Harnessing science, technology and innovation for sustainable development

A report from the ICSU-ISTS-TWAS Consortium *ad hoc* Advisory Group

This report was produced by the Ad Hoc Advisory Group to the Consortium on S&T for Sustainable Development, which was established and sponsored by three international scientific organizations – ICSU, ISTS, and TWAS. This report is an independent assessment that is being submitted to the three sponsoring organizations; it represents the views and recommendations of the Advisory Group members, not necessarily those of the sponsoring organizations.

ICSU: The International Council for Science

Founded in 1931, the International Council for Science is a non-governmental organization representing a global membership that includes both national scientific bodies (103 members) and international scientific unions (27 members). The ICSU 'family' also includes more than 20 Interdisciplinary Bodies - international scientific networks established to address specific areas of investigation. Through this international network, ICSU coordinates interdisciplinary research to address major issues of relevance to both science and society. In addition, the Council actively advocates for freedom in the conduct of science, promotes equitable access to scientific data and information, and facilitates science education and capacity building. [http://www.icsu.org/index.php]

ISTS: The Initiative on Science and Technology for Sustainability

The international Initiative on Science and Technology for Sustainability was founded in 2001 in response to the call of the October 2000 Friibergh Workshop on Sustainability Science for a flexible means to pursue three broad and interrelated goals: expanding and deepening the research and development agenda of science and technology for sustainability; strengthening the infrastructure and capacity for conducting and applying science and technology for sustainability; and connecting science and policy more effectively in pursuit of a transition toward sustainability. The Initiative has evolved as an open-ended network of individuals committed to these goals. [http://sustainabilityscience.org/ists]

TWAS: The Academy of Sciences for the Developing World

The Academy of Sciences for the Developing World (formerly known as the Third World Academy of Sciences) was founded in Trieste, Italy, in 1983, by a distinguished group of scientists from the South under the leadership of the late Nobel laureate Abdus Salam of Pakistan. TWAS is a knowledge-based institution promoting scientific excellence in developing countries. The Academy, at its core, consists of an extensive network of scientists throughout the South who are key actors for the implementation of sustainable development policies both in developing countries and as participants in international research initiatives. Together with the Third World Network of Scientific Organizations (TWNSO), the Third World Organization for Women in Science (TWOWS) and the Inter-Academy Panel on International Issues (IAP), TWAS helps countries in the South build scientific and technological capacities that contribute directly to sustainable economic development. [http://www.twas.org/]

Additional copies of this report may be obtained from:

ICSU, 51, boulevard de Montmorency, 75016 Paris, France
Tel. +33 (0)1 45 25 03 29 • Fax +33 (0)1 42 88 94 31 • secretariat@icsu.org

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Preface

It is increasingly clear that current business-as-usual trajectories of development are unsustainable, both in their inadequacy of fulfilling the social and economic development needs of billions of inhabitants of the planet, and in the dangers they pose to environmental resources and life-support systems (United Nations, 2002; Dasgupta, 2003; MA, 2003). In some cases, impacts of human activities have reached planetary proportions and are pushing the Earth system into unprecedented states, or 'uncharted territory' (Steffen et al., 2004). And yet at the same time, many positive developments are occurring in society. Improvements in health and education, gains in life expectancies and living standards, more opportunities for information sharing, and environmental remediation in many places across the globe, are just a few examples.

Science and technology (S&T) have been important forces behind both positive and negative development trends. Although S&T by itself does not hold the power to achieve the goal of greater sustainability (since individuals and institutions must choose if and how to use the information and knowledge produced by S&T), it is nonetheless essential for providing options and informing decisions that enable society to move towards more sustainable pathways. In doing so however, it is important to examine closely the ways in which social institutions, processes, and values shape the priorities of research and development, and the conditions under which its potential benefits can be reaped.

Sustainable development is a subject of enormous complexity that has been written about in countless publications. In this report, we do not attempt to reinvent the existing body of work with an in-depth discussion of the definition and goals of sustainable development. Rather, this report focuses on the question of how a partnership of international organizations can help to integrate a broader set of perspectives into the workings of the S&T communities, and can help these communities not only to generate new knowledge, but also to implement robust solutions to society's most pressing development challenges.

The ad hoc Advisory Group that was convened to carry out this task (see Annex 1) brought together specialists from fields as diverse as ecology, economics, political science, public health, and engineering, and from many different cultural backgrounds in both developing and industrialized nations. Forging effective communication and consensus among such a diverse group, over the course of a few brief meetings, was a challenge that required bridging different disciplinary languages and research methods, as well as different personal perspectives and value systems. Among the Advisory Group members, and among all of those people who reviewed the Advisory Group's draft report, there was a broad array of opinions about the roles that S&T can and should play in addressing major sustainability concerns. Although it was not possible to forge a complete consensus among this tremendous diversity of perspectives, we have attempted in this report to capture the themes that most people viewed as essential.

The Advisory Group has suggested that ICSU[1], ISTS[2], and TWAS[3] (the three organizations that established the Advisory Group) can play a valuable role by creating new channels for open dialogue between the producers and the end-users of scientific and technical knowledge, and by fostering new types of thinking about holistic, systems-oriented approaches to research and innovation for sustainable development. These organizations have unique, complementary roles within the international S&T community. They have the potential to stimulate a multitude of locally-driven initiatives, and to reshape the playing field of S&T efforts worldwide.

The report discusses the needs for new ways of doing business within the realms of science and technology, for instance, by creating participatory processes for defining research priorities; by

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[1] The International Council for Science (ICSU): www.icsu.org/
[2] The Initiative for Science and Technology for Sustainability (ISTS): sustainabilityscience.org/
[3] Academy of Sciences for the Developing World (TWAS): www.twas.org/

integrating indigenous knowledge and grassroots technological innovation into formal research and development (R&D) endeavors; and by changing the incentive systems that structure the habits, practices, and norms of the research community. These suggestions are motivated by the fact that in some parts of the world, there is a widespread view of modern S&T as a largely a market-driven enterprise, dominated by an excessive technological optimism, with research agendas that often do not address the hardships faced by billions of impoverished people around the world. Regardless of whether or not one agrees that such criticisms are justified, it is increasingly clear that more public engagement is needed in order to address these barriers of distrust, and to build more robust partnerships with all of the world's societies. If progress is to occur, such issues must, at a minimum, be openly and respectfully debated within scientific and engineering communities.

It is in this spirit that the Advisory Group submits this report, in the hope that it will constructively facilitate a new and productive level of collaboration among international organizations that recognize the importance of science, technology, and innovation in support of sustainable development. It is a major challenge, but also an exciting opportunity, for scientists and engineers to harness their knowledge and creative capacity to contribute to the goals of sustainable economic development, environmental stewardship, and improved and equitable human well-being.

Hebe Vessuri

(Ad hoc Advisory Group, Co-Chair)
Instituto Venezolano de Investigaciones Científicas
Caracas, Venezuela

Robert Corell

(Ad hoc Advisory Group, Co-Chair)
American Meteorological Society,
Washington, D.C., USA

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The Advisory Group's work was greatly enhanced by the contributions of people who participated as invited guests at the meetings (listed in Appendix 1), those who reviewed the Advisory Group's draft report, and those who contributed via informal discussion and consultation. Financial support for this effort came from the Social Sciences Directorate of the U.S. National Science Foundation, and from the David and Lucille Packard Foundation. Each of the three organizations that convened the Advisory Group – ICSU, ISTS, and TWAS – generously hosted meetings; and the ICSU Secretariat played an especially valuable role as an organizational base for the Advisory Group's efforts. We give special thanks to the Secretariat staff who contributed most directly to these efforts – including Rohini Rao for administrative and logistical support, and Laurie Geller for her critical role in strategic planning and report development, without which this report would not have been possible.

Executive Summary

In this report, we present the Advisory Group's views on the fundamental principles that should underlie efforts to harness science and technology for sustainable development. We first present a conceptual framework for understanding the relationships among the different types of activities and stakeholders involved in these efforts. This framework emphasizes the need to view the creation of new scientific information and technical capabilities as part of an experimental, social process in which the producers and end-users of scientific and technical knowledge interact to identify R&D priorities, and to translate knowledge into real-world action.

We suggest a set of initial priorities for issues where greater scientific understanding and technical capacity is most critical. This includes four broad cross-cutting themes: Resilience and Vulnerability of Social-Ecological systems; Governance Institutions for Sustainable Development; Sustainable Production and Consumption; and the Role of Behaviour, Culture, and Values. Many existing R&D programmes are addressing these issues, but there is a need to augment such efforts with place-based, systems-oriented investigations that not only bridge divides among natural science, social science, and engineering disciplines, but that also integrate 'formal' R&D efforts with 'informal' grassroots knowledge and innovation.

There are numerous ways in which international scientific organizations can contribute to the development of new R&D efforts worldwide, and can help enhance the capacity of all nations to engage in such efforts. This includes greater mutual support of existing activities, and active contributions to new efforts such as the UN Decade on Education for Sustainable Development. We suggest, however, that a key role for the Consortium organizations (operating either as individual entities, or in a formal partnership) is to create an ongoing mechanism for convening dialogues among natural scientists, social scientists, engineers, and the wide array of societal actors who have the potential to utilize new scientific and technical information for addressing problems of sustainable development. The goal of these dialogues is share information and perspectives, and to develop common agreement on priorities for future R&D efforts. This must be a long-term, evolving process that develops in response to new input and changing needs. The Multi-Stakeholder Dialogue process that takes place within the meetings of the UN Commission on Sustainable Development could provide an excellent platform for building such efforts. In the longer-term, this could become a high-profile activity that attracts tremendous public interest, and that is seen as a central 'hub' of knowledge, leadership, and exchange of new ideas among the global community.

Context for this report

1.1 FORMATION OF THE CONSORTIUM AND THE ADVISORY GROUP

There are numerous definitions of sustainable development, but for reference we begin with the classic 'Brundtland' definition of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This simple statement belies the vast and complex nature of the challenges that must be addressed, ranging from profligate overconsumption in many industrialized countries to crushing poverty in many developing countries. A common way to describe the goal of sustainable development, which is particularly useful in the context of this exercise, is the effort to balance and integrate the three 'pillars' of environmental protection, economic growth, and social well-being.

Sustainability concerns have occupied a place on the global agenda since at least the 1980s, with publication of the International Union for the Conservation of Nature's World Conservation Strategy (IUCN, 1980) and the Brundtland Commission's Our Common Future (WCED, 1987). Calls for strengthening S&T programmes focused on sustainable development have been growing over the past two decades. Two particularly important milestones were the 1992 United Nations Conference on Environment and Development (UNCED) and the 2002 World Summit on Sustainable Development (WSSD).

In the UNCED Agenda 21 (UN, 1993), a number of Major Groups were identified to move towards real partnerships in support of common efforts for sustainable development. One of the nine groups identified as vital for this process was the Scientific and Technological Community. The International Council for Science (ICSU) and the World Federation of Engineering Organizations (WFEO) were invited to represent the S&T community in preparation for and at WSSD. ICSU and WFEO, in turn, invited the InterAcademy Panel for International Issues (IAP), the Academy of Sciences for the Developing World (TWAS), and the International Social Science Council (ISSC) to join in the efforts to provide input to the WSSD preparatory meetings (PrepComs II[4] and IV[5]). ICSU also published the 'Rainbow' Series on Science for Sustainable Development (ICSU, 2002-3,a-k).

The submissions to WSSD argued that science must become more policy relevant, that research agendas must be defined through broad-based participatory approaches, and that gender equality in science must be promoted. The S&T community called for a new contract between S&T and society, including the following crucial components: (i) improving education and capacity building, (ii) bridging the North-South divide in scientific and technological capacity, (iii) developing clean technologies and sustainable production and consumption patterns, (iv) transforming governance institutions to ensure incorporation of the best available scientific and technological knowledge, (v) establishing long-term monitoring systems, and (vi) augmenting financial resources for S&T for sustainable development. At the summit itself, the S&T delegation participated actively in all parts of the proceedings, and S&T played a substantial role in the overall agenda of the WSSD through a series of workshops, seminars, and presentations.

In addition to the formal input to the preparatory process, a workshop jointly organized by ICSU, TWAS and the Initiative on Science and Technology for Sustainability (ISTS), was held in Mexico City in May 2002, to review the results of more than a dozen regional studies and workshops (See Annex 2) focused on the question "How can science and technology contribute more effectively to

Box 1

THE MILLENNIUM DEVELOPMENT GOALS

In September 2000, the United Nations General Assembly adopted the Millennium Declaration (http://www.un.org/millennium/declaration/ares552e.htm) which included a set of Millennium Development Goals (MDGs). The MDGs are a set of specific targets to: (1) Eradicate extreme poverty and hunger, (2) Achieve universal primary education, (3) Promote gender equality and empower women, (4) Reduce child mortality, (5) Improve maternal health, (6) Combat HIV/AIDS, malaria and other diseases, (7) Ensure environmental sustainability, and (8) Develop a global partnership for development. The MDGs represent an important, widely-shared initial vision of sustainable development, and they can serve as useful guideposts for the efforts of the science and engineering communities -- recognizing, of course, that S&T has more to contribute to some of these goals than others; and that in general, such goals represent only a starting point for the developments that need ultimately to be achieved. We emphasize also that simple, single-dimension analyses of progress in achieving the MDGs can be misleading, since in some cases, the means that are used to achieve this progress (such as heavy reliance on foreign development aid) are not themselves sustainable.

