not in any absolute sense, but compared to our global foe in a closed system. The zero-sum, no out-of-bounds nature of the nuclear stand-off allowed Cold War thinkers to abstract the competition from any outside context; the contest lent itself to analysis by game theory, computer simulations, and mathematical models of stability. Much of that thinking and vocabulary inappropriately carries forward today.

This approach is irrelevant today because the threat I need to pose is tied to the prizes that you may try to seize, and today the fate of the world is not being contested; the prizes in play are much smaller. At first blush it seems reasonable that if the Russians are tempted to hurl a thousand nuclear bombs at us, we have to threaten to hurl eleven hundred back to deter that attack. That only works if destruction of Russia is our gain and outweighs equivalent pain on our part, which it does not. We have to ask why Russia is hurling missiles at us, what are the stakes in play, and what would make seizing those stakes seem unattractive. We can imagine that Russia and the United States could fall into a war. Just as hypothetical examples, Russia might make an incursion into one of the Baltic countries, which are NATO allies, because of mistreatment of the Russian minority, or into Kosovo in anticipation of NATO's military enforcement of Kosovo's independence from Serbia. But how many nuclear weapons have to go back and forth before the destruction makes the importance of the original issue pale in comparison? I cannot say exactly but the number may well be one. If the Russians in any case hurl a thousand missiles at us and we throw eleven hundred back, that is not really deterrence; that is nuclear war-fighting or revenge or something else, and we should not confuse ourselves by calling it deterrence. It is precisely because Russia today has the option of destroying the United States with thousands of nuclear weapons, and vice versa, even though no rational, sane situation would call for such an act, that we should find ways of dramatically reducing Russian and American arsenals.

Nuclear weapons are sometimes promoted as essential to deterrence because of their unique military capabilities. In a remarkable essay written after the end of the Cold War, Stephen Younger, the former associate director of Los Alamos National Laboratory, wrote that to effectively deter the Russians we have to be able to destroy anything and everything in Russia and only nuclear weapons can hope to do that.[2] If fact, in only one case does he suggest the possibility of negotiating limits with the Russians and that is to limit the possibility that they might build something that we could not destroy.

Drs. John Foster and Keith Payne, in their essay in this series [Physics & Society, October 2007], make essentially the same logical error, arguing that nuclear weapons may be needed for deterrence because some targets cannot be destroyed any other way. But this assumes that my enemy, not I, gets to decide how I inflict pain on him. Their assertion implies that I may be able to destroy North Korea's army, navy, air force, its infrastructure, economy, transportation, food supply, indeed, its entire population, but if there is some tunnel somewhere that I cannot destroy, then deterrence might fail. This proposition is indefensible on several counts. If nothing else, it is utterly contrary to historical experience. No nation at war has ever had as a goal the utter destruction of every possible enemy target; no war has ever been won or lost on that basis. Moreover, if survival of some targets makes deterrence impossible then deterrence is impossible, first, because certain targets, such as deep tunnels, are immune to attack even by the most powerful nuclear weapons and, second, because we cannot destroy targets that we cannot find (or, perhaps, are not even aware oft). Remember that Saddam Hussein was at large for some time even though we had occupied his country and had troops on the ground. Saddam was finally captured by a soldier with a pistol, not destroyed by a nuclear weapon. With or without nuclear weapons, there will be targets that are immune to attack. Nuclear weapons cannot be essential for an essentially unobtainable goal.

Some argue that nuclear weapons have a special character that makes them the only instruments that can deter in some cases; again, Drs. Foster and Payne's essay is a particularly clear example of this position. The special cachet of nuclear weapons may be completely illogical—after all, why should a potential enemy care *how* I destroy targets and inflict deterring pain? —but we are dealing with human beings so perhaps perceptions create their own reality and logic does not always apply. This is a proposition that I believe is impossible to unambiguously prove but, once accepted, equally impossible to clearly disprove. Yet, careful examination undermines the premise that nuclear weapons have some special role in deterrence.

One problem with any historical analysis of deterrence is that successes can be hard to see, but failures are painfully obvious. Every day that a war does not break out can be claimed as a deterrent success, but was war avoided because of the threat of nuclear retaliation, or of conventional retaliation, or because of domestic political considerations, or any of a thousand other reasons, or was war never really seriously taken under consideration, so never really deterred?

One thing that *can* be proven is that nuclear weapons are not *sufficient* for deterrence. Since the United States has had nuclear weapons, it has experienced major deterrence failures in China, Korea, Vietnam, Iraq, and numerous lesser cases. What also seems inescapable is that every time there is an aggression that is not met with nuclear weapons, the credibility of nuclear weapons as a deterrent for that type of event is further reduced. It has been over six decades since the United States has used nuclear weapons. Is their use still plausible in response to another event like the Iraqi invasion of Kuwait? Will it be after a hundred years of non-use? The Department of Energy, in justifying the need for a so-called Reliable Replacement Warhead, claims that U.S. warheads, now 98-99% reliable, need to be more reliable—as though the difference between 99, 95, or 90% could make any conceivable difference in any potential enemy's deterrent calculation—when any technical difference is completely swamped by the implausibility of use created by decades of non-use.

This does not mean that nuclear weapons have no deterrent value. As the physicists among the readers know, we do not measure time directly, we count off some event that we assume is regular, whether it is the rising of the sun, the swing of a pendulum, or the oscillation of the magnetic moment of a cesium atom. If we measure "deterrence time," not in the passage of years, but in the passage of events, then much time has passed in terms of Koreas, Vietnams, and Iraqs. Even more time has passed in terms of Haitis, Panamas, Rawandas, and Dafurs. And as time passes without nuclear use, the plausibility of nuclear use continues to decline. Thus, it is inescapable: The only way to make the use of nuclear weapons more plausible in these types of cases is to occasionally use them in these types of cases, and I know of no one advocating this. But no time at all has passed in terms of nuclear attack on the United States or its allies. Thus, a nuclear response to nuclear use is as fresh and intensely plausible today as it would have been in 1945. And this is the only justifiable use for nuclear weapons, the use for which a few should be reserved, as a response to nuclear use by others.

