FPS APRIL 2004 NEWSLETTER
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EDITOR'S COMMENTS

In this issue of Physics and Society, we continue with two "conversations" that took place in our January 2004 issue. One of them concerns the danger of nuclear weapons after the Cold War. In this issue, we are very pleased to present an article by Professor Scott Sagan regarding the issue of stability of the nuclear face-off between India and Pakistan. Our other conversation is in the form of what has become a written debate between Steve Fetter and Arthur Smith concerning the feasibility of developing space-based photovoltaics (or SSP, for space solar power) as a major source of power. Smith started that debate last October with a piece in support of the development of SSP. Fetter responded in our last issue with a quantitative analysis, the conclusion of which was that SSP is, for economic reasons, not feasible. In this issue, we present Smith's response to Fetter's analysis and Smith's conclusion that monies spent for research in support of SSP is money well spent.

On a much (MUCH!) lighter tone, we present a physics professor's analog of *Travels with Charlie*, John Steinbeck's book about his travels around the United States in a camper with a dog named Charlie. Professor David Hafemeister, from the physics department at California Polytechnic State University in San Luis Obispo, deliberately set out to travel around the U.S. in a van while giving colloquia and seminars having to do with physics and society. In addition to sharing with us his motivation for the venture, Professor Hafemeister even shares with his readers his rate of loss of money on his continental sojourn. His article will doubtless leave most of his readers wondering who "fair Gina" is. I still don't know.

Art Hobson, our review editor, gives us a detailed review of a book concerning global warming and the policy issues surrounding it, and Durruty Jesus de Alba Martinez reviews for us a book about creationists and evolutionists in the United States; we remain very much indebted to Audrey Leith and Richard Jones of the AIP for their FYI articles that provided us with most of the information of our news section.

Bruce Blair, who heads the Center for Defense Information, provides us with a technical article on the relationship between intelligence and policy decisions. His piece suggests that we should not be so quick to criticize the intelligence community for the disaster that befell the U.S. on September 11, 2001, nor for the Bush Administration's decision to go to war in Iraq.

Jeffrey Marque

ARTICLES

NUCLEAR DANGERS IN SOUTH ASIA

Scott D. Sagan

(Note: This is based on Scott D. Sagan; "The Perils of Proliferation in South Asia" *Asian Survey*,

Nov/Dec 2001, vol 41, n 6)

On May 11 and 13, 1998, India tested five nuclear weapons in the Rajasthan desert. By the end of the month, Pakistan had followed suit, claiming to have detonated six nuclear devices at an underground facility in the Chagai Hills. With these tests, the governments in Islamabad and New Delhi loudly announced to the world community, and especially to each other, that they both held the capability to retaliate with nuclear weapons in response to any attack.

What will be the strategic effects of these nuclear weapons developments? There are many scholars and defense analysts who argue that the spread of nuclear weapons to South Asia will significantly reduce, or even eliminate, the risk of future wars between India and Pakistan. These "proliferation optimists" argue that statesmen and soldiers in Islamabad and New Delhi know that a nuclear exchange in South Asia will create devastating damage and therefore will be deterred from starting any military conflict in which there is a serious possibility of escalation to the use of nuclear weapons. Other scholars and defense analysts, however, argue that nuclear weapons proliferation in India and Pakistan will increase the likelihood of crises, accidents, terrorism and nuclear war. These "proliferation pessimists" do not base their arguments on claims that Indian or Pakistani statesmen are irrational. Instead, these scholars start their analyses by noting that nuclear weapons are controlled by military organizations and civilian bureaucracies, not by states or by statesmen. Organization theory, not just deterrence theory, should therefore be used to understand the problem and predict the future of security in the region.

These two theoretical perspectives thus lead to different predictions about the consequences of nuclear proliferation in South Asia. Fortunately, a new history of nuclear India and nuclear Pakistan is emerging, a history by which scholars and policy makers alike can judge whether the predictions of the deterrence optimists or the organizational pessimists have been borne out. Unfortunately, the emerging evidence strongly supports the pessimistic predictions of organizational theorists.

There are four requirements for stable nuclear deterrence: prevention of preventive war during periods of transition when one side has a temporary advantage; the development of survivable second-strike forces; the avoidance of accidental nuclear war; and finally the ability to keep nuclear weapons out of the hands of terrorists. Each of these requirements will be examined in turn.

The Problem of Preventive War

Military officers often have biases in favor of preventive war because they believe that war is inevitable in the long term and that thus it is advantageous to strike first when your state has a strong advantage and the other side is catching up. Pakistan has been under direct military rule for almost half of its existence, and the military ran the nuclear weapons program even during the periods in which civilian prime ministers have held the reins of government. Many scholars therefore worry primarily about Pakistani military officers making poor decisions about war initiation.

The preventive war problem in South Asia is not so simple, however, for new evidence suggests that military influence in India produced serious risks of preventive war in the 1980s, despite strong institutionalized civilian control there. The most important example of preventive war thinking influencing Indian nuclear policy can be seen in the 1986–87 Brasstacks crisis. This serious crisis began when the Indian military initiated a massive military exercise in Rajasthan. The Pakistani military, fearing that the exercise might turn into a large-scale attack, alerted military forces and conducted their own exercises along the border, which led to Indian military counter-movements closer to the border and an operational Indian Air Force alert.

The Indian chief of the army staff, General Krishnaswami Sundarji, apparently believed that India's security would be greatly eroded by Pakistani development of a usable nuclear arsenal and thus deliberately designed the Brasstacks exercise in hopes of provoking a Pakistani military response. This in turn could then provide the New Delhi government with an excuse to implement existing contingency plans to go on the offensive against Pakistan and take out the nuclear program in a preventive strike.

George Perkovich reports in his book India's Nuclear Bomb, that considerations of an Indian attack on Pakistani nuclear facilities went all the way up to the most senior decision-makers in New Delhi in January 1987.

> [Prime Minister] Rajiv [Gandhi] now considered the possibility that Pakistan might initiate war with India. In a meeting with a handful of senior bureaucrats and General Sundarji, he contemplated beating Pakistan to the draw by launching a preemptive attack on the Army Reserve South. This would have included automatically an attack on Pakistan's nuclear facilities to remove the potential for a Pakistani nuclear riposte to India's attack. Relevant government agencies were not asked to contribute analysis or views to the discussion. Sundarji argued that India's cities could be protected from a Pakistani counterattack (perhaps a nuclear one), but, upon being probed, could not say how. One important advisor from the Ministry of Defense argued eloquently that "India and Pakistan have already fought their last war, and there is too much to lose in contemplating another one." This view ultimately prevailed.

The preventive war problem may emerge again in South Asia, however, if either side develops ballistic missile defenses. The Indian government has already expressed interest in eventually procuring or developing its own missile defense capability. Given the relatively small number of nuclear warheads and missiles in Pakistan, however, such Indian defenses could reopen the window of opportunity for preventive war advocates.

Survivability of Nuclear Forces in South Asia

The fear of retaliation is central to successful deterrence, and the second requirement for stability with nuclear weapons is therefore the development of secure second-strike forces. Before the 1998 nuclear tests, proliferation optimists used to assume that second-strike survivability would be easily maintained because India and Pakistan had a form of non-weaponized deterrence and thus could not target each other. It is by no means certain, however, that this condition of non-weaponized deterrence will continue as both India and Pakistan develop advanced missiles in the coming years.

Two organizational problems can be seen to have reduced (at least temporarily) the survivability of nuclear forces in Pakistan. First, there is evidence that the Pakistani military deployed its first missile forces, following standard operating procedures, in ways that produce signatures giving away their deployment locations. The Indian press, for example, has reported that Indian intelligence officers identified the locations of Pakistani deployments of M-11 missiles by spotting the placement of defense communication terminals and wide-radius roads outside special garages.

Second, analysts should also not ignore the possibility that Indian or Pakistani intelligence agencies could intercept messages revealing the secret locations of otherwise survivable military forces, an absolutely critical issue with small or opaque nuclear arsenals. The 1999 Kargil conflict provides evidence of the difficulty of keeping what are intended to be secret operations secret from one's adversary. Throughout the conflict, the Pakistani government insisted that the forces fighting on the Indian side of the LOC were *mujahideen* (indigenous Islamic freedom fighters). This cover story was exposed, however, when some of the *mujahideen* failed to leave their Pakistani military identification cards at their base in Pakistan while others wrote about General Musharraf's involvement in the operation's planning process in a diary that was later captured. Finally, Indian intelligence organizations intercepted a critical secret telephone conversation between General Musharraf and one of his senior military officers, which revealed the Pakistani Army's central involvement in the Kargil intrusion.

The Risks of Accidental Nuclear War

Social science research on efforts to maintain safe operations in many modern technological systems suggests that serious accidents are likely over time if the system in question has two structural characteristics: high interactive complexity and tight-coupling. While the Indian and Pakistani nuclear arsenals are small and not complex, it is also clear that the South Asian nuclear relationship is inherently tightly coupled because of geographical proximity. With inadequate warning systems in place and with weapons with short flight times emerging in the region, the time-lines for decision making are highly compressed, and the danger that one accident could lead to another and then lead to a catastrophic accidental war is high and growing. The proximity of New Delhi and Islamabad to the potential adversary's border poses particular concerns about rapid decapitation attacks on national capitals. Moreover, there are legitimate concerns about social stability, especially in Pakistan, that could compromise nuclear weapons safety and security.

Proliferation optimists will cite the small sizes of India and Pakistan's nuclear arsenals as a reason to be less worried about the problem. Yet the key from a normal accidents perspective is not the numbers, but rather the structure of the arsenal. Here there is good and bad news. The good news is that under normal peacetime conditions, India, and most likely Pakistan as well, do not regularly deploy nuclear forces mated with delivery systems in the field. The bad news is that they both can quickly initiate nuclear alert operations such as during the 1999 Kargil conflict.

