Sustainability Science: Challenges for the New Millennium

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by

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I am honored and delighted to be here today at the launching of the Zuckerman Institute for Connective Environmental Research (ZICER). With many of my colleagues around the world, I look on ZICER as both as a grand new home for many of the uniquely strong programs in environmental science and policy that the University of East Anglia has nurtured over the years, and as an exciting experimental response to Lord Zuckerman's prescient call for "something absolutely new and fresh"[2] to harness the potential contributions of scientific research to the challenges of the day.

The Zuckerman Institute is the latest in a series of institutional and programmatic innovations emerging over the last decade in response to the growing recognition that science and technology must be more effectively mobilized to support a transition toward sustainability.[3] Under the impetus of the World Summit for Sustainable Development, held last year in Johannesburg, a substantial number of studies, workshops and conferences were held with the goal of exploring the most urgent priorities for narrowing the gap between knowledge and action in meeting the challenges of sustainable development.[4] I had the privilege over that period of working with several of the individuals present here today in the Initiative on Science and Technology for Sustainability -- an international effort to connect and integrate the findings of those many dialogues and committee efforts.[5] My goal in this presentation is to summarize what the efforts synthesized by the Initiative have identified as the most important challenges for innovative experiments such as the Zuckerman Institute that are seeking to discover how, in the words Director Kerry Turner has used in summarizing ZICER's mission, "to ensure that their research produces workable solutions" to the most important sustainability challenges of the day.

The sustainability challenge

What those challenges are is reasonably clear. To paraphrase a recent report I co-chaired for the US National Academy of Sciences, a transition is underway to a world in which human populations on earth are more crowded, more consuming and more connected than at any time in history. The good news is that the human population is well on its way to stabilization, and is unlikely to double again in the next century, despite having done so 3 times in the last. The less good news is that by the time population stabilizes, we will have added another 3-4 billion or so people to the planet, almost all of them in urban areas of the developing world. Meeting the most needs and wants of a population half again as large as today's implies greater production and consumption of goods and services; more demand for land, water, energy, and materials; and more stress on the world's environment and living resources. Can the transition toward a stabilizing population that will be experienced by our grandchildren also become a transition toward sustainability, in which they learn to shape a good life for themselves while helping to alleviate poverty and hunger in those less fortunate, and actively nurturing and restoring the planet's life support systems? Or will the other transition visible today be accentuated, with a small fraction of the planet's human population increasingly gated off in well-fed, air-conditioned comfort while its continuing demands for increased consumption continue to cook the planet, empty the seas, and poison the land from which everyone else will be expected to scratch an ultimately inhuman and unsustainable living?[6]

The contribution of science and technology

The community-wide dialogues to which I referred earlier shared the view that science and technology are central to both the origins of the sustainability challenge, and to the prospects for successfully dealing with it. Science and technology played a central role in bringing about the increases in agricultural yields and distribution systems that have helped to keep most of the world from famine… but only at the cost of significant environmental degradation. They brought us the CFCs that preserved our foods, cooled our homes… and depleted the ozone layer. But they also brought us the research and monitoring programs that raised the ozone alarm, and the substitute technologies that have allowed us to continue providing the services originally met through CFCs, but in a manner less damaging to the environment. Promoting similar transitions toward sustainability in the 21st century will require much more than improvements in the production and effective use of science and technology. But no serious analysis has suggested that it will be possible to meet the challenge of sustainable development without intelligent and effective use of science and technology to help do the job.[7]

The question is *how* society can better mobilize S&T to support and accelerate a transition toward sustainability. Frankly, no one knows. But a growing number of experiments are now underway to find out. In the South, these include institutions such as the African Center for Technology Studies, SE Asia's Unit for Social and Environmental Research, and India's Society for Research and Initiatives for Sustainable Technologies and Institutions. North America has a growing number of university-based projects such as Columbia University's Earth Institute and Stanford's Institute for the Environment. Europe has exhibited the most impressive and sustained public investments in science and technology for sustainability, supporting such ventures as the International Institute for Applied Systems Analysis, the Potsdam Institute, and, of course, UEA's School of Environmental Studies and its newly launched Zuckerman Institute for Connective Environmental Research.[8]

But however encouraging the number and variety of these experiments, they are just that: *experimental* responses to the need identified by Lord Zuckerman for "something absolutely new and fresh" in harnessing the sciences of the environment to the challenges of the day. As experiments, some of these ventures will -- and probably should -- fail. The trick, as always in experimental science, will be to recognize the failures early, to learn from them, and to get on with the job. To do this, however, will require some specific targets or criteria against which to measure progress, or the lack of it. Such targets will certainly need to be modified to reflect the particular circumstances of particular experiments in particular places. Nonetheless, it may be worthwhile for the individual experimenters – including those of you here at ZICER -- to have some shared vision of what the world is hoping that we, collectively, will produce. Such a consensus on what science for sustainability might seek to accomplish is what the dialogues I referred to earlier have been pursuing over the last several years, and to which I now turn.

