THE STRATEGIC IMPLICATIONS OF GLOBAL WARMING

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At least to the frontline climate scientists, it is becoming increasingly evident that the process of global warming presents a threat to human societies of essentially unprecedented proportions. They know beyond any reasonable doubt that the thermal impulse now being imparted to the earth's ecological system by aggregate human activity is occurring at a rate greater than any that has been documented in the entire 65 million year paleoclimate record. The current rate of CO_2 accumulation in the atmosphere is ten times higher than at any time over the past 400,000 years for which annual estimates have been made based upon ice core data.[1] For earlier periods estimates are made for longer time periods, but the natural rate of CO_2 accumulation that 50 million years ago drove atmospheric concentrations and deep ocean temperatures to the highest estimated levels on record was a factor of 20,000 less than the current rate.[2] That distant process occurred over millions of years. At the higher rates currently prevailing, the inexorable process of reestablishing energy equilibrium will occur over a time span that will certainly be much shorter and will certainly affect the operating conditions of human societies, but the exact character, magnitude, timing, or location of the consequences cannot yet be determined.

The paleoclimate record that is the source of these observations is summarized in figure 1, which displays deep ocean temperatures over the 65 million year period for which empirical estimates have been made. As noted by Hansen and Sato, current deep ocean temperatures are roughly comparable to those that prevailed during the Eemian interglacial period 130,000 years ago but current sea levels are 4 – 6 meters lower than they were during the Eemian period. Moreover, under the impulse of global warming current deep ocean temperatures are virtually certain to match by mid century those of the earlier Pliocene period when sea levels were 25 meters higher than they currently are. Those comparisons indicate that much of the energy balance adjustment necessitated by the current global warming trend has yet to occur, and they suggest either that sea levels will rise more rapidly than currently expected or that some other dynamic not yet identified is at work. And indeed we are beginning to see changes in sea ice formations more rapid that prevailing climate models can account for, as figure 2 indicates. These observations provide compelling and indisputable strategic warning but the immediate implications cannot be specified with any degree of consensus.

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[1] (http://www.ncdc.noaa.gov/paleo/icecore/antarctica/vostok/vostok_co2.html

[2] Hansen, J.E., and Mki. Sato, 2012: Paleoclimate implications for human-made climate change.

Figure 1. Deep Ocean Temperatures

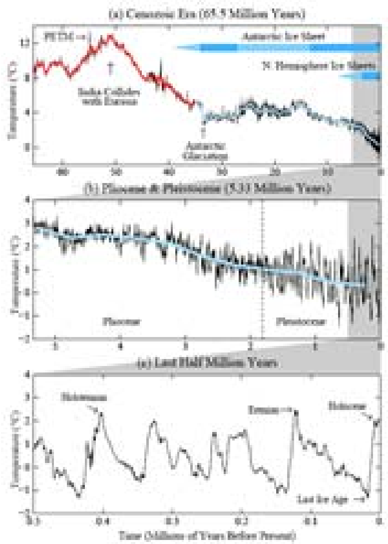
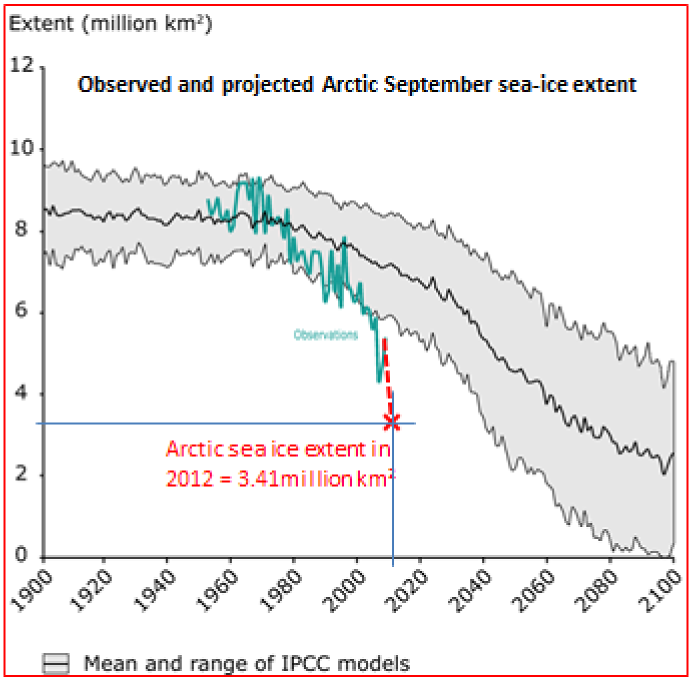