The nuclear "posture" we have today, the combination of weapons, their number and characteristics, that we keep them on hair-trigger alert, constantly deployed, many on submarines forward deployed off the coasts of Russia and China just minutes from their targets, demonstrates that the United States maintains nuclear war fighting options including disarming first strikes. Reserving nuclear weapons solely for the mission of responding to nuclear attack, thereby deterring such an attach in the first place, implies a decisive no-first-use posture, weapons off alert, perhaps even stored separately from their delivery systems. And since the pain that must be inflicted today should be proportionate to the stakes in play, not a potential enemy's arsenal, the number of weapons needed is almost certainly only in the double digits.

Nuclear weapons once dominated security thinking but, as instruments of national power, their time has come and gone. The United States and the Soviet Union once had nuclear-armed surface-to-air missiles and air-to-air rockets, nuclear depth charges and torpedoes, nuclear land mines and demolition charges, and nuclear-armed rockets that could be launched from the back of a jeep. All of these missions have fallen away, not because of arms control agreements or political pressure but because nuclear weapons have been displaced in each case by technologically and militarily superior solutions made available by advances in miniaturized sensors and computers. Nuclear advocates are forced to ever more contrived and convoluted missions to justify nuclear weapons, for example, the nuclear bunker buster, which required very cooperative enemies who buried vital targets just out of reach of conventional attack but not so deep that they were out of reach of even nuclear weapons. Nuclear weapons have simply become almost entirely obsolete.

Moreover, nuclear weapons are no longer morally acceptable except to deter nuclear use. The United Stats used fleets of B-17s and B-29s to carpet bomb German and Japanese cities in World War II in part because that was the greatest degree of targeting discrimination that the technology of the day allowed. Using B-17s against Baghdad in the same way in the recent war would have been universally denounced as a war crime because today militarily effective alternatives of greater discrimination exist; similarly, using nuclear weapons when any other alternative is available, now that alternatives are available, is immoral.

Nuclear weapons loom so large in the national security calculus today primarily because of inertia, because of the legacy of the Cold War. The question in the title of this series, "What Are Nuclear Weapons For?" is the wrong question. Any analysis that involves nuclear weapons will, of course, find missions for them. But any analysis that starts with security challenges facing the world and rationally examines alternatives will rarely lead to nuclear weapons as the optimal solution. There will be non-nuclear alternatives that are better, whether measured by military, technical, cost, moral, or political criteria. With repeated iterations of the process of elimination, we are finally left with virtually no missions for nuclear weapons at all. The United States should lead the world toward their elimination.

Footnotes

1 These last proposals are elaborated in some greater detail in Toward True Security: Ten Steps the Next President Should Take to Transform U.S. Nuclear Weapons Policy, jointly published by the Federation of American Scientists, the Union of Concerned Scientists, and the Natural Resources Defense Council. Available at http://www.fas.org/press/_docs/Toward%20True%20Security%202008%20.pdf

2 Stephen M. Younger, Nuclear Weapons in the Twenty First Century, Los Alamos National Laboratory, LAUR-00-2850, June 27, 2000. Also available at http://www.wslfweb.org/docs/SteveYounger.pdf.

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Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy[1]

Arjun Makhijani

A three-fold global energy crisis has emerged since the 1970s; it is now acute on all fronts:

1. Carbon dioxide (CO_2) emissions due to fossil fuel combustion are the main culprit in the buildup of greenhouse gases in the atmosphere, and fossil fuels— coal, oil, and natural gas—provide over 85 percent of the U.S. and world commercial energy supply. Fossil fuels account for about 84 percent of U.S. greenhouse gas emissions.
2. Rapid increases in global oil consumption and conflicts in and about oil exporting regions have driven prices high, even as supplies become more insecure. The United States imports 60 percent of its petroleum requirements. At the same time, producing oil in sensitive areas like the Arctic National Wildlife Reserve, from tar sands or shale, or turning coal into liquid fuels raises a host of environmental and resources questions that are difficult, including in some cases, increasing greenhouse gas emissions relative to oil imports.
3. Proliferation of nuclear weapons is being exacerbated partly by the spread of commercial nuclear power technology. If one uranium enrichment plant in Iran poses such vast security challenges, how will the world cope with a situation where one or more new enrichment plants would need to be built somewhere in the world each year?

Yet, the three problems tend to be treated separately in the policy debate. An integrated energy policy that aims at an efficient U.S. economy based entirely on renewable energy sources like wind and solar energy would address them all simultaneously. Further, a zero-CO_2 emissions economy in the United States is not only desirable: Something close to it is a treaty obligation under the United Nations Framework Convention on Climate Change (UNFCCC), given the current state of knowledge about global climate change.

Specifically, the Intergovernmental Panel on Climate Change has estimated that it will require global CO_2 emissions to be reduced by 50 to 85 percent relative to the year 2000 in order to limit average global temperature increase to 2 to 2.4 degrees Celsius relative to pre-industrial times. The former represents a 15 percent chance of limiting the temperature rise to this range; the latter an 85 percent chance. If a global norm of approximately equal per person emissions by 2050 is created along with a 50 percent global reduction in emissions, it would require an approximately 88 percent reduction in U.S. emissions. An 85 percent global reduction in CO_2 emissions corresponds to a 96 percent reduction for the United States.[2] China, India, and other developing countries are unlikely to accept anything less than a uniform per capita global norm —though they may argue for a more stringent standard given historical inequities. If the United States adopts a target of 80 percent CO_2 emission reductions, and if a similar per capita level (the U.S. per capita level in 2050 after 80 percent reduction in total CO_2 emissions) became the norm worldwide, energy sector CO_2 emissions in the year 2050 would be about the same as they are today.