How could S&T better support a transition toward sustainability?[9]

I begin with the sobering observation that the single dominant view of the dialogues noted earlier is that most of the experiments in S&T for Sustainability now underway will, a few years hence, have slipped back into doing their conventional research in conventional ways with only their names and funding sources changed. This is not to doubt the sincerity of the leaders of the experiments, but a simple observation on the number of fads that have swept the science community over the years, and the enormous conservatism of our disciplines, universities, funding organizations -- present company accepted -- and honorific academies in the face of those fads. There was, however, reasonable consensus among the participants in the sustainability dialogues of what would be needed to keep today's experiments focused on "the something new and absolutely fresh" required to advance sustainability. Among those to which we, the experimenters, might want to hold ourselves accountable are the following:

1) A goal of finding solutions, not just of characterizing problems. Decision makers, and development and conservation practitioners involved in our dialogues had great respect for the contributions made by science to identifying the hazards of unconstrained growth. But they also pointed out that the same scientists who would talk forever about problems often found other things to do when asked to participate in the dirty work of crafting workable solutions. This, of course, fits a long-standing (if pernicious and historically unjustified) academic prejudice for "fundamental" over "applied" work. Serious work on solutions – so nicely captured in Prof. Turner's characterization of ZICER – would seem to be a fundamental requirement for the "new and fresh" science of sustainability.

2) **An integrative, holistic approach to sustainability** instead of a preoccupation with single stressors (even climate change) or single solutions (even solar energy). This need for an integrative approach showed up in the dialogues in three complementary ways:

a) **Nature-society interactions**: A science that can systematically advance sustainability needs to be a science of the interactions between nature and society. It is not enough to maintain the traditional focus on one element of this pair while treating the other as an external constraint or forcing function. Rather, sustainability science needs to integrate natural and social science perspectives to better understand the dynamical interplay by which environment shapes society, and society in turn reshapes the environment.[10]

b) Place-based: One of the most robust findings of recent research and practice is that the greatest threats to sustainability are almost certainly not from single stressors such as climate change or biodiversity loss, but rather from the intersection and interaction of multiple stresses -- environmental and social -- coming together in specific regions and locals.[11] A useful science for sustainability would need to balance its conventional preference for universal truths with a deep commitment to engaging the unique sustainability challenges of specific places. The integrated work on coastal zone sustainability being pursued here in East Anglia through the Tyndall Center, ZICER and their collaborators is a good example of what the dialogues suggested is needed.

c) **Sectoral or service focus:** One of the greatest wastes of analytic effort in the sustainability debate has been the tendency to focus on the potential risks and benefits of particular technologies and behaviors, rather than the comparative risks of alternative technologies or behaviors for providing specified services. A useful sustainability science would spend little time trying to determine, for example, the (absolute) risks of genetic technologies, but lots looking at whether a choice of Bt-cotton, or cotton-plus-conventional pesticides, or polyester fibers was a more sustainable approach to providing the clothing fibers people want.

3) A third need to keep the science of sustainability "new and fresh" is **a commitment to the co-production of usable knowledge by scientists and stakeholders in sustainability.** It has become increasingly clear over the last decade that science no longer is automatically deferred to by society or decision makers on matters of practical importance. People remain prepared to change their behaviors or beliefs in response to new knowledge. Increasingly, however, they will do so primarily for new knowledge that they have had a hand in shaping. This may be as simple as participating in the formulation of questions to be asked by the experts, or having a say in who will sit on expert committees. It may be as fundamental as actually participating in the experiments on which experts base their conclusions. In any case, an effective science of sustainability will almost certainly need to be a science in which academics, government, business people and lay citizens see themselves vested in the production as well as the use of knowledge.[12]

4) A final and related point to emerge from the dialogues is that scientists – and scientific institutions – seeking to make a substantial contribution to sustainability will need to conduct themselves more as **facilitators of social learning and less as sources of social guidance**. Virtually anything worth doing to promote sustainability needs widespread support by multiple sectors of society to move forward. Virtually anything worth doing will be hard enough that it is likely to require multiple successive approximations to get it even approximately "right." Science has a great deal to contribute in helping society to design policy experiments from which it can learn, and in helping to design the monitoring and assessment systems necessary to carry through the learning. But this "facilitator" role has not always come easily to scientists, especially those brought up in an earlier tradition of "science advice to government."[13]

What methods and models would a useful science of sustainability need to develop?