Fig. 1. Estimated Cenozoic global deep ocean temperature. Pliocene/Pleistocene is expanded in (b) and the last half million years in (c). High frequency variations (black) are 5-point running means of original data (Zachos et al., 2001); red and blue curves have 500 ky resolution. PETM is the Paleocene Eocene Thermal Maximum. Blue bars indicate ice sheet presence, with dark blue for ice sheets near full size. Holsteinian and Eemian are known in paleoclimate literature as Marine Isotope Stages 11 and 5e.
Source: Hansen and Sato.

Figure 2 Artic Sea Ice Observations and Model Projections.



Original graph is from the Europa, and shows Arctic sea ice extent observations (blue line) and the IPCC AR4 projections (black line is the mean of the model runs). Arctic sea ice summer minimum extent in 2012 was 3.41 million km², according to NSIDC and is plotted in red.

Emily Lewis-Brown. Sept 2012. www.lewis-brown.net

Those who reject the warning categorically or attribute the implications to some safely distant time period are intent on imposing the burden of proof on those who credit it, and the skeptics are advantaged by established scientific rules that require a high level of statistical confidence for any assertion of causal effect. Climate scientists are aware that unqualified adherence to that rule probably means that a consequence of global warming disastrous to human societies would be unavoidable by the time it could be documented, but they are handicapped in issuing credible warning that extends beyond the scope of their current evidence. As a practical matter the skeptics have prevailed up to this point, and reaction to the global warming process is best described as marginal and indecisive. Public awareness is developing in reaction to experience with local effects, however, most recently in the United States to hurricane Sandy. The burden of proof question is becoming a battle line. Given the evidence that is emerging, it is reasonable to expect that at some point a sense of serious danger will override the impulse for denial, and it is not too early to anticipate the implications.

Those implications fall into two main categories. In principle it would be possible to contain the process of global warming by transforming the basis for energy generation and use, an option widely known as mitigation. The degree of mitigation required to preserve the current operating conditions of human societies is a matter of disputable judgment, but those who currently take the danger seriously are suggesting that atmospheric CO_2 concentrations would have to be held to 450 ppm or less to give reasonable chance of assuring that outcome. That means that that energy generation would have to shift from approximately 20% reliance on sources that do not emit carbon to something like 80% by mid century as overall energy use is increased by a factor or 2 to 3 to accommodate the projected increase in the human population. Such a transformation is technically conceivable but would require a massive redirection of current market circumstances that is not being attempted and not even seriously discussed. Without effective mitigation, the burden of response to global warming will fall on the process of adaptation as communities throughout the world are forced to respond to the environmental circumstances they encounter. Mitigation would require explicitly organized global coordination. Adaptation is a more distributed process strongly affected by local circumstance. Since effective mitigation is a distant prospect, it is evident that adaptation will carry the main burden for several decades, and it appears that the ability to organize effective mitigation will substantially depend on failures of adaptation establishing global warming as a serious threat in public consciousness.

There is in addition a third option that is more appropriately considered an ominous temptation than a legitimate alternative. As demonstrated by large volcano eruptions that have periodically occurred, sulfate particles injected into the stratosphere can reduce average surface temperatures by as much as a half of a degree Celsius over the course of a single year by reflecting some portion of incident sunlight back into space. That and other measures that would have the same effect have been termed geoengineering or, more recently and more circumspectly, solar radiation management (SRM). Since a single sulfate particle can offset the thermal effect of 200,000 or more CO_2 molecules, it is reasonably apparent that particular technique would not be expensive or technically demanding. Most countries and even wealthy entrepreneurs could do it. SRM techniques are being advocated as emergency measures that may be urgently required if a disastrous global warming effect appears on a schedule more rapid than any conceivable mitigation effort, but the compelling question is how that judgment is to be made. Actions with major global consequence will have to be globally vetted in some accepted way, and there is no procedure currently in place that is adequate to deal with the consequences that an effective SRM technique would have.