From an organizational perspective, it is not surprising to find evidence of serious accidents emerging in India's and Pakistan's nuclear and missile programs. On January 4, 2001, Indian Defense Secretary, Yogender Narain, led a special inspection of the Milan missile production facility in Hyderabad where a missile was accidentally launched, flying through the body of one official, catching on fire, and injuring five other workers. The false warning incident that occurred just prior to the Pakistani nuclear tests in May 1998 is a second case demonstrating the dangers of accidental war in South Asia. During the crucial days just prior to Prime Minister Sharif's decision to order the tests of Pakistani nuclear weapons, senior military intelligence officers informed him that the Indian and Israeli air forces were about to launch a preventive strike on the test site. Such false warnings could be catastrophic in a crisis whether they are deliberate provocations by rogue intelligence officers, or genuinely believed, but inaccurate, reports of imminent or actual attack.

The New Challenge of Terrorism

After the tragic events of September 11, 2001, no one doubts that terrorists might be interested in killing a lot of people. In our effort to understand the level of risk of nuclear terrorism in the future, it is therefore worth considering the relationship, if any, between the spread of nuclear weapons to increased numbers of states and the danger that terrorist organizations will get and use nuclear weapons.

Some terrorists, like Osama bin Laden and the Al Qaida network, have been quite open in stating their desire for nuclear weapons. Indeed, after Osama bin Laden declared a Jihad (holy war) against the United States, he was asked about reports that he wanted nuclear weapons and replied, "…to possess the weapons that could counter those of the infidels is a religious duty." Any terrorist leader with this kind of strategic vision is not likely be deterred from using nuclear weapons or radiological weapons against the United States.

Pakistan is clearly the most serious concern in this regard. Prior to September 11th, there were no specialized Pakistani teams trained on how to seize or dismantle a stolen nuclear weapon. No dedicated personnel reliability program (PRP) was in place to insure the psychological stability and reliability of the officers and guards of Pakistan's nuclear forces.

It was clear after September 11th, however, that this organizational arrangement was an inadequate answer to the vexing question of who would guard the guardians. After Pakistani President Musharraf decided to support the U.S. war against Bin Laden and the Taliban regime, he forced a number of senior and junior officers of the Inter Services Intelligence (ISI) to leave office because of their ties to the Taliban. This was certainly reassuring news, but it is impossible for the United States (or even President Musharraf) to know many secret Jihadi supporters still exist inside the shadows of Pakistan's military intelligence agencies. Nor do we know how close those shadows fall to nuclear weapons storage sites.

The danger of terrorists gaining access to a Pakistani nuclear weapon is heightened during crises when Pakistan is likely to go on a nuclear alert and disperse weapons from secure storage sites to make them invulnerable to an Indian attack. Dispersal, however, makes such weapons more vulnerable to attack or seizure by terrorists or terrorists aided by military insiders. The existence of this "vulnerability/invulnerability paradox" should provide a strong incentive to avoid military threats and crises in South Asia.

Conclusions: Beyond Denial

India and Pakistan face a dangerous nuclear future because they have become like other nuclear powers. Their leaders seek perfect security through nuclear deterrence, but imperfect humans inside imperfect organizations control their nuclear weapons. If my theories are right, these organizations will someday fail to produce secure nuclear deterrence. Unfortunately, the evidence emerging from these first five years of South Asia's nuclear history suggests that this theoretical perspective is powerful, and its pessimistic predictions are likely to come true.

An important structural difference between the new nuclear powers and their Cold War predecessors, however, is that each new nuclear power is born into a different nuclear system since other nuclear states exist and influence their behavior. On the one hand, the ability of other nuclear powers to intervene in future crises may be a major constraint on undesired escalation. On the other hand, this ability may encourage the governments of weaker states to engage in risky behavior—initiating crises or making limited uses of force—precisely because they anticipate (correctly or incorrectly) that other nuclear powers may bail them out diplomatically if the going gets rough.

The possibility that other nuclear states can influence nuclear behavior in South Asia does lead to one final optimistic note. There are many potential unilateral steps and bilateral agreements that could be instituted to reduce the risks of nuclear war in between India and Pakistan, and the U.S. government can play a useful role in helping to facilitate such agreements. Many, though not all, of the problems identified in this article can be reduced if nuclear weapons in both countries are maintained in a de-mated or de-alerted state, with warheads removed from delivery vehicles, either through unilateral action or bilateral agreement. U.S. assistance could be helpful in providing the concepts and arms verification technology that could permit such de-alerting (or non-alerting in this case) to take place within a cooperative framework. The U.S. could also be helpful in providing intelligence and warning information, on a case-by-case basis, in peacetime or in crises to reduce the danger of false alarms. In addition, safer management of nuclear weapons operations can be encouraged through discussions of organizational best practices in the area of nuclear weapons security and safety with other nuclear states.

There will be no progress on any of these issues, however, unless Indians, Pakistanis, and Americans alike stop denying that serious problems exist. A basic awareness of nuclear command and control problems exists in New Delhi and Islamabad, but unfortunately Indian and Pakistani leaders too often minimize them. Government officials in New Delhi and Islamabad sometimes speak as if nuclear safety and security problems have been successfully addressed, though there is little evidence that this is really the case.

A first useful step for the U.S. is to accept that nuclear weapons will remain in Pakistan and India for the foreseeable future and that the problem of Kashmir will not be solved easily or quickly. The political problems between the two South Asia nuclear powers may someday be resolved. Until that day comes, the U.S. government has a strong interest in doing what it can to reduce the risk that India and Pakistan will use nuclear weapons against each other.

Scott Sagan is a Professor in Political Science at Stanford University and a Co-Director for Stanford's Center for International Security and Cooperation. He is the author of "Moving Targets: Nuclear Strategy and National Security" (Princeton University Press, 1989), "The Limits of Safety: Organizations, Accidents, and Nuclear Weapons," (Princeton University Press, 1993), and co-author with Kenneth N. Waltz "The Spread of Nuclear Weapons: A Debate Renewed" (W.W. Norton, 2002). Currently, his main research interests are nuclear proliferation in South Asia, ethics and international relations, and accidents in complex organizations.

ARTICLES

Earth *vs* Space for Solar Energy, Round Two

By Arthur Smith

Can renewable solar energy for terrestrial use be collected more efficiently and cleanly in space than on Earth[1]? Steve Fetter argues[2] that five unlikely conditions would need to be met before space could ever compete economically with Earth in use of solar photovoltaics (PV). Economic competitiveness is a relevant question, and I appreciate the challenge posed by Fetter's arguments; in contrast the variety of contributions on fuel cells and nuclear power listed at the Forum on Physics and Society's web site [3], generally ignore serious economic discussion. Fetter would seem to agree that there are no physical obstacles to space solar power (SSP) deployment, only economic ones.

Economic cost is in fact a major issue for every proposed non-fossil energy source; with nuclear fission, for example, just capital costs to address world non-fossil energy needs of 3-5 TW (electric) by mid-century would amount to 5-15 trillion dollars[4]. Even the lowest projections of capital costs for wind or terrestrial solar power (TSP) see a need for at least ten trillion dollars in spending, if they are the primary solution; those estimates depend on order of magnitude or more improvements in the cost or performance of PV, energy storage, and transmission system components.[4] Probably every physicist would love to see superconducting cables form a mainstay of world energy transmission capacity, but in reality they are still at least an order of magnitude away from being cost competitive with traditional transmission lines.

But these economic and performance issues in most fields are seen as challenges stimulating research and development, in PV materials and electric power transmission and storage technologies for example. Governments also regularly issue technology incentives promoting alternatives believed beneficial to the public good, including providing training and information, promoting standards, building infrastructure and demonstration projects, and very often tax credits and subsidies for the favored technology (or additional taxation on the disfavored, as in proposed carbon taxes and high European gasoline taxes)[4]. Most of Fetter's conditions for SSP to be economically competitive actually translate to research challenges on PV, wireless power transmission, lightweight space structures, and cost effective space launch, for which government demonstration projects and infrastructure development could be key to bringing down costs and increasing capabilities. The challenges are considerably more achievable than Fetter's list would indicate. Fetter claims the comparison argues against SSP research, but a similar analysis for fusion, based on current estimates for ITER and NIF, would find an even worse situation, with costs 10 to 20 times more than could possibly be commercially competitive over the next few decades[5]. Should fusion energy research cease?

Fetter's first condition, that solar supply 100% of electric demand, is the least sensible; demand for electricity varies by region and time, so there is no single market for electric power either at the consumer or production level. In fact generation is traditionally divided into three distinct markets: base, intermediate, and peaking power[6]. The base market reflects the underlying need for round-the-clock electricity and accounts for over 70% of electric power produced in the US. High efficiency, high capacity factors, and low fuel cost are the economic drivers, and coal and nuclear plants (even with their rather high capital costs) are the primary suppliers in the base power market. In contrast, for the peaking power market the drivers are a capability for on-demand start-up and low capital cost, since that capital has to earn returns through sales of many fewer kW-hours of production year round. Oil-fired plants and gas turbines dominate in the peaking supply markets, despite their higher fuel costs.

These distinct markets for power generation and sunk capital costs of existing plants mean competitive technologies will always see gradual introduction, in whichever markets they are competitive (including effective government technology incentives). In particular, SSP meets well the high capacity-factor round-the-clock nature of the base power market, and so is perfectly positioned to displace coal-fired electric plants, the worst of our current CO2 emitters. In contrast, TSP has high capital cost, low capacity factor, intermittency, and location dependence, which doesn't match well any existing power market's requirements. The coincidence between TSP availability and peak demand means TSP can, at least in some regional markets, address some of the peak capacity needs. But the high capital cost and "when available" rather than "on demand" character actually put it closer to the intermittent/intermediate power market typically filled by renewable options such as hydroelectric and wind.

Energy storage systems can move power demand between the primary time-domain markets (for example pumped hydro at night to supply peaking power during the day) just as the transmission grid can move power from one regional market to another; storage and transmission have their own capital costs, however, as well as losses that reduce final power availability. These costs are sufficient with current technology that the divisions between the distinct power markets are reasonably sharp.