Is a reliable energy system constructed entirely from renewable sources of energy that has the same material benefits as would otherwise be available in the absence of climate change concerns technologically and economically feasible? That is the central question addressed in my book, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy*.

The starting point for such a study is the set of economic projections used by the Energy Information Administration to assess U.S. energy requirements normatively, assuming a business-as-usual approach. The same number and area of residential and commercial buildings, cars and other vehicles, aircraft passenger miles, and GDP growth in industry and commerce are assumed in the renewable energy economy as in the business-as-usual approach. In other words, no changes in values or lifestyles are assumed, even though such changes may accelerate the transition to a renewable energy economy. The analysis is carried out based on delivered energy to residences, business, vehicles, and industry, after which energy processing losses at power plants and biofuel plants are added. This ensures comparability between the assumptions used to model a renewable energy economy with business-as-usual.

It should be noted that business-as-usual requirements are projected assuming the increases in energy efficiency that have been typical since the energy crisis of the 1970s. In recent years, GDP growth of about 3 percent has been accompanied by energy growth of about 1 percent, in contrast to the pre-1973 period, when energy and economic growth rates tended to be about the same. The change has been much more marked in the industrial sector, where energy use has not grown since 1973, than in the residential, commercial, or transportation sectors.

The increases in efficiency in a fully renewable economy are relative to business-as-usual. A detailed analysis shows that a reduction of one percent per year in end use energy in absolute terms, and even somewhat more until 2050, is fully compatible with the same GDP growth as in business as usual. In other words, an increase in end use efficiency of about two percent per year relative to business-as-usual is shown to be feasible by the analysis in *Carbon-Free and Nuclear-Free*.

The other keys to phasing out of fossil fuels and nuclear power are:

1. optimizing solar, wind, standby capacity, and storage to produce a reliable electricity sector;
2. biofuels made from biomass with high solar energy capture efficiency (defined as being considerably greater than one percent).

If hydrogen production from wind-generated electricity using electrolysis and/or direct solar hydrogen production (for instance, using thermal cracking) can be accomplished economically ($3 to $ 4 per kilogram or less of compressed hydrogen), the transition would be considerably eased. Hydrogen fuel would be produced on a distributed basis to be used in industry as a raw material and possibly as compressed fuel in internal combustion engines for a part of transportation fuel requirements, if the tanks for storage at 10,000 psi can be commercialized. Fuel cell vehicles and are not envisioned in this analysis.

Efficiency

Affordable technologies and practices for vastly improved efficiency already exist in the residential and commercial sectors. Figures 1 and 2 show the current average consumption of energy at the point of use in residential and commercial buildings, compared to efficient buildings.

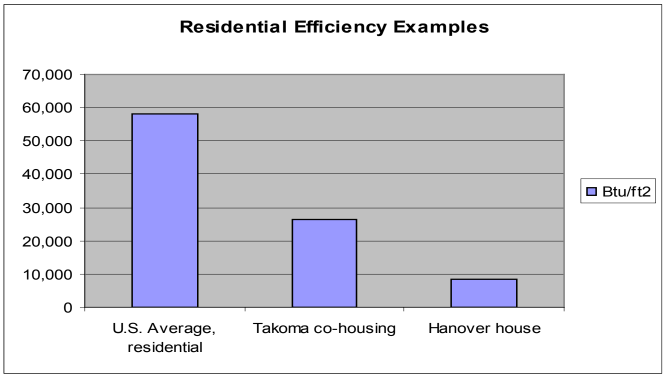

Figure 1:
Delivered energy use, Btu per square foot, residential

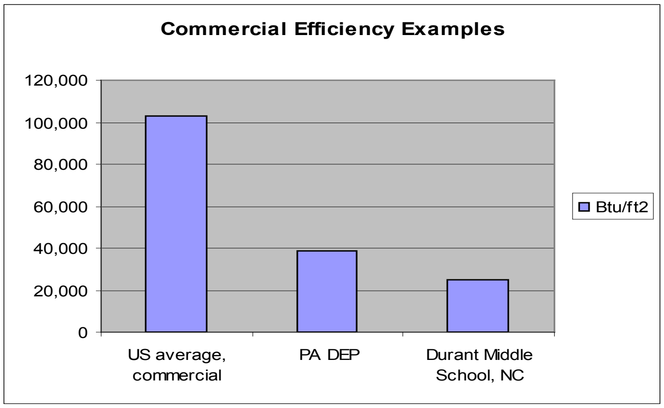

Figure 2:
Delivered energy use, Btu per square foot, commercial

It is evident that reductions of a factor of three to seven of delivered energy are quite possible using sound principles of building design, such as appropriate thermal mass, south-facing windows and the right levels of insulation. The example of Hanover House in New Hampshire, shown in Figure 1, is especially interesting. It uses active solar thermal heating as well, with a large hot water storage tank (4,500 liters) for space and water heating. It is an all-electric house that gets its energy from the grid and uses electric resistance heating to supplement the solar thermal system. Even though resistance heating is among the most inefficient, the overall energy use is very low. The annual electricity consumption averaged about 5,000 kWh. This could be supplied by a grid-connected solar PV system of about 3.5 kW. The cost of house construction was $111 per square foot, with the owner serving as the general construction contractor.[3] Overall specific end use in the residential sectors in the reference scenario developed for a renewable energy economy is estimated to be about 39,000 Btu per square foot in 2050, which is still well above the potential for energy efficiency. Commercial buildings can often meet the highest green energy and environmental recognition (the "platinum" level Leadership in Energy and Environmental Design certification) for less than $10 per square foot in investment, which can be generally recovered relatively easily in reduced energy costs.