ADAPTATION

Adaptation, successful and otherwise, is, of course, the core process that drives evolution, and it has generated the remarkable diversity of life in which we are all embedded. The process produces highly functional outcomes but does so at the cost of an appreciable rate of failure. It is much easier to endorse the operative rule – survival of the fittest – when it applies to distant eons and when the victims – the unfit—are anonymous. It is much harder to accept that rule as the proper and necessary order of things when the victims are contemporary and charismatic to at least some observers – polar bears, of example, or Bengal tigers. If it turns out that entire societies are at risk or even the human species as a whole, resignation to the relentless logic of evolution is not likely to be the dominant reaction.

The hard reality is that human societies differ very substantially both in their exposure to climate dynamics and in their capacity to adapt. In general poorer populations are more exposed to climate perturbations and have less capacity to adapt, but they have consequence in numbers. In a globalizing economy already beset with serious issues of social and economic equity and already experiencing substantial endemic violence, it seems unlikely that the fittest can prosper or even survive without any regard for victims. Serious failures of adaptation are likely to occur and are likely to become both serious problems of economic development and serious issues of international security.

The question of how serious and over what period of time are matters of disputable judgment, but it is prudent to expect that crisis episodes more intense than any yet on record will occur over the next decade and will recur with increasing severity and frequency thereafter. The potential for unmanageable internal disintegration in a society of global consequence is sufficient to warrant more systematic preparation than is yet occurring. And there are some strong clues to work with. Although climate scientists are not yet able to carry a completely decisive burden of proof, they do have empirical reason to believe that the process of global warming is increasing the frequency and intensity of extreme weather events. They are observing more severe drought in areas susceptible to drought and increased precipitation in areas susceptible to flooding. They are observing increased severity of violent storms.[3] There is some evidence that an intensive heat wave in Russia in 2010 causing devastating forest fires was the result of a weather pattern that simultaneously produced devastating floods in Pakistan.[4] The instrumental record is too short – only about 130 years – and the incidence of extreme events too infrequent to support definitive conclusions, but available evidence does suggest that extreme weather will accompany the global warming trend.

So far at least climate events have been detectably but not strongly related to the incidence of violence.[5] The effects of climate perturbations are mediated by social and political circumstances; most notably, the inherent exposure of populations, their susceptibility to climate induced damage, their spontaneous coping capability, and the organized reaction of the responsible government. Prudent precautions and effective reaction have been able to control the consequences of severe climate events in some cases, but in others inadequate preparation and ineffective reaction have amplified those consequences. The evident concern is for

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[3] National Research Council/National Academy of Sciences, *Climate and Social Stress: Implications for Security Analysis*, 2012. http://www.nap.edu/catalog.php?record_id=14682

[4] *Ibid.* p. 68

[5] Cullen S Hendrix and Idean Salehyan, "Climate Change, Rainfall and Social Conflict in Africa," *Journal of Peace Research,* 2012 http://jpr.sagepub.com/content/49/1/35.

situations in which unusually severe climate effects occur at locations that are especially susceptible to disruption, and ominously Pakistan is one of the principle candidates.

Pakistan is a fragile society inherently sensitive to climate variations. Its territory is arid and semi-arid, and the agricultural sector of its economy is heavily dependent on water drawn from the Indus river. The agricultural sector provides 23% of Pakistan's overall GDP, employs 44% of its labor force and generates 65% of its export earnings. There is sharp competition for available water between the internal provinces requiring agricultural irrigation and between all irrigation claims and hydroelectric power generation. The prevailing allocation rules are based on unrealistic estimates of water availability and are determined by political influence rather than by intrinsic need or economic efficiency. Irrigation for Punjab is favored over irrigation for the more arid Sind province and irrigation generally is favored over power generation.

Against that background situation, the entire water allocation process in Pakistan is being burdened by one of the more notable climate perturbations currently occurring. Water flow in the Indus river watershed is currently running some 30% below historical levels and the evident reason is an anomalous pattern of high altitude accumulation in the Karakoram glaciers combined with recession of the glaciers at lower altitudes. Glacier and snow melt provide 30 – 40% of the Indus river flow in contrast to the river systems to the East that are primarily fed by monsoon rains. There is some uncertainty about the cause and duration of the Karakoram anomaly but nonetheless there are coherent reasons to believe it is the result of global warming[6]. At any rate in addition to reduced river flows, Pakistan has recently experienced extreme variations in drought and flood conditions as well as disruptive changes in agricultural product cycles that are generally recognized consequences of global warming.