So Fetter's claim that competition will happen only in some sort of aggregate way, and needs to involve complete replacement in one market ("solar provides over 20% of power", capturing the peaking market) before it can start on another, makes little sense under current and reasonably projected electric market conditions. When TSP becomes competitive in the peaking/intermediate power market in the desert southwest region of the US, say, it will grow within that market meeting the need for new and replacement generators. At the same time, if SSP is competitive for base power (and it could compete in every regional market, since SSP receivers could be located within a few hundred km of any major power user) it can grow in that market, independent of what is happening with TSP. A long-term energy future with base power provided by SSP, summer daytime peak power supplied by TSP, and transportation fuels (for non-electric vehicles) supplied by biomass is a reasonable long-term possibility. In reality a mix of all these energy sources will be around for a long time to come.

This also has immediate consequences for the numbers in most of the rest of Fetter's analysis. Making the comparison only for the primary base power market, the factor of $(1-f(1-\varepsilon'))$ everywhere becomes simply ε', the overall efficiency for storage and transmission of terrestrial solar to those regions that need it (assuming production in cloudless desert regions; ε' can also serve as a proxy for lower solar flux for TSP systems closer to end users). Fetter's ρ becomes ε/ε', and for the assumed $\varepsilon = \varepsilon' = 0.4$ condition, ρ=1, or roughly double what Fetter assumes. This adds roughly a factor of two more leeway for SSP in all the subsequent conditions.

Regarding the factor χ, representing the relative capital cost of the PV modules: as Fetter notes, right now commercially available space power modules run several hundred times the cost of terrestrial solar modules, due to their low volume production. Crystalline silicon is the most widely used PV material in both markets, so mass production of space modules should not cost significantly more than for terrestrial modules. Additional component costs (weather-resistant coverings and structural components for terrestrial cells, light-weight structural materials and components associated with launch packaging and orbital unpacking for space cells) could make a cost difference, but in the end χ

should be much closer to 1 than the current several hundred, with sufficient R&D effort and market scale. In any case, rather than Fetter's second condition that χ be less than 1, in reality χ can be as high as 3 or 4 and still be competitive for base power, given the corrections to ρ mentioned earlier. This certainly seems achievable.

Fetter's assumption that "in order to be economically competitive [...] CPV' must fall below \$1000/kWp" hides another interesting issue: currently solar PV modules cost \$2500 to \$3000 per peak kW. If CPV' instead stays at around \$2500 and with ρ=1, the constraint on launch costs becomes only CLM < \$10,000. Beating that requires only M<5 kg/kWp and CL< \$2,000/kg, both conditions that are very close to being met with current space technology. But neither TSP nor SSP can practically compete with other options at those prices. Even at the \$1,000/kWp level, TSP still is well on the high end with likely costs per base-power kW of \$10,000. In any scenario where the cost of PV components dominates total costs, SSP sustains a 3 to 5-fold advantage over TSP due to the smaller quantities needed, per average kW. The point here is that the higher the basic PV costs are, the more favorably SSP competes with TSP. Solar PV prices have been close to flat since the mid 1990's; in fact average module prices in the US were up 9% in 2002 from 2001, at \$3740/kWp [7].

Another significant omission in Fetter's discussion is the widely differing physical characteristics, and therefore likely costs, associated with terrestrial storage and transmission, vs. space-based wireless power transmission. Instead both are lumped into per kW-hr transmission costs cT and cT', where it is assumed that cT/cT' is the same ratio χ as for space vs. Earth PV panel costs. In fact, SSP has no analog of the significant energy storage requirements for TSP, and wireless transmission obviously has no wires that need installation and maintenance. Both of these, given TSP location dependence and intermittency, add significant capital costs, \$2,000/kW or more for storage, \$10,000/kW or more for several thousand miles transmission, with current technology. Fetter's suggestion to use wireless power transmission as an Earth-space-Earth "backstop" may make sense, but losses would be somewhat greater than for just space-Earth transmission, and the doubled distance means double the capital cost for transmitters and receivers (for a given size ratio and wavelength, they scale linearly with distance). So even with Fetter's "backstop", cT/cT' could well be less than 1/2. In reality we have no firm basis for speculation on these numbers without considerable further R&D on wireless power transmission, and of course refinement of terrestrial energy storage and transmission technologies. So Fetter's third and fourth conditions on relative transmission and O&M costs have insufficient basis in data at this point to draw any conclusions.

The final major issue is launch costs, which are indeed far from zero. However, commercial services are already selling low earth orbit launches for \$5,000/kg, rather than the \$10,000 Fetter cites, and one new contender, Space-X, plans to launch for \$3,000/kg soon. It should also be noted that the system that launches the space shuttle actually puts over 100 tons in orbit if one counts orbiter as well as nominal payload a cargo-only shuttle variant should easily be capable of well under \$5,000/kg launch costs. NASA's Space Launch Initiative, before it was recently terminated, was looking at new technologies that could provide \$1,000/kg launches; a number of other promising approaches, for example efficient two-stage launch with a reusable air-breathing hypersonic first stage, seem to be languishing only for a lack of R&D funding. The National Research Council report [8] noted that chemical rocket fuel was only needed for launch to low earth orbit; the additional energy needed for travel to geosynchronous orbit can be met (especially for a solar power satellite) through solar electric propulsion, demonstrated recently on the European SMART-1 craft. Fetter notes there are physical limits to chemical rocket launch costs in the fuel costs themselves. But we¹re roughly two orders of magnitude away from that limit; the main current problem seems to be market size. A major effort in space solar power would at least greatly expand the launch market.

The second component of launch costs is mass to launch. Thus far most satellites launched, other than the international space station, have had power levels on the order of several kW, i.e. at most a few dozen square meters of solar cell material. The best mass ratio launched so far was probably for NASA's Deep Space-1 solar electric propulsion craft, at about 20 kg/kW. The same company that developed those has new solar panels available for just 5 kg/kW (in both cases using Fresnel lens concentrators with GaAs cells). A lower bound on solar panel mass would likely be the thin mylar material deployed to several hundred square meters in the Planetary Society's Cosmos-1 solar sail craft, at 0.02 kg/m2 or less than 0.1 kg/kW for 20% efficient cells. Power conversion and transmission components also need to be factored in, but there are some proposed designs (high voltage, embedded waveguide or fiber optic, local phased array-style microwave beaming) with mass estimates as low as 1 kg/kW. There seems no physical reason either solar cells or transmission components should have significantly more mass than the Cosmos-1 craft; an overall mass of 1 kg/kW looks achievable, with sufficient R&D effort. A completely different alternative here are the proposals to use the elements of the Moon or asteroids in SSP construction. This has the effect of requiring launch of manufacturing facilities, rather than the final product; there are only wild guesses at this point on the mass ratios, but this could potentially (for a higher startup cost) lower Earth launch mass to well below 1 kg/kW.

It is also possible transmission efficiencies could be well above the 40% assumed by the NRC report [8]; doubling transmission efficiency would cut all the cost numbers in half, making it even easier to meet the competitive requirements. There hasn't been much real experience with wireless power transmission since William Brown's [9] early experiments, which saw DC to DC efficiencies of over 60%; a project for wireless transmission over about half a mile in Reunion Island expects 57% efficiency from one grid to the other [10]. It's impossible at this point to estimate these numbers accurately without some real R&D effort. A demonstration plant would greatly reduce this and many other uncertainties in the economic analysis.

In summary, there are four technology challenges in the standard scenario for SSP where there are enormous uncertainties in what may be technically achievable:

1. χ, the ratio of space to terrestrial PV module costs, is currently several hundred. Can we achieve $\chi <$ 3 as seems needed for SSP to compete with TSP?
2. ε, the efficiency for wireless power transmission; is $\varepsilon = 0.4$ practically achievable over tens of thousands of km? How high can it go?
3. M - the mass per peak kW of the solar modules and transmission system: the best currently deployed has M about 20 kg/kW; commercial modules of 5 kg/kW seem to be available. Is 1 kg/kW practically achievable? Could we go lower?
4. CL - launch costs. Is the $1000/kg NASA projected for SLI actually achievable? How much lower can we get?

Obviously SSP has some challenges - order of magnitude scale improvements needed in several immature technologies, and significant improvement in PV costs via mass production. But TSP also needs an order of magnitude improvement in cost for much more mature technologies in order to compete with other base power options. Speculation about which of these is more likely to happen over the next decade or two seems premature; rather we should be investing in the R&D, building demonstration projects, and pursuing other technology development incentives to make our choices clearer[4].

The new international "contraction and convergence" plan[11], which seems likely to replace the Kyoto accord as a more complete solution to the CO2 problem, calls for replacement of almost all fossil fuel use by 2050. Aside from the relatively dubious concept of carbon sequestration with coal, for base power production the only multi-terawatt scale options seem to be fission, fusion, TSP, and SSP [12]. Fission is by far the most well-established of those four, but it may be more limited than we think - a recent MIT analysis[13] sees at most a tripling of world-wide nuclear power installations to 1500 GW capacity over the next 50 years, just to maintain nuclear power at roughly the 20% of electric power it generates today. Given the severity and urgency of the energy transition problem, and the fact that multi-trillion-dollar investments will be required, technologies in support of all four energy options (along with carbon sequestration) should be generously funded. SSP and TSP would both benefit from PV-related R&D funding; other R&D areas for SSP include wireless power transmission, lightweight space structures, and cost effective space launch, all of which could have significant spinoffs to other areas (for example, communications satellite capabilities) as well. Funding this range of technologies adequately, at least at the billion-dollar per year level that fission and fusion currently receive, will be essential to our future prosperity.

