Planning for Future Energy Resources

WE AGREE WITH M. I. HOFFERT ET AL. (“Advanced technology paths to global climate stability: energy for a greenhouse planet,” Review, 1 Nov., p. 981) that stabilizing atmospheric CO2 concentrations at 550 parts per million (ppm) or below will require investment in energy research and development well in excess of current levels. However, their conclusion—that known technological options are not up to the task—suffers from two shortcomings related to how much decarbonization is required and how soon we need it. First, they do not consider uncertainty in future energy demand, basing their analysis on a single reference scenario (1). In contrast, the most recent Intergovernmental Panel on Climate Change (IPCC) report on emissions scenarios (2) forecasts a wide range of plausible development paths leading to global primary energy demand of anywhere from 20 to 50 TW by 2050. Relative to these scenarios, as quantified by six different integrated assessment modeling teams, stabilizing at 550 ppm may not require any additional energy from carbon-free technologies over the next 50 years beyond that produced by known technologies for reasons unrelated to climate change. Or it could require that additional zero-carbon generating capacity deliver nearly 600 TW-years of energy over that same period. Policy responses to climate change should be robust across this wide range of uncertainty.

Second, we doubt whether the development and implementation of the radically new technologies such as fusion or solar power satellites advocated in the article are feasible within the time horizon necessary for CO2 stabilization. The process from invention, to demonstration projects, to significant market shares typically takes between five and seven decades (3). Fundamentally new technologies that have not been demonstrated to be feasible even on a laboratory scale today would therefore likely come much too late to contribute to the emissions reductions necessary by 2050, particularly for stabilization at 450 ppmv or below (4). We believe that the appropriate mix of investments must include an initial focus on technologies with proven feasibility if we are to embark on a path to stabilization. At the same time, we should begin to explore new energy sources that might then be available in the long term to finish the job.

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References

THE REVIEW BY M. I. HOFFERT ET AL. (“Advanced technology paths to global climate stability: energy for a greenhouse planet,” 1 Nov., p. 981) discusses a wide range of advanced technology solutions to achieving global climate stability. Their treatment of nuclear energy, however, is completely inadequate. Nuclear electric power and, with a small extension, nuclear process heat are the only alternatives among those considered that have been tested at a commercial scale. Because noncarbon alternatives to nuclear energy are not yet proven on a commercial scale, a wide range of options for sustainably applying nuclear technology must receive increasing attention.

In the short term, there is no fuel resource problem. Even a trebling of capacity to meet the Kyoto accords is possible with uranium fuel at reasonable cost for 50 years. Beyond this, W. C. Sailor et al. (1) estimated that one-third of a postulated (high) 900 EJ/year primary energy demand in a 2050 world could be met by nuclear fission. To meet this level of demand, either cheaper fuel must be found, an increased cost must be accepted, or fuel must be bred from 239U or 232Th.

Breeding plutonium from 239U would extend the uranium resource base by a factor of about 70; higher-cost uranium resources would then become feasible, extending that resource for 1000 years. Although Hoffert et al. state that “breeder reactors are needed for fission to significantly displace CO2 emissions by 2050,” the need for a breeder reactor is less immediate than was perceived in the 1970s. The decrease in the price of raw uranium presently makes breeding uncompetitive and reduces the need for a rapid expansion, so that even more safe and economic reactor designs with a lower breeding ratio can now be considered. Moreover, reprocessing and recycling of spent fuel can dramatically reduce the heat load and radio toxicity of the long-lived actinides sent to any waste repository. "Waste form modification,” therefore, is being reconsidered for improved repository performance independently of perceived uranium resource issues.

Contrary to what Hoffert et al. state, breeding as well as reprocessing has not been illegal since the Reagan administration. Hoffert et al. raise concerns about nuclear energy but do not describe how these concerns are being addressed. Indeed, major accidents have occurred at the Windscale, Chernobyl, and Three-Mile Island nuclear power plants. Much has been learned and applied from these events. Analyses of these few serious accidents have improved operational safety, which was already high.

Nuclear fission technology is indeed deeply rooted in the bomb-making military. Materials generated as a byproduct of commercial nuclear power might lead to undesirable proliferation of nuclear weapons. Proliferation-resistant commercial fuel cycles are being explored, although no nuclear weapons proliferation has been attributable directly to a commercial power plant or the attendant fuel cycle. Inefficiencies and public concerns led to cost increases between 1973 and 1990; however, since 1990, the economics of nuclear power have improved significantly. Several avenues should now be developed simultaneously: (i) further developing low-cost uranium and (ii) improving the economic and environmental characteristics of various breeder technologies. Fossil-coal and fossil-uranium share one common feature—they do not have a resource problem on the time horizon of 500 years. It is the environmental issues, in their broadest sense, that are likely to determine the choice.