[4] *Dialogue paper by the scientific and technological communities: Role and contributions of the scientific and technological community to sustainable development. UN E/CN.17/2002/PC.2/&/Add. 8.*

[5] *Dialogue paper by the scientific and technological communities: Science and technology as a foundation for sustainable development. UN A/CONF.199/PC/18/Add. 8.*

achieving society's goals of sustainable development"? The synthesis report from the Mexico City workshop became a key input for the WSSD (ICSU, 2002-3,i).

It is from this successful foundation at WSSD that ICSU, ISTS, and TWAS decided to continue their collaborative exploration of ways to more effectively harness S&T for sustainable development. The leadership of the three organizations began informal discussions in early 2002 about forming a Consortium on S&T for Sustainable Development. The agenda that emerged from the Mexico City workshop and the WSSD was taken to the respective General Assemblies (or equivalent) of the three organizations for discussion and endorsement. At a meeting in November 2002, representatives of ICSU, ISTS and TWAS agreed to establish an ad hoc Advisory Group that would develop recommendations for:

- A process for harnessing the perspectives from a broad range of local, sectoral, regional and international efforts now underway to enhance the contribution of science and technology to sustainable development;
- A research and development agenda and a programme of activities that will promote problem-driven research and development, and the capacity-building necessary to carry out such work; and that will link research and development to actions that facilitate sustainable development;
- Strategies and mechanisms that would more fully enable the Consortium members jointly and individually to address the challenges and opportunities in harnessing science and technology for sustainable development;
- A draft plan of implementation for the programmatic and operational activities, including funding aspects.

The Advisory Group, established in early 2003, was formed as an international, interdisciplinary panel of scholars and practitioners, including both social scientists and natural scientists, and representatives of developing and industrialized countries (see Annex 1 for membership list and Terms of Reference). The Advisory Group has developed the ideas and recommendations contained in this report over the course of four meetings, in July 2003 (Paris, France), January 2004 (Paris, France), June 2004 (Laxenburg, Austria), and October 2004 (Trieste, Italy).

1.2 DEPARTURE POINTS FOR THE CONSORTIUM'S EFFORTS

As discussed in Lubchenco (1998), public funding support for the scientific enterprise has traditionally been predicated upon an expectation that scientific research will contribute to the achievement of goals that society has deemed important. This basic role has not changed over the years, but the needs of society have changed dramatically. To meet these needs, the scientific and technological communities must provide new kinds of knowledge and new ways to apply this knowledge. In order to play an effective role in addressing the challenges of sustainable development, the S&T enterprise needs to closely examine its own culture and modes of operation. Too often our visions of the future emphasize only the opportunities of new S&T applications, without due regard to potential unintended consequences. Further, compartmentalization among disciplines, and a linear model of the research enterprise ('science discovers, technology applies') pose a risk of separating the objectives of S&T from the needs of the underprivileged and the aspirations of society at large.

Cutting-edge scientific and technological developments will continue to rest upon the foundation of basic disciplinary research; but at the same time, there is a paradigm shift emerging that calls for more creative forms of collaboration between scientists and society, and for a broader range of disciplines and competencies to take part in the process (Jasanoff et al., 1997). There are encouraging signs that, on many fronts, the S&T enterprise is already evolving towards new paradigms of operation. For instance, advances in complex system modeling and integrated assessment methodologies are providing new opportunities to overcome traditional disciplinary compartmentalization, and to aid decision-making under conditions of persistent uncertainty. International and interdisciplinary scientific assessments (such as the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, and Arctic Climate Impact Assessment) offer opportunities for integration of knowledge across a broad range of disciplines and development experiences, and involving an array of stakeholders. Progress in information technology and infrastructure (especially the continuing rapid development of Internet access) offer new opportunities for knowledge sharing, and for giving a voice to groups that have traditionally been in the geographical, institutional, or disciplinary periphery of the S&T enterprise.

These new modes of operation, when combined with ongoing creative efforts within the basic disciplines, offer tremendous potential to extend and deepen the role of S&T in meeting the profound needs of a more sustainable future. These evolving paradigms highlight the critical role of innovation, the mechanism by which scientific findings and technological advances are implemented as productive contributions to society (see Box 2).

As a result of such developments, sustainability-related research efforts will likely be perceived as increasingly relevant to political and social needs, and as able to deliver practical results for society. There is evidence that many countries are now attempting to incorporate sustainable development principles into national policies and planning (e.g., Iceland, 2002), but such efforts generally lack rigorous methods for defining and measuring progress towards sustainability. Focused S&T efforts can help develop methodologies and approaches that make the concepts of sustainability more demonstrable and measurable (for instance, see the SCOPE Assessment of Sustainability Indicators: www.icsu-scope.org) for all levels of decision-making within government, industry, and civil society.

There is also a need to develop a greater constituency for such efforts within the S&T community itself. In order to attract the brightest young scientists and engineers to new types of interdisciplinary, sustainability-focused research, this must be seen as an intellectually stimulating and a professionally rewarding realm of endeavour. At the same time, it is clearly essential to combine these integrated approaches with an ongoing commitment to excellence in traditional disciplinary-based research.

The Advisory Group believes that the research foci and recommendations proposed herein will have a strong and complementary relationship with efforts in the realm of global change research. Over the past two decades, global change research has led to countless new insights about the magnitude and rate of human-driven changes to the Earth System, and the degree to which the Earth is a highly complex, interconnected system, with 'teleconnections' that link changes in one part of the world to impacts elsewhere. Among the key players in this work are the four Global Change Research Programmes -- the International Geosphere-Biosphere Programme (www.igbp.kva.se), the International Human Dimensions Programme in Global Environmental Change (www.ihdp.org), the World Climate Research Programme (www.wmo.ch/web/wcrp/wcrp-home.html), and DIVERSITAS, an international programme on biodiversity science (www.diversitas-international.org). In addition, these programmes have developed START (www.start.org), a programme which seeks to build regional networks of scientists and institutions in developing countries.

Recently, the Global Change Research Programmes have joined together to form the Earth System Science Partnership (ESSP: www.ess-p.org), with four initial joint projects for analysis and advanced modeling, including the Global Carbon Project, the Global Water System Project, the Global Environmental Change and Food Systems project, and the Global Change and Human Health project that is currently under development. These efforts are explicitly focused on questions of global sustainability, and thus will undoubtedly play an important role in addressing some of the research needs discussed herein. Whatever actions emerge from this report should be closely integrated with these ongoing global change research activities.

Box 2

SCIENCE, TECHNOLOGY AND INNOVATION

It has become common practice to speak of science and technology for sustainable development, but we suggest that this paradigm should be expanded to encompass the concept of innovation. Innovation can be described as the means by which individuals and groups apply their creative, adaptive capacities and their social, organizational, and institutional knowledge for the generation and application of new scientific and technical knowledge. Innovation is a broadly-inclusive term that can encompass the work of both formal S&T enterprises, and the informal, grassroots ideas and inventions of people not associated with official institutions. The complementary, interdependent nature of these different concepts means that they must be considered in concert. Thus we refer herein to 'Science, Technology, and Innovation' for Sustainable Development (STI for SD). Similar terminology has been adopted by other related bodies such as the UN Millennium Project Task Force on Science, Technology, and Innovation (www.unmillenniumproject.org).

2 A framework for harnessing science, technology and innovation for sustainable development

2.1 ELEMENTS OF THE FRAMEWORK

In this section we present a general conceptual framework to illustrate the interrelationships that exist among the various efforts needed for effectively harnessing STI for SD, and the ways in which an evolving research agenda can be integrated into this framework. Figure 1 is a matrix that illustrates the different types of activities, and different levels of integration among these activities, that should occur over a broad continuum of spatial and temporal scales. For the sake of simplicity, we specify three main spatial scales at which action may take place: global, national, and local. Time scales are represented in the various feedback pathways.

- Column 1 refers to the identification of the most urgent sustainability problems, the factors that drive these problems, and the consequent needs and priorities for new knowledge and technical capabilities.
- Columns 2 - 4 refer to the R&D activities needed for producing new knowledge and technical capabilities; and Column 5 refers to efforts to strengthen integration across these different disciplinary realms.
- Column 6 refers to the efforts that are required for linking 'knowledge' and 'action' communities; that is, the interaction among those who generate, and those who ultimately apply, new scientific and technical knowledge.
- Column 7 refers to the actual implementation of new knowledge and technical capabilities by different societal actors, such as policy makers, natural resource managers, industry, and society at large.

Different activities will map onto different spaces within this framework, and the total amount of sustainable development achieved is a function of the degree of effort that takes place across these various types and scales of activity. Some elements of the framework represent both actions and important areas of research. For instance, social science research is needed to advance the knowledge-to-action efforts of Column 6; specifically, to better understand how scientific and technical information is transmitted and applied by various social groups, and to identify the political and cultural barriers that can keep this

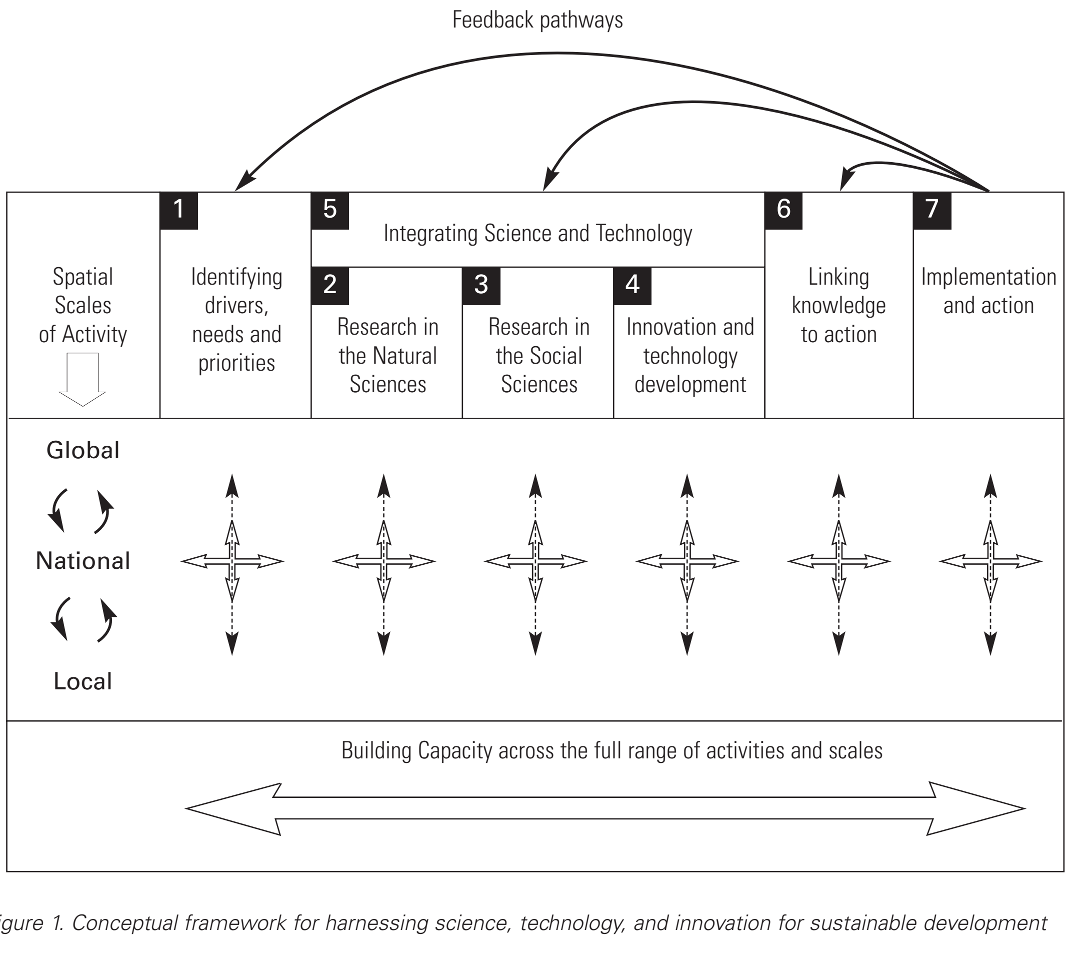

Figure 1. Conceptual framework for harnessing science, technology, and innovation for sustainable development

information from being transmitted or applied.

This framework is aimed at conveying the critical importance of linking across different scales of interaction. Locally focused studies and actions are often of limited value if they do not account for the larger-scale forces that affect immediate, local dynamics. Development specialists often cite this limited understanding of cross-scale interactions as one of the main obstacles to progress. For instance, in our rapidly globalizing world, the decisions made by international organizations such as the WTO can have major impacts upon the livelihood of small-scale farmers and entrepreneurs around the world. Conversely, the actions of individual consumers aggregate to become major driving forces in regional-to-global scale sustainability problems. Developing research and assessment approaches that can capture these complex, cross-scale dynamics poses a central challenge[6].

The proposed framework highlights the role of rigorous scientific analysis and input (Columns 2 - 6) as important intermediate steps in moving from recognition of a problem (Column 1) to the implementation of actions that address the problem (Column 7). This is necessary for ensuring that response actions are based on a clear understanding of the different response options available and the possible consequences of these various options.

This should not be viewed as a simple linear process, but rather, as a highly interactive framework. Although the work of science and engineering communities may focus primarily on basic R&D efforts (Columns 2 - 5), they should also strive towards a broader conception of their role, one that encompasses greater participation in the communication and implementation efforts of Columns 6 and 7. Likewise, it is essential that the various end-users in Column 7 play an active role throughout, from identifying and defining the problems to be addressed, to evaluating and communicating research results, to developing solutions and management policies.