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1. "Energy for Society from Space", by Arthur Smith, Physics and Society, October 2003.
2. "Space Solar Power: An Idea Whose Time Will Never Come?", by Steve Fetter, Physics and Society, January 2004.
3. See http://www.aps.org/units/fps/energy/ for a list of contributions by physicists to the "Energy and Environment debate".
4. *Innovative Strategies for CO2 Stabilization*, edited by Robert G. Watts, Cambridge University Press, 2002.
5. The National Ignition Facility, to be completed in 2008, is currently funded at about $2.25 billion for construction, with GAO cost estimates of $4 to $5 billion. Total thermal output is less than 200 MW, or 67 MW electric, for a capital cost over $30,000/kWe. ITER, projected to be online in about 2013, is the top priority for research funding at the DOE's Office of Science. Costing over $5 billion, ITER will produce 400 MW thermal power, or over $40,000/kW electric.
6. 1998 electricity market structure, from the US Energy Information Administration: See http://www.eia.doe.gov/cneaf/electricity/chg_stru_update/chapter3.html
7. "Renewable Energy Annual 2002" report, November 2003, from the US Energy Information Administration.
8. "Laying the Foundation for Space Solar Power: An Assessment of NASA's Space Solar Power Investment Strategy" (2001) - National Research Council; see http://www.nap.edu/execsumm/0309075971.html
9. W.C. Brown, "The history of wireless power transmission" Solar Energy, Vol. 56, pp. 3-21, 1996.
10. J. D. Lan Sun Luk et al., "Point-to-point wireless power transportation in Reunion Island" 48th International Astronautical Congress, Turin, Italy, 6-10 October 1997 - IAF-97-R.4.08
11. Contraction and Convergence, from the Global Commons Institute (2003), See: http://www.gci.org.uk/contconv/cc.html
12. M. Hoffert et al., "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet", Science Vol. 298, p. 981 (2002).
13. John Deutch, et al., "The Future of Nuclear Power" (2003) http://www.mit.edu/afs/athena/org/n/nuclearpower

ARTICLES

THE LOGIC OF INTELLIGENCE FAILURE

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INTRODUCTION

The severe post 9/11 criticism of the U.S. intelligence system for underestimating the terrorist threat to America, and for overestimating weapons of mass destruction in Iraq, would be sharply tempered if critics understood the laws and limits of reasoning. Uncertain threats tend to be misestimated initially, and only repeated assessments can close the gap between threat perception and reality. Even when the strict rules of inductive reasoning are applied to spy data, ten or twenty successive reviews are typically needed to ensure that perceptions match reality.

> Critics presume that far fewer assessments should suffice, and accuse users of intelligence with dogmatism if they do not respond with alacrity to the first alarm bells warning of a rising threat, or to the latest report discounting a threat. This criticism implies that intelligence analysts should suspend their prior beliefs and seize upon only the latest intelligence inputs. At the same time, if the inputs prove to be wrong, critics blame intelligence analysts for not seeing beyond the evidence and divining intentions.
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> While intelligence analysts cannot be psychics, psychology does, and should, figure prominently in the process of interpreting intelligence. Subjective opinion and preexisting beliefs, held by intelligence analysts and users of finished intelligence, including the top national security decision makers, are core elements of reasoned interpretation. The key to success or failure in interpreting intelligence information lies in rationally adjusting prior beliefs to make them conform to incoming intelligence information.
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> Prior opinion plays a critical role in every intelligence endeavor associated with current national security priorities: avoiding accidental nuclear war, detecting weapons of mass destruction, anticipating terrorist attacks, and preempting America's enemies. The initial bias of decision makers can be a blessing or a curse, but all that we can reasonably expect is that it is properly revised as new intelligence arrives.

An argument can be made that the processing of intelligence followed laws of reason in the cases of 9/11 and Iraq weapons of mass destruction. Applying a rule of logic known as Bayes' law to these cases shows that the intelligence process produced conclusions that were not only plausible but reasonable.

AVOIDING ACCIDENTAL NUCLEAR WAR

An illustration of the dramatic effect of initial opinion on intelligence interpretation is a hypothetical situation in which top leaders with their fingers on the nuclear button receive indications of an incoming nuclear missile attack.

The most dangerous legacy of the Cold War is the continuing practice by Russia and the United States of keeping thousands of nuclear weapons on high alert, poised for immediate launch on warning. The danger is that false indications of an incoming enemy missile strike could produce a mistaken launch in "retaliation."

The need to react rapidly under the time pressures of incoming submarine missiles with flight times as short as 12 minutes and land-based missiles capable of flying half way around the globe in 30 minutes would be strongly felt from the top to the bottom of the U.S. or Russian nuclear chain of command. In order to unleash retaliatory forces before they and their command system are decimated by the incoming missiles, the early warning sensors (satellite infra-red and ground-based radar sensors) must detect the inbound missiles within seconds after their firing, and the detection reports must be evaluated within several minutes after they are received. That is the current requirement for the warning crews stationed deep inside Cheyenne Mountain, Colo. Then the president and his top nuclear advisors would convene an emergency telephone conference to hear urgent briefings from the warning team and from the duty commander of the war room at Strategic Command, Omaha, which directs all U.S. sea-, land-, and air-based strategic nuclear forces. The Stratcom briefing of the president's retaliatory options and their consequences has to be accomplished in a mere 30 seconds (a longstanding procedural requirement), and then the president would have between zero and 12 minutes to choose one. A launch order authorizing the execution of this option would flow immediately to the firing crews in underground launch centers, in submarines, and in bombers, and within three minutes, thousands of nuclear warheads would be lofted out of silos toward their wartime targets, followed ten minutes later by many hundreds of nuclear warheads atop submarine missiles ejected from their underwater tubes.

These pressure-packed timelines reduce decision making to checklists, and increase both the likelihood and the consequences of human and technical error in the nuclear attack warning and command system. Ironically, the risk of false warning of an incoming missile attack has actually been increasing since the end of the Cold War as a result of the steady deterioration of the Russian early warning network. Both its satellite and ground-based sensors have fallen into disrepair, and the human organizations that operate the network have been weakened by economic and social stresses and inadequate training.

There is an offsetting factor of crucial significance, however. While the risk of false warning has increased, the danger that Russia or the United States would actually launch on that false warning has declined dramatically. The reason is that the leaders of these two countries would presumably heavily discount if not entirely dismiss reports of an attack, simply because the reports would be so incredible.

Russia and the United States are no longer enemies. That either country would deliberately attack the other is so utterly implausible that a neutral observer would rightly suppose that their top leaders would rise above the noise, emotion and time pressure of a reported incoming nuclear strike. These leaders cannot mechanically tie their actions to any warning and intelligence network, however highly touted it may be. At their lofty pay grade, what they think of the warning information would be inevitably and properly weighed by the background information they bring to it. Their prior opinion about the other side's good or ill intentions must be brought to bear on the situation, and that prior opinion today surely would cause them to disbelieve the warning and delay the fateful decision long enough to discover that the alarm was indeed false. On the other hand a continuing stream of attack indications from multiple reliable warning sensors would compel a rationally calculating leader to believe that in all likelihood an attack actually is underway. The stream of data would compel a dramatic revision of the initial disbelief until the harsh reality sank in.

In other words, the effect of prior beliefs and psychology on the process of nuclear decision making is very great in the context of launching nuclear missiles on warning that an attack is underway with missiles in the air. That was true during the Cold War, and it is true today.

PREEMPTING (PREVENTING) ENEMY ATTACK

The psychology of decision making is even more pivotal in a context of launching counterattacks before any opposing missiles have been fired. Anticipating a first strike by a nation or group before the strike has actually started involves a certain amount of conjecture and demands a more careful screening of more ambiguous intelligence. Human factors are thus especially important today in the context of counterproliferation and homeland defense under the new national security strategy of the United States announced in September 2002 by the Bush administration.

This new strategy elevates preemption from the level of tactics to the level of strategy. It assumes that rogue states and terrorist groups cannot be reliably deterred, and therefore must be neutralized before they pose a clear threat of imminent attack. The strategy seeks to prevent America's enemies from acquiring weapons of mass destruction in the first instance, using U.S. military force if necessary, and seeks to disarm them after they have acquired such weapons, whether or not their use against the United States is imminent.

Because this strategy seeks to eliminate incipient threats before they materialize full blown, preemption is a misnomer, a mischaracterization. The strategy embraces preventive war as much as preemptive attack. It even covers the case in which the U.S. would attack a putative adversary before the adversary realizes it is going to attack the United States – a wag would say that the idea in this case is that the United States would help the adversary make up its mind about attacking the United States by attacking the adversary first.

The new U.S. strategy is actually not so new. It is reminiscent of U.S. nuclear thinking in the early days of the Cold War when the United States was trying to figure out how to deal with the original "rogue" state developing weapons of mass destruction – the Soviet Union. President Bush's new strategy is a throw back to the 1950s and 1960s when the United States was not yet prepared to accept deterrence as the primary, let alone sole, basis of U.S. security vis-à-vis the Soviet Union. The U.S. security establishment considered and pursued every option under the sun in addition to deterrence – preemption, preventive war, surgical decapitation strikes, counterforce first strike, missile defense, bomber defense, civil defense (homeland defense), and even covert special operations to assassinate key leaders.

In the end, the U.S. and Russian security establishments realized that they could not meaningfully protect their countries and citizens from devastating strikes by the other side. None of the multitude of options being pursued could prevent either side from destroying the other in a nuclear war. Mutual vulnerability, despite intermittent attempts to remove it through Star Wars defenses or some other scheme, was a constant of the Cold War confrontation. But instead of despairing, both countries discovered salvation in this predicament. They were forced to rationalize mutual vulnerability as a virtue and learn to live with mutual deterrence as the centerpiece of national security, and eventually they celebrated this newfound source of security.

In contrast to this Cold War experience, however, the U.S. security establishment so far has rejected out of hand the idea of basing U.S. security on deterrence alone in confronting the far weaker axis of evil countries and terrorists. For understandable reasons, the United States is pursuing the same old options to protect itself from the rogue threats – active and passive defense and offense in line with the mindset of the early Cold War period.

A list of criticisms of the current U.S. preemptive strategy could run for pages. Its defects range from its dubious legitimacy under international law, to the bad example it sets for other countries eager to justify a preemptive or preventive attack on their neighbors. Already we have seen Russia and France follow in America's footsteps to declare similar doctrine for themselves, and the list of emulators will undoubtedly grow.

High on this list of liabilities is one particular difficulty that is the focus of this essay: the enormous burden that preemption places on intelligence – not only intelligence collection and analysis, but its interpretation by those at the top who, as noted earlier, inevitably filter the intelligence information they receive through their own presumptions. The buck stops at a level at which leaders must fuse incoming intelligence with their own prior beliefs. It is crucial to the shaping of U.S. security policy that this highly subjective process be understood well. Intuition suggests that human intellectual and psychological limitations undercut the feasibility and sensibility of a preemptive strategy.