Lighting efficiency is especially important in the commercial sector, where it is the largest single energy use, if thermal losses at the power plant are included. It can be reduced by a factor of five or more with existing and emerging technologies. One of the best of the latter is hybrid solar lighting, invented at Oak Ridge National Laboratory.[4] A four-foot parabolic solar concentrator focuses sunlight onto a four-inch bundle of optical fibers, which are incorporated into especially designed luminaires, which also have electric lights. The electric lighting component automatically compensates for varying solar light availability, maintaining a constant output. An added benefit is reduced air-conditioning electricity use during sunny days, since the thermal loading of the solar part of the luminaire is negligible compared to electric lighting.

Oil use in transportation is even more inefficient than energy use in buildings. The net average efficiency of personal car transport is currently only about one percent, based on the payload transported – the people in the car.5 Besides automobile efficiency standards, one logical place to start is plug-in hybrids – gasoline-electric cars that have extra batteries that store enough charge to enable much or most commuting on electricity only. Depending on the battery capacity, the liquid fuel efficiency is 70 to 100 miles per gallon, plus an input of 0.1 to 0.15 kWh per mile. There is no real obstacle to commercialization of this technology. Efficiency standards set for the year 2020 should reflect this.

Plug-in-hybrids can be charged using renewable energy sources. This will reduce both oil imports and CO2 emissions. They can also be used in a "vehicle-to-grid" arrangement—V2G for short. When the batteries are low, the car is charged from the grid; when grid needs power, it can draw on the electricity stored in parked cars that are plugged in. The first small-scale practical trial of V2G is being prepared in Google's Silicon Valley parking lot. A V2G system can provide electricity storage to help solve the one real difficulty associated with very large-scale use of solar and wind energy: they are intermittent.

A V2G scheme was economically unthinkable even two years ago. The batteries wore out much faster than the rest of the car, making it prohibitively expensive to use them in a V2G system. But tests show that newly designed lithium-ion batteries will last far longer than the car. With them, V2G can provide one way for solar and wind energy to reliably provide the majority of the electricity we need. The batteries are still being made on a small scale. A cost reduction of about a factor five is needed; it is expected in the next few years as production technology matures and economies of scale kick in. Most cars are parked over 90 percent of the time. Only a few percent of all cars would be needed to provide large-scale back up for renewable electricity sources.

All-electric cars using advanced lithium-ion batteries also appear to be on the horizon. Phoenix Motorcars is making an all electric five-passenger pick-up truck, with a range of ~130 miles and an efficiency of about 3.5 miles per kWh. Tesla Motors is making a sports car that goes from zero to 60 mph in four seconds and has an efficiency of about 5 miles per kWh. Lithium-ion battery pack costs need to come down by about a factor of five before such cars can be commercially competitive. One great advantage of such vehicles, of course, is that they can be charged using renewable electricity sources. The greatest energy efficiency improvements are assumed to occur in the transportation sector, because that has the greatest potential, especially in a transition to electric or mostly electric personal vehicles.

Liquid fuels

What about fueling aircraft, trucks, and industry? Let's first note that, except for waste cooking oils, using food sources for energy is not a very good idea. The net energy balance of ethanol from corn is poor. The net greenhouse gas emission reduction is modest, at best. Even at moderate levels of production, using corn for ethanol fuel is causing a rise in food prices in the United States, Mexico, and elsewhere. Using palm oil for biodiesel is even worse than ethanol from corn. The emissions of CO_2 from the destruction of the peat bogs in Indonesia, where the palms are grown, are much greater than if petroleum were used in transport. Using food crops as a major source of fuel is unsustainable in a world of eight to ten billion people (by 2050) who are acquiring the means to eat well.

Biofuels are important for a renewable energy future, but we must use a sharp pencil to choose the right ones. Some approaches that are being funded, like converting corn stover and prairie grasses to ethanol ("cellulosic ethanol"), are worthwhile. But the most promising approaches are not on the national policy radar yet.

Consider microalgae — tiny, ubiquitous plants that can even grow in salty water. The right species can provide 5,000 to 10,000 gallons of biodiesel per acre, compared to about 300 gallons of gasoline equivalent for ethanol from corn. The main inputs are water, sunshine, and today's pollutants — carbon dioxide and nitrogen oxides from power plant exhaust.

The technology has been demonstrated on a small-scale at the Massachusetts Institute of Technology. Larger scale tests have been done at power plants in Arizona and Louisiana. A pilot test over 19 summer days at the Arizona power plant produced an yield of 98 grams of dry matter per square meter per day, indicating an annual potential at present of 200 metric tons per year or more.

Other high productivity biomass includes aquatic plants that are now considered as nuisances or worse. Of special note are water hyacinth and duckweed. The former may be the most productive plant on Earth, with a solar energy capture efficiency of up to 5 percent — yielding up to about 250 metric tons of dry organic matter per hectare per year. Aquatic weeds grow well in high-nutrient content water, such as agricultural run-off and municipal wastewater. They have been used as part of experimental wastewater treatment systems, off and on since the 1970s, but they have never been a significant part of energy considerations. That needs to change.

Overall, the requirements for liquid and gaseous biofuels in the residential, commercial, transportation and industrial sectors present possibly the most difficult challenge to a transition to a renewable energy economy. The main issue is land area requirements. Combing high productivity prairie grasses and very high productivity aquatic plants (including microalgae) with high efficiency would still result in requirements of 5 to 6 percent of the land area of the United States. But with the right choices of plants, the biofuels could be grown on land that is now not suitable for agriculture — even in desert areas. For instance, wastewater from the Los Angeles metropolitan area could be treated in the Owens Valley, where aquatic plants could be grown as part of the treatment. In any case, much of the water for the Los Angeles region comes from the Owens Valley.