Given the scales and complexity involved, such efforts need to be considered in an experimental, adaptive management context. Solutions that are simply handed over to the end users are not likely to be effective. It is necessary to view the creation of new knowledge not as an end in itself, but as part of an experimental, social process in which producers and users interact with each other to shape the broader purpose of R&D efforts. The iterative nature of these interactions should be emphasized as well. The actions taken in Column 7 will, over time, change the nature of the problems to be addressed; and thus the identification and prioritization of activities must be an ongoing, evolving process. Figure 2 depicts an alternative view of the conceptual framework,

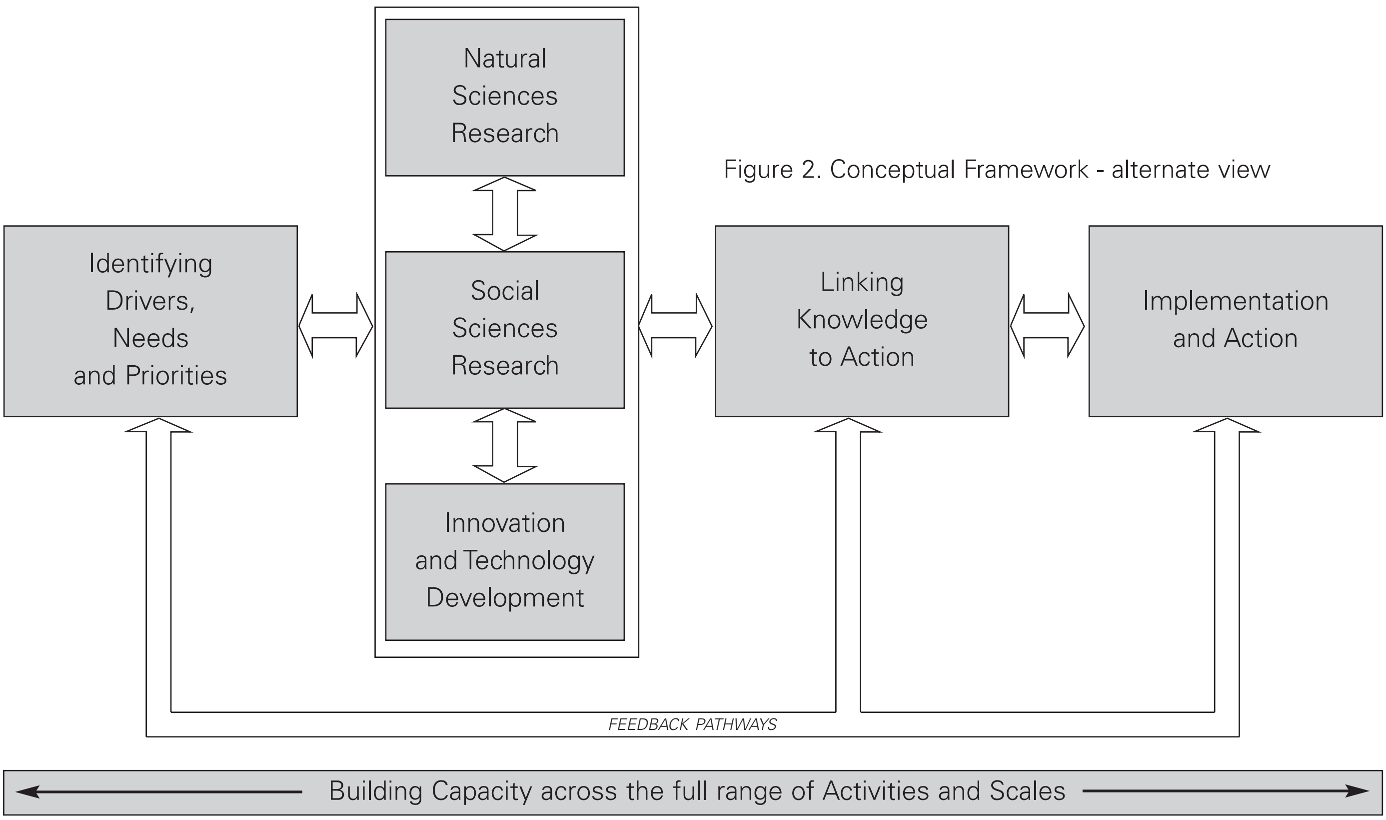

Figure 2. Conceptual Framework - alternate view

[6] *The MA offers some encouraging examples of multi-scale assessments. For instance, see the Southern African Sub Global Assessment (www.millenniumassessment.org/en/subglobal.safma.aspx) and the proceedings of the conference 'Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Multi-Scale Assessments' (www.millenniumassessment.org/en/about.meetings.bridging.aspx).*

emphasizing the temporal nature of the processes involved.

In the following sections, we examine in greater detail some of the central elements of this framework, including priorities for an R&D agenda, the challenges of linking knowledge to action, and the cross-cutting needs for building capacity.

2.2 SUGGESTED 'RESEARCH FOR DEVELOPMENT' PRIORITIES

The Advisory Group was asked to suggest an initial set of research priorities from among the vast array of sustainable development issues for which attention is needed. As discussed earlier however, we suggest that the identification of research priorities must be a broad-based, participatory process that incorporates perspectives from well beyond the confines of the research community itself. The Advisory Group did not have the resources or mandate to carry out this type of extensive outreach effort; and thus as an alternative strategy, we chose to build upon the results of a series of regional priority-setting workshops organized as part of the WSSD preparatory efforts (see Annex 2 for details). In these workshop discussions, a few general topics consistently emerged as high priority concerns across almost all regions and across widely varying development circumstances. These were the issues of: (i) Resilience and Vulnerability, (ii) Sustainable Production and Consumption, and (iii) Governance and Institutions. These three topics are thus suggested here as initial research priorities. In addition, the Advisory Group agreed on the importance of highlighting a fourth general set of issues - Behaviour, Culture and Values - that represent an important area of research, and an underlying factor in essentially all aspects of sustainable development.
Each of these topics is discussed further in the following sections.

2.2.1 Resilience and Vulnerability of Social-Ecological Systems

People and nature interact in dynamic social-ecological systems that are adaptive and sometimes self-organizing, that exhibit non-linear, emergent behaviour, and that have characteristic dynamics that play out at various spatial and temporal scales with strong cross-scale interactions. Understanding the linkages across these scales is essential to understanding environment-human interactions. Failure to do so lies at the heart of many of the world's most pressing problems.
In developing a framework for assessing and understanding the long term dynamics of social-ecological systems it is therefore useful to envision the world as consisting of hierarchies of multi-scale social-ecological systems behaving as complex adaptive systems (ICSU 2002-3c). In such a framework, sustainable development requires the enhancement of three social-ecological system capacities: resilience[7], adaptability, and transformability .

Box 3

CROSS-SCALE AND CROSS-DOMAIN THRESHOLD EFFECTS IN SOCIAL-ECOLOGICAL SYSTEMS

Evidence emerging from comparisons of a variety of social-ecological systems -- an agricultural region in southern Madagascar, irrigated agriculture in SE Australia, sheep farming and cheese production in central France, wheat farming in Western Australia (Kinzig et al., in prep.) -- emphasises the importance of interactions of thresholds across different scales, and across different domains (ecological, economic, and social). Each region has either changed, or has the potential to change, from one system regime to another (known as a 'regime shift'). The propensity for a regime shift, and the nature of the new system regime, are a consequence of the interactions amongst the three different kinds of thresholds (ecological, economic, social), at three different scales: a fine (patch) scale, a mid- (farm) scale, and a regional (community) scale.

An example: In a dry forest region of southern Madagascar, levels of forest disturbance and degree of isolation are combining to produce a threshold beyond which the forest patch cannot self organise. At the farm scale, levels of crop production are determined by insect pollination. The pollinators live in the forest patches. Below a certain level of pollination, production of insect-pollinated crops fails, and the farm economy can thus fail, usually resulting in replacement by people from outside the region. At the region scale, the system of forest patch maintenance depends on social cohesion. This is because the patches are all sacred forests, and as the proportion of newcomers increases, the religious control over entry into and use of forests weakens. There is a likely threshold in the proportion of newcomers, above which control suddenly collapses. As forest patches disappear, connectivity between them decreases, further reducing the capacity for self-maintenance. The nature and pattern of the regime shifts within this agricultural social-ecological system depends upon the interactions amongst these various threshold effects.

[7] *Resilience is the capacity of a system to absorb disturbance and re-organise while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks. Adaptability is the capacity of actors in the system to manage resilience, by changing the 'stability landscape' of the system or controlling the trajectory of the system. Transformability is the capacity to become (or to create) a fundamentally different system when ecological, social and/or economic conditions make the existing system untenable (Walker et al., 2004).*

Building resilience of a desired system regime requires enhancing the social, ecological, and economic processes that enable it to reorganize following a disturbance (and conversely, reducing those processes that tend to undermine this re-organizational capacity). It must be recognized, however, that resilience is not always desirable. System regimes that decrease social welfare (e.g., polluted water supplies, political dictatorships) can be highly resistant to change. A sustainability framework must therefore also account for situations in which social well-being will be enhanced by lowering resilience, and perhaps even transforming the system into some other, completely different system (Walker et al., 2004).

A core aspect of resilience is the existence of thresholds between alternate states of a system (more generally termed system 'regimes'). There are many examples of regime shifts across thresholds, as evidenced by a developing thresholds database (Walker and Meyers, 2004). Though almost all of these published examples are of single thresholds in a system (ecological, social, or social-ecological), sustainable development in whole social-ecological systems is likely to be strongly influenced by interactions amongst different kinds of thresholds occurring at different scales (see Box 3).

A related concept - vulnerability - is increasingly visible on the international agenda. Vulnerability assessment is aimed at determining the risk of specific adverse outcomes for a particular group or unit of concern, in the face of a variety of stresses, and identifying factors that may reduce the response capacity and adaptation to stressors. Significant progress has been made in the past decade in understanding vulnerability in multi-stress contexts, making detailed local case studies, and designing broad integrative analyses (e.g., Turner et al., 2003a and 2003b). But further progress is needed on many fronts, including understanding cross-scale relationships; linking structural and behavioural approaches to testing and validating indicators; and perhaps most importantly, development of conceptual frameworks for comparison and integration of the hundreds of existing local case studies in order to create integrated, structured knowledge.

The concepts of resilience and vulnerability are closely connected, since the vulnerability of a social-ecological system to stresses and perturbations depends on its adaptive capacity and resilience. One outcome of the research advocated here will be to clarify these relationships through comparative studies that examine the dynamics of vulnerability and resilience for specific social-ecological systems. Examples of important questions that can be addressed through such studies include:

- What are the general attributes of social-ecological systems that promote or diminish resilience, adaptability and transformability, and how do they relate to those identified as important for vulnerability?

- For a particular social-ecological system, are there alternate regimes in which the system can exist? If so, along which variables do the thresholds between these regimes occur? What determines the positions of the thresholds? Can human intervention influence the positions of thresholds, and thereby make the system more or less resilient?

- What types of coping mechanisms, institutional arrangements, and innovations have different communities developed to manage resilience and reduce vulnerability? How can these mechanisms be enhanced and maintained to favour sustainable development?

2.2.2 Sustainable Production and Consumption

There are huge differences between the per-capita consumption levels of wealthy and poor societies around the world[8]. In industrialized nations, consumption of household goods, energy, and other materials has reached very high aggregate levels, which is placing tremendous stresses upon the environment and natural resource bases. In contrast, in many developing countries, large segments of the population struggle with under-consumption of food and other basic needs, posing serious health concerns and limiting prospects for creative, productive livelihoods.

In recent decades, considerable attention and resources have been devoted to technology-oriented approaches to reduce pollution and increase efficiencies of material and energy use. These are critically important efforts, but in terms of achieving transitions to sustainability, it is necessary to develop a more holistic understanding of production/consumption systems. For instance, questions about consumer decisions (including the role of both individuals and institutions) require far greater attention. Although research on this issue has thus far been highly fragmented and hampered by disciplinary barriers, a number of interesting research approaches have been developed; for instance:

- Measuring the resources consumed to support people's lifestyles in terms of 'ecological footprints'[9] (Wackernagel and Rees,1996);
- Evaluating the values and attitudes that drive consumption-related behaviour and lifestyle (de Sherbinin and Curran, 2004);
- Studies focusing on households and settlements as primary units of analysis, since this is the level at which most consumption decisions are made;

[8] As an indication of the wide range of differences across the globe, note that average per capita GDP ranges from >$30,000/annum for the high-income OECD countries to < $1300/annum for the least developed countries (UNDP, 2004).
[9] Ecological footprints research has been controversially debated, in particular with respect to issues of measurement and usefulness for policy, but inasmuch as the work builds on earlier efforts to estimate carrying capacity, it remains a potential methodology to account for the externalities of human activity.

- Systems analyses that are place-based, but at the same time, that consider the globalization of production/consumption cycles (for instance, that examine how consumption patterns of industrialized countries are linked to the export of natural resources from developing countries)[10];
- Production/consumption systems through a life-cycle approach (Hertwich, 2003), which refers to the life cycles of products, from the extraction of raw materials, through processing, distribution, use, and disposal.

The United Nations Environment Programme (Division of Technology, Industry, and Economics) has numerous activities for promoting environmentally-sound technologies and industrial management practices, and building worldwide linkages among industry leaders and experts in clean, efficient production technologies. Such efforts could be greatly enhanced by engaging a broader segment of the S&T community to work on these issues. For instance, sociological analyses are needed to understand how advertising and the popular media influence consumer choice and the 'aspiration gap' (i.e., the distance between what people currently have and what they feel they need). Economic and political science studies are needed for developing efficient mechanisms to monitor and/or control aggregate levels of consumption and resource use. Input from fields such as ecology and biogeochemistry are needed, to develop a systems perspective on how energy and materials flow through particular places and production/consumption cycles. And of course, there is an ongoing need for chemists, physicists, and other basic sciences to continue advancing technologies for 'decarbonization, dematerialization, and detoxification' of energy and material cycles.