Let me turn now from *how* science and technology might conduct itself in an effort to contribute to sustainability, to *what* the resulting research might do. I begin with a consideration of methods and models, before turning to possible priority areas for topical research.

1) Assessing sustainability: It is well established in the history of science that the methods we have shape the questions we ask, and thus the answers we get. Present methods for addressing the environmental impacts of human activities impose a bias toward treating sustainability problems as though they were merely technocratic exercises in forecasting the impact of single stressors on simplified systems with linear responses and minimal uncertainty. In fact, many of the greatest challenges to sustainability could not be more different from this method-driven cartoon: They involve multiple, interacting stresses; complex, non-linear responses; systemic uncertainty and multiple stakeholders. A serious effort to develop integrated assessment methods more appropriate to these real challenges of sustainability is needed. Such an effort would almost certainly have to engage qualitative approaches to the mathematics of complex systems, advances in numerical computation, and computer-aided visualization of results. And it would need to do so in ways that can engage the meaningful participation of stakeholders in sustainability, not merely communities of technical experts. A successful program in the developing and testing of methods for sustainability assessment would be one metric by which to evaluate the development of sustainability science over the next decade.

2) Measuring Sustainability: Assessment, however, can be no better than the measures of the state of the world on which it is based. When asked in the 1970s how economic science was most likely to contribute to improving policy-relevant forecasts over the coming decades, the Director of Britain's National Institute of Economic and Social Research noted recent improvements in computer models, but responded that "the main improvement [would] come… from knowing more accurately where the economy actually is…."[14] The same has been said for recent improvements in the forecasting of climate anomalies associated with El Nino and the Southern Oscillation. Analogously, we are unlikely to see a sustained impact of science on a transition toward sustainability until we have a stable, meaningful and well-grounded set of indicators and measurements that reflect more accurately where the coupled system of human well-being and the environment "actually is."

At present, a great variety of ad-hoc indicator systems about sustainability exist, one of the best of which is run by the UK government. We know, however, that indicator systems which have proven to be truly useful in guiding policy on volatile political topics -- systems such as the national income accounts, or the global temperature trends so famously assembled by UEA's Climate Research Unit -- have been grounded in coherent theory and exhibited a substantial degree of sampling and methodological sophistication. No operational set of sustainability indicators in use today has such properties, though the conceptual groundwork has been laid by such scholars as Cambridge's Partha DasGupta.[15] The challenge ahead is the hard work of matching general concept with specific needs and operational measurement, and doing so through participatory processes that bring multiple sectors of society to support the resulting product. Putting in place an operational system of scientifically credible, practically useful, and politically unbiased sustainability indicators could be a central objective of sustainability science over the next decade.

To what solutions should an effective program of S&T for sustainability contribute?[16]

A surprise from our dialogues was how different the priorities for sustainability problems and solutions were for different groups in different parts of the world. In fact, the dialogues' initial goal of producing a comprehensive set of "global" priorities was abandoned in favor of more regionally-attuned efforts. That said, however, three areas stood out as high on the priority lists for virtually every region involved in the dialogues. These topics therefore might be ones for which most of the ZICER-like "experiments" in sustainability science now underway might be expected to devote some serious attention:

1) Adaptiveness, vulnerability, and resilience in complex socio-ecological systems: Sustainability depends on building and maintaining the adaptive capacity needed to deal with the shocks, surprises, and longer-term structural transformations that are increasingly characterizing our world. Existing understanding of adaptiveness, vulnerability, and resilience has tended to adopt either nature- or society-oriented views of the world. Needed are new tools and concepts that facilitate management of these properties for the tightly linked socio-ecological systems that are at the heart of the sustainability challenge. Such understanding will have to address the embedding of particular socio-ecological systems – and their adaptive capacity – within larger regional and global contexts. John Schellnhuber, Neil Adger and others associated with ZICER are already playing leading roles in this important area of work.[17]