It would be highly desirable to reduce land area requirements in a renewable energy economy. One way would be to focus on commercializing direct solar hydrogen production technologies, which are still largely in the laboratory stage. Electrolytic hydrogen using wind power plants is closer to commercial. However, large-scale development of this technology would also require development of a hydrogen pipeline infrastructure, which would be a major undertaking amidst several other major transformations. Such an infrastructure is not envisioned in the analysis. Hydrogen use would be mainly for industry as a feedstock and possibly as compressed hydrogen for use in internal combustion engines, if developmental problems are resolved.[6]

A Renewable Electricity Grid

The United States is blessed with enormous renewable energy potential. North Dakota, Texas, Kansas, South Dakota, Montana, and Nebraska each have wind energy potential greater than the electricity produced by all 103 U.S. nuclear power plants. Wind energy is already more economical than nuclear. Solar energy is even more abundant. Assuming 20 percent efficiency, 0.1% of the land area of the United States would provide almost all U.S. electricity requirements. Indeed, the area of parking lots and commercial rooftops is large enough to provide most U.S. electricity requirements. Wind energy is presently economical. Solar energy costs are running at about 20 cents per kWh and are declining. The small scale of manufacturing capacity is a major contributor to high cost. That is changing rapidly. The Department of Energy expects commercial competitiveness by about 2015. The land area requirements of wind and solar electric power plants are

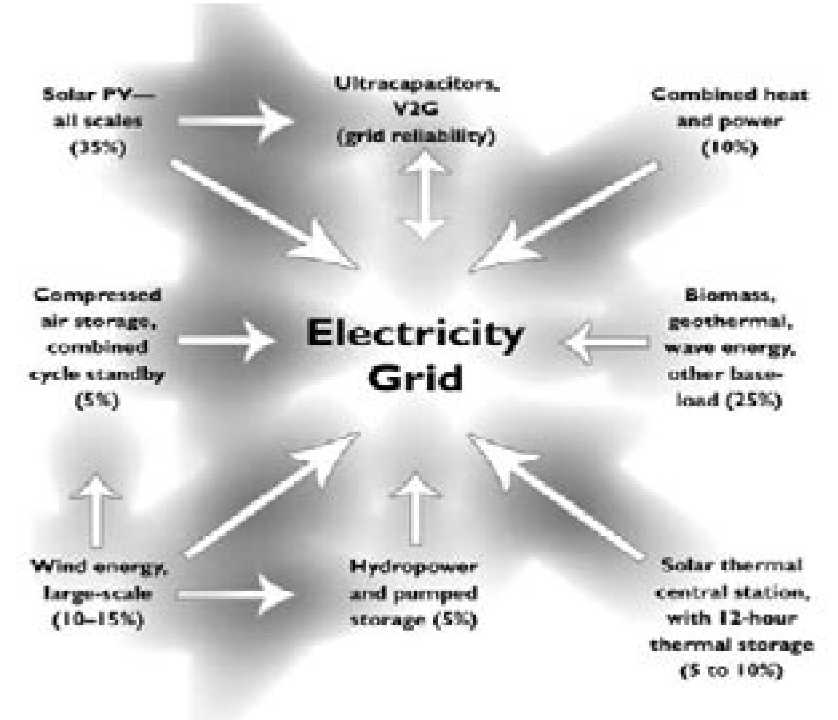

Figure 3: A renewable electricity grid configuration

modest. The footprint of wind turbines, including roads and other infrastructure is ~0.6 hectares per megawatt (though it varies a good deal). A trillion kWh of solar electricity can be generated on less than 1,600 square miles in sunny areas, including a 30 percent allowance for infrastructural land.

Individual technologies aside, can a reliable electricity grid be created using renewables alone? If so, how do we get from here — coal, nuclear, natural gas, and hydropower — to there? One key is to use existing infrastructure to make the transition. For instance, hydropower use can be restricted mainly to times when the wind is not blowing. This is being demonstrated in Washington State.

A large economic miscalculation made in the last 15 years can also be turned to advantage. During that time, natural gas-fired power plants with a capacity three times larger than U.S. nuclear capacity were built, in anticipation of continued low natural gas prices. But prices have tripled and the plants sit idle over 80 percent of the time. This huge capacity can be used to provide backup for wind and solar, at night and times of low wind. In 20 or 30 years, natural gas can be replaced by methane from biomass. With this approach, the fraction of solar and wind energy in the grid can be increased from under one percent at present to 30 percent or more over the next two decades, without resort to storage technologies that are now uneconomical. Intermittency of solar and wind is therefore no bar to meeting electricity growth requirements with a combination of efficiency and an optimized mix of solar, wind, hydro, and natural gas standby power for about two decades. New nuclear and coal-fired power plants are quite unnecessary to a reliable grid. In fact, a distributed grid that uses commercial rooftops and parking lots as a key feature, would be more secure than the one we have today.

In the longer term, some baseload power plants using solid biomass, geothermal energy, and some intermediate load solar thermal power plants with thermal storage will be necessary to anchor the system, unless electricity storage technologies such as ultracapacitors and sodium-sulfur batteries become much more economical than they are today. A possible configuration for a renewable energy grid is shown in Figure 3.

The costs of electricity per kWh from such a grid may be in the range of 12 to 18 cents per kWh, if solar energy costs continue to decline for the next few years. This is higher than those prevailing in most parts of the country. However, the overall cost of energy services will not be higher if appropriate investments are made in efficiency.

It will not be easy. Determination, a vigorous research, development, and demonstration program, and sensible overall policies are essential requirements. But we can solve all three problems — climate change, nuclear power as a source of proliferation, and insecurity of oil supply — simultaneously. Done right, it will not burn a hole in the national pocketbook — the amount we spend on energy services, such as heating, cooling, lighting, and personal transportation, as a fraction of Gross Domestic Product would remain about the same as energy expenditures in 2005 — about eight percent. But more will be spent on efficiency and less on fuels and electricity.

The main policy recommendations arising from the analysis are as follows:

1) Enact a physical limit of CO2 emissions for all large users of fossil fuels (a "hard cap") that steadily declines to zero prior to 2060, with the time schedule being assessed periodically for tightening according to climate, technological, and economic developments. The cap should be set at the level of some year prior to 2007, so that early implementers of CO2 reductions benefit from the setting of the cap. Emission allowances would be sold by the U.S.

government for use in the United States only. There would be no free allowances, no offsets, and no international sale or purchase of CO2 allowances. The estimated revenues – approximately $30 to $50 billion per year – would be used for demonstration plants, research and development, and worker and community transition.