This issue can provide interesting opportunities to reverse the traditional knowledge sharing roles of developing and industrialized countries (typically seen as a one-way, North-to-South flow of information). The South perspectives are needed to help analyze consumption-related behaviour and values, and to help the North countries develop policies and practices for curbing excessive consumption levels.

Some key questions in consumption/production research include:

- How are material 'wants' created? What are the primary determinants that drive wasteful, over-consumption behaviour? How can the values that encourage unsustainable consumption be changed?
- What kinds of policies have been effective at decoupling improvements in well-being from increasing consumption of energy and materials?
- What are the major patterns and trends of social, economic and environmental change related to consumption/production systems. What are the vulnerabilities of important consumption/production systems to these changes?
- What new tools and methodologies are needed for robust comparative studies of production/consumption systems?
- What are the roles of institutions, new technologies and innovation in influencing the dynamics of consumption/production systems?
- What are the sustainable development implications of incipient trends such as green consumerism, diet changes, stricter product labelling, etc.?

2.2.3 Governance Institutions to Foster Transitions Towards Sustainability

Institutions for governance[11] and for developing incentive structures are an essential ingredient of any strategy for achieving sustainable development. Effective institutions must be able to: (a) lengthen the time horizons for which individual and societal decisions are made, (b) broaden the orientation of governments to the needs of the many over the long-term, (c) enable individuals, firms, governments, and entire societies to consider short-term sacrifices that offer long-term improvements, and (d) include the capacity for rapid, constructive response to evidence of unsustainability of a certain course of action.

Social science research (e.g., from political science, economics) has provided numerous insights about many of these issues, for instance: about the social and political conditions and the types of institutions that are associated with lengthening of time horizons for collective decision-making; about the circumstances that foster diffusion of desirable governance practices, and the barriers that can prevent effective institutions from being adopted; and about the ways in which governments gain and maintain popular support, and the circumstances under which these dynamics can shift the attention of narrowly-based governments to broader concerns about social, economic, and environmental sustainability.

The qualities of governance that are most likely to foster sustainable development are hard to establish and maintain. Yet our increasingly interconnected world presents many new opportunities for influence, synergy, and cooperation across national boundaries, which improves the possibilities for building appropriate institutions, even in inhospitable settings. It must be acknowledged, however, that even when effective institutional arrangements and incentives are in place, a successful transition to sustainability requires citizens that place a high priority upon meeting such goals. And thus,

[10] For example, see studies of shrimp aquaculture systems in South-east Asia (Lebel et al., 2002); the wheat system of the Indo-Gangetic plains (www.gecafs.org); the IHDP project on Industrial Transformation (Vellinga, 2002).
[11] "Governance" as used here refers to whatever arrangements are used to govern a group or for a group to govern itself. This may range from self-organized self-governance to autocratic, oppressive governance, and thus by necessity includes considerations of the distribution of political power. In using this term we do not mean to imply "apolitical" management, though the term is perceived to mean this in some communities.

as argued in the following section, issues of behaviour, culture, values must also be considered.

In defining a research agenda from which we can learn how to improve the design and adoption of effective institutions for sustainability, some key issues include the following:

- The *globalization of world markets* has greatly increased interactions among global, national, and local institutions, for instance, increasing the vulnerability of small scale producers to fluctuations in commodity prices occurring at the international level. Does globalization of trade offer any self-correcting features that can help reduce risk and vulnerability where it is now most severe, or that can offer the possibility of using institutions such as the WTO as an international instrument for advancing sustainability?
- What are the impacts of *rapidly rising power and influence of multi-national corporations and financial institutions*? What mechanisms are available to monitor and possibly to govern their behaviour? Might these globally interconnected organizations offer an effective vehicle for transmission of new ideas and technologies for enhancing sustainability?
- We are also seeing a *globalization of civil society and networks of non-governmental organizations and advocacy groups*. The changing balance of power between formal institutions and informal knowledge networks (due in large part to the revolution in ICT capabilities) could affect the diffusion of policies and new institutional forms. Can international alliances among NGOs promote national-level policy reforms on issues related to sustainable development? Does globalization offer new opportunities for broader diffusion of local-level technical innovations that contribute to sustainability?
- There is much to learn from *common property regimes*, wherein communities have developed institutions to share the use, management, and sometimes ownership of natural resource systems. There are numerous individual case studies of common property regimes, but very few studies that incorporate multiple cases and that allow us to test causal hypotheses about what makes for good design, what kinds of communities acquire and maintain these arrangements, what kinds of resources these arrangements seem best suited for, and how these systems behave over time. Comparative and longitudinal studies are needed, involving both natural and social scientists, to help disentangle causal relationships.
- There is growing enthusiasm for *participatory decision-making* in the environmental arena and other realms, but we do not yet fully understand the effectiveness or ultimate impacts of these participatory processes. What are the attributes of effective systems for negotiating trade-offs, resolving conflicts, and taking into account multiple interests in decision-making about development strategies? Do these methods actually improve the quality of decisions being made? Do they enhance social learning?
- Sustainability also requires that societies have a good system for *responding to crisis and shocks*. What types of institutions and governance arrangements are most effective for dealing with low-probability / high-consequence events, slowly emerging problems, situations of high uncertainty, and circumstances involving severe disagreements over values?
- There is mounting evidence that informal *social networks* among individuals and groups within a community are an important complement to formal institutions for governance. These networks can act as agents of change that bridge formal institutional boundaries; and they provide a critical means for community members to interact and develop bonds of trust. Understanding the dynamics of such networks is a rapidly developing research area. There is likewise a growing appreciation of the need to view *learning and leadership as dynamic, evolving processes* (within both formal institutions and informal social networks), and as critical determinants of a community's ability to adapt to changing social, economic, and environmental conditions.

2.2.4 The Role of Behaviour, Culture, and Values in Sustainable Development

The challenge of effectively harnessing STI for SD requires linking the universal aspirations of science to the diverse realities of social life embedded in different cultural contexts. Culture and values define our goals, frame our attitudes, and provide standards against which the behaviour of individuals and societies can be judged. Social systems are characterized by their values, from which are derived norms, that is, concrete patterns of action that can include legal norms (maintained by a special apparatus of adjudication and sanctioning), moral norms (located in the conscience of the individual), and a wide range of social norms. The change over time of prevailing norms and values is influenced by numerous forces, including social structures and power relations, and personal perceptions and identification processes.

There are growing efforts to identify global norms and values with regard to issues such as human rights and environmental protection. At the same time, the globalization of markets is driving demands for new concepts of global governance and regulatory norms. The Millennium Development Goals represent an affirmation of values associated with human, as opposed to purely economic, development. The fundamental elements of the Millennium Declaration (UN, 2000) - *freedom, equality, solidarity, tolerance, respect for nature, and shared responsibility* - can be viewed as a statement of core values needed for a transition to sustainable development.

As discussed in Kates et al. (2003): "The last 50 years have also seen extraordinary changes in values, attitudes, and actual behaviour. The World Values Surveys (www.worldvaluessurvey.org) have marked a generational transition in many countries from 'traditional' to 'modern' and most recently 'postmodern' values that include the values underlying the great attitudinal and behavioural shifts in sex and reproduction, the role of women, the environment, and human rights. Economic development tends to push societies in this common direction, but societal values, rather than converging, seem to move on parallel tracks distinctly shaped by their cultural heritages."

The needs for scientific investigation of this topic are discussed in Mabojunge (2004): "Most advocates of sustainable development recognize that for it to be realized would require changes in human values, attitudes and behaviours... Despite the importance of such value changes, however, relatively little is known about the long-term global trends in values, attitudes, and behaviours that will both help or hinder a sustainability transition. There are a number of isolated studies which attempt to show how integrated conservation and development projects have, over the medium term, assisted in changing local attitudes and behaviour, but global data on sustainability values, attitudes and behaviour, however, do not exist."

Improving our understanding of the ways in which behaviour, values, and culture relate to sustainable development is a challenge that requires long-term evaluation and monitoring studies. Examples of questions to be addressed include:

- What explains the huge variance of values and norms over space and time? How are values and norms being affected by trends such as globalization of popular culture?
- What values are important for achieving sustainability, and what do we know about the prevalence and trends of these values? How can the needed value changes be brought about?
- How can a balance be achieved between the values of what should be sustained (e.g., nature, community) and the values of what should be developed (e.g., people, economy)?
- What are the individual and the socially mediated factors that influence and determine personal choice and behaviour with respect to patterns of consumption?

Box 4

INTEGRATING DIFFERENT FORMS OF KNOWLEDGE

In addition to the study of culture and values within society at large, it is important to consider the culture and values of the research community itself, as this affects the choices that are made regarding what to observe and study, and what types of information are considered to be legitimate knowledge.

History provides a rich record of the ways in which knowledge undergoes transformation and exchange between different cultures, and between 'certified', empirical science and traditional systems of knowledge and innovation. These exchange processes are an integral part of the generation, growth, and diffusion of knowledge in the world. In order to effectively address the complex challenges of sustainable development, scientists and engineers need to engage in open, constructive dialogue with a broad diversity of cultures, and recognize that a great deal of relevant, locally-based expertise resides outside of the formal research community. Layman experts harbor valuable knowledge about local experiences and perspectives, and can contribute information and insights to scientific investigations. In other words, those who experiment with and develop solutions to local sustainability problems in the 'laboratory of life' should be engaged as an important complement to formal, institutional S&T.

Some scientific disciplines, such as anthropology and ecology, are increasingly seeking to facilitate the recovery and exploration of local knowledge and traditions that exist among cultures around the world. An encouraging example of this integrated approach can be found in the Convention of Biological Diversity (http://www.biodiv.org) , which acknowledges the existence of a rich body of knowledge about ecosystem change and management practices developed through local, traditional knowledge systems. Likewise, the Millennium Ecosystem Assessment (MA, 2003) argues that it makes little sense to exclude knowledge just because it is not certified through formal S&T institutions. A reason why some efforts at reducing poverty and stimulating development have failed (and in fact, have had damaging effects upon the communities being targeted) is because they have favored the indiscriminate influx of modern technical 'fixes' from industrialized to developing societies. Effective development efforts often require encouraging autochthonous, locally-driven solutions, and the judicious dissemination of technologies and strategies that build upon local knowledge and innovation.

This co-production of knowledge -- through close collaboration among scholars, practitioners, and lay experts --- is a necessary but difficult challenge. It requires that all parties involved make serious efforts to express their knowledge in a fashion that is comprehensible and meaningful to those beyond their social/professional peers; and it requires effective mechanisms for judging the quality of the information that is used (ICSU 2002-3d; MA 2003). At the same time, one must vigilantly guard against misappropriation and misuse of indigenous knowledge and grassroots innovations. The growing interest in intellectual property rights associated with the use of locally cultivated biological resources is an example of a positive step forward in confronting the ethical and cultural dimensions associated with the sharing of scientific knowledge.

- How are lifestyle patterns related to sustainability determined and changed?

2.2.5 Technological Innovation for Sustainable Development

Technological innovation plays an important role across the full range of issues described in the previous sections, and is highlighted here because of its critical relevance to both short and long-term economic, societal, and environmental sustainability. Technological innovation can be seen as a double-edged sword with respect to sustainable development. There is no doubt that much of the improvement in human welfare over the past century can be accounted for by technological innovations in areas such as public health and agriculture. But at the same time, many of the world's critical sustainability problems are unintended consequences of technological developments, especially those aimed at increasing production and extraction of natural resources.

In some cases, the primary need is to enhance implementation of existing technologies; but in other cases, the magnitude and fundamental characteristics of the challenges to be addressed are so great that radical technological advancements are required (for instance, with respect to the challenge of meeting the world's growing energy demands in a sustainable manner). Depending upon the issue involved, the scale of required efforts ranges from international-level technology development and dissemination programmes, to grassroots innovations driven by individuals or communities at the local level.

A recent report from the UN Millennium Project Task Force on Science, Technology, and Innovation (Juma and Lee, 2005) provides a detailed discussion of the challenges and opportunities related to technological innovation, especially with respect to the needs of developing countries. The Millennium Project report highlights many of the same issues discussed within this Advisory Group report; for instance, the need for strengthening and re-orienting science and engineering education and training; the need for mechanisms to provide sound scientific and technical advice to policy makers; and the need for new institutions and governance mechanisms for managing the benefits and risks of science and technology developments. In addition, the report highlights issues such as the following:

- One of the fundamental problems hindering reduction of poverty and the achievement of other development goals in many countries is the lack of adequate infrastructure for basic services such as electric power, transportation, communications, and sanitation. The development of such infrastructure should be viewed as a dynamic technological learning process, and a critical opportunity for integrating technological considerations into development goals.
- Most countries distinguish between R&D policies that focus on the generation of new knowledge, and industrial policies that focus on building and manufacturing capabilities. Convergence of these two approaches could foster the expanded use of existing technologies, while also building a foundation for long-term R&D efforts. This requires paying particular attention to technologies that have broad applications and profound implications for long-term economic transformation (for instance, ICT, biotechnology, nanotechnology, and new materials).
- Creating links between knowledge generation and enterprise development is one of the most important challenges facing developing countries. There are a variety of ways in which governments can help stimulate small and medium-sized enterprises; for instance, by supporting business and technology 'incubators', export processing zones, and production networks that allow small enterprises to pool business services and labor pools. Targeted taxation regimes and market-based instruments, and a wide variety of strategies for unlocking financial capital, are needed to create and sustain enterprises that contribute to sustainable development.

