Science for Sustainable Development

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Science for Sustainable Development

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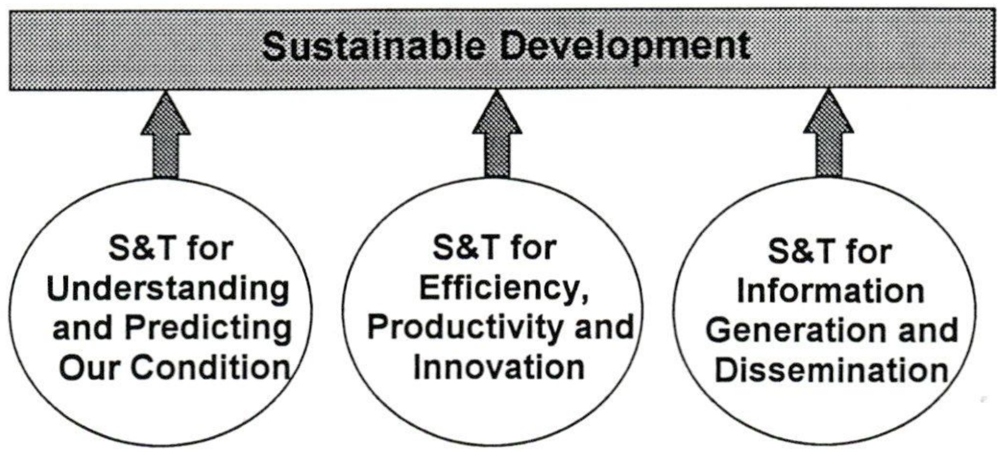
Contents

PART 1

Overview of Major Themes for Attention

Science and Technology for Sustainable Development

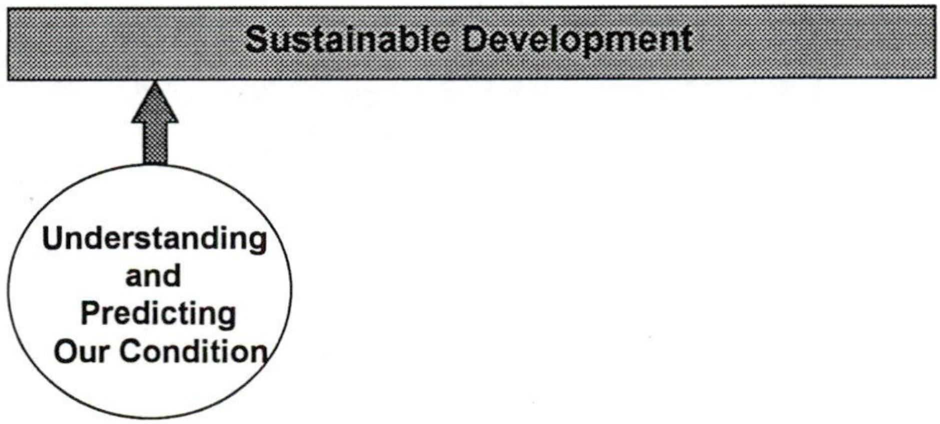
Science and technology are essential for sustainable development. Science and technology provide a means of assessing, as well as predicting, the state and functioning of the earth's environmental carrying capacity. Through contributions to knowledge used by humans for technical change, innovation and better decision making, science and technology offer potential for allowing economic and population growth to continue within the limits of environmental carrying capacity. Science and technology also underlie the generation and dissemination of information that enables community-based capacity building and local-level decision making in support of sustainable development.



S&T supports sustainable development in three fundamental ways:

- *understanding and predicting our condition* (i.e. allowing us to better understand the environmental carrying capacity of the world we live in and predict the effects of stress on the earth's carrying capacity);
- *efficiency, productivity and innovation* (i.e. allowing economic signals to act as a trigger for achieving much greater economic efficiency); and
- *generating and disseminating information* (i.e. allowing us to have a much greater quality and quantity of information that supports capacity building and decision making at all levels from local to international).