2) Sustainability in complex production-consumption systems: There have long been independent calls for deeper understanding of how the environmental impacts of production, on the one hand, and consumption, on the other, can be lowered. An important insight emerging from our dialogues is that the greater need is for an integrated understanding of the relations between consumption and production. These are becoming increasingly complex as globalization increasingly separates locations at which production and consumption occur. Incentives and technologies work on both ends of the production-consumption chain, and an integrated understanding of their impacts on sustainability is badly needed as a guide for targeting specific policies. This afternoon's seminar on "A sustainable energy economy", hosted by ZICER's long time advocate Sir Crispin Tickell, will explore current thinking in the one sector for which such integrated perspectives are perhaps most advanced.

3) Institutions for sustainable development: The systems of rules, procedures, and expectations that guide social interactions shape both the challenges of, and the opportunities for, sustainability. Experience reviewed in the dialogues makes it clear that the ability of our institutions to deal with the cross-scale aspects of interactions among politics, markets, and knowledge will be especially important in determining the prospects for sustainability. Our dialogues not only highlighted the wealth of experience in institutional experimentation that is underway around the world, but also revealed a deep thirst for systematic efforts to analyze comparatively and dispassionately the performance of those experiments, to identify how and under what conditions some institutions advance sustainability goals better than others, and above all to help the groups running the existing institutions to learn from one another. International forums on such as that being hosted by UEA's Professor Tim O'Riordan as part of this week's "Sustainability Days" celebrations are just the sort of beginnings that are needed.[18]

What reforms in our national and international systems of science and technology would be necessary to grow the global capacity for sustainability science?[19]

The challenges of sustainability are great, and urgent. Daring experiments such as ZICER and the others mentioned earlier are necessary early steps in harnessing the potential of science and technology to address those challenges. But moving a substantial fraction of the world toward a sustainability transition will need not one or a even a dozen ZICERs, but rather hundreds if not thousands of them. Crafting a strategy for creating such a global population explosion of ZICER cousins and descendents is a matter in need of careful thought and institutional attention. But it is worth contemplating as we head off to eat and celebrate how profoundly ZICER and its relatives are challenging the larger S&T establishment within which they are taking their unconventional and sometimes uneasy places:

* Who should ZICER -- and others like it that truly want to advance science for sustainability -- be recruiting as professional staff?

* Where should their students come from, and how should they be trained – in what combination of disciplines, and what combination of academic, government, and private practice?

* By what criteria should those training and working in ZICER-like institutions around the world be promoted and rewarded?

* Who will honor their most creative and productive members, in a world dominated by academic departments and conservative academies?

* Who will fund their work, as we move from a few experiments to the scale of investment necessary for the operational promotion of a world-wide sustainability transition?

* How will fortunate leaders like ZICER support the emergence of similar institutions in parts of the world most in need and least able to afford them?

I am enormously grateful to have had the opportunity to join you here today at the launch of this grand experiment that is ZICRE. As befits, I suppose, a sometimes researcher, I can hardly wait for the results.

Thank you.

ENDNOTES

[1] The author is Harvey Brooks Professor of International Science, Public Policy and Human Development at Harvard's Kennedy School. He can be reached at Kennedy School of Government, Harvard University, 79 Kennedy Street, Cambridge 02138 Massachusetts, USA; William_Clark@harvard.edu. This presentation draws heavily on collaborative work with colleagues in three area: 1) sustainability science (Research and Assessment Systems for Sustainability Program. 2003. "Science and Technology for Sustainable Development." *Proceedings of the National Academy of Sciences of the United States of America*. Special Feature. **100**(14): 8059-8091, http://sust.harvard.edu/pnas); 2) the Initiative on Science and Technology for Sustainability (http://sustainabilityscience.org/ists); and 3) the US National Academy of Sciences (United States National Research Council, Board on Sustainable Development. 1999. *Our Common Journey: A Transition Toward Sustainability*. Washington, D.C.: National Academy Press, http://www.nap.edu/catalog/9690.html). I am indebted to a large number of collaborators in each of these efforts for their insights, patience and work.

[2] Letter from Lord Zuckerman to Sir Christopher Ingold in 1960, quoted from pg. 591 of P.L. Krohn. 1995. "Solly Zuckerman." *Biographical Memoirs of Fellows of the Royal Society* 41: 576-598.