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Reference
WE DISAGREE WITH M. I. HOFFERT ET AL’S
(“Advanced technology paths to global climate
stability: energy for a greenhouse planet,”
Reviews, 1 Nov., p. 981) characterization of
the IPCC Third Assessment Report’s conclusion
that “known technological options could
achieve a broad range of atmospheric stabi-
"zation levels, such as 550 ppm, 450 ppm
or below over the next hundred years or more” (1,
2, p. 8), as “a misperception of technological
readiness.” First, Hoffert et al. analyze (and
dismiss) individual technologies in isolation
and do not consider their full combined poten-
tial. Absent detailed argumentation at the
energy system level, background reports (3, 4)
suggest that their critique rests on pessimistic
assessments of the availability and efficiency
of renewable energy. The IPCC evaluated a
broad array of demand and supply studies, not
just individual supply-side technologies (5).
Most of these studies are much less pessimistic
than Hoffert et al. about biomass, solar energy,
efficiency, and fossil fuel decarbonization.
Second, the authors imply that technologies
not technically feasible today (nuclear fusion
and space solar power) are needed to stabilize
concentrations. But their development and
diffusion may require more than 50 years, too
long for timely carbon stabilization at accept-
able levels. None of the studies assessed by
the IPCC assumed penetration rates of new tech-
nologies higher than historical experience.
Third, Hoffert et al. ignore the IPCC conclu-
sion that no simple technological fix exists and
that a portfolio of available technologies must
be evaluated “in combination with associated socio-
economic and institutional changes” (5). Fourth, they
ignore possible carbon emissions reductions unrelated to
energy sources, such as options in the area of land-use
changes.

We agree that carbon stabilization at low
levels will be difficult and not cost-free. We
agree that enhanced R&D and investment in
conventional and new technologies is neces-
sary. But we stand by the IPCC conclusion that
today’s technically feasible technologies
including energy efficiency improvements
could stabilize carbon concentrations if further
developed and deployed, and if complemented
by necessary nonenergy initiatives and associ-
ated socio-economic and institutional changes.

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References and Notes
1. “Known” refers to “technologies that exist in opera-
tion or pilot plant stage today. It does not include any
new technologies that will require drastic technolog-
ical breakthroughs” (2, p. 8).
2. B. Metz, O. Davidson, R. Swart, J. Pan, Eds., Climate Change
University, Montreal, Canada, 2002).
4. H. D. Lightfoot, C. Green, Report No. 2002-9 (McGill
University, Montreal, Canada, 2002).
5. T. Morita et al., in Climate Change 2001, B. Metz, O.
Davidson, R. Swart, J. Pan, Eds. (Cambridge Univ. Press,

Response
EXISTING TECHNOLOGIES CAN CONTRIBUTE
to global warming mitigation. However, projected levels of emission-free power
needed later this century to stabilize climate change appear to be so unprecedented (1, 2)
that it would be foolhardy not to assess a broad spectrum of advanced energy sources,
converters, and enabling technologies.

The IPCC Special Report on Emission Scenarios (SRES) projects 40 energy
scenarios (3). Unfortunately, no reliable theory exists to assess their probabilities. Our
33 TW primary power in 2050 is close to the midcentury mean of the SRES range. Unlike
SRES, we specify a range of concentration targets and compute CO2 emission-free power required as a function of
time. We recently extended our analysis to global warming targets, including climate sensi-
tivity uncertainty effects (4).

For example, a 2°C warming target (which can still produce adverse climate impacts)
requires non-CO2-emitting primary power in the 10 to 30 TW range by 2050.

The crux of our disagreement with the
IPCC Mitigation Panel is whether “known
technologies”—which they define as already
existing “in operation or as pilot plants”—can
generate such massive emission-free power.
Remarkably, their definition excludes fossil-
fueled zero emission plants (ZEPs), with CO2
sequestered. DOE just announced plans to
build the first ZEP pilot plant by 2010–15 (5).

O’Neill et al. say that fusion and solar
power satellites are not feasible because the
process “from invention, to demonstration
projects, to significant market shares typically
takes between five and seven decades.”
Fusion power reactors may be unlikely before
the latter half of the 21st century, but a fission
path employing fusion-fission hybrid breeders
based on paid-for tokamak technology (advo-
continued 235U burning at 10 TW rates will commercial breeder reactor programs). To our knowledge (the United States, France, fissile fuels is not being done anywhere today in the United States, commercial breeding of nuclear scenario (~10 TW from fission by 2050 in their independently recognized this by putting power sources. W. C. Sailor and colleagues plausible economic growth, regardless of global warming to <2°C requires 10 to 30 TW emission-free power in 50 years for today, anxieties over waste disposal and diversion to weapons are evident in Nevada’s opposition to a spent nuclear fuel repository in Yucca Mountain and the Pentagon’s deployment of long-range bombers capable of destroying North Korea’s Yongbyon reactor complex. These issues may indeed be amenable to technical solutions (12). But, as indicated above, holding global warming to <2°C requires 10 to 30 TW emission-free power in 50 years for plausible economic growth, regardless of power sources. W. C. Sailor and colleagues independently recognized this by putting ~10 TW from fission by 2050 in their nuclear scenario (13).