What is needed is a rigorous approach to analyzing whether the top leaders can interpret intelligence with sufficient accuracy and speed to meet the demands of the new strategy, even assuming that high-quality intelligence information can be collected and analyzed at lower levels. One such rigorous approach is to apply a proven formula for estimating the probability of an event – Bayes' formula for contingent probabilities. This formula (see Figure 1) provides an account of how the required judgment, or interpretation, might be made in a disciplined, responsible manner. Bayes' formula shows how well a perfectly rational individual can perform, providing a measure of the best judgment that can be expected of leaders in interpreting intelligence.

Our application of Bayes theorem is as follows:

Definitions:

Prob (attack|warning) = P(A|W)

Prob (attack|no warning) = P(A|NW)

Prob (warning|attack) = P(W|A) = 1 - prob (type I error)

Prob (warning|no attack) = P(W|NA)⟶type II error

Prob (no warning|attack) = P(NW|A)⟶type II error

Prob (no warning|no attack) = P(NW|NA) = 1 - Prob (type II error)

Prior initial subjective expectation of an attack: prior (A)

Posterior subjective expectation of an attack after either receiving or not receiving warning: Post (A)

Formulas:

Given warning is received during warning report period:

$$\text{Post}(A|W) = \frac{P(W|A)\ \text{prior}(A)}{P(W|A)\ \text{prior}(A) + [P(W|NA)(1 - \text{prior}(A)]}$$

Given warning is not received during warning report period:

$$\text{Post}(A|NW) = \frac{P(NW|A)\ \text{prior}(A)}{P(NW|A)\ \text{prior}(A) + [P(NW|NA)(1 - \text{prior}(A)]}$$

[Figure 1]

Bayes' analysis is often called the science of changing one's mind. The mental process begins with an initial estimate – a preexisting belief – of the probability that, say, an adversary possesses weapons of mass destruction, or that an attack by those weapons is underway. This initial subjective expectation is then exposed to confirming or contradictory intelligence or warning reports, and is revised using Bayes' formula. Positive findings strengthen the decision maker's belief that weapons of mass destruction exist or that an attack is underway; negative findings obviously weaken it. The degree to which the initial belief is increased or decreased depends on the intelligence system's assumed rate of error – its rate of detection failure and its rate of false alarms. Bayes' formula takes both rates of error – known as type I and type II – into account in re-calculating probabilities.

All prior and posterior probabilities are strictly subjective in the Bayesian model. They are opinions that exist in the minds of individuals. Assessments supplied by intelligence and warning sensors do not objectively validate the probabilities, but merely enable existing opinion to be revised logically by the successive application of Bayes' formula. This process can be considered objective, however, in the sense that as more intelligence assessments based on real data become available, the subjective probabilities will eventually converge on reality. People with different initial beliefs will eventually agree with each other completely, if they are thinking logically. This consensus will be reached faster if the intelligence system is not prone to high rates of error.

Two Hypothetical Cases: Iraq WMD and 9/11 Terrorist Threat

How subjective probabilities should be revised logically, according to Bayes' formula, are illustrated below for two hypothetical cases. One case resembles the problem of overestimating Iraq's weapons of mass destruction, and the other resembles the pre- 9/11 intelligence failure in which a terrorist threat was underestimated.

In the case akin to pre-war Iraq, suppose that the national leader believes that dictator X is secretly amassing nuclear, biological or chemical weapons, but that U.S. spies cannot deliver the evidence proving the weapons' existence. What should the leader believe then? Should the indictment be thrown out if the spies cannot produce any smoking guns? How long would a reasonable person cling to the presumption of the dictator's guilt in the absence of damning evidence?

The mathematics of rationality (according to Bayes) throws surprising light on this question. It proves that a leader who continues to strongly believe in the dictator's guilt is not being dogmatic. On the contrary, it would be irrational to drop the charges quickly on grounds of insufficient evidence. A rational person would not mentally exonerate the dictator until mounting evidence based on multiple intelligence assessments pointed to his innocence.

The extent to which a rational person should change their mind about guilt and innocence depends on how reliably accurate the intelligence system normally is. Let's suppose the track record of the system suggests that it normally detects clandestine proliferation in 75 percent of the cases, and also that it avoids making false accusations in 75 percent of the cases. Thus, it misses proliferation in one-fourth of the cases, and mistakenly cries wolf in one-fourth of the cases. These rates of error seem to be reasonable approximations of current U.S. intelligence performance in monitoring clandestine proliferation.

If the leader interpreting the intelligence reports holds the initial opinion that it is virtually certain that the dictator is amassing mass-destruction weapons – an opinion that may be expressed as a subjective expectation or probability of, say, 99.9 percent – then what new opinion should the leader reach if the intelligence community (or the head of a UN inspection team) weighs in with a new comprehensive assessment that finds no reliable evidence of actual production or stockpiling?

Adhering to the tenets of Bayes' formula, the leader would combine the intelligence report with the previous opinion to produce a revised expectation. Upon applying the relevant rule of inductive reasoning, which takes into account the 25 percent error rates, the leader's personal subjective probability estimate (the previous opinion) would logically decline from 99.9 percent to 99.7 percent! (see Figure 2). The leader would remain highly suspicious, to put it mildly, indeed very convinced of the dictator's deceit.

Initial and Revised Expectations of Hidden WMD (Given No Detection) Assuming a Detection System with 25 Percent Types I and II Error Rates.

	Revised estimate given no detection													
	Number of Negative reports:													
Initial estimate [a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.0001	0.000													
0.001	0.000													
0.01	0.003	0.001	0.000											
0.05	0.017	0.006	0.002	0.001	0.000									
0.10	0.036	0.012	0.004	0.001	0.000									
0.20	0.077	0.027	0.009	0.003	0.001	0.000								
0.30	0.125	0.045	0.016	0.005	0.002	0.001								
0.40	0.182	0.069	0.024	0.008	0.003	0.001								
0.50	0.250	0.100	0.036	0.012	0.004	0.001								
0.60	0.333	0.143	0.053	0.018	0.006	0.002	0.001							
0.70	0.438	0.206	0.080	0.028	0.010	0.003	0.001							
0.80	0.571	0.308	0.129	0.047	0.016	0.005	0.002	0.001						
0.90	0.750	0.500	0.250	0.100	0.036	0.012	0.004	0.001						
0.95	0.864	0.679	0.413	0.190	0.073	0.025	0.009	0.003	0.001					
0.99	0.971	0.917	0.786	0.550	0.289	0.120	0.043	0.015	0.005	0.002	0.001			
0.999	0.997	0.991	0.974	0.925	0.804	0.578	0.314	0.132	0.048	0.017	0.006	0.002	0.001	
0.9999	0.999	0.997	0.992	0.976	0.932	0.821	0.604	0.337	0.145	0.053	0.016	0.006	0.002	0.001

a. Degree of belief in the hypothesis "weapons of mass destruction exist."

[Figure 2]

A leader believing so strongly in the correctness of that judgment might well order another independent intelligence review, expecting that it would produce positive findings this time around. Suppose that this review, much to the leader's surprise, repeats the earlier negative findings - no reliable evidence of weapons proliferation. What new opinion should the leader form then? A rationally calculating person would undergo another change of opinion after absorbing the second intelligence report, revising downward again, this time dropping from 99.7 percent to 99.1 percent. Believe it or not, a rational leader could receive four negative reviews in a row from the spy agencies and would still harbor deep suspicion of the dictator because the leader's logically revised degree of belief that the dictator was amassing weapons would only fall to 92.5 percent.

This seemingly dogmatic view is in fact the logically correct one. Why? Because top leaders do not function in a contextual vacuum. They inevitably depend on their own presumptions. And in the Iraq case, a very strong initial presumption of guilt is understandable in view of the regime's history. In late 1998, UNSCOM issued its final report listing WMD capabilities that remained unaccounted. Iraq still had not disclosed those capabilities fully in its December 2002 report to the United Nations. In view of this failure and of Iraq's historical intentions to acquire WMD, it's not surprising that leading up to the U.S. invasion of Iraq in 2003, the overwhelming bipartisan expert consensus of the United States and practically all other nations with modern intelligence capabilities was that Iraq certainly possessed at least a stockpile of chemical and biological agents.

Nobody seriously challenged that assessment, and if the rational calculations discussed above bear any resemblance to actual intelligence assessment during this period and after the war, it is no surprise that many of the most informed experts to this day still cling to the belief that Iraq possesses such weapons. Exhibit "A" is the recent public defense of the infamous National Intelligence Estimate of October 2002 mounted by the key CIA official responsible for its conclusion that Iraq had chemical and biological weapons. As Stuart Cohen, the official in question, puts it in his closing editorial comment.

> "Men and women from across the intelligence community continue to focus on this issue because finding and securing weapons and the know-how that supported Iraq's WMD programs before they fall into the wrong hands is vital to our national security. If we eventually are proved wrong – that is, that there were no weapons of mass destruction and the WMD programs were dormant or abandoned – the American people will be told the truth; we would have it no other way."
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> (*The Washington Post*, "Myths About Intelligence," Nov. 28, 2003, P.A41).

In the case of the Sept. 11 attacks, the initial apprehension of suicide attack using hijacked planes against buildings was as low as the Iraqi WMD threat estimate was initially high. The terrorist strikes came as such a total surprise that the furious criticism levied against the intelligence community seemed wholly deserved, especially after a mosaic of terrorist warnings contained in neglected FBI field reports came to light. But the criticism should have been tempered. It was neither realistic nor fair. The seeming understatement of the risk of foreign terrorism inside U.S. territory once again can be characterized as a reasoned view. A logical analyst would not have transcended the rules of evidence and could not have divined the intentions of the terrorists.

To illustrate this case, assume that the top analyst (or leader) initially estimated the risk of an attack on the United States by a terrorist group flying hijacked planes to be one-tenth of 1 percent. Then how much should the expectation of attack have grown after receiving, say, four successive intelligence reports warning of an imminent attack? The surprising answer based upon the rules of logic, and assuming the same error rates used in earlier calculations (25 percent rate of failing to detect an attack that is actually underway; and 25 percent false alarm rate) is that the probability would grow from less than 1 percent to less than 10 percent after four alarming reports in a row (see Figure 3).