[3] The case has been made, among others, by the Third World Network of Scientific Organizations (TWNSO), http://www.ictp.trieste.it/~twas/TWNSO.html; the Commission on Science and Technology for Sustainable Development in the South (COMSATS), http://www.comsats.org.pk; the Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI), http://www.sristi.org/; the South Center http://www.southcentre.org/ (see particularly the *Elements for an Agenda of the South: Report of the NAM Ad Hoc Panel of Economists*, section 4 on "science and technology" at http://www.southcentre.org/papers/nam/namfinal-02.htm#P287_47302). See also policy statements by the International Foundation for Science (IFS), http://www.ifs.se/index.htm; the International Science Programme (ISP), http://www.isp.uu.se/Home.htm; and the Millennium Science Initiative (MSI), http://www.msi-sig.org/MSI-SIG_summary.htm. Scholarly works making the case for the role of knowledge in sustainable development include a series of Annual Reports by the German Advisory Council on Global Change (WGBU), has also been influential in shaping the argument, particularly its *World in Transition: The Research Challenge, Annual Report 1996*. Berlin: Springer-Verlag, 1997, http://www.wbgu.de/wbgu_publications.html; World Bank. 1998. *Knowledge for development: The World Development Report for 1998/9*. Oxford: Oxford Univ. Press; H. J. Schellnhuber and V. Wenzel, eds. 1998. "Earth System Analysis: Integrating Science for Sustainability." Berlin: Springer-Verlag; S. Funtowicz and M. O'Connor, eds. 1999. "Science for sustainable development." Special issue of *International Journal of Sustainable Development* 2: 3.; United States National Research Council, Board on Sustainable Development. 1999. *Our Common Journey: A Transition Toward Sustainability*. Washington, D.C.: National Academy Press, http://www.nap.edu/catalog/9690.html; African Academy of Sciences' *Tunis Declaration: Millennial Perspective on Science, Technology and Development in Africa and its Possible Directions for the Twenty-first Century* (Fifth General Conference of the African Academy of Sciences, Hammamet, Tunisia, 23-27 April 1999), http://www.unesco.org/general/eng/programmes/science/wcs/meetings/afr_hammamet_99.htm.; UNESCO. 1999. *World Conference on Science for the 21st Century: A new commitment*. Paris: UNESCO http://www.unesco.org/bpi/science/content/press/anglo/4.htm; C. E. Rocha-Miranda, ed. 2000. "Transition to Global Sustainability: The Contributions of Brazilian Science." Rio de Janeiro: Academia Brasiliera de Ciências, http://sustainabilityscience.org/keydocs/brazilsci.htm; Science Council of Japan. 2000. *Towards a comprehensive solution to problems in education and the environment based on a recognition of human dignity and self-worth*. Science Council of Japan; Royal Society. 2000. *Towards sustainable consumption: A European perspective*. London: The Royal Society; J. D. Sachs. 2000. "A new map of the world." *The Economist* 355: 81-83 (24 Jun 2000); United Nations Development Program. 2001. *Making new technologies work for human development: The Human Development Report 2001*. Oxford: Oxford Univ. Press.

[4] Many of these are summarized in International Council for Science, Initiative on Science and Technology for Sustainability, and Third World Academy of Sciences. 2002. *Science and Technology for Sustainable Development: Consensus Report and Background Document for the Mexico City Synthesis Workshop on Science and Technology for Sustainable Development, 20-23 May 2002.* ICSU Series on Science for Sustainable Development, No. 9. Paris: ICSU. http://www.icsu.org/Library/WSSD-Rep/Vol9.pdf (cited hereafter at ICSU/ISTS/TWAS 2002). I prepared the background paper for the Mexico City conference drawing on the individual reports of many of the meetings summarized there. I draw extensively on that report, and thus on those who participated in the meetings, in the present paper.