Understanding and Predicting Our Condition



The role of S&T in understanding our condition focuses on providing better and more efficient ways to acquire, integrate, assess and process information needed to understand the earth's environmental carrying capacity and whether this carrying capacity is being exceeded. It includes development of indicators and benchmark tools, monitoring of progress, and implementation of full cost accounting systems for economic, natural and social capital.

A key element of this effort is the development of new techniques and technologies that allow humans to obtain more or better information at a lower cost. S&T information associated with understanding and predicting our condition also needs to cover a wide range of time spans — from minutes to centuries.

New satellite observation technologies such as remote sensing, coupled with information management technologies, have enabled the rapid collection, downloading and processing of enormous amounts of geo-spatial and other forms of environmental data. Computer simulations and models are continuously being improved to enhance our predictions of how complex environmental systems can react to stress.

Sophisticated information integration and assessment tools such as GIS (geographic information system) have allowed for the integration of environmental, economic and social data. New prediction and decision support systems are enabling local communities as well as international scientific teams to insert various parameters into information management tools designed to aid decision making in support of sustainable development. Further refinement of such efforts over time will continue to improve our ability to translate information into knowledge, wisdom and action.

Efficiency, Productivity and Innovation

With the right economic signals, S&T can be the engine behind the most important aspect of sustainable development — the movement of economic and industrial systems towards greater eco-efficiency. Eco-efficiency is the drive to find innovative means for dramatically reducing the use of raw materials and energy in our economic systems.

Three types of economic signals hold enormous potential for eco-efficiency:

- market signals (e.g. producer-consumer relationships, consumer demands, producer-supplier relationships);
- cost signals (e.g. full cost accounting, taxing pollution); and
- policy signals (e.g. regulations, reforming subsidies and taxes, providing financial incentives, etc.; shifts in automotive engineering are one example).

S&T for eco-efficiency means:

- helping shift production of goods towards production of services (the production of services is more eco-efficient and leads to new research that is service-oriented rather than mass production-oriented);
- greater efficiency and less environmental impact in the use of renewable and non-renewable natural resources, for example, by exploiting the benefits of genetic engineering, using all parts of resource inputs (industrial ecology) and developing means of affecting smaller areas with less invasive technologies; and

- focusing on the "top line" by going beyond eco-efficiency towards development of new services that add value to shareholder capital while lessening environmental impacts.

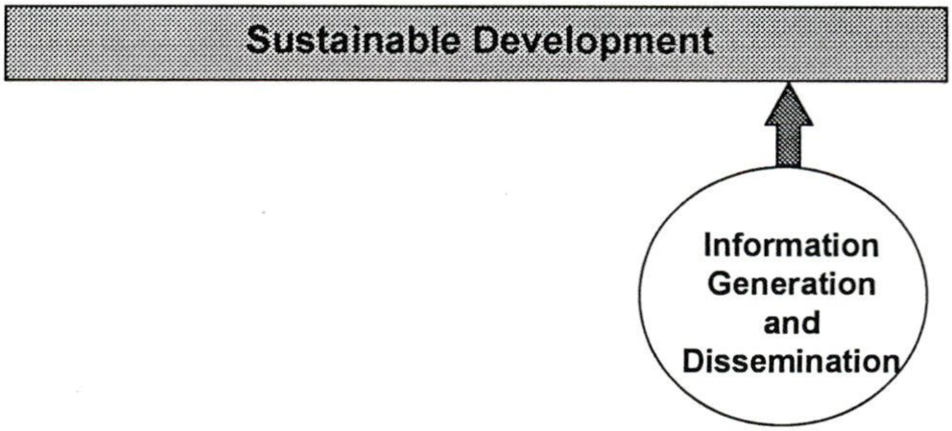
While incremental innovations are needed to make step-by-step improvements in eco-efficiency, radical "breakthrough" innovations are also needed to achieve much larger reductions in inputs or environmental impacts.

At current rates of growth, world gross domestic product is expected to grow to be 2.5 times larger than the 1995 level by 2020. The economy in 2020, however, will have to function within the same finite global environmental system. The equivalent of factor of 4 to 10 improvements in many areas of economic efficiency will need to be achieved in many areas just to stand still in terms of environmental impacts.