Once again, this does not suggest dogmatism in the face of discrepant information. On the contrary, it shows that a belief should not be overridden lightly. The math shows that a person whose initial expectation of a terrorist attack is very low will need to be exposed to a stream of alarming evidence – seven intelligence alarms in a row – before the person logically should estimate the risk of attack to exceed 50 percent.

Initial and Revised Expectations of Terrorist Attack (Given Attack Warning) Assuming a Warning System with 25 Percent Types I and II Error Rates.

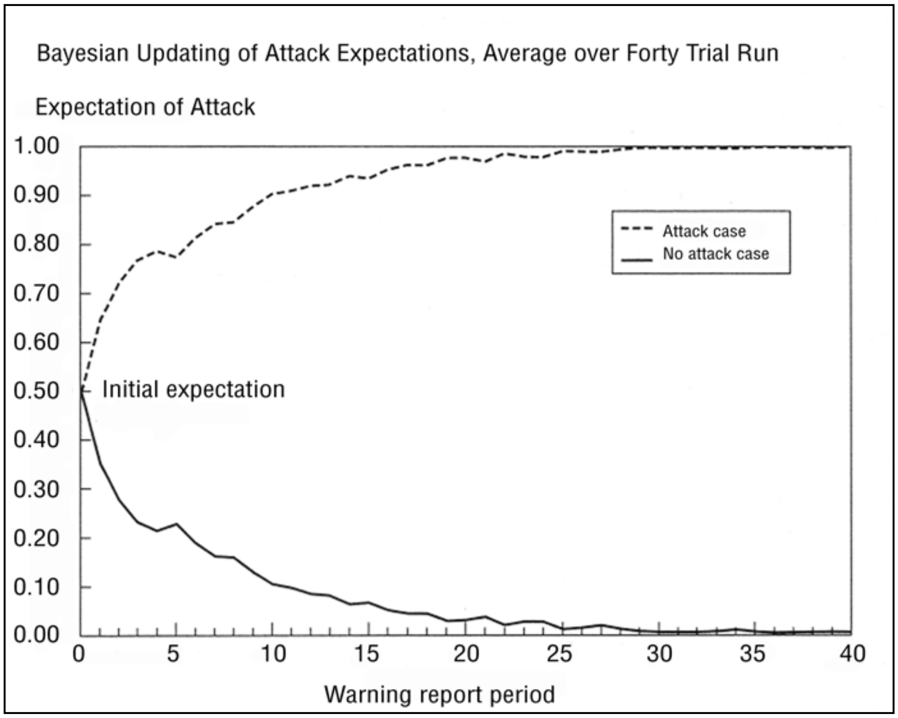
	Revised estimate given attack warning															
Initial estimate [a]	Number of positive Warning Reports: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.0001	0.000+	0.001	0.003	0.008	0.024	0.068	0.179	0.396	0.663	0.855	0.947	0.982	0.994	0.998	0.999	1.000
0.001	0.003	0.009	0.026	0.075	0.196	0.422	0.686	0.868	0.952	0.983	0.994	0.998	0.999			
0.01	0.029	0.083	0.214	0.450	0.711	0.880	0.957	0.985	0.995	0.998	0.999					
0.05	0.136	0.321	0.587	0.810	0.927	0.975	0.991	0.997	0.999	1.000						
0.10	0.250	0.500	0.750	0.900	0.964	0.988	0.996	0.999								
0.20	0.429	0.692	0.871	0.953	0.984	0.995	0.998	0.999								
0.30	0.563	0.794	0.920	0.972	0.990	0.997	0.999									
0.40	0.667	0.857	0.947	0.982	0.994	0.998	0.999									
0.50	0.750	0.900	0.964	0.988	0.996	0.998										
0.60	0.818	0.931	0.976	0.992	0.997	0.999										
0.70	0.875	0.955	0.984	0.995	0.998	0.999										
0.80	0.923	0.973	0.991	0.997	0.999											
0.90	0.964	0.988	0.996	0.999												
0.95	0.983	0.994	0.998	0.999												
0.99	0.997	0.999														
0.999	1.000															

a. Degree of belief in the hypothesis "a terrorist attack is under way."

[Figure 3]

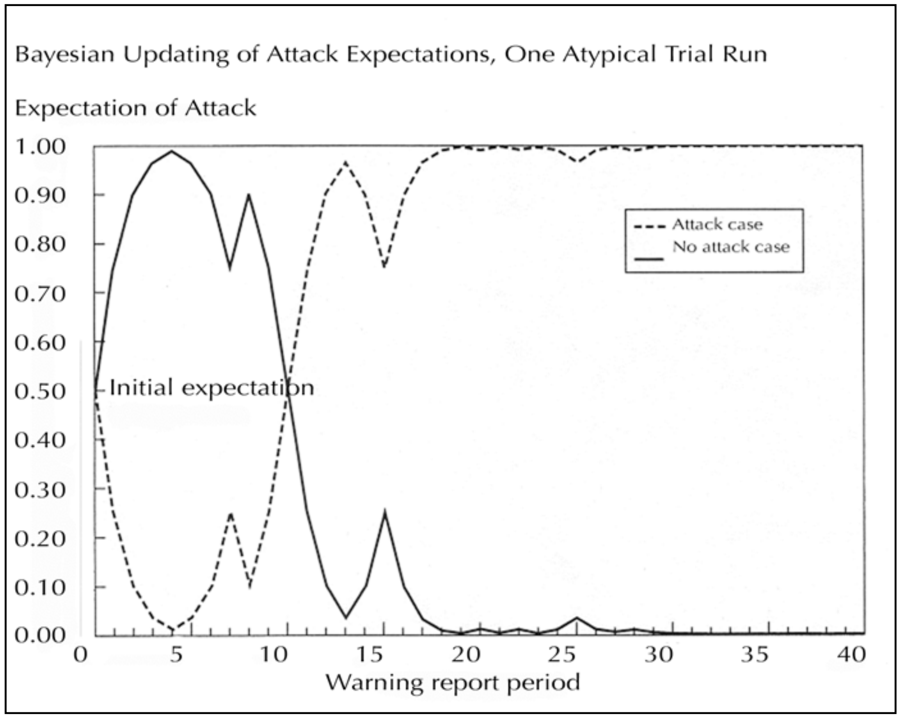
This slow revision of subjective opinion eventually converges on objective reality (see **Figure 4**) which illustrates a case in which the initial estimate is 50 percent). As more intelligence data become available and are brought to bear on opinion, the weight of initial opinion declines, eventually yielding completely to the data - assuming the data are not intentionally twisted or manufactured for political reasons.

How long does Bayes' formula suggest it should take for this process to iterate itself to the truth? Unless some momentous event like an actual terrorist strike or the actual use of mass-destruction weapons intrude to compress the iteration time, 10 to 20 successive cycles of judgment are normally necessary across a fairly wide spectrum of conditions. Over the course of these cycles of assessment and warning there would be, in the case of an actual attack underway, occasional failures to detect the attack (reflecting a 25 percent error rate) which in turn stretches out the period of warning review needed to reach the proper conclusion. By the same token, in the case of no attack underway, occasional false warnings (reflecting a 25 percent false alarm error rate) would stretch out the time needed to realize that no attack was actually being mounted. A computer simulation was run to capture these statistical risks in which erroneous warnings would be mixed in with correct warnings (which the intelligence collection achieves 75 percent of the time).



[Fig. 4]

In short, anything less than a lengthy series of spy reviews would represent a rush to judgment. Bayesian calculations in fact show that it is quite possible for the intelligence findings to be wildly off the mark for 10 or more cycles of assessment before settling down and converging on the truth (see Figure 5). A run of bad luck – failures to detect an actual attack, or false alarms if there is no actual attack – could drive the interpretation perilously close to a high-confidence wrong judgment. Although it would be unusual to experience a long run of bad luck, it is probable enough to play it safe and not preemptively attack or adopt draconian homeland defense measures after only a few intelligence reports in succession have set alarm bells ringing loudly.



[Fig. 5]

CONCLUSION

This perspective on the intelligence process leads to an exonerating statement and a cautionary note. The exonerating point is that people who clung to their belief that Iraq possessed mass-destruction weapons in spite of the inability of intelligence efforts and inspectors to find them during the run up to the 2003 invasion, and even people who still believe today that mass-destruction weapons remain hidden in Iraq, have had a strong ally in logical reasoning for a lengthy period of time. A case can be made that their view has been intellectually the most coherent and consistent view of the threat. However, logical minds open to fresh intelligence reports should by now harbor serious doubt. The facts on the ground are speaking loudly for themselves in challenging the presumption used to justify the war with Iraq.

The cautionary note is that Bayesian math points to a fairly slow learning curve that also challenges the wisdom of making preemption a cornerstone of U.S. security strategy. The intelligence burden of this strategy is generally very heavy, too heavy for any leader to consistently shoulder. In all likelihood, a prudent interpretation of intelligence would fail to clarify the actual threat, the appropriate targets, and other contours of a preemptive strike. The strategy is not a feasible or sensible approach to U.S. national security.

Bayesian analysis proves that even good intelligence and interpretation are unlikely to meet the high threshold of waging preemptive or preventative war. In reality, intelligence information is more murky than our Bayesian analysis assumed. Bits of information in the real world are often ambiguous in their very meaning – thus two observers with different preexisting beliefs will often believe that the same bit of behavior confirms their beliefs – hawks seeing aggressive behavior and doves seeing evidence of conciliatory behavior.

Bayesian analysis does not confuse the meaning of bits of information, as though drawing balls of different color from a jar. And still, it shows what a mountain of evidence is needed to rationally change one's mind and arrive at the truth.