This situation is already generating internal tension within Pakistan. There are frequent riots in Pakistani villages protesting regularly recurring power outages that result from deficiencies in hydroelectric power generation. The Pakistan government blames India for violating water management agreements, but the Pakistani head of the Indus river water commission, which includes India, recently declared in a small public gathering that climate change is the primary reason for reduced flows in the Indus river. He was immediately arrested and charged with treason, indicating the political sensitivity of the situation. The underlying security question is whether incrementally increasing climate pressures in Pakistan and elsewhere , the equivalent of a chronic infection, are capable of triggering acute episodes than might generate unmanageable internal violence and might threaten fundamental governability -- in particular in Pakistan's case the capacity to exercise responsible control over an arsenal of nuclear weapons.

[6] T. Bolch et al, "The State and Fate of Himalayan Glaciers ," *Science,* Vol. 336, 20 April 2012 pp 310-314.

So far, radical internal disintegration has not occurred in any major society, and the direct effect of climate events on the global incidence of civil conflict has been, statistically at least, fairly modest.[7] That record is reassuring, but it does not provide decisive or indefinite confidence. Again, we do know that the unmitigated thermal impulse being generated by aggregate human activity is capable in principle of generating climate dynamics that exceed the capacity for local adaptation, and there is no guarantee that the most severe episodes will occur in marginal societies. Moreover, the process of economic globalization has put many national economies under severe stress and has generated a highly inequitable pattern of income and wealth distribution.[8] If climate severity begins to interact with economic stress, internal coherence will be an issue everywhere. And however successfully most societies might respond, it is prudent to expect some failures of unprecedented magnitude and consequence.

MITIGATION

In the familiar parable of the boiling frog, gradual temperature increases are tolerated until they become fatal in contrast to sudden surges which trigger timely escape. That story suggests that unless episodes of failure prove to be frequent and truly dramatic, the adaptation process might perversely do more to retard than to induce mitigation efforts. There are conceivable consequences of global warming, however, that would certainly seize attention and presumably trigger insistent demands for mitigation if they did begin to occur. The most serious of these would be a surging release of frozen gas hydrates injecting methane into the atmosphere. Since the radiative forcing effect of methane is 21 times greater than that of $C0_2$ and since there are large ocean deposits, there is some inherent possibility of a self-reinforcing process that would accelerate the global warming trend with consequences that could be truly catastrophic for human societies. That is a scare scenario that appears in principle to be capable of causing global panic, and for that reason climate scientists are appropriately cautious about it. In a recent book entitled "Fate of the Species: Why the Human Race May Cause Its Own Extinction and How We Can Stop It," Fred Guterl, Executive editor of Scientific American reviews a number of apocalyptic scenarios but tellingly steers away from the menace of gas hydrates, arguing that the amounts trapped in frozen tundra are not sufficient to have a major global

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[7] Hendrix and Salehan op.cit.

[8] Anand Banerjee and Victor M Yakovenko "Universal Patterns of Inequality**,"** 2010 New J. Phys. 12 075032, (http://iopscience.iop.org/1367-2630/12/7/075032); Branko Milanovic , Worlds Apart: Measuring International and Global Inequality, , Princeton University Press, 2005:

effect.[9] He does not to mention ocean deposits or the East Siberian ice shelf where methane is currently being released into the atmosphere.[10]

The burden of proof currently falls on anyone warning of imminent danger from surging methane, but if it should shift requiring climate scientists to issue credible reassurance, they could not do so. That situation presents risks of contrasting errors – irresponsible complacency on one hand and misplaced urgency on the other. The relative balance of the two is impossible to determine at the moment, but together they assure the immediate relevance of mitigation despite the glaring deficiencies of current efforts.

The basic mitigation options are summarized in table 1, which lists the current and prospective output of various energy generating technologies. The ultimate energy requirement is likely to be at the top of the indicated range. The table indicates that there are five technologies that can in principle contribute to energy output in significant amounts by mid century, and all will certainly be pursued. As technical development efforts proceed, assessments of their relative prospects will improve, but the basic story is already reasonably apparent. The potential for wind is certainly too limited for that to be the prime or even major basis for transformation. Similarly biomass technologies are limited by the surface areas that can be allocated to their production without interfering with other vital uses. Solar technology is burdened by large fluctuations imposed by nighttime and cloud cover, by conversion efficiencies, and by the limitations of storage technologies. Carbon capture and sequestration, politically popular because of the abundance of coal and the established industry of extracting it, encounters fundamental uncertainties that appear ultimately intractable. The core problem is assuring that the sequestration technique would be reliable over century long time spans—that is, that the storage technique would not leak or surge. In principle CO_2 can be turned into rock that would meet that standard of assurance, but doing that on gigaton scale would be unfeasibly expensive. Less fixed forms of sequestration that are more plausibly feasible in economic terms are very unlikely to be able to meet an appropriate standard of reassurance and are likely to involve unacceptable risk. Prime reliance on a technology that leaked could seriously compound the global warming problem.