In industries subject to strong price or competitive pressures, labour and energy productivity have increased in the region of 4-8% per year. Over 30 years, these rates would lead to factor of 4 to 10 increases. However, no OECD country has achieved such rates of change throughout the economy and over several decades. Unless initiatives by firms, governments, non-governmental organizations and communities are applied throughout the economy, they will not reverse unsustainable trends in resource use and environmental damage.

On the positive side, significant economic opportunities and benefits will accrue to those nations that can steer their economic systems towards eco-efficiency. For example, strains on the carrying capacity of the global atmosphere are creating a growing demand worldwide for cost-competitive renewable energy technologies, non-polluting transportation vehicles and systems, energy-efficient construction techniques, and non-polluting energy-efficient agricultural methods.

Information Generation and Dissemination



The Rio Declaration (1992) emphasized the need to involve citizens as well as a wide range of social institutions in decision making.

Science and technology for information generation and dissemination can play a key role in adapting forms of governance at a wide range of levels to take advantage of information in support of sustainable development (e.g. supporting capacity development, informing policy instrument choice and appropriate decision making, fostering international collaboration).

New knowledge-producing networks and information dissemination technologies (e.g. the Internet) are leading to widespread capacity building and new forms of governance.

Improved knowledge production and networking to share information among a diverse range of societal interests has resulted in the speedy development of accords to govern the management of natural resources.

Science and technology have also made possible the evolution of information technologies that enable society to access information in a way that builds broad-based capacity for assessing and managing risks and ensuring the social relevance and safety of new technologies.

Social interest in science and technology has also inspired the development of innovative social arrangements such as cooperative, community-based research and risk management networks and socially responsible co-management boards that apportion or manage wildlife, water, grazing fields and other common pool resources.

Community groups have taken advantage of more pervasive and better-quality information to support initiatives that reduce environmental impacts and achieve quality of life with less material consumption. The availability of local expertise and information is essential for sustainable development. The preferences of local communities often change once they fully understand the alternatives available to them.

While there are numerous possible routes to improve eco-efficiency, the greatest potential lies in initiatives that combine technical and social changes to improve quality of life with less material consumption.

Implications for Government

Canadians expect the federal government to play a key role in using scientific information to detect, assess and manage risks to public health and safety, as well as to preserve natural, economic and social capital.

This is a matter of leadership, responsibility, vision and communication. It requires the articulation and widespread communication of a common vision, which will result in important impacts including the reorientation of scientific institutions towards sustainable development; the development of new linkages across S&T institutions; the further enhancement of information flows; further efforts to create conditions for incremental and radical innovation and technological advancement; and increased communication within and across sectors.

Specific Requirements

1. The federal government needs to demonstrate that all science and technology departments, as well as key departments affecting the science and technology nexus (e.g. finance), are oriented to support S&T for sustainable development.

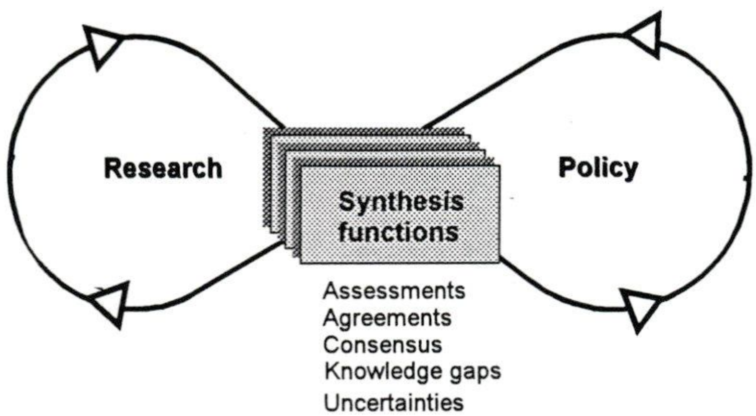
    - One option that could be explored is to build on the use of departmental sustainable development strategies, generating a government-wide vision and approach to using federal science and technology to support sustainable development. This would require coordinated and consistent integration of S&T considerations (such as S&T objectives, performance and capacity aspects) into sustainable development strategies and reports.

    - Key to such strategies would be a review of major policy instruments that can be used to facilitate science and technology in support of technological and social innovation for sustainable development.