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COMMENTARY

Physics and Society Travels with Dave

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I recently retired and will be 70 this year! It is time to take stock and be decisive. After 30 years of “doing” physics and society, it is time for me to "outreach" to the physics community. I believe that science is the driving force of history as it changes our lives. Physics plays a major role in military, energy and environmental policy. For this reason, presidential science advisors continue to be physicists, not yet biologists. Since the technological imperative pushes new inventions into the market place, we must educate ourselves on the implications to avoid the worst aspects of the new technologies. The progression of public policy does not follow a linear, logical pathway. John Milton understood this when discussing the adoption of Ptolemy’s planetary system in *Paradise Lost*:

The mighty frame, how build, unbuild, contrive
To save appearances, how grid the sphere
With centric and eccentric scribbled o’er
Cycle and epicycle, orb in orb

During John Steinbeck’s last days on planet Earth, he decided to travel with his dog Charlie. His trip and subsequent book, *Travels with Charlie*, explored the human dimension along America’s byways. I decided to take the traveling page from Steinbeck’s book. I raced to the public library and checked out Steinbeck’s biography video. This was followed with a visit to the Steinbeck museum in Salinas and the purchase of *Travels with Charlie* and other of his books. As a youth before age twenty-one, I had hitch-hiked enough miles in Europe and North America to circle the globe. Am I now too old for the open road? Well, maybe not hitching, as I do not have that clean 20-year-old look. Perhaps, I should consider a softer mode of travel, such as a recreational vehicle? I discussed with the fair Gina a plan to journey to America’s physics departments to give physics and society talks. Gina responded that she would be delighted to accompany me to Washington, DC, but her Fall-2003 schedule was too busy for more than a one week. What to do? I then hit upon a brilliant idea. My neighborhood chum of thirty years, Roger Longden, looked ready for adventure. Roger said yes, he would join me and rent to me his RV *Ma-blue* to make *the van plan* possible.

For two months (September and October 2003) Roger and I traveled to universities between Washington, DC and Utah. In all, 44 talks were given, 21 colloquia and 23 seminars (See Table 1).

Table 1. Physics of Societal Issues Talks. George Washington U, National Academy of Science, Johns Hopkins, U. Delaware, Princeton, Princeton Plasma Physics Laboratory, Rutgers, CUNY Graduate Center, US Military Academy, SUNY-Stony Brook, U. Connecticut, Tufts, U. Massachusetts, Amherst, Williams, Cornell, Penn State, Carnegie Mellon, U. Pittsburgh, Ohio State, U. Michigan, Michigan State, U. Illinois, Argonne, U. Chicago, Northwestern, U. Wisconsin-Milwaukee, Milwaukee Physics Club, U. Wisconsin-Madison, U. Minnesota, Macalester, Carleton, Iowa State, U. Nebraska, U. Colorado, Colorado State, U. Wyoming, Utah State, U. California at Santa Barbara and Santa Cruz, 2004-March APS.

The attendance varied between 7 and 130, with an average of 45. I spent $5000 and received $2500. This result cost me $1 for each listener hour, which is more than the $5-10 per student listening-hour we are paid. But I was very happy with the result, meeting many students and renewing old acquaintances. Half the talks were on arms control and the other half were on energy and environment (see Table 2).

Table 2. Colloquium and Seminar Topics. See http://www.calpoly.edu/~dhafemei for abstracts and book information.

1. Comprehensive Nuclear Test Ban Treaty: A review of the 2002 National Academy technical study on CTBT verification, stockpile stewardship, and military significance of cheating.
2. Strategic Arms Control after START: How nuclear warheads can be monitored in a region of fewer warheads.
3. Verification of Arms Treaties: Effective verification measures for monitoring strategic nuclear weapons and nuclear testing. The quantification of the "effective" verification standard.
4. Nuclear Proliferation in the Post Soviet World: The actions being taken to reduce the pathways to plutonium and highly-enriched uranium.
5. Boost Phase Missile Defense: A review of the 2003 American Physical Society study.
6. Current Energy Situation: An update of the 1996 APS-POPA study. Six case examples.
7. Buildings and Energy: A scaling model of a cubic building with solar inputs.
8. Electromagnetic Fields and Public Health: A review of the 1996 APS-POPA study.
9. Climate Change: Pedagogical modeling of global climate change.

The talks emphasized technical matters, using equations where appropriate. (This is the theme of my forthcoming book, *Physics of Societal Issues: Calculations on National Security, Environment and Energy.)* (see Table 3)

Table 3. D Hafemeister, *Physics of Societal Issues: Calculations on National Security, Environment and Energy*, Springer-Verlag and American Institute of Physics Press, New York, 2004.

1. Nuclear Weapons and Effects
2. The Offense: Missiles and War Games
3. The Defense: ABM/SDI/BMD/NMD
4. Verification of Arms Control Treaties
5. Nuclear Proliferation
6. Air and Water Pollution
7. Nuclear Pollution
8. Climate Change
9. Electromagnetic Fields and Epidemiology
10. The Energy Situation
11. Energy in Building
12. Solar Buildings
13. Renewable Energy
14. Enhanced End-Use Efficiency
15. Transportation
16. Energy Economics

I was pleased to learn from the students that there is a great deal of interest in science/society topics. We all agree that physics education must be specialized to be competitive, but some physics students clearly thirst to know more about societal issues.

Hernando de Soto may not have found the "elixir of life" when tramping through Florida in 1539, but I found it in US physics departments in 2003. At the end of this trip I could barely walk or stand, but after spinal back surgery at L4-5, "all is well that ends well" (W. Shakespeare). With renewed vigor I will live in Vincent House and walk spryly through London, continuing on these talks during April and May of 2004.

NEWS

The following news items are derived directly from the electronic FYI publications of the American Institute of Physics, authored by Audrey T. Leath and Richard M. Jones.

From "FYI this month: December 2003"
- An OSTP official reported that the Bush Administration was strongly supportive of fusion energy. The same official warned that calling for balance in the federal research budget [presumably between physical and biological/medical sciences] is "divisive" and is "…just not going to help." (see FYI #156)
- An AGU statement released December 16, 2003, stated that human activities are "altering the Earth's climate" and "it is virtually certain" that increasing greenhouse gas concentrations "will cause global surface climate to be warmer". (see FYI #164)

From "FYI this month: January 2004"
-The AIP and many of its member societies played an active role during 2003 in trying to keep religion out of the K-12 science classroom, and peer-reviewed science in those classrooms. Specifically, the societies supported peer-reviewed science for New Mexico's classroom science standards and Texas' biology textbooks.
- Shortly after China announced its intentions to initiate a program leading to a manned landing on the Moon, President Bush announced that the US would be involved in "human missions to Mars and beyond" after achieving extended human missions to the Moon by 2015. (see FYI #6) [Editor's note: The APS' Robert Park subsequently appeared on The News Hour (PBS) as a critic of Bush's plan, along with a NASA administrator who praised Bush's plan.]

From FYI #11, February 4, 2004

The Bush Adminstration requested a 3.0% increase for the NSF for the fiscal year starting on October 1. This represents an increase from the current $5.578 billion budget to $5.745 billion. NSF Director Rita Colwell commented, " In light of the significant challenges that face the nation – in security, defense, and the economy – this increase is a tribute to the extraordinary performance of the 200,000 plus students, teachers, and researchers who are directly supported by NSF each year, and a vote of confidence for the National Science Foundation's performance. Thanks to strong support for NSF's vision and mission in the Administration and Congress, the NSF budget has grown steadily…" A different view was presented by Representative Eddie Bernice Johnson (D-TX), a senior Democrat on the House Science Committee, "Two years ago, the Congress sent the President a bill authorizing a doubling of NSF's programs over five years. Despite signing that bill to glowing reviews, the President has sent us two successive budgets that fall far short of reaching that goal. With this budget submission we stand $3 billion below the doubling path…. The only thing more surprising is the 18% cut to the education and human resources budget account from an Administration that has claimed education of our youth as one its rhetorical hallmarks."

From FYI #22, February 27, 2004

The House Science Committee has pressed NASA and the White House for a clearly defined goal for human space flight, but some members of that committee are reluctant to endorse Bush's manned Moon/Mars exploration vision. "…this will not be an easy year to start major new initiatives in the face of a growing deficit." remarked Bart Gordon, a Democrat (Tennessee) on the committee. OSTP Director John Marburger and NASA Administrator Sean O'Keefe said that the program's total cost and schedule were impossible to predict at this time. Gordon repeatedly pushed Marburger and

O'Keefe for a cost estimate, but they were never given a numerical answer. Several of the other committee members expressed concern that the Moon/Mars program would land up taking funds from NASA's other missions. Marburger said that much of the $11 billion dollars in NASA that were to be shifted to Moon/Mars would come from "reprioritizing" space station research and from phasing out the shuttle program. Regarding the intention to cancel the last Hubble Space Telescope servicing mission, Marburger said that with the safety recommendations made by the Columbia Accident Investigation Board, the approaching end of the Hubble's design life, and the increasing capabilities of adaptive optics, "the risk-benefit equation has been altered." Support for the President's vision came from committee members Tom Feeney (R-FL), "I do believe that this vision is focused, I think it is bold, it's affordable."

From FYI #23, February 27, 2004

The Senate VA, HUD, and Independent Agencies Appropriations Subcommittee held hearings on February 26 regarding the NSF. Subcommittee Chairman Christopher Bond (R-MO) and Ranking Minority Member Barbara Mikulski (D-MD) are united in their support for NSF. Both have expressed deep disappointment in the Adminstration's request for a 3% increase for NSF. However, there is very little additional money. "…with major funding shortfalls throughout the VA-HUD account, it is going to be a major and perhaps an impossible challenge to find additional funds for NSF for FY 2005", was how Bond put it.

Bond and Mikulski have criticized the Administration's proposal to phase out NSF's Math-Science Partnership Program. They also discussed nanotechnology and their concerns that public fears could derail it *a la* genetically engineered foods. Mikulski urged NSF to engage the critics of nanotechnology and meet the challenge head on via public education campaigns.

This last news item is from Bob Park's What's New column dated March 5, 2004:

Sixty prominent scientists issued a statement charging the Bush administration with manipulating the science advisory process to further serve the political agendas of the administration. Subsequently, two advocates of stem cell research were removed from the Council on Bioethics and replaced by three people opposed to stem cell research on religious grounds.

REVIEWS

Climate Protection Strategies for the 21st Century: Kyoto and Beyond

Special Report by the German Advisory Council on Global Change, WBGU, Berlin, 2003, ISBN 3-936191-04-2, 77 pp., available at http://www.wbgu.de .