The unavoidable implication of these impediments is that mitigation has to depend on a very substantial expansion of nuclear power generation that has its own obvious and serious impediments. As demonstrated in the Fukushima disaster in Japan, all currently operating nuclear power reactors depend on emergency cooling which makes them inherently susceptible to catastrophic failure. Moreover, as reflected in the current dispute over Iran's

[9] Fred Guteral *Fate of the Species: Why the Human Race May Cause its Own Extinction and How We Can Stop It,* Bloomsbury, New York 2012.

[10] Natalia Shakhova et al," Extensive Venting to the Atmosphere from Sediments of the East Siberian Arctic Shelf," *Science,* vol. 327, no. 5970,pp 1246 -1250, 5 March 2010

uranium enrichment activities, producing fuel nuclear reactors enables the production of nuclear explosive isotopes and thereby the acquisition of nuclear weapons. It is reasonably evident nuclear power generation cannot be expanded to the extent required for effective mitigation on the basis of current reactor designs or current fuel cycle supply arrangements. The operational safety and proliferation risks are too large to be tolerated.

Table 1. Current and potential contributions of carbon-free energy supply

	Primary Energy Production (EJ_p/y) [1 EJ = 10^{18} J ≈ 160 million barrels of oil] 500 – 900 EJ_p/y needed by 2050			Natural flow/ resource base (EJ_p)
Energy Source	2001	Potential by 2050	Long-term Potential	
Hydroelectric	28	40–60	60–100	400/y
Geothermal	0.7	5–10	5–20	10,000,000
Ocean	0.006	0–1	1–5	2,000,000/y
Nuclear fusion	0	0	?	4,000,000,000+
Nuclear fission	28	70–220	500+	10,000,000
Biomass	4*	50–150	50–500	2,000/y
Solar	0.2	50–150	500+	3,000,000/y
Wind	0.6	20–50	100–250	40,000/y
Decarbonized fossil (CCS)	0	150+	500+	250,000

*Commercial biomass only; traditional biomass is variously estimated at 15–65 EJ/y.

Source: Fetter and Gulden *op.cit.* Primary energy in the table is measured in terms of thermal output.

But that is not the end of the story. The impediments to the expansion of nuclear power can be overcome more readily than the ones that limit the alternative mitigation technologies. There are nuclear reactor designs that are inherently safe in that they do not depend on emergency cooling and are not internally susceptible to a catastrophic accident. And if the production of nuclear fuel were consolidated in a few protected locations under representative international management, the risk of national state proliferation could be eliminated and the risk of terrorist access held to a minimal and tolerable level. In principle small modular reactors with sealed fuel designs – the equivalent of batteries – could be produced in protected locations under international supervision, transported to service sites and then returned for refueling or deactivation. That would entail a dramatic revision of current operating and licensing practices and would certainly encounter institutionalized resistance from the current industry. Nonetheless the conception is feasible in principle and that makes mitigation feasible as well.

IMPLICATIONS

At the moment it is not possible to judge with any confidence how long it will take for the relentless process of global warming to command the level of attention and consensus required to organize adequate adaptation and mitigation efforts. The question is when not whether, but plausible answers range over several decades. In the meantime, there are things that can and should be done within the limits imposed by available science and by prevailing political attitudes.

Adaptation monitoring

It will clearly be important to learn as much and as rapidly as we can from operational experience. We need to capture the record of adaptation success and failure as it unfolds and we particularly need to improve anticipation. As with any serious malady, preventive efforts are more effective that acute reaction and both are served by dedicated monitoring. In principle advanced sensing, information processing and data management techniques can detect emerging adaptation issues before they become acute, but current practice in that regard is far below its potential. Satellites are being used to monitor climate variables, but there is no global arrangement either to optimize coverage or to organize access to the resulting data. All of the relevant satellites are maintained by national governments. Their investment decisions are not effectively coordinated, and in the US case current coverage is not being sustained let alone expanded. National satellite data is not comprehensively shared, nor is it systematically integrated with more detailed ground monitoring data. With regard to South Asia, a region especially susceptible to climate perturbations, both India and Pakistan refuse to allow international access to ground station monitoring data. Pakistan imposes national security classification on its ground station monitoring data.