Although it is no longer technically illegal in the United States, commercial breeding of fissile fuels is not being done anywhere today to our knowledge (the United States, France, Japan, and Germany have suspended their commercial breeder reactor programs). Continued 233U burning at 10 TW rates will require finding major new high-grade uranium deposits to prevent rapid exhaustion (2). Low-grade ores face serious environmental and cost issues. Our finding of massive flow rates needed for seawater extraction of 235U surprised us. And we are nowhere near able to breed on the scale needed to realize theoretical factors of 60 (233U → plutonium) or 180 (Th → 233U) increase in fissileable fuels. The issue for global warming is not breeding, as such, but our ability to breed fast enough. This will require drastic shifts in technology and substantial research and development.

We are astonished at continued confident forecasts by Swart et al. that “existing” technology can accomplish the mitigation job ahead, while they discount or ignore technologies they deem too advanced. Expert predictions of technological readiness are notoriously unreliable (14). The near-term maturity of highly desired technologies is commonly overestimated (ballistic missile defense, cancer cures, controlled fusion), even as promising innovations perceived as too futuristic are often underestimated (8, 15–17).

Market penetration rates of new technologies are not physical constants. They can be strongly impacted by targeted research and development, by ideology, and by economic incentives. Apollo 11 landed on the Moon less than a decade after the program started. We are confident that the world’s engineers and scientists can rise to the even greater challenge of stabilizing global warming. But it does not advance the mitigation cause to gloss over technical hurdles or to say that the technology problem is already solved.

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References and Notes
CORRECTIONS AND CLARIFICATIONS

Technical Comments: Response to a Comment on “No major schizophrenia locus detected on chromosome 1q in a large multicenter sample” by D. F. Levinson [20 Dec., www.sciencemag.org/cgi/content/full/298/5602/1674a]. In further discussion after publication, the authors of the Technical Comment (A. S. Bassett et al.) and the Response (Levinson et al.) have concluded that there was an error in the Response. The empirical P values reported by L. M. Brzustowicz et al. [Science 288, 678 (2000)] were incorrectly interpreted in the Response as pointwise (uncorrected) values, but they were actually corrected for multiple testing, as described by F. Bonnet-Brilhaut et al. [Eur. J. Hum. Genet. 7, 247 (1999)] and C. R. Cloninger et al. [Am. J. Med. Genet. 81, 275 (1998)]. The genome-wide P value for linkage to schizophrenia on proximal 1q in the Canadian sample was 0.0002 to 0.00002, a highly significant result. The Response also noted that significant linkage had not been reported in the largest family in the Brzustowicz et al. sample. As a point of clarification, the Zmax in this family at D1S1679 was 2.98 under a recessive model of inheritance, considering individuals with schizophrenia or schizoaffective disorder as affected. Single-family lod scores were not presented in the original publication because of space limitations.

TECHNICAL COMMENT ABSTRACTS

COMMENT ON “Arsenic Mobility and Groundwater Extraction in Bangladesh” (I)

Pradeep K. Aggarwal, Ashish R. Basu, Kshitij M. Kulkarni

Harvey et al. (Reports, 22 November 2002, p. 1602) concluded that irrigation pumping caused an influx of labile, carbon-laden recharge water in Bangladesh aquifers. In contrast, we present groundwater tritium data indicating similar vertical flow times in pre- and postirrigation pumping periods, and long-term water level records showing consistent seasonal fluctuations over a 30-year period.

Full text at www.sciencemag.org/cgi/content/full/300/5619/584b

COMMENT ON “Arsenic Mobility and Groundwater Extraction in Bangladesh” (II)

Alexander van Geen, Yan Zheng, Martin Stute, Kazi Matin Ahmed

Harvey et al. (Reports, 22 November 2002, p. 1602) claimed that elevated groundwater arsenic levels in Bangladesh are linked to water pumping for irrigation. This does not appear to be supported by their data and other data indicating high arsenic concentrations in groundwater recharged well before the onset of massive irrigation in the region.

Full text at www.sciencemag.org/cgi/content/full/300/5619/584c

RESPONSE TO COMMENTS ON “Arsenic Mobility and Groundwater Extraction in Bangladesh”


Hydraulic and geochemical data indicate that groundwater flow, and hence pumping, influence arsenic concentrations at our site. These data contradict the van Geen et al. claim that arsenic is mobilized in stagnant water and the Aggarwal et al. claim that flow is unaffected by pumping. Their contrasting regional generalizations, crafted with selected data from the same set, contain serious inconsistencies and ignore basic hydrologic processes.

Full text at www.sciencemag.org/cgi/content/full/300/5619/584d

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