The list above is by no means comprehensive, but it illustrates the depth of the challenges that need to be addressed, and provides a valuable foundation for further analysis of the role of technological innovation in sustainable development.

2.2.6 The Research Agenda: Conclusions

The research themes discussed in the preceding sections are each complex topics that cut across almost all major sustainable development concerns, and that are also inextricably linked to each other. An example of these interlinkages is discussed in Box 5. We thus emphasize that these issues should be viewed as parts of an integrated whole, rather than as isolated areas of research.

The overall research agenda is aimed at addressing questions of critical importance to policy-makers, development specialists, and the public at large. Such questions are most effectively addressed through a 'research for development' approach, in which solutions for local priority problems are sought, and the more generic, principle-based solutions are then derived from a multi-site, multi-country analysis of these local solutions. In many cases, it will be important to consider data at scales above and below that of the target system, in order to identify the driving forces or the ultimate impacts of the problem in question. This will contribute to the development of robust indicators of sustainable development, and to efforts to monitor and predict the sustainability pathways of selected social-ecological systems. Decision makers at appropriate levels must be involved in all stages of research, and the research must be geared towards providing practical options, solutions, and operational means of attaining sustainability goals. The goal of this research is not just to gain a better understanding of the sustainability problems that exist, but also to identify and evaluate options for solving these problems.

All of the issues identified here are, to varying degrees, the focus of attention from existing research organizations and programmes. For instance, issues related to the resilience of social-ecological systems are addressed by the Resilience Alliance (www.resalliance.org/ev_en.php); issues related to governance institutions, and sustainable production and consumption, are addressed by the IHDP Institutional Dimensions of Global Environmental Change project and Industrial Transformation project (http://130.37.129.100/ivm/research/ihdp-it/index.html), respectively. There is clearly a need for this work to expand, and additional R&D activities should be designed to build upon and complement existing efforts. For instance, globally-focused research programmes can be enhanced by fostering more local- to regional-scale analyses. Research efforts that currently reside exclusively within the scientific community can be greatly enhanced by forging closer linkages with economic development specialists. And in general, there is a need for greater emphasis on integrating and communicating the results of existing research efforts.

International organizations such as ICSU, ISTS, and TWAS are not the most appropriate entities for carrying out small, targeted R&D activities that address specific sustainability problems in specific places. At the same time, the creation of new international-level, centralized research programmes (akin to the types of structures created in the global change research arena) is not necessarily an effective strategy, since the tremendous diversity of sustainable development issues that must be addressed are all highly embedded within local political and cultural contexts. Rather, as discussed in Section 2.5,

Box 5

INTEGRATED RESEARCH ON SUSTAINABILITY CHALLENGES IN URBAN DEVELOPMENT

As an example of how the proposed research themes can be applied in an integrated fashion to real-world concerns, we look to the sustainability challenges associated with urban development.

The emergence of ‘city clusters’ or ‘megacity corridors’ is an entirely new phenomenon in the history of humankind. Strings of interconnected cities, in which human interactions are enabled by high capacity transport and communication infrastructures, have emerged almost on all continents. In the year 2000, it is estimated that the ten largest megacity corridors were inhabited by some 360 million people, including for instance the Baltimore-Washington corridor in the U.S., and the Shinkansen corridor in Japan, with 30 and 40 million inhabitants respectively. Over the coming decades, an urban corridor could emerge on the east coast of China with a population approaching 100 million. Due to their sheer size and high population density, these urban corridors overwhelm the capacity of local environments to provide water, energy, and dissipation of wastes of the urban metabolism. In addition, the unprecedented magnitude and pace of human and capital mobility occurring within these urban complexes has a wide variety of social and economic implications.

Much of this rapid urban development (including eight of the world’s ten largest megacities) is occurring in coastal zones, areas that are home to some of the world’s most fragile ecosystems like coral reefs, mangroves and estuaries. Coastal zones are particularly attractive for the growth of cities, and the industries that develop around cities, as ports provide easy access for transportation, and the coast is often used for the release of industrial effluents. The infrastructure developed to support this urban and industrial growth encourages greater migration of people from rural to urban areas, placing an ever increasing demand for urban public services in the crowded coastal cities, and giving rise to a host of environmental stresses.

Some of the key question that must be addressed in dealing with these urbanization challenges include:

- What new institutional and governance structures are needed to deal with sustainability problems on the scale of a city-cluster?
- What technological developments are needed (for instance, in the sectors of housing, transport, production of industrial goods) to enhance the sustainability of these urban complexes?
- How do the values and norms of urban residents affect their willingness to accept institutional and technological innovations, as well as their personal lifestyle choices and consumption patterns?
- What are the key environmental, social, economic factors that affect the vulnerability and resilience of different populations and ecosystems within these urban clusters?

Each urban cluster poses unique and widely varying social, economic, and environmental sustainability challenges, thus highlighting the necessity of place-based research. Mitigating undesirable consequences and identifying sustainable pathways of development for these urban clusters will require integration of scientific, technical, and policy research that is driven by the perspectives and needs of local stakeholders. We note with a sense of encouragement, the rapidly expanding suite of research efforts focusing on such issues. For instance, see the IHDP Urbanization Initiative (http://www.ihdp.uni bonn.de/html/initiatives/initiatives.html); the Urban Environmental Management Project of the Japanese Institute for Global Environmental Strategies (http://www.iges.or.jp/); and the Sustainable Industrial and Urban Development research of United Nations University (http://www.unu.edu/env.html) the Advisory Group suggests that one of the most critical needs on the international level is a forum for ongoing dialogue and identification of priorities for an R&D agenda. If this agenda is developed through a broadly inclusive and credible process, it could become a highly influential base for implementing new scientific and technological efforts worldwide.

2.3 LINKING KNOWLEDGE TO ACTION

A central characteristic of harnessing STI for sustainable development, as shown in Figures 1 and 2, is the need to go beyond generating new, integrated knowledge towards actively applying this knowledge to real world problems, helping decision-makers evaluate the possible benefits and pitfalls of different response options, and facilitating implementation of required actions.

Linking knowledge to action is carried out by a range of organizations. For example, reports from the Intergovernmental Panel on Climate Change and the Millennium Ecosystem Assessment integrate and communicate scientific knowledge in a form that is useful for policy makers. Similar activities are carried out by national academies of science and a wide variety of organizations that focus on specific issues (energy, water, health, etc.). Some effective mechanisms exist for enabling scientific input into international-level policy discussions, such as the processes of the UN Commission on Sustainable Development (CSD). However, similar types of mechanisms are often lacking at national and local levels, where many important decisions and actions take place. Moreover, there is a need for mechanisms to link these different scales; for instance, so that the information and perspectives emerging from local dialogues can flow back into the national and international level discussions.

Box 6

AN EXAMPLE OF A BOUNDARY ORGANIZATION

The ascendance of acid rain on the political agenda in the 1970s and 1980s challenged European nations to manage a problem characterized by transboundary pollution flows, multiple stakeholders, and high uncertainty. International negotiations produced the Convention on Long-Range Transboundary Air Pollution (LRTAP) in 1979 and, under the auspices of this treaty, several innovative approaches were developed to assess the problem, evaluate options, and support negotiations. Ultimately a system was developed that engaged independent institutions such as the International Institute for Applied Systems Analysis (IIASA) in roles that spanned the boundaries between scientists and negotiators. The success of LRTAP in reducing transboundary air pollution is largely due to an assessment and decision support system that has enabled adaptive and flexible use of science in decision making (Cash et al., 2003).

The actions that contribute to sustainable development goals occur on all spatial levels, ranging from international framework agreements, to national policies and action plans, to the decisions and behaviour of local communities, families, and individuals. The actions are taken by governments, business and industry, and a wide range of civil society organizations. There is therefore a need for a wide range of mechanisms to inform and influence the actions taken at these different levels and different actor groups. For instance, at the international level, there is a need to continue input from the science and technology communities in intergovernmental ministerial conferences, whereas local- and individual-level decisions may be most effectively informed through long-term commitments to strengthening educational curricula and institutions. These mechanisms will have to evolve over time in response to the evolving overall agenda for harnessing science and technology for sustainable development.

Organizations that facilitate the flow of information across the boundaries between knowledge and action, referred to as boundary organizations, are particularly important for ensuring that science and technology play a more central role in sustainable development (Cash et al., 2003). Identifying relevant boundary organizations, using them effectively, and creating organizations where a need is identified, are critical tasks. Integrated research should continue (see section on Governance Institutions), in order to understand how boundary organizations can be made more effective.

When choosing the appropriate level and mechanisms by which to engage decision-makers, it is important to understand barriers to flows of information within and between the global, regional, and local levels; and to remain cognizant of the ways in which the distribution of power within particular societies can restrict the flow or accessibility of certain kinds of knowledge. Past experience has shown that if scientific knowledge is perceived by the target audiences as credible, salient, and created through legitimate processes, it is much more likely to be heeded and applied. And yet at the same time, even highly credible, salient, and legitimate information is often disregarded (or even deliberately misused) as a result of personal biases, moral judgements, political considerations, etc.. Likewise, when individuals or societies feel at risk, they often lower their requirements for facts before taking action, and may exhibit behavioural responses that are based more on superstition than on rational analysis of available information. Social science research will continue to be important for helping us to better understand these complex dynamics.

In summary, the concept of translating knowledge to action is neither simple nor straightforward. Some of the key needs are to:

- Identify and use boundary organizations to facilitate the interactions between scientific experts, decision makers in governments, business and industry and other parts of civil society; and facilitate the development of new boundary organizations where a need is identified;

- Convene broad-based dialogues between the S&T and action communities focused on specific sustainable development issues;
- Translate R&D findings into a form and language that is understandable to all relevant audiences;
- Facilitate the continuous development of research and action agendas.

Box 7

THE TOGA PROGRAMME - LINKING RESEARCH, OBSERVATION, AND DECISION SUPPORT

Developed by the World Climate Research Programme, TOGA (Tropical Ocean and the Global Atmosphere) is a useful example of an international, interdisciplinary research project that has integrated environmental monitoring and modelling with decision-support efforts to provide significant societal benefits.

TOGA established a systematic, comprehensive monitoring system (now operational) in the Equatorial Pacific that led to major strides in understanding the ENSO (El Niño-Southern Oscillation) phenomenon. TOGA showed that model predictions of sea surface temperature in the Tropical Pacific could be made using these observations. This has led to some skill to forecast major ENSO events and the related seasonal temperature and precipitation changes in many parts of the world. These forecasts are shared with the appropriate decision makers through various national and international institutions (such as the International Research Institute for Climate Prediction -- http://iri.columbia.edu/), and are used to help guide crop-planting decisions, water resource management, and food-security warnings in areas that are particularly sensitive to ENSO events (e.g. Australia, Northeast Brazil).

Understanding the role of such institutions in communicating knowledge between the science and policy realms, and in reducing vulnerability of human-environment systems, is an area of great relevance to sustainable development.

2.4 BUILDING CAPACITY TO IMPLEMENT THE FRAMEWORK

The concept of capacity building means different things to different people. Here we define the concept in a very broad sense, to encompass any activities that enhance the capabilities of individuals, institutions, and organizations to contribute to effectively harnessing STI for SD. The needs for building capacity cut across all elements of framework discussed in Section 2.1, and apply to practically all sectors of society, in both developing nations and in wealthy industrialized nations. Below we discuss the needs for building the capacity of scientists and engineers worldwide, through innovative new forms of education, training, and professional opportunities. But in addition, there must be efforts to develop the capacity of society at large (including policy makers, industry leaders, etc.) to be active players in efforts to define research priorities and to help implement the solutions that emerge from this research.

There are numerous reports that discuss the needs and strategies for building scientific and technological capacity worldwide, and many of these reports explicitly discuss the linkages between a country's basic S&T capacity and its economic and social well-being (for instance, see IAC, 2004 and ICSU, 2002-3e). In addition to these 'classical' capacity building goals, a wide variety of specifically targeted new approaches are needed for developing awareness of and skills related to STI for SD. Some of the key needs are discussed below. This is presented with implicit recognition that there is no simple, one-size-fits-all formula for capacity building activities; they must be context specific, locally sensitive, and responsive to the evolving needs of the different actors involved.

Education and Training

An underlying component of building capacity the world over is strengthening science education, at primary and secondary school levels, and in higher education. Increasing basic scientific education, literacy, and numeracy is a matter of pressing urgency for all nations. But with respect to the goals of SD, it is also necessary to encourage and develop innovative new approaches to education and training. Educational curricula at all levels, but particularly in higher education, should be re-examined from a sustainability viewpoint. Educational and training efforts should encourage linkages between natural and social science disciplines, development studies, and applied technology and engineering fields (although at the same time, this must be balanced against an ongoing need for strong grounding in the basic disciplines of science and engineering). There are several major new international initiatives underway that are aimed specifically at addressing the challenges of education for sustainable development; for instance:

UN Decade on Education for Sustainable Development. In December 2002, the United Nations General Assembly adopted a resolution to establish a Decade of Education for Sustainable Development (2005-2014). UNESCO was designated as lead agency for the promotion of the Decade. A detailed implementation plan is available at http://portal.unesco.org/education/en/ .