A monitoring system worthy of the situation would have to combine not only data from all sources on some judicious selection of essential climate variables but also critical social impact data measuring the exposure of populations to climate induced damage. Priorities would have to be set, coverage would have to be apportioned among national programs, the resulting data base would have to be continuously managed, and global contribution and access rules would have to be negotiated and implemented. At the moment the state of environmental monitoring is very far from that standard. An organized effort to achieve it is an immediate priority.

Prototype development

In anticipation of the ultimate need for an operationally safe and proliferation resistant nuclear reactor technology, it is important to begin the process of prototype development. Table 2 summarizes the characteristics of four reactor designs that could be developed to support the small modular concept, although none of them at the moment have the sealed fuel feature that is essential for proliferation control. There are many other potential contenders as well.

Table 2. Summary of Small Reactor Options

	Reactor type	**Power level**	**Refueling frequency**	**Fuel type**	**Fuel cycle**	**Special features**	**Time to market**
IRIS (int'l consortium led by Westinghouse	LWR	100 - 335 MWe	3.5 years	UO2 -- < 5 % enrichment	Once through	Integral Primary System Reactor	Applying for design cert. in 2012
AFPR (PNNL)	LWR	100 MWe	20 or 40 years if equipment brought to refuel on site to refuel once	Spherical Zr/LEU pebbles (like TRISO); could fuel w. uranium-thorium or reprocessed U (19.5% U235)	Once through or closed	TRISO fuel more robust at high temps.	10-15 years
SSTAR (Argonne)	Fast reactor, Pb or Pb-Bi cooled	20 MWe	20 years	Mixed oxide or nitride fuel, about 17% Pu	Closed		15-20 years (low level of current investment)
ENHS (UC Berkeley)	Fast reactor, Pb-cooled	50 and 75 MWe	20 years	Different options, all include about 13% Pu	Closed		15-20 years

In principle small modular reactors offer three basic advantages that might make them competitive investments for carbon free power generation: the cost per unit would be substantially less than large light water reactors and hence the burden of marginal investment by power generating companies more tractable; fabrication costs would benefit from serial production learning; and the burden impose on power grids would be substantially less. But technical feasibility and relative costs cannot be reliably determined without developing prototypes to the point that they could actually be produced.

It is generally estimated that prototype development for any of the designs listed on the table or for any of the plausible alternatives would cost on the order of $1 billion over 10 years per design. That is not large sum for what is at stake, but there is no current source for that investment. It is too risky for private investors under current market conditions and too much of a departure for governments heavily implicated in subsidizing and licensing large light water reactors and not able to command political consensus. Since government investment will eventually have to initiate the process, however, it is appropriate to begin discussion. The US government recently committed $10 billion to an international consortium pursuing nuclear fusion technology that has at the moment almost no prospect of being commercially available by mid century. If that venture can be justified, a small modular fission reactor development program has a much stronger claim. At half that amount -- $5 billion -- four competing reactor prototypes could be developed with much greater prospects for success. Notionally that might involve both standard light water and alternative designs in the 35 – 45 MW range and in the 250 – 300 MW range. The smaller size could be transported to inland service locations by rail, the larger size to coastal locations by barges. The first step in such a program would be a competitive evaluation process to select the designs to be developed. That should be a component of any national energy plan worthy of the name.

In addition and even more indisputably, a prototype needs to be developed for a global nuclear materials accounting system. The legacy accounting systems currently operated by national governments cannot keep track of nuclear materials with the precision and assurance that is technically feasible, and as a result there is greater risk of unauthorized diversion than is necessary. Application of advanced sensing and information processing techniques would enable a system of accounting and physical security capable of instantaneous monitoring of all materials. Such a system could establish and enforce appropriate access rules. Agreed aggregates could be routinely reported while the details of national inventories were available only to the responsible national governments. It is predictable that the process of global warming will make the sharing of sensitive information for purposes of mutual protection generally important and will force the development of institutional arrangements designed for that purpose. Accounting and physical control of nuclear materials is likely to be one of the primary instances.