2) Eliminate all subsidies and tax breaks for fossil fuels and nuclear power (including guarantees for nuclear waste disposal from new power plants, loan guarantees, and subsidized insurance).
3) Eliminate subsidies for biofuels from food crops.
4) Build demonstration plants for key supply technologies, including central station solar thermal with heat storage, large- and intermediate-scale solar photovoltaics, and CO_2 capture in microalgae for liquid fuel production.
5) Leverage federal, state, and local purchasing power to create markets for critical advanced technologies, including plug-in hybrids.
6) Ban new coal-fired power plants that do not have carbon storage.
7) Enact at the federal level high efficiency standards for appliances.
8) Enact stringent building efficiency standards at the state and local levels, with federal incentives to adopt them.
9) Enact stringent efficiency standards for vehicles and make plug-in hybrids the standard U.S. government vehicle by 2015.
10) Put in place federal contracting procedures to reward early adopters of CO_2 reductions.
11) Adopt vigorous research, development, and pilot plant construction programs for technologies that could accelerate the elimination of CO_2, such as direct solar hydrogen production (photosynthetic, photoelectrochemical, and other approaches), hot rock geothermal power, and integrated gasification combined cycle plants using biomass with a capacity to sequester the CO_2.
12) Establish a standing committee on Energy and Climate under the U.S. Environmental Protection Agency's Science Advisory Board.

Endnotes

1 Based on a forthcoming book of the same title, published by RDR Books. The book can be downloaded free at http://www.ieer.org/carbonfree/CarbonFreeNuclearFree.pdf Details of the analysis and references can be found there.

2 Based on a global population of 9.1 billion and a U.S. population of 420 million in the year 2050.

3 More details about this house are on the Internet at http://www.buildinggreen.com/auth/article.cfm?filename=070201a.xml&printable=yes. The solar PV installed capacity requirement would, of course, be lower in sunnier parts of the United States.

4 Details are available at http://www.ornl.gov/sci/solar/

5 Vehicle efficiency = 15%; average vehicle weight of 3,240 pounds; occupancy of 1.64 person-miles per vehicle mile. Average weight (all ages) ≈ 130 pounds.

6 The APS's Panel on Public Affairs, The Hydrogen Initiative, March 2004 concluded that one to two orders of magnitude improvements in technology and discovery of a new material for vehicle storage tanks would be needed for a fuel cell car to be able to compete with gasoline cars. See Hydrogen Initiative link at http://www.aps.org/policy/reports/popa-reports/index.cfm

Arjun Makhijani is president of the Institute for Energy and Environmental Research. In November 2007 he was elected a Fellow of the American Physical Society "for his work to provide the public with accurate and understandable information on energy and environmental issues," having been nominated by the Forum on Physics & Society.

COMMENTARY

A Bribe to Escape Moscow

David Hafemeister

It was December 1991, the last week of the Soviet Union. Considerable uncertainty was in the air as Ukraine just voted to leave the Soviet Union. It was my task as a member of the American delegation in Moscow to deal with the coming changes on nuclear weapons. The American delegation consisted of nuclear weapon designers and laboratory directors, the CIA, several non-governmental organization scientists and myself, representing the Senate Foreign Relations Committee (SFRC). The meetings dealt with implementing the newly–passed Nunn-Lugar legislation to protect nuclear warheads from theft, to dismantle warheads and missiles, to store nuclear materials, to convert weapons–grade uranium into reactor fuel, and to verify the results. After successful high-level meetings in Moscow and Kiev, the US delegation departed.

I stayed on for further discussions at the Soviet Ministry of Defense and the Soviet On-Site Inspection to prepare for the SFRC hearings on the Strategic Arms Reductions Treaty. This forced me to stay two days beyond the length of my visa. I was confident the authorities would honor my government passport and ignore this detail. But life became complicated. Moscow's Sheremetyevo Airport was mobbed as Russians and foreigners were fleeing Moscow to avoid the chaos. The panic level was compounded by a lack of jet fuel as the Soviet system started to collapse. As I waited in line, a petite Russian woman came and beat on me with her fist as she thought (incorrectly) that I had a better place in line. Her husband apologized to me as his wife was panicking about obtaining a flight to Soviet Georgia for their family of four.

Finally the Air France line began to move. As I reached the head of the line, I noticed three ominous–looking Soviet soldiers, packing AK–47's. I held my breath and handed them my passport with its outdated visa. My heart sank as they quickly spotted the discrepancy. They pointed towards Moscow and said that I must get a new visa. But how could that really happen as the Soviet Union was crashing, while the new Russian government barely existed? It could take months. Where was I to stay? There were the forthcoming hearings on START, and my family in DC was awaiting my Christmas arrival. At last I thought of something I had never done before (or since). Why not try good old–fashioned bribery? I stuck three ten–dollar bills into my passport and said something in English, which I knew they could not understand. At this time a $10 bill was worth about $1000 as the ruble crashed. The senior officer and the two young recruits huddled in the corner. I broke into a sweat. Will they send me to jail? Will they send me back into uncertain Moscow? Happily, they motioned to me to enter the plane. Here we were, former enemies but yet four humans reaching out to survive. After all, these were decent soldiers put into an impossible situation. Their lives were going to get much worse before they got better. I view the $30–visa expense as a necessary evil for me and as a bonus for the three soldiers and their families. I hoped things worked well for them as I returned to the comforts of the US.