Global Higher Education for Sustainability Partnership (GHESP).
Several international organizations (including the International Association of Universities; University Leaders for a Sustainable Future; COPERNICUS-CAMPUS; and UNESCO) have combined forces to

form GHESP, an effort to promote better understanding, and more effective implementation of strategies for the incorporation of sustainable development in universities and other higher education institutions. GHESP is developing an online 'Global Higher Education for Sustainability Toolkit', to provide regionally-relevant resources, tools, and change strategies to individuals and institutions around the world. (http://www.unesco.org/iau/ghesp/index.html)

Ubuntu Alliance.

At the WSSD, several of the world's foremost global educational and scientific organizations[12] came together to sign the Ubuntu Declaration, an effort to ensure that educators and learners are aware of the imperatives of sustainable development, and pronounce in their work and life habits the values and principles of sustainability. The Ubuntu Alliance, currently in the planning stages, is seen as a vehicle by which the signatories can work together to implement the principles of the Declaration.

One important though often overlooked means of linking research and education (and of linking knowledge and action) is ensuring that research results are shared with the communities that were the subjects of this research. This may require communicating findings in the local language/dialect, and sometimes through non-traditional mechanisms. For instance, in the Millennium Ecosystem Assessment's Southern African Sub-Global Assessment, a dramatic play was developed to communicate study results to the villagers that contributed to these investigations. Providing this type of feedback is also important for ensuring that the knowledge of local communities is not exploited to serve only the professional gain of those conducting the research.

Capacity building for scientists and engineers

Effectively harnessing STI for SD involves building the capacity of scientists and engineers worldwide:

- to engage in both basic research (in the natural, social, health and engineering sciences) and multidisciplinary research efforts that integrate these different realms;
- to develop holistic, systems-oriented research strategies, and novel approaches for understanding and characterizing cross-scale linkages (e.g. linking global-scale changes to local-scale drivers and impacts);
- to contribute to integration and assessment efforts that draw clear, applicable information from broad, complex bodies of research;
- to work directly with development specialists, policy makers, citizens groups, and other stakeholders to identify and define R&D needs and translate knowledge to action;
- to develop skills in communicating with non-technical audiences and in effectively operating within negotiation- and advocacy-type settings.

Box 8

AWARDS AS A TOOL FOR BUILDING S&T CAPACITY

Prestigious awards can provide a powerful tool for encouraging future efforts in the realm of STI for SD. Awards can create role models and enhance recognition of innovations that are unknown to the larger world; can help to change the culture of organizations, communities, and peer groups to which the awardees belong; and can give signals to society about new directions in which promising innovations are emerging. Some examples of awards that could be considered include:

- Lifetime Achievement Award for groups or individuals who have made the significant long-term contributions to STI for SD, including innovations that have provided unique insights about sustainability of socio-ecological systems.
- Young Scholar Awards to encourage the work of early-career scientists whose work is assessed as having tremendous potential for influencing future directions in R&D and for building new bridges among traditional disciplines.
- Grassroots Innovation Awards for technological solutions to pressing sustainability challenges generated by individuals or network thereof, including 'informal' science and technology contributions.
- Problem-Solving Awards to challenge the global research community to develop robust solutions to specific problems of day-to-day survival faced by poor and marginalized sectors of society.

In order to attract the highest-quality applicants, such prizes must be seen to be prestigious and offer monetary or other incentives that enable the winners to significantly expand their current work. The prizes could be awarded in high-profile ceremonies, and those selected to serve as judges should be widely respected individuals from a broad cross-sector of cultural backgrounds and expertise.

[12] *Current partners include: African Academy of Science; Copernicus-Campus; Global Higher Education for Sustainability Partnership; International Association of Universities; International Council for Science; Science Council of Asia; Academy of Sciences for the Developing World; United Nations Educational, Scientific and Cultural Organization; United Nations University; University Leaders for a Sustainable Future; World Federation of Engineering Organizations.*

Building institutional capacity

A lesson learned over the past several decades of development efforts is that in order to ensure lasting success, capacity building must encompass not only individuals, but also the institutions and communities in which these individuals operate. Thus a central challenge is to enhance the ability of existing institutions to address sustainability issues. This includes boundary organizations (such as national science academies) that can directly influence policy-making processes. This also includes universities and science funding organizations, which often inhibit the development of integrative new R&D approaches due to rigid disciplinary-oriented structures. At the same time, there is a need to build new institutions that allow for sustained interactions among natural scientists, social scientists, engineers, and specialists in economic development and public policy[13]. Such institutions must offer the infrastructure and career opportunities that will enable trained professionals to use their skills effectively, and will encourage them to remain engaged in this realm of work over the long-term.

Strengthening existing activities

There currently exists a wide array of efforts that contribute to the various capacity building goals discussed above. For instance, many development assistance organizations support regional networks for capacity building in research and graduate training, centres of excellence that operate as regional hubs for training, as well as 'virtual universities'[14]. Organizations such as the International Foundation for Science (IFS) and TWAS sponsor small competitive grant schemes to provide support to developing country scientists for work in their home institutions. TWAS also supports fellowship programmes that enable young scientists from developing countries to work in centres of

Box 9

PROFITING FROM LOCAL RESOURCES AND KNOWLEDGE: AN EXAMPLE OF HOLISTIC CAPACITY BUILDING

African societies harbour a rich, but largely undocumented, body of indigenous knowledge about the continent's biodiversity, including medicinal plants. The UNDP Regional Bureau for Africa is supporting a project Promoting Sustainable Development from Africa's Biodiversity, based at the University of Namibia, which promotes the application of this indigenous knowledge, together with cutting-edge S&T advances, to permit sustainable utilization of Africa's vast biological reserves.

For example, water hyacinth (Eichhornia crassipes) has historically been viewed as an unwanted weed; and the World Bank has spent millions of dollars helping countries in Africa to destroy the plant. Through investigations carried out under the UNDP/UNOPS Regional ZERI Project for Africa[15], with complementary support from the United Nations University (UNU), scientists have discovered a variety of valuable uses for this bioresource: as an agrofertilizer base especially for growing edible mushrooms, as an efficient biological-based sewage treatment system, and as a source of fibres for furniture and housing material. Another notable success has been efforts to encourage the farming of seaweeds that provide hydrocolloids with many industrial applications, and with iodine-rich nutrients for the many African communities afflicted by endemic goitre and related micronutrient deficiency disorders. As a result of these efforts, today thousands of individuals in Tanzania (mostly women) generate a lucrative income by farming seaweeds in their coastal lagoons. Creative, cutting-edge research is needed to identify and optimize these bioresource applications, and to develop sustainable practices for farming and wise harvesting of such resources.

A central element of these initiatives is building the capacity of local citizens, and awareness amongst political leaders, to appreciate, utilize, and profit from new scientific knowledge and technological innovations. For instance, it includes community awareness programmes that provide information about the potential uses of local resources; demonstration and training programmes, to teach communities how to apply new technologies in a sustainable manner; strategies to sensitize local political and business leaders to the potential benefits and impacts of the proposed applications; and assistance to participating African countries interested in designing new projects to suit their local natural resource endowments and development needs.

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[13] A few such institutions currently exist (e.g., the International Institute for Applied Systems Analysis, Columbia University's Earth Institute, the Tyndall Centre for Climate Change Research), but they are very limited in number.

[14] Examples include the Consortium for Social and Economic Research in Latin America; the Economy and Environment Program for Southeast Asia; the African Economic Research Consortium; the Forum on Agricultural Resource Husbandry; the University Science, Humanities, Engineering Partnership in Africa; and the African Virtual University. Four U.S. Foundations have also committed $100 million to a collaborative Partnership for Higher Education in Africa that provides a mix of individual awards, faculty development, improving individual department programmes, and strengthening the national university systems.

[15] That is, the UN Development Programme / UN Office for Project Services 'Zero Emissions Research Initiative' (http://www.zeri.unam.na/), an effort that promotes the study of materials often conceived of as waste, to be converted into possible new

excellence, short-term guest lectureships, summer schools and institutes, and awards for distinguished young scientists. It is important to acknowledge and support such efforts, and to enhance the linkages and synergies among them. Any new programmes, focused specifically on capacity building for sustainable development (including S-N, S-S and N-N collaborative activities), should be designed to reinforce and enhance existing efforts.

2.5 KEY NEEDS FOR EFFECTIVELY HARNESSING STI FOR SD

All elements of the conceptual framework for harnessing STI for SD (see Section 2.1) require substantial attention, but some of these elements are being actively addressed through the ongoing efforts of individuals, R&D programmes, and institutions around the world. Other elements of the framework, in contrast, are unlikely to be adequately addressed without concerted new leadership efforts. These key gaps are discussed below.

Convening Key Constituencies and Providing Space for Dialogue

Achieving a transition to sustainable development is inconceivable without meaningful dialogue and partnerships among the many different groups that should be involved in such efforts, including natural and social scientists, engineers and technologists, business and industry, development practitioners and development assistance agencies, policy makers, and civil society groups. There is a need for platforms (consultations, dialogues, thematic workshops, etc.) to build mutual understanding and to share information about research and practice that is conducted in isolation in different places around the world. Such platforms currently exist for only a few selected issues and in some parts of the world, but what is missing is a 'meta-level' process that looks across the full scope of sustainability concerns and related R&D efforts.

These platforms for dialogue and information sharing must involve widely accepted organizations that have credibility across scientific, governmental, civil society groups; and that have the convening power to bring the key players to the table. Without this leadership role being filled, the aforementioned dialogues either will not take place, or will not be as effective as needed. Organizations that are seen as honest brokers (without particular ideological or political agendas) can play this role most effectively, and are most likely to be accepted as providing a neutral platform upon which priorities can be debated. No single organization is likely to have the necessary legitimacy and accountability among the wide array of relevant communities, and thus a consortium effort may be the most effective approach.

Agenda Development and Priority Setting

R&D efforts that contribute to the goals of Sustainable Development are carried out by scientists and engineers working in many countries around the world, and in the settings of academia, government, industry. Identification of R&D agendas and priorities is a task often carried out in isolation, without a broader consideration of regional and international perspectives, or interdependencies among different sustainable development issues. The result is a general lack of coherence (and in some cases, clear conflicts) among different national, regional, and international level programmes and policies.

There is a need for new participatory mechanisms for different groups to share perspectives about critical gaps in knowledge and technical capabilities, to develop common agreement on priorities for future R&D efforts, and to develop frameworks under which research can be organized as effectively as possible. The outcome of these efforts would be an R&D agenda that is primarily targeted towards the research community and the individuals and institutions that influence R&D funding priorities. In addition, the dialogue process itself could provide valuable

Box 10

BUILDING UPON THE PLATFORM OF MULTI-STAKEHOLDER DIALOGUES

Given the impossibility of engaging civil society as a whole in the types of dialogues discussed above, there is a strong motivation to build upon existing mechanisms for convening legitimate representatives of these diverse elements of society. One existing platform that could be particularly useful in this respect is the 'Multi-Stakeholder Dialogue' process that has become a regular feature of UN intergovernmental meetings, most notably, meetings of the UN Commission on Sustainable Development (CSD). This process brings together leading representatives of nine major groups of civil society, namely, Scientific and Technological Communities, Women, Children and Youth, Indigenous People, Non-Governmental Organizations, Local Authorities, Workers and Trade Unions, Business and Industry, and Farmers. ICSU and WFEO have been identified by the UN as the two organizations that represent the Scientific and Technological Communities.

The Stakeholder groups participate in many aspects of intergovernmental dialogues and negotiations (including identifying problems, designing and applying solutions, and monitoring results), and they have gained broad visibility and legitimacy among the communities they represent and among the world's governments. The CSD platform offers dialogue possibilities with government agencies and relevant UN bodies. Moreover, scientific organizations such as ICSU have already formed effective working relationships with these stakeholder groups, through their participation in earlier CSD sessions. Thus it seems well worth exploring the possibility of using the annual CSD meetings, and the CSD Multi-Stakeholder Dialogue process in particular, as a vehicle for organizing the priority-setting dialogues discussed above.

opportunities for capacity building and networking among the groups involved.

In order to be effective, this mechanism must be a dynamic process, providing regularly updated information that is relevant across a wide array of scales. This may ultimately need to be a relatively decentralized exercise, given the heterogeneous nature of sustainable development concerns that exist around the world. As articulated in the synthesis report from the Mexico City workshop (ICSU 2002-3, i), "Agenda setting at the global, continental, or even national scale will miss a lot of the most important needs. The transcendent challenge is to help promote the relatively local dialogs from which meaningful priorities can emerge".

Appropriate monitoring systems should be established to continually evaluate the effectiveness of these efforts. This should include feedback from the user communities (to assess whether their priorities and needs are truly reflected in the outcomes of the dialogues), and an assessment of the degree to which the recommended R&D agenda is actually being adopted and implemented by different groups around the world.

These priority-setting efforts will only be of real value (in terms of contributing to the goals of sustainable development), if the results are effectively communicated to the people who have the power to act upon this information. Communication efforts must reach well beyond the usual audiences for scientific reports, including for instance, direct engagement with the political process and with the popular media.

3 The Consortium's role in advancing science, technology and innovation for sustainable development

3.1 RECOMMENDED ACTIONS

The overall aim of this report is to provide a conceptual foundation for co-ordinated international efforts to advance the science, technology, and innovation needed for achieving the goals of sustainable development. A great deal of highly relevant and valuable R&D work is already being carried out by individuals and groups around the world. What is needed in addition however, is a concerted effort to identify, promote, and support priority R&D needs that are not being adequately addressed.

Accordingly, we recommend the creation of a new mechanism for convening dialogues among natural scientists, social scientists, engineers, and the wide array of societal actors who have the potential to utilize and implement new scientific and technical information (such as development specialists, natural resource managers, and leaders in government, industry, and civil society). The goal of these dialogues would be to discuss what new knowledge and technical capabilities are most needed for meeting the challenges of sustainability, and based on this input, to develop a prioritized 'Agenda on R&D for Sustainable Development'.