SRM regulation

Since it will almost certainly be feasible to offset the warming effect of GHG emissions to some meaningful extent by one or more of the solar radiation management techniques, It is quite important and in fact urgent to work out credible arrangements for responsible vetting of SRM programs. Recognizing the apparently compelling need for emergency reaction that could arise, the American scientific community has moved beyond categorical aversion to the entire idea of SRM to conceptual exploration of the basic science involved. And there has been one recent episode in which a wealthy entrepreneur operating outside of the scientific mainstream spread iron filings over a substantial ocean area episode claiming it to be an exercise in benign geoengineering. That generated vehement objection challenging both the validity of the claims and the alleged violation of reporting and oversight procedures said to be required under international agreements.[11] The episode basically revealed, however, that review procedures adequate to the situation have not yet been developed. With responsible scientists beginning to contemplate field trials designed to measure SRM techniques, oversight rules have become immediately urgent.

Appropriate rules will have to consider not only traditional questions of scientific merit and individual safety but broad social impact as well. It is prudent to assume that field trials capable of having some measurable global effect will have to be cleared through a review process that is both scientifically credible and globally representative. These are distinctly different criteria that must somehow be blended, and the relevant experience in doing so is meager at best. There are nonetheless some common sense guidelines that can readily be identified. To be acceptable to research scientists, an authoritative review process would have to be protected from ideological obstruction, and that means the criteria for judging social impact would have to have some objective basis with appropriate burden of proof rules. That implies that any candidate experiment or SRM procedure that has measurable global effect would have to specify regional and local consequences as well and would have to defend the hypothesized balance of merit. For any project there would have to be good reason to believe that the justifying global benefit would reliably outweigh any deleterious regional or local effects, that harmful effects would be measured, and that compensation for harmful effects would be possible. For field trials with modest global effects, those conditions would plausibly be

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[11] http://www.cbc.ca/news/canada/british-columbia/story/2012/11/02/bc-un-ocean-fertilization.html

sufficient and not impractically onerous. For an SRM operation designed to have an effect on mean surface temperature that is of significant magnitude and duration, there would be an additional requirement; namely, that the project be accompanied by mitigation actions of comparable magnitude and duration. Since SRM techniques offset the thermal impulse of GHG concentrations but do not diminish them, SRM without simultaneous mitigation is the social equivalent of heroin addiction – that is, unacceptably irresponsible under any circumstance.

Realignment of strategic relationships.

Adaptation monitoring, prototype development and SRM oversight rules are all specific actions that can and should be initiated in response to global warming within the limits of current political consensus. They would not be immune to controversy, but they are within reasonable aspiration. They are not alone sufficient, however, and should not be the limit of aspiration. They need to be accompanied by dedicated efforts to adapt prevailing attitudes to the emerging threat. In the United States that might be seen as the equivalent of overcoming isolationist sentiment in the 1930s in responding to the threat of imperial aggression. One can at least aspire to accomplishing the corresponding revision of prevailing attitude without having to experience the equivalent of surprise attack.

As an enduring consequence of World War II experience, the American security culture has been riveted on the threat of imperial aggression. That has been an organizing principle for the entire political system, a source of consensus running across sharp partisan and ideological divisions. When the question is explicitly posed, most Americans do understand that imperial aggression has receded as an immediate threat, but they still cling to the presumption of intrinsically hostile enemies. They readily impose that presumption on Iran and North Korea at the moment, and it more implicitly lurks behind contemporary discussion of the "rise" of China. Differences in culture and in forms of political organization are presumed to create differences of "interest" and to mandate politically contentious and potentially violent competition in the exercise of "influence" and "power." The terms interest, influence and power are assumed to have intuitive meaning not requiring any detailed definition or justification. They can be and usually are asserted without having to be defended.

The process of global warming will assuredly corrode these entrenched presumptions. Whatever effects the global warming process has on the relative advantages and disadvantages of national governments will almost certainly be overridden by the threat it poses to the human species as a whole. The global warming impulse is an unorganized collective human action, but it will require a highly organized collective human response to contain the increasingly serious threat it imposes. Containing the consequences of global warming is now a common imperative whose intrinsic importance dominates separate national interest.

In particular effective mitigation will require that global technical and financial resources be mobilized for application in India and China which together contain 40% of the world population and project much of the relative economic growth projected to occur over the period when mitigation needs to be accomplished. That means that security relationships among the US, the EU, Russia, China and India will have to be rendered fundamentally collaborative in character, and the legacy of confrontation will have to be subordinated to that requirement. That is likely to be the work of a generation or more, but it has to begin as an enabling condition for protective monitoring, prototype development and SRM regulation.