David Hafemeister
San Luis Obispo, California

Thanks for a great conference

Jeffrey Marque

More than two hundred people, including myself, had the great privelege of attending a two-day conference, called the Physics of Sustainable Energy, held at the University of California at Berkeley on March 1 &2, 2008 and sponsored by the Forum on Physics & Society of the American Physical Society. The conference included about two dozen talks by some of the leading experts in various aspects of energy, including appliances, lighting, buildings, windows, energy use in China, wind, nuclear power, ... and too many others to list in their entirety. My position as co-editor of this newsletter gives me the welcome opportunity to express my deep thanks to all of the speakers and to David Hafemeister, Barbara Levi, Pete Schwartz, and Mark Levine, the conference organizers. The conference was not only very interesting, but also successful in its announced purpose, namely, "to acquaint physicists with an in-depth technical knowledge of the more promising developments in energy research and to enable them to evaluate energy issues for teaching or for research." I'm quite sure that I express the sentiments of the majority of the attendees when I extend my heartfelt thanks to the organizers and speakers for their work.

This conference was billed as "The Woodstock of Sustainable Energy", but in at least one respect, our conference was superior to the "other Woodstock physics meeting", i.e., the APS March meeting of 1987 in Manhatten: I was there in 1987, and I therefore know that nobody at the March 1987 meeting handed out delicious box lunches to all the attendees, as was done at our conference in Berkeley. J. Robert Oppenheimer, once on the faculty at UC Berkeley, remarked in the context of the fission bomb creation that physicists "...have known sin." In the context of sustainable energy research, I would add that we physicists have also known good food and very good company.

Jeffrey Marque is the Senior Staff Physicist at Beckman Coulter Corporations's Centrifuge Development Center in Palo Alto, California, where he has worked on structural dynamics and acoustics since 1988. Prior to that, he taught physics at the University of San Francisco and did protein dynamics research at Cornell University and at the biophysics group at Rikagaku Kenkyusho (RIKEN) in Wako-shi, Japan. He has served as co-editor of this newsletter for several years.

REVIEWS

Nuclear Weapons: What You Need to Know.

Jeremy Bernstein (Cambridge: Cambridge University Press, 2008) ISBN 978-0-521-88408-2, xi + 299 pp, $27.

Readers familiar with Jeremy Bernstein's writing know that, upon picking up one of his books or articles, they are always in for a good read: accurate, well-described physics, interesting historical sidelights, and engaging personality profiles and personal anecdotes. In his careers as both a physicist at the Stevens Institute of Technology and as a science journalist for the New Yorker Bernstein has worked with, interviewed, and/or personally known many of the key figures of twentieth-century physics. He draws on that experience to good effect in his latest work.

This book is a history of nuclear weapons written to address the "appalling lack of understanding" of these devices on the part of the general public and the misinformation offered by media commentators as they attempt to explain issues of weapons programs and proliferation. The author points out that it has been nearly 30 years since a human being has actually witnessed an aboveground nuclear test and that the ranks of those who can personally testify to the power of these devices is steadily dwindling: humanity needs to be reminded what is at stake when a single Nagasaki-type bomb is equivalent to some 8000 Oklahoma City truck bombs.

This book comprises an introduction, twelve chapters, and a handy table of units and sizes. The first three chapters offer a brief tour of the history of the elucidation of atomic structure from the work of Thomson up to the discovery and interpretation of fission. Chapter 4 takes up the work of Bohr and Wheeler on the theory of fission, along with Leo Szilard and his role in Einstein's letter to President Roosevelt. Chapter 5 describes the process of fission, the work of Fermi and Szilard in looking for prompt neutrons which could sustain a chain reaction, the Frisch-Peierls memorandum, the concept of critical mass, and the British MAUD report. Chapter 6 offrers a brief description of the periodic table before moving on to Lawrence's development of cyclotrons and the work of McMillan, Abelson, and Seaborg in synthesizing and isolating plutonium. Particularly interesting in this regard is the largely unappreciated early work of William Zachariasen in trying to establish the density of that unusual element, experiments which were confounded by the simultaneous presence of a number of allotropic forms. This chapter concludes with a description of Fermi's Chicago pile and how that led to the Hanford piles.

Chapter 7 offers a detailed description of how Robert Serber's Los Alamos Primer lays out many of the scientific and technical challenges of building atomic bombs and associated issues such as initiation and spontaneous fission. Chapter 8 is devoted to the plutonium bomb, the spontaneous fission crisis of 1944, work on the metallurgy of plutonium, and the difficulty of developing an implosion assembly.

Chapter 9 is the most personal of this work, a description of how the author came to be an intern at Los Alamos in 1957 and had the opportunity to witness two aboveground tests and to hold a bomb core in his hands. He relates how this experience made him feel that he had crossed a divide into a secret world that had given him some kind of power, a feeling that he did not appreciate as absurd until some time later. This sets the stage for a detailed description of what actually happens in a nuclear explosion from the moment of "second criticality" (when more neutrons are escaping than causing fissions) to the formation of the now-iconic mushroom cloud and the consequent effects. Chapter 10 reviews the development of fusion weapons, emphasizing the contributions of Fuchs, von Neumann, Ulam and Teller toward the development of practical hydrogen bombs. Chapter 11 examines the German nuclear program, the response of German scientists to the news of Hiroshima, and espionage at Los Alamos with emphasis on what Klaus Fuchs transmitted to the Russians.

Chapter 12 examines some of the history of nuclear proliferation. Bernstein outlines how German scientists captured by Russia at the end of World War II aided that country in centrifuge development. One of these men, Gernot Zippe, returned to the West in 1956 and carried plans in his head, information that came to A. Q. Khan, who was then working in the Netherlands. Khan offered his services to his adopted country of Pakistan and soon had his own laboratory. The story of Khan's deals with China, North Korea, Iraq, Iran and Libya to trade centrifuge plans and parts for bomb designs, missiles and substantial amounts of money is chilling. This chapter concludes with a summary of current nuclear weapon states and numbers of warheads along with brief discussions of the complications of reactor-grade plutonium in proliferation issues and the North Korean test of October 2006. Bernstein reminds us that the most important aspect of inhibiting proliferation is to secure fuel fabrication.