This must be a long-term, evolving process that develops in response to new input and changing needs. The results should be widely disseminated and promoted among relevant research and funding communities around the world; and the process must have enough credibility and visibility to influence the actions of individuals and organizations that are involved in setting priorities for future directions of scientific research and technology development. This must be a truly global effort that is tackled across multiple scales and that involves multiple sectors of society. The initial set of research topics described in this report could be used as starting point for the priority-setting process, with the assumption that the proposed agenda will continue to evolve as new parties add their perspectives to the dialogues.

Given the magnitude and universal importance of the issues being addressed, it is not difficult to imagine this type of international R&D agenda-setting activity eventually becoming a high-profile summit that attracts tremendous interest from the world's top scientists and engineers, from leaders in government and industry, and from the media and general public. Akin to the World Economic Forum's annual meeting in Davos, it could become a central hub of knowledge, leadership, and exchange of new ideas among the global community. Such a major effort cannot be effectively accomplished by any one existing organization or programme.

A Consortium on Science, Technology, and Innovation for Sustainable Development could provide an important vehicle for accomplishing these goals. The success of this effort, however, would require a broad group of participating organizations.

In addition, ICSU, ISTS, and TWAS are all engaged in numerous activities that advance various elements of the proposed framework for harnessing science, technology, and innovation for sustainable development (see Box 11). We strongly encourage such efforts to be continued and expanded in ways that build upon the respective

Box 11

RELEVANT STRENGTHS AND ACTIVITIES OF THE CONSORTIUM PARTNERS

The following are some of the strengths and existing efforts of ICSU, ISTS, and TWAS that could be important for the overall goals discussed in this report.

- ICSU is looked to by the UN and other major organizations as a voice for the S&T community in international policy fora.
- ICSU's National Members and Regional Offices provide a means to reach out to the scientific community on a truly global basis; and likewise, ICSU's International Scientific Unions provide a conduit for reaching out to, and building linkages among, a wide array of scientific disciplines.
- ICSU has a record of building groundbreaking international research programmes, most notably the Global Change Research Programmes, which could contribute to the R&D efforts discussed herein.
- ISTS's online Forum on S&T for Sustainability provides a valuable platform for linking and sharing information among scholars and practitioners around the world.
- ISTS has developed networks among many of the world's leading thinkers about sustainable development issues.
- ISTS has significant experience in organizing participatory dialogues among scientists, practitioners, and other stakeholder communities.
- TWAS has high standing and a broad network of contacts across the scientific communities of developing countries.
- TWAS has a strong record of activities for building scientific capacity through activities such as research grants, fellowships, and visiting scientist programmes.
- TWAS has experience with programmes to identify and share local knowledge and innovations related to sustainable development.

strengths and constituencies of each organization. It seems most feasible for such efforts to continue to be led by the individual organizations, and yet they should not be viewed as isolated activities. Mutual support and information sharing among the three organizations can bring added value to these activities, and can help ensure that all relevant efforts are contributing to the larger, integrated framework.

3.2 OUTREACH AND PARTNERSHIPS

There is a large, growing array of entities that address various aspects of sustainable development, including academic institutions, private sector initiatives, governmental and intergovernmental organizations, NGOs, and informal knowledge networks. The Consortium organizations would need to reach out to this broader community, if the aforementioned dialogues and agenda-setting exercises are to be seen as authoritative, legitimate, and truly reflective of society's needs.

There would be costs and benefits of expanding a formal group of Consortium partners. Additional partners can mean a broader base of expertise and resources to build upon, but it can also mean more complex management and decision-making structures, and greater chance of conflicts among organizations that have differing goals and operating strategies. At least initially, it may be prudent to focus on building relatively informal linkages with other organizations, as needed for specific activities, rather than establishing formal, permanent partnerships.

The selection of new partners is a matter to be decided by the leadership of ICSU, ISTS, and TWAS, and of course is subject to the interest of the potential partner organizations themselves. As a starting point, however, we present in Figure 3 several 'clusters' of organizations and programmes, each of which represents a general realm of expertise and perspective beyond that covered by ICSU, ISTS and TWAS. Forming some sort of linkages to these different cluster groups will likely be critical for the overall success of proposed activities.

3.3 STRUCTURE AND MANAGEMENT OF THE CONSORTIUM

It is the prerogative of the Consortium partners to decide upon the structure and management of future Consortium efforts. To aid in this analysis, however, the Advisory Group considered three possible modes of operation, each discussed below (see Annex 3 for a detailed listing of relative strengths/weaknesses for each

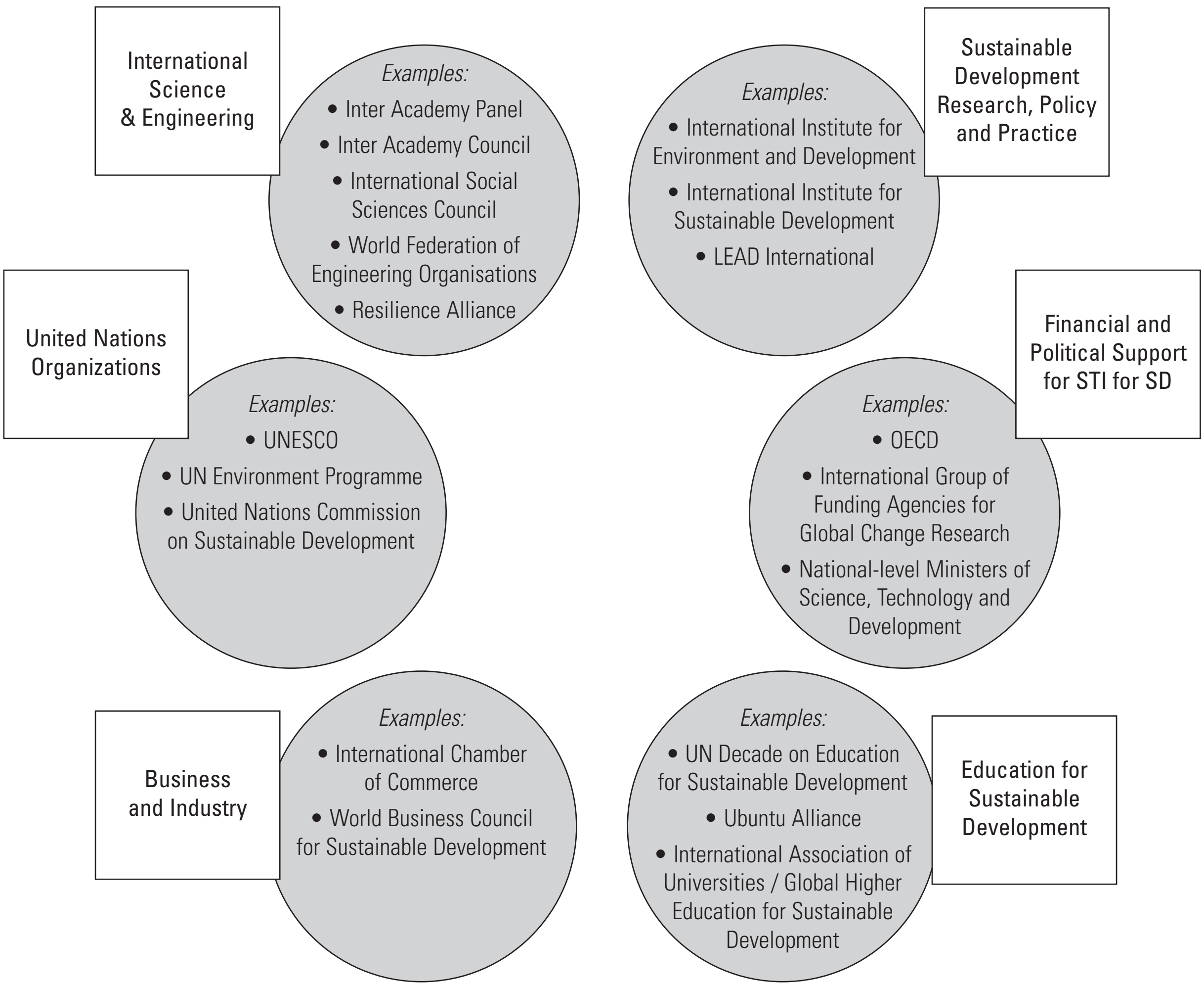

Figure 3. Clusters of other potential collaborating organizations.

of these modes).

a) A strongly centralized, formalized organization, with joint commitments to operations and fund-raising by all Consortium partners, and a formal process for adding other partners. A centralized Secretariat and Steering Group would be appointed by the partners.

b) A loose network in which ICSU, ISTS and TWAS move forward individually with activities that they consider to be in their area of competence and interest. No Secretariat or Steering Group, but ongoing informal consultations to exchange information and plan joint activities.

c) A structured network, in which there is some coordination of activities, including funding applications, through agreements between the partners on which parts of the agenda they will pick up, and ad hoc collaboration on specific projects. No Secretariat or Steering Group, but annual meetings of the leaders (Chairs and/or Directors and/or their appointees) and interim electronic communication and teleconferences as necessary.

In reality, a full spectrum of operational modes is possible, with modes A and B representing the potential endpoints of that spectrum. The exact mode of operation should be developed to best suit the activity at hand, as well as the interests and programmes of the participating organizations. We note, however, that for the dialogue and agenda-setting processes recommended above, a long-term, coordinated process will be required.

3.4 FINANCIAL SUPPORT FOR THE PROPOSED ACTIVITIES

The suggested activities will require at least a modest level of financial support. The Consortium partners may wish to each contribute (internal) funds to a core operating budget to support essential administrative functions for the dialogue and agenda-setting processes. In addition, external sources of funding would be required for support of these activities. The efforts outlined in this report will ultimately serve the interests of a broad cross-section of society, and thus support for these efforts could potentially come from a wide array of entities, reaching well beyond traditional funding sources. For instance, these entities may be:

- *National (or sub-national) governments*
  e.g.: National science funding agencies, Departments or Ministries of Environment, Education, Energy, Health, Agriculture, Transportation, and Development Assistance.
- *Regional and multi-national organizations*
  e.g.: European Commission, North American Commission for Environmental Cooperation, Association of Southeast Asian Nations, New Partnership for African Development, Mercosur, Andean Community of Nations.
- *Multilateral financial institutions*
  e.g.: World Bank, Global Environment Fund, OPEC Fund for International Development.
- *Private Sector institutions*
  e.g.: David and Lucile Packard Foundation, Rockefeller Foundation, MacArthur Foundation.

3.5 NEAR-TERM ACTIVITIES

The David and Lucile Packard Foundation recently agreed to provide funding to move ahead with the following activities:

- *Partnerships for linking knowledge and action in emerging areas of STI for SD*
  International partnership teams consisting of approximately 10 distinguished individuals coming from the science, technology, development, and environmental protection communities, will be convened to focus on specific research-for-development themes. These efforts will start with the topics of production/consumption and resilience/vulnerability. For each topic, a partnership team will be asked to assess what knowledge is most needed to facilitate solutions to sustainability problems; to evaluate which of these needs can be met by applying existing information, versus which needs require new research and innovation; to illustrate the potential for better linking knowledge to action through one or more case studies; and to prepare implementation guidelines to facilitate action. This activity contributes to meeting the need for agenda and priority setting outlined above.
- *International Scientist-Practitioner Dialogue*
  Planning has begun for an International Scientist-Practitioner Dialogue on STI for SD, to be held in 2006. The meeting will provide a platform for bringing scientists and engineers together with policy-makers, resource managers, development specialists, educators, and other relevant stakeholders, to discuss the types of information that are most needed from the research community, the challenges of linking knowledge to action, and the institutional requirements needed in all societal sectors to respond to these issues. The Dialogue will emphasize bringing together senior leaders in the field with young scientists and practitioners from developing countries; and financial support will be sought to help assure the participation of such groups. This activity contributes to meeting the need for dialogues, and will be supported by other dialogue activities in which ISTS and TWAS play a role.

These activities will undoubtedly provide a valuable base for exploring and further developing some of the concepts raised in this report. These should, however, only be viewed as initial steps in a much longer-term process. The types of goals outlined herein (such as building effective working relationships with a broad array of stakeholder communities, and influencing the evolution of R&D priorities on a global scale) will undoubtedly require many years of persistent effort and the development of enduring mechanisms for interaction.

