Sustainability science: The emerging research program

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The last decade has witnessed the emergence of an array of increasingly vibrant movements to harness science and technology (S&T) in the quest for a transition toward sustainability. These movements take as their point of departure a widely shared view that the challenge of sustainable development is the reconciliation of society's development goals with the planet's environmental limits over the long term. In seeking to help meet this sustainability challenge, the multiple movements to harness science and technology for sustainability focus on the dynamic interactions between nature and society, with equal attention to how social change shapes the environment and how environmental change shapes society. These movements seek to address the essential complexity of those interactions, recognizing that understanding the individual components of nature–society systems provides insufficient understanding about the behavior of the systems themselves. They are problem-driven, with the goal of creating and applying knowledge in support of decision making for sustainable development. Finally, they are grounded in the belief that for such knowledge to be truly useful it generally needs to be "coproduced" through close collaboration between scholars and practitioners. The research and applications program that has begun to emerge from these movements has been called "sustainability science"[†] by the National Research Council (1). This Special Feature highlights this emerging program and some of the new results it is beginning to produce.

The need for sustainable development initiatives to mobilize appropriate science and technology has long been recognized. Early research on sustainable yield management of renewable resources provided the foundation for the International Union for the Conservation of Nature's seminal *World Conservation Strategy*, published in 1980. The case for making appropriate research and development (R&D) an integral component of sustainable development strategies was broadened by a number of international scientific organizations during the mid-1980s, promoted by the Brundtland Commission's report *Our Common Future* in 1987, and enshrined in the Agenda 21 action plan that emerged from the United Nations Conference on Environment and Development in 1992. Over the succeeding decade, the discussion of how S&T could contribute more effectively to sustainability intensified, involving numerous researchers, practitioners, scientific academies, and development organizations from around the world (2). By the time of the World Summit on Sustainable Development, held in Johannesburg in 2002, a broadly based consensus had begun to take shape on the most important ways in which S&T has already contributed to sustainability, on what new R&D is most important, and on what stands in the way of getting it done (3–8).

Sustainability science focuses on the dynamic interactions between nature and society.

Many of the most valuable contributions of S&T to sustainable development predate the term itself. These range from the "mundane technologies" that have improved delivery of basic needs for sanitation and cooking (9), through the yield-enhancing, land-saving accomplishments of the international agricultural research system (10), to the fundamental scholarship of geographers and anthropologists on nature–society interactions (11). In more recent times, a host of R&D efforts explicitly aimed at promoting sustainability have been launched. These extend from a rich tradition of work on energy systems (12) and ecosystem resilience (13) to new initiatives in industrial ecology (14) and earth system complexity (15). A feel for the breadth and scope of relevant R&D now underway around the world is suggested by the rapidly growing list of entries on the virtual "Forum on Science and Technology for Sustainability" (16).

However, much remains to be done. Perhaps the strongest message to emerge from dialogues induced by the Johannesburg Summit was that the research community needs to complement its historic role in identifying problems of sustainability with a greater willingness to join with the development and other communities to work on practical solutions to those problems. This means bringing our S&T to bear on the highest-priority goals of a sustainability transition, with those goals defined not by scientists alone but rather through a dialogue between scientists and the people engaged in the practice of "meeting human needs while conserving the earth's life support systems and reducing hunger and poverty" (17). At the international level, the Johannesburg Summit, building on the United Nations Millennium Declaration, has defined these priorities in terms of the so-called "WEHAB" targets for water, energy, health, agriculture, and biodiversity (18, 19). A more systematic study of internationally sanctioned goals and targets for a sustainability transition, together with an evaluation of the state of reporting and assessment on progress in attaining those goals, is provided by Parris and Kates in their contribution to this Special Feature (20). As important as this international consensus on goals and targets may be for targeting problem-driven research in support of a sustainability transition, however, it is not sufficient. A joint workshop held by the International Council for Sciences, the Third World Academy of Science, and the Initiative on Science and Technology for Sustainability concluded that "agenda setting at the global, continental, and even national scale will miss a lot of the most important needs. . . . The transcendent challenge is to help promote the relatively 'local' (place- or enterprise-based) dialogues from which meaningful priorities can emerge, and to put in place the local support systems that will allow those priorities to be implemented" (21). Where such systems exist, the production of usable, place-

Abbreviations: S&T, science and technology; R&D, research and development.