I found a few errors in this book. Figure 16 (p. 130) shows the projectile piece in a gun-type bomb being shot toward the tail from the nose. A description of the implosion process on p. 150 is reversed from the accompanying diagram.

Equations concerning fusion reactions on pages 205 and 209 have suffered some minor typesetting errors. However, these should not cause great difficulties for readers, especially those familiar with the physical ideas to begin with.

In contrast to Richard Rhodes' monumental The Making of the Atomic Bomb with its many diversions, Bernstein has produced a compact description of the underlying physics and development of nuclear weapons that is scientifically meaty while remaining accessible and engaging to intelligent lay readers willing to work through it; it is to be highly recommended. Finally, full disclosure: I am grateful to Dr. Bernstein for acknowledging me in this book for having pointed out a minor numerical error in his recently-published Plutonium.

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Hell and High Water

By Joseph Romm (William Morrow. 2007) ISBN:978-0-06-117212-0, 292pp

AUX ARMES! Be worried, be very worried! But there is a glimmering of hope that ultimate disaster will be avoided-if we act fast. This is Joseph Romm's message. This is not the scream of an ignorant doomsayer, but the rational analysis of the current global warming scene by a Ph.D physicist from MIT with a remarkable background, both scientific and political, in climate knowledge. Romm has seen service at the U.S. Department of Energy; he was the principal investigator of the National Science Foundation project, "Future Directions for Hydrogen Energy Research and Education"(2004); at present he is Executive Director and founder of the non-profit Center for Energy and Climate Solutions, an organisation that helps businesses and states adopt high leverage strategies for saving energy and cutting pollution and greenhouse gas emissions.

There is minimal history of the evolution of the science of climate change in this book. Instead it is primarily concerned with our present predicament and a prognosis of the future.

A major contribution of this book is Dr. Romm's clear answers to many continually recurring questions which are asked by the public and politicians, and which are not readily accessible. The absence of answers to these questions is frequently used by those who would deny the effects of global warming. These questions include: Why do climatologists believe that global warming is due to human inducement rather than natural cycles (Ch. 2)? The vast majority of climatic scientists agree on the key issues and are very concerned about the situation and yet the full impact of the seriousness of the situation has not yet penetrated into the minds of the public and the politicians. Why (Ch. 5)? Most of the scenario painted by Dr. Romm comes from computer modelling. Is this a reliable source of information (Ch. 4)? Can we not put our faith in technological breakthroughs in the future to pull us through a difficult period (Ch. 6)? One of the reasons that the US rejected the Kyoto agreement was that it set targets and timetables for the emissions from rich countries only. In more recent guise why should the US make cuts while China continues unabated to spew pollution (Ch. 9)?

To get a focus on our present situation I concentrate on one of several aspects namely the inherent rise in sea levels. On our current greenhouse gas emissions path, the Earth's average temperature will probably rise another 1.5 oC by mid century. The last time Earth was 1 oC warmer than today, sea levels were 20 feet higher. If we stopped increasing the level of greenhouse gases in the atmosphere right now, Earth would still warm another 0.6 oC, well on the way to 1 oC and the 20 feet rise in sea level. But emissions are at present rising ~2% per year! So we might anticipate rises in sea level to much greater heights. How can we alleviate a potentially disastrous situation? Romm's answer uses ideas expressed in 2004 and 2006 papers of Stephan Pacala and Robert Sokolow (*Science* 305, 968-972, 2004; *Scientific American* 295 , 50-57,2006) which show that humanity already has the fundamental scientific, technical and industrial know-how to solve the climate problem. For the next 50 years, eight truly monumental efforts are required. For example, in *one* such effort we need to build, throughout the world, 50 times our current wind-electric generating capacity. Even if we succeeded in eight such efforts and then were able to decrease global emissions in 2061, the temperature would still rise by ~1.5 oC by 2100. The sea level would rise by ~20 feet or more but a more catastrophic rise of 40 to 80 feet might be avoided.

Dr. Romm divides his analysis into 3 periods. The first is "Reap the Whirlwind, 2000-2025." Katrina, forest fires, and floods are already symptoms of wild weather resulting from human produced greenhouse gas warming of the oceans. During this period we can expect stronger hurricanes farther north along the US Atlantic coast and more intense storms earlier and later in the season.

Next, "Planetary Purgatory, 2025-2050." This is a period of extreme drought and gross shortages of water. If we start the eight monumental efforts mentioned above in 2010, then we can live through this period with hope that the apocalypse can be avoided. If we continue our current path until 2025, the "easy" technology-based strategy will not be enough. A much greater and more expensive effort will be necessary to avoiding a grim fate for the next 50 generations.

Third, “Hell and High Water, 2050-2100.” Sea-level rise of 20-80 feet will be all but unstoppable by mid-century if current emission trends continue. Some 100 million people will be displaced. All the US gulf and Atlantic coast cities will be below sea level and facing super hurricanes.

With the grim situation described above what hope is there? Certainly the world must push on in its quest for green energy in all its forms, but while these are being developed, Dr. Romm asserts we must use the little time available to use energy more efficiently, thus avoiding the need to build more coal-fired plants. One major recommendation is that other states and countries emulate California’s energy efficiency programs which lead to a flat consumption per capita over the past 25 years during which US consumption per capita almost doubled. This whole question is studied in detail in Chapter 7.

In parallel with the fight against greenhouse warming is the question of energy security in the US and elsewhere. In Chapter eight possible green fuels are discussed. His overall conclusion is that plug in hybrid cars operating largely on green electricity will be the predominant way for some time.

Dr. Romm is well aware of the political problems in putting his program into operation. Indeed he calls his scenario The Two Political Miracles because it requires a radical conversion of American Conservative leaders-first to completely accept climate science, and second, to strongly embrace climate solutions that they clearly view as anathema.

The book gives a very readable, graphic and timely warning of things to come unless the world acts now. I highly recommend it.

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