[5] The Initiative on Science and Technology for Sustainability is an open-ended network that seeks to enhance the contribution of knowledge to environmentally sustainable human development around the world. (http://sustainabilityscience.org/ists). The Initiative was founded in late 2000 by an independent group of scholars and development practitioners gathered at the Friibergh Workshop on Sustainability Science (see R. Kates et al., 2001. "Sustainability science," *Science* 292: 641-2.). Among other activities, it runs the *Forum on Science and Technology for Sustainability*, a web-based activity that seeks to highlight principal publications, programs, and people involved in the field: http://sustainabilityscience.org.
[6] The preceding paragraph is a combination of quote, paraphrase and extension from the US National Research Council, Board on Sustainable Development. 1999. *Our common journey: A transition toward sustainability.* (Washington, DC: National Academy Press), pg. 1. http://www.nap.edu/catalog/9690.html; See also Schellnhuber, H. J. 1999. "Earth System Analysis and the Second Copemican Revolution." *Nature* **402** SUPP.: C19-C23. http://www.pik-potsdam.de/nature_supp_esa.pdf .
[7] The preceding paragraph is paraphrased from what the Consensus Report of the Mexico City Synthesis Conference on Science and Technology for Sustainability, op. cit. as ICSU/ISTS/TWAS, 2002, pg. 5.
[8] Many of the programs and institutions active in this area are summarized on "Programs" page of the Forum on Science and Technology for Sustainability at http://sustainabilityscience.org/links.htm. Additional information on the programs cited here can be found at http://www.acts.or.ke/index.htm, http://www.sristi.org/, http://cesp.stanford.edu, http://www.earthinstitute.columbia.edu/, http://www.uea.ac.uk/zicer/.
[9] This section draws extensively on ICSU/ISTS/TWAS, 2002, op. cit.
[10] See, for example, National Science Foundation Advisory Committee on Environmental Research and Education 2003. *Complex Environmental Systems.* Natl. Science Foundation, Washington, DC.
[11] See especially National Research Council, (op. cit.), pg. 8; Kates et al., op. cit.; WGBU, op. cit.
[12] For this and the next item in the list, see Cash, David W., William C. Clark, Frank Alcock, Nancy M. Dickson, Noelle Eckley, David H. Guston, Jill Jäger, and Ronald B. Mitchell. 2003. "Knowledge Systems for Sustainable Development." *Proceedings of the National Academy of Sciences of the United States of America* **100**(14): 8086-8091. http://ksgnotes1.harvard.edu/BCSIA/sust.nsf/pubs/pub81
[13] See Social Learning Group. 2001. *Learning to manage global environmental risks. Vols. 1,2.* Cambridge: MIT Press. http://www.ksg.harvard.edu/sl/ .
[14] Quoted in T.W. Hutchison. 1977. *Knowledge and ignorance in economics.* Oxford: Blackwell, p. 26.
[15] For a review of existing indicator systems, see National Research Council, op cit. A solid conceptual framework is set out, but not implemented, in Partha Dasgupta. 2001. *Human well-being and the natural environment.* Oxford: Oxford Univ. Press.
[16] This section draws extensively on ICSU/ISTS/TWAS, op. cit.
[17] For recent efforts to integrate natural and social science perspectives, see Turner, B. L., II, Roger E. Kasperson, Pamela A. Matson, James J. McCarthy, Robert W. Corell, Lindsey Christensen, Noelle Eckley, Jeanne X. Kasperson, Amy Luers, Marybeth L. Martello, Colin Polsky, Alexander Pulsipher, and Andrew Schiller. 2003. A Framework for Vulnerability Analysis in Sustainability Science. *Proceedings of the National Academy of Sciences of the United States of America* **100**(14): 8074-8079. http://ksgnotes1.harvard.edu/BCSIA/sust.nsf/pubs/pub82.
[18] T. O'Riordan, ed. Forthcoming. *Governance for sustainability: A workshop within the UEA Sustainability Week, Friday 5 September 2003.* Zuckerman Institute for Connective Environmental Research, Norwhich.
[19] This section draws on ICSU/ISTS/TWAS, op. cit.; Clark, William C. 2003. "Research systems for a transition toward sustainability," in W. Steffen, J. Jäger, D. J. Carson, and C. Bradshaw, eds. *Challenges of a Changing Earth. Proceedings of the Global Change Open Science Conference, Amsterdam, The Netherlands, 10-13 July 2001.* Berlin: Springer-Verlag, http://sustainabilityscience.org/keydocs/fulltext/BC_ResSys_Amsterdam02.pdf ;and Cash, David W., William C. Clark, Frank Alcock, Nancy M. Dickson, Noelle Eckley, David H. Guston, Jill Jäger, and Ronald B. Mitchell. 2003. "Knowledge Systems for Sustainable Development." *Proceedings of the National Academy of Sciences of the United States of America* **100**(14): 8086-8091, http://ksgnotes1.harvard.edu/BCSIA/sust.nsf/pubs/pub81.

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