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[†]The term "sustainability science" has been controversial, connoting to some a mature discipline with shared conceptual and theoretical components that most certainly does not exist. One alternative descriptor is "the science of sustainability," which conveys the notion of multiple sciences addressing a common theme. Our use of "sustainability science," like that of the National Research Council, carries this last meaning.

based knowledge for promoting sustainability has been impressive indeed.

The commitment of sustainability science to problem-driven agenda setting does not mean that it has been confined to "applied" research. Indeed, pursuit of practical solutions to the pressing challenges of sustainability has driven the field to tackle an array of fundamental questions. The Friibergh Workshop on Sustainability Science (5) identified a half-dozen such core conceptual questions that have been further developed through the virtual Forum on Science and Technology for Sustainability (22) and are beginning to appear in the context of emerging agendas in other more established fields, such as global environmental change (23). Examples of the new sorts of research now beginning to emerge on several of those core questions are reported elsewhere in this Special Feature: Kates and Parris (24) on "How are long-term trends in environment and development reshaping nature–society interactions in ways relevant to sustainability"; Turner *et al.* (25, 26) on "What determines the vulnerability or resilience of the nature–society systems in particular kinds of places and for particular types of ecosystems and human livelihoods?"; and Cash *et al.* (27) on "How can today's relatively independent activities of research planning, observation, assessment, and decision support be better integrated into systems for adaptive management and societal learning?" The sustainability science program is also beginning to address a range of fundamental observational and methodological challenges. For example, H. J. Schellnhuber and his colleagues at the Potsdam Institute for Climate Impact Research have developed innovative new answers to the question "How can the dynamic interactions between nature and society—including lags and inertia—be better incorporated in emerging models and conceptualizations that integrate the Earth system, human development, and sustainability?" (28). Wolfgang Lucht, writing in the *IHDP Update*, summarizes current work on answering "How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?" (29). And a number of groups are calling for reexamination of national and international social account measures to include sustainability considerations.

Activities to advance the sustainability science program are moving forward on a number of fronts and at scales from the global to the local. One of the more up-to-date lists of programs and projects is maintained on the Forum on Science and Technology for Sustainability (30). As an indication of the range of activities underway internationally, the International Council for Science, Third World Academy of Sciences, Initiative on Science and Technology for Sustainability, and other organizations have formed a Consortium for promoting a coordinated international program of research, capacity building, and applications. The Earth System Science Partnership of the Global Environmental Change Programmes has launched a series of "Joint Projects on Sustainability" focused on problems of food security, water, and carbon management. An increasing number of international science assessments for environmental protection (e.g., the Intergovernmental Panel on Climate Change and Millennium Ecosystem Assessments) are incorporating sustainability concerns. And a rapidly expanding set of multistakeholder "Partnerships for Sustainable Development" are developing in the wake of the Johannesburg Summit (31). An even greater variety of S&T-based efforts are underway at the local, regional, and national levels around the world. The research products of some of these efforts are beginning to appear in the published literature, although many of the relatively local results remain largely unknown beyond their places of origin and application.

Sustainability science is not yet an autonomous field or discipline, but rather a vibrant arena that is bringing together scholarship and practice, global and local perspectives from north and south, and disciplines across the natural and social sciences, engineering, and medicine. Its scope of core questions, criteria for quality control, and membership are consequently in substantial flux and may be expected to remain so for some time. Nonetheless, as the papers included in this Special Feature are meant to suggest, something different is surely "in the air," something that is intellectually exciting, practically compelling, and might as well be called "sustainability science."

The set of papers introduced here is dedicated to Jeanne X. Kasperson, a longstanding scholar of human–environment studies, especially those dealing with risk, hazards, and vulnerability. Jeanne was a member of the Research and Assessment Systems for Sustainability Program that produced this set and an author of the paper on vulnerability. Jeanne passed away unexpectedly in 2002. This work was supported by a grant from the National Science Foundation (BCS-0004236), with contributions from the National Oceanic and Atmospheric Administration's Office of Global Programs for the Research and Assessment Systems for Sustainability Program (http://sust.harvard.edu).

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