The world is nearing a critical climate demarcation point. As this report shows, we must reduce annual carbon emissions by 45-60% by 2050, relative to 1990. Failure implies multiple climate catastrophes. Yet emissions since 1990 have increased by over 10%. The United States increased emissions by 18% during 1990-2000 and has announced a plan that would allow emissions to continue growing at 14% per decade. The European Union (1.8% decrease during 1990-2000), and in particular Germany (19% decrease) and the United Kingdom (5% decrease), have been notable good guys.

The German Advisory Council on Global Change (WBGU) is an interdisciplinary council of experts that reviews research findings and derives policy recommendations. It currently comprises nine members, including Hartmut Grassl (chair), Director of the Max Planck Institute for Meteorology in Hamburg, and leading experts in economics, business law, applied sciences, solar energy, international development, public health, climate change research, and biogeochemistry. They have issued 15 reports on sustainable energy and other topics since 1992, available in German and English at the above web site.

This report is the first complete plan I've seen for getting safely and equitably through the energy transition that is essential to preventing dangerous global warming. It is well referenced, thoroughly researched, and as comprehensive and detailed as one could imagine in only 77 pages.

The introduction recognizes the Kyoto Protocol as only a first step, emphasizing that, "as there are no alternatives, calling the Kyoto Protocol into question throws global climate policy back by many years and severely hampers efforts to prevent dangerous climate impacts."

The analysis begins by estimating the temperature threshold beyond which unacceptable damage would probably occur. WBGU estimates this to be around 2^{o}C above the pre-industrial value, i.e. an additional 1.4^{o}C above today's value. Beyond this lie unacceptable risks: 20% of ecosystems would shift significantly, numerous species would be endangered, food production would be reduced in many areas by severe weather and pests, world food disparities would increase, net food production losses could set in and cause widespread famine, an additional two billion people would become at risk for water shortage, large regions would face intolerable economic burdens, most people would suffer economic losses, and hundreds of millions more would be exposed to malaria, malnutrition, diarrhea and flood-related accidents. The possibility of catastrophically large nonlinear events would pose a "devastating risk." Although low in annual probability, "the impacts could be so abrupt and severe that damages would be very high and adaptation almost impossible." These changes, which must be prevented, include a North Atlantic thermohaline circulation shutdown, a runaway greenhouse effect due to marine methane hydrate destabilization, transformation of the Asian monsoons, long-term disintegration of the West Antarctic ice sheet, and an irreversible melting of the Greenland ice in its entirety. WBGU warns that "even within these [2^{o}C warming] limits, the risk of triggering irreversible large-scale events is not negligible."

The 2^{o}C limit implies a certain atmospheric carbon limit, which in turn depends on the "climate sensitivity," defined as the amount of warming caused by a doubling of carbon concentrations from their pre-industrial 280 ppm. Based on computer simulations, the Intergovernmental Panel on Climate Change (IPCC) estimates climate sensitivity as 1.7-4.2^{o}C, a range that is the most significant global warming uncertainty. Clearly, to keep warming below the 2^{o}C limit with high probability, concentrations should remain well below 560 ppm. Research shows that it's very costly to set a limit that turns out to be dangerously high and to then be forced to rapidly reduce this limit. So WBGU recommends a 400-450 ppm limit. Note that concentrations are already 373 ppm.

What is the best pathway to such a limit? Arguing that only an equal per-capita emission right can be considered just, WBGU recommends a "contraction and convergence" model: During the next several decades, the world should reduce (contract) emissions in such a way as to arrive, during 2050-2100, at a global concentration of 400-450 ppm, while converging on equal per-capita emission rights for all nations.

To study detailed pathways to this goal, the report begins from three IPCC emission scenarios. For example, the most optimistic IPCC scenario assumes rapid economic growth, dynamic technology development, globalization, strong emphasis on sustainability, a less materialistic lifestyle, low population growth (9 billion in 2050, 7 billion in 2100), and a 2%/year reduction of energy intensity. To this scenario, WBGU adds its own requirements: The development of sustainable energy systems, and contraction and convergence to 400 ppm by 2050-2100. From WBGU's previous studies, "sustainable energy systems" means biomass ≤ 100 EJ/y (1 exajoule = 10^{18} J), wind ≤ 140 EJ/y, hydro ≤ 15 EJ/y, fission is phased out (Germany is phasing out nuclear power), fusion = 0, while solar electricity (photovoltaics and solar thermal for electricity and for making hydrogen) and solar heat are essentially unlimited. CO_2 storage is permitted temporarily, to be phased out by 2100.

It then becomes an exercise to work out the implications of this scenario. Some of the results (presented as detailed graphs): World energy production increases from its present 400 EJ/y to 900 EJ/y in 2060 then down to 700 EJ/y in 2100, coal zeroes out by 2060, oil and natural gas increase slightly until 2060 and then decline to100 EJ/y by 2100, solar electricity and solar hydrogen increase to 200 EJ/y by 2040 and level off at 400 EJ/y by 2080, other renewables including wind and solar heat increase and level off at 150 EJ/y by 2040.

Carbon emissions rise from their present 6.5 Gt/y (giga-tonnes per year) to nearly 8 Gt/y in 2020, then drop to 5.5 Gt/y in 2040, 3 Gt/y in 2060, and 1.5 Gt/y in 2100. Carbon reductions are caused in roughly equal parts by price-driven demand reductions, structural changes due to resource shifting, and carbon storage. Carbon storage begins in 2020, reaches a maximum of 4 Gt/y in 2060, and declines to zero by 2100.

Warming increases from its present 0.6°C to 1.1°C in 2020, 1.7°C in 2040, and levels off at 1.9°C by 2080. But the uncertainty in this final value ranges over 1.1-2.9°C, so even if this optimistic scenario is followed there is still considerable chance of exceeding the 2°C "safety zone." Sea-level, relative to 2000 levels, rises roughly linearly by 35 cm by 2100, showing little sign of slowing at that time.

Per-capita emissions (enforced by issuing emissions rights under international agreement) for North America drop by a factor of 6 from their present 5.8 t/y to their "convergence" value of 0.9 t/y in 2050. Western European per-capita emissions drop from 2.5 t/y to 0.9 t/y, China rises from 0.6 to 0.9 t/y, Africa rises from 0.2 to 0.9 t/y. The world as a whole drops from 1.2 today to 0.9 t/y in 2050. All nations then drop from 0.9 in 2050 to 0.3 t/y by 2100.

Emissions trading is essential. A "cap and trade" system in assigned emission rights will encourage underdeveloped regions to expand renewable energy sources, leaving them with excess emissions certificates that can then be sold to developed regions that remain temporarily trapped in fossil-fuel economies. The price of carbon certificates is expected to reach $250 (expressed in year 2000 dollars) per ton of carbon (or 75¢ per gallon of gasoline) in 2020, and peak at $750 per ton in 2050. Annual worldwide economic costs of the transition are expected to peak at 1.5% of world GDP in 2050—far smaller than the costs of waiting until too late to act against global warming.

Land-use changes, which contribute 10-30% to global emissions, are treated in detail in a separate chapter. In order to avoid complicating international negotiations, WBGU recommends covering these in a separate agreement with its own trading scheme.

WBGU anticipates that essentially all nations, including the USA but excepting a few very poor nations, will join the emissions control regime by 2012. But it "is aware that individual states could entirely refuse to adopt emission limits." The report recommends that the cooperating nations agree in advance to impose political and economic sanctions against such "free rider" nations.

The conclusion stresses that "without a fundamentally new orientation of energy systems towards sustainability, it will not be possible to protect the world's climate." And finally: "With every further delay of consistent climate protection policy, the scope for action narrows."

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REVIEWS

Where Darwin Meets the Bible: creationists and evolutionists in America,
by *Larry A. Witham*, Oxford University Press, 2002; 344 pages, $30.00 hardcover; ISBN 0-19-515045-7

As a reporter and senior writer at the national desk of *The Washington Times*, Larry A. Witham possesses tools, training and experience that are well represented across the pages of *Where Darwin Meets the Bible*. Interviews, taped conferences, surveys, polls, newspaper and magazine articles, proceedings, research reports, seminal books and journal papers are the sources from which the author draws a complete, well balanced picture of the perennial creation-evolution controversy in USA. Practically each paragraph is supported by references, many of them corresponding also to interviews with the author of the cited work. Both sides of the debate are covered.

The book comprises fifteen chapters plus preface, introduction, appendix, notes and analytical index. For possible future editions, it would be useful for academic purposes to include an alphabetized bibliography and alphabetized references. This edition mixes explanatory notes and bibliographic references. For those that prefer a first quick reading a differentiation between them would be helpful.

The first chapter titled “Darwin’s Legacy in America” is devoted to describing how the debate began. Witham relates the origin of the debate to the appearance of *The Origin of Species* and to the opinions that the book provoked, presenting the scientific and educational context from that epoch to today. Chapter Two uses a “two books” parable concerning the two ways of knowing: scriptural and natural. Witham describes the initial interactions and contradictions between these two ways.

The third chapter uses the “boundary theory" concept from the social sciences to initially identify several groups involved in the controversy. Witham characterizes a vast spectrum of such groups, including evolutionists, theistic evolutionists, progressive creationists and young-Earth creationists.

The fourth to seventh chapters cover in detail the battles between creationists and evolutionists over the origin of life forms on this planet. Chapters eight to ten consider specific venues and vehicles of the debate such as schools, textbooks, higher education, museums and sanctuaries. In the section on higher education, Witham shows how various universities treat the opposed positions.

Chapters 11 to 14 discuss the beliefs of scientists, mass media coverage, and how scientific and theological viewpoints could develop an American definition of human nature. The last chapter, "Search for the Underdog," covers five issues that remain controversial, and how the debate continues.

There are some small errors, such the omission of an “A” in "AAAS" that changes the American Association for the Advancement of Science into the American Astronomical Society (p. 43), or *lapsus calami* I guess, giving 1840 instead of 1844 as the year of first edition of Robert Chamber’s *Vestiges of the Natural History of Creation*, and the confusion between the persons of paleontologist Richard Owen and socialist thinker Robert Owen (p. 181).

Witham’s book is a clear and superb example of neutral investigative journalism, if such a thing exists. It is a broad but stenographic history of science and religion interactions concerning evolution and creationism. It should be read by anyone desiring an introduction to this subject.

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