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Annexes

ANNEX 1: MEMBERSHIP AND TERMS OF REFERENCE OF THE AD HOC ADVISORY GROUP

Robert Corell (Co-chair), American Meteorological Society, Washington, DC, USA

Hebe Vessuri (Co-Chair), Instituto Venezolano de Investigaciones Científicas; Caracas, Venezuela

Dorairajan Balasubramanian, Hyderabad, India

Partha Dasgupta, University of Cambridge; Cambridge, UK

Anil Gupta, Indian Institute of Management; Gujarat, India

Hartmut Graßl, Max-Planck-Institut für Meteorologie; Hamburg, Germany

Arnulf Grübler, Int. Institute for Applied Systems Analysis; Laxenburg, Austria

Anne-Marie Izac, CIRAD – Direction scientifique; Montpellier, France

Jill Jäger, Vienna, Austria

Margaret McKean, Department of Political Science, Duke University; Durham, NC, USA

Keto Elitabu Mshigeni, University of Namibia; Windhoek, Namibia

Lynn Mytelka, United Nations University, Institute for New Technologies; Maastricht, The Netherlands

Brian Walker, CSIRO Sustainable Ecosystems; Canberra, Australia

Anne Whyte, Mestor Associates; Russell, Ontario, Canada

Abdul Hamid Zakri, UNU Institute of Advanced Studies; Tokyo, Japan

We also wish to acknowledge the following people who participated in Advisory Group meetings and contributed valuable perspectives to the group's deliberations:

Shere Abbott, AAAS; Washington DC, USA

Benedito Braga, Agencia Nacional de Aguas; Brasília, Brazil

Thomas Egwang, Med. Biotech Labs; Kampala, Uganda

Gisbert Glaser, ICSU; Paris France

Barbara Goebel, IHDP; Bonn, Germany

Mohamed Hassan, TWAS; Trieste Italy

Roger Kasperson, Stockholm Environment Institute; Stockholm, Sweden

Ali Kazancigil, International Social Science Council; Paris, France

Ann Kinzig, School of Life Sciences, Arizona State University; Tempe, USA

Albert Koers, InterAcademy Council; Amsterdam, Netherlands

Akin Mabogunje, Development Policy Centre; Ibadan Nigeria

Julia Marton-Lefevre, LEAD International; London, England

Veena Ravichandran, TWAS; Trieste, Italy

Thomas Rosswall, ICSU; Paris, France

Daniel Schaffer, TWAS; Trieste, Italy

Lisen Schultz, Department of Systems Ecology, Stockholm University; Stockholm, Sweden

Will Steffen, IGBP; Stockholm, Sweden

Nico Stehr, Sustainable Dev. Research Initiative; University of British Columbia, Vancouver, Canada

Peter Tyson, Bryanston, South Africa

Jack Whelan, International Chamber of Commerce

Terms of Reference of the Ad hoc Advisory Group:

Introduction

The Initiative on Science and Technology for Sustainability (ISTS); the International Council for Science (ICSU); and the Third World Academy of Sciences (TWAS) have decided to establish a **Consortium for Science and Technology for Sustainable Development**. The idea for a Consortium developed during discussions at the Mexico City Synthesis Workshop, May 20 – 23, 2002 (ICSU Series on Science for Sustainable Development No. 9, 2002) and was discussed further at an informal meeting in Paris in November 2002. The initial members of the Consortium are the organisers of the May 2002 Mexico City Synthesis Workshop on Science and Technology for Sustainable Development (see Annex 1). Other organisations may join at a later date.

The underlying purpose of the Consortium will be to promote and strengthen efforts around the world to enhance the contribution of science and technology to sustainable development. To this end, the Consortium will take into account whenever possible ongoing and planned efforts of numerous individuals, groups and institutions worldwide currently engaged in science and technology for sustainable development. The Consortium partners have agreed that a widely inclusive Ad hoc Advisory Group should be formed to help formulate goals, an integrated agenda for research and development, capacity building, and linking research to action, an implementation plan, and the structure of the Consortium, and expand its intellectual, societal and institutional scope.

Mandate

The Advisory Group established by the Consortium founders is asked to recommend:

1. A process for bringing into the Consortium perspectives from a broad range of local, sectoral, regional and international efforts now underway to enhance the contribution of science and technology to sustainable development;

2. A research and development agenda and a programme of activities of the **Consortium for Science and Technology for Sustainable Development** that will promote problem-driven research and development, the capacity-building necessary to carry out such work; and that will link research and development to actions that facilitate sustainable development;

3. Strategies and mechanisms that would more fully enable the Consortium members jointly and individually to address the challenges and opportunities in harnessing science and technology for sustainable development;

4. A draft plan of implementation for the programmatic and operational activities, including funding aspects, of the Consortium;

Guidelines

In fulfilling its mandate, the Advisory Group is asked to take into account the following guidelines:

A. For bringing into the Consortium perspectives from a broad range of relevant local, sectoral, regional and international efforts now underway

- Recommend processes for engaging a large number of those involved in such efforts in the Consortium's activities;
- Consider how the Consortium might best facilitate productive consultation, collaboration, and network building among those efforts.

B. For developing a programme of activities of the Consortium with integrated agendas for research and development, capacity-building, and linking research and development to action, aimed at sustainable development, through consultation with the Consortium members and others focussing on problem-driven approaches

- Recommend steps for the initiation of a stimulating and in-depth programme to attract the best scientists, technologists, development specialists, and decision makers, in the public and private sectors, to become involved in exciting and relevant research for science for sustainable development ;
- Consider how the R&D and development agendas can be identified and expanded in close consultation with stakeholders who are affected by the challenges of sustainable development, through broad-based participatory approaches;
- Propose means for influencing processes setting R&D priorities at local, regional and international scale with the aim of incorporating a significant amount of solution- and action-oriented work, in addition to basic, curiosity-driven research. This solution-driven component of international, national and institutional R&D strategies will need to pay particular attention to addressing, in an integrated manner, problems that span the environmental, social and economic pillars of sustainable development and provide a better understanding of place-based, coupled socio-ecological systems;
- Pay particular attention to studying adaptation, vulnerability and resilience in coupled socio-ecological systems;
- While focusing on place-based research, identify and address relevant linkages and feedbacks to the regional and global scales;
- In addition to place-based research, identify areas which require sectoral studies and propose appropriate research approaches;
- Recognizing that research and development for sustainable development must be policy-relevant, cover the spectrum of efforts from research, monitoring and assessment, to decision support mechanisms and seek to link research and development to action;
- Ensure that the research and development agenda give particular attention to generating knowledge and S&T capacity for sustainable development, including combating poverty, in developing countries. Unsustainable production and consumption patterns worldwide should also be addressed;
- Address the methodological challenges of science for sustainable development and how to move forward through learning by doing.

C. For preparing an implementation plan for the Consortium activities

- Define clearly expected outputs of the Consortium;
- Develop a clear and pragmatic strategy on how to achieve these outputs
- Based on this strategy, develop a programmatic and operational implementation plan with timelines and a sunset clause, as well as clear targets for each time horizon. The detail of advance planning for different components of the implementation plan can vary;
- Include in the plan proposals for the institutional set-up, including needs for technical coordination and governance mechanisms, for the implementation of the Consortium activities, taking into account the need for intellectual leadership, different stakeholder interests, and the need for financial and political support;
- Include in the plan proposals for evaluation mechanisms, which would ensure effective evaluation of programme implementation;
- Also include in the plan budget estimates, and advise the

Consortium constituent members on a fund raising strategy for the implementation of the proposed activities.

D. For enhancing the dialogue with the potential users of the outcome of the Consortium activities

- Arrange for broad multi-stakeholder consultations in its work;
- Recommend as part of the plan of implementation, provisions for an ongoing multi-stakeholder consultation process as an integral part of the Consortium activities. Further, feedback mechanisms should be recommended that provide institutional mechanisms within the Consortium that adjust its activities to integrate evolving needs and concerns expressed by stakeholders.

ANNEX 2: REGIONAL WORKSHOPS ON SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY

In preparation for the WSSD, a series of workshops were organized for the purpose of creating a research agenda that is prioritized by stakeholders and that is relevant to the sustainable development needs of different regions. The events included:

10-12 April 2002; Cambridge, Massachusetts, United States
Mobilizing Science and Technology for Sustainable Development

25-26 March 2002; Ottawa, Canada
Ottawa Regional Workshop on Science and Technology for Sustainability: North American Challenges and Lessons

5-7 March 2002; Santiago, Chile
Santiago Regional Workshop on Sustainability Science: Science and Technology for Sustainable Development

27 February - 1 March 2002; Walberberg (Bonn/Köln), Germany
Bonn Regional Workshop on Science for Sustainability - Achievements and Challenges

4-6 Feb. 2002; Paris, France
Workshop organized under the auspices of the Global Change Science Programmes

4-6 February 2002; Chiang Mai, Thailand
Chiang Mai Regional Workshop on Sustainability Science: Knowledge, Technology and Institutions for Sustainability Transitions in Asia

6-9 February 2002; Trieste, Italy
Science, Technology and Sustainability: Harnessing Institutional Synergies

13-15 November 2001; Abuja, Nigeria

Abuja Regional Workshop on Sustainability Science

10-13 July 2001; Amsterdam, The Netherlands
Challenges of a Changing Earth: Global Change Open Science Conference

11-14 October 2000; Friibergh Manor, Örsundsbro, Sweden
Friibergh Workshop on Sustainability Science

15-18 May 2000; Tokyo, Japan
Transition to Sustainability in the 21st Century

For more details on the processes and outcomes of these workshops, see ICSU (2002-3 i).

ANNEX 3: ANALYSIS OF RELATIVE STRENGTHS/ WEAKNESSES OF DIFFERENT MODES OF OPERATION FOR A CONSORTIUM ON STI FOR SD

Mode A: A strongly centralized, formalized organization, with major joint commitments to operations and fund-raising by all three Consortium partners and a process for adding other partners. A centralized Secretariat and Steering Group would be appointed by the partners.

Strengths

- The possibility to take a strong position with respect to funding agencies.
- The possibility to develop a strong 'corporate identity' (logo, web-site, publication series, etc).
- The opportunity to build on the strengths of the partners.
- A clear strategy and justification for adding partners.
- The possibility to develop high credibility in the agenda-setting process.

Weaknesses

- Difficult to operate, given the different governance structures of the present partners. Adding new partners could add even more structures, which all have to be negotiated in order to reach strong joint decisions and commitments.
- The perception of this mode is that it adds another layer of bureaucracy.
- The perception of competition for financial and human resources with the global change research community (ESSP; IHDP in particular) and other activities of the Consortium partners.
- Too much concentration of power in the Secretariat/Steering Group.
- A 'megastructure' should not be created before the joint activities have been decided and tested.
- The requirement of a high initial financial investment from each Consortium partner.
- The partners do not currently have the human or financial resources for such a major commitment.

Mode B: A loose network in which ICSU, ISTS and TWAS, and other groups, move forward individually with activities that they consider to be in their area of competence and interest. No formal Secretariat or Steering Group, but possibilities of informal information sharing and ad hoc joint projects.

Strengths

- No threat to the GEC programmes or other activities of the three organizations.
- No extra layer of bureaucracy.
- No commitments of financial or human resources from the three organizations.
- No overhead expenses for running a Consortium.
- The three organizations maintain their identities and mandates.
- Allows 'a thousand flowers to bloom' -- both among the three organizations and with others outside -- and fosters the variety of contributions; everyone does what they like in terms of activities seen to contribute to the agenda.

Weaknesses

- No 'corporate identity' for a Consortium (in fact, essentially no Consortium at all).
- Nothing for which other partners would be formally sought.
- Potential competition among the three organizations for funding and people.
- Potential for important research areas to be ignored because everyone assumes that others are taking care of them.
- Reduced opportunity to take advantage of the complementarities that the three organizations offer, or to co-ordinate activities or allow for synthesis and generalisation.
- No joint convening power for dialogues or agenda-setting activities

Mode C: A structured network, in which there is some coordination of activities, including funding applications, through agreements between the partners on which parts of the agenda they will pick up, and ad hoc collaboration on specific projects. No Secretariat or Steering Group, but annual meetings of the leaders (Chairs and/or Directors and/or their appointees) and interim electronic communication and teleconferences as necessary. On an annual basis one of the Consortium partners would take the lead in arranging meetings and conference calls, contacting funding agencies etc..

Strengths

- Possibility to create a (weak) form of 'corporate identity'.
- Allows partners to maintain their identities and mandates, and to continue working on their own agenda.
- No large commitment of financial or human resources by the partners.
- Co-ordination of initiatives and exchange of information.
- Only small overhead required for a regular meeting of the leaders of the partners and for teleconferences (perhaps for a consortium web-site and other information material).
- Allows partners to work together on areas of common interest as desired.
- Possibility to expand through strategic partnerships.

Weaknesses

- Success depends on trust between all partners.
- Sends a weaker signal to potential funding agencies about the importance of the Consortium agenda and the commitment of the partners.
- Would require a clear strategy for adding new partners. On what basis would they be selected? What reasons could be given to encourage others to join the Consortium?
- Possible perception of competition for financial and human resources with the global change research community (ESSP; IHDP in particular) and other activities of the Consortium partners.
- Organizational structure not strong enough to meet the demands of international, long-term efforts at agenda-setting.

ANNEX 4 ACRONYM / ABBREVIATION DEFINITIONS

AAAS	American Association for the Advancement of Science
CSD	Commission on Sustainable Development
ENSO	El Nino Southern Oscillation
ESSP	Earth System Science Partnership
GHESP	Global Higher Education for Sustainability Partnership
IAC	Inter Academy Council
IAP	Inter Academy Panel
ICSU	International Council for Science
ICT	Information and Communication Technologies
IGBP	International Geosphere Biosphere Programme
IHDP	International Human Dimensions of Global Change Programme
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
ISSC	International Social Science Council
ISTS	Initiative on Science and Technology for Sustainability
IUCN	International Union for Conservation of Nature
LRTAP	Long Range Transboundary Air Pollution
MDG	Millennium Development Goals
NGO	Non Governmental Organisation
R&D	Research and Development
S&T	Science and Technology
STI for SD	Science, Technology & Innovation for Sustainable Development
TOGA	Tropical Ocean and the Global Atmosphere
TWAS	The Academy of Sciences for the Developing World
UNDP	United Nations Development Programme
UNCED	United Nations Conference on Environment and Development
UNOPS	United Nations Office for Project Services
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU	United Nations University
WFEO	World Federation of Engineering Organizations
WSSD	World Summit on Sustainable Development
WTO	World Trade Organization
ZERI	Zero Emissions Research and Initiatives

ICSU
International Council for Science

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ISTS