2. The federal government must continue to play a major role in generating, integrating and assessing scientific information to make public policy in

support of sustainable development. As the figure below illustrates, this is a continual process that is not finished once policy is made. There must be constant feedback at the science-policy interface in order to determine whether policy decisions are effective.

- Sustaining sufficient scientific knowledge capacity to enable assessment decision making at the science-policy interface is an area of particular importance for the federal government, since credibility of scientific information and the sources of the information are important issues of public concern. This requires a wide range of skills linking production of knowledge with synthesis, integration and communication of knowledge, as well as the use of knowledge for policy making. Federal science-based departments have been uniquely positioned to develop, integrate and coordinate this needed range of skills to address issues of national concern. As scientific information becomes much more readily available, and its distribution to the public is aided by new information technologies as well as the Internet, there is growing pressure on the federal government to ensure the quality control of scientific information used to support policy and decision making and ultimately protect the public's interests in areas such as health, safety and protection of the environment.



3. The federal government needs to demonstrate that it is a leader and model in the conduct of science and technology for sustainable development by getting its house in order — building on the success of the interdepartmental Memorandum of Understanding on Science and Technology for Sustainable Development; investing in the development of advanced monitoring and prediction systems for understanding carrying capacity at a variety of temporal and spatial scales; orienting and promoting R&D programs that can support incremental and radical innovations in eco-efficiency; and further supporting S&T initiatives that lead to informed community-based decision making and social innovation.

PART 2

Background Study and Literature Review

Table of Contents

Introduction

In the past decade a substantial literature base has embraced and debated the concept of sustainable development. Many academic scholars and international organizations have speculated about the underlying principles upon which sustainable development should be based, as well as the specific actions required for its achievement. These analyses have generated a wide range of recommendations for government policy.

The continuing challenge of sustainable development can best be described in the words of Doern (1993, p.173) as "an effort to transform a latent policy paradigm into a real and operational one." Most individuals familiar with the concept agree that current development trajectories are unsustainable in absolute terms. Therefore, changes must occur to produce new development trajectories based on different values, social structures and economic assumptions. Renewed effort, moreover, must be directed towards identifying characteristics that can be qualitatively or quantitatively assessed in order to determine whether society is going in a desired direction.

Atkinson and Coleman (1989) have documented the realities needing confrontation for the development of new policy. In particular, they expressed concern about whether members of existing policy networks can see the broad challenges inherent in new concepts like sustainable development, as well as rise above parochial interests and develop the necessary organizational capacity inside and outside of government to move policy networks onto a new plane. In order for policy networks, institutions and individual human beings to meet the broad challenges of sustainable development, many new ideas must be refined and applied, and innovations must be adopted on a broader scale. Successful approaches also need to be transferred to different sectors, institutions and geopolitical regions. These changes will have to occur despite the serious impediments that continue to hamper collaboration and co-ordination of actors and institutions within policy communities and human society.

Science is essential for sustainable development. Science has enabled understanding of the mutually dependent relationships that exist between human activities and environmental health. Science provides a means of assessing, as well as predicting, the state of human conditions and environmental factors that sustain human life. Moreover, it is through its contribution to knowledge used by humans for decision making, innovation and technical change that science enables actions which improve the human condition while respecting the essential role that environmental health plays in sustaining human life.

The purpose of this paper is to provide a conceptual basis for understanding the role that science can play in making sustainable development a reality. The paper is divided into three sections. The introductory section discusses the concept of sustainable development, the principles underlying this concept, and the implications of these principles with respect to the planning, conduct and assessment of science activities. The second section of the paper explores the types of science activities required to contribute to the production of knowledge for sustainable development, as well as the types of outputs that science needs to provide for institutional and individual decision makers. This section includes a discussion of the relationship between technological change and sustainable development, and concludes with a summary of some key challenges inherent in orienting science towards sustainable development. The third and final section of the paper focuses on science policy in support of sustainable development. Important issues addressed in the final section are science policy instruments necessary to support sustainable development, and the governance of science in order to support sustainable development.

What Is Sustainable Development?

The most commonly used definition of sustainable development is that given by the World Commission on Environment and Development in their report *Our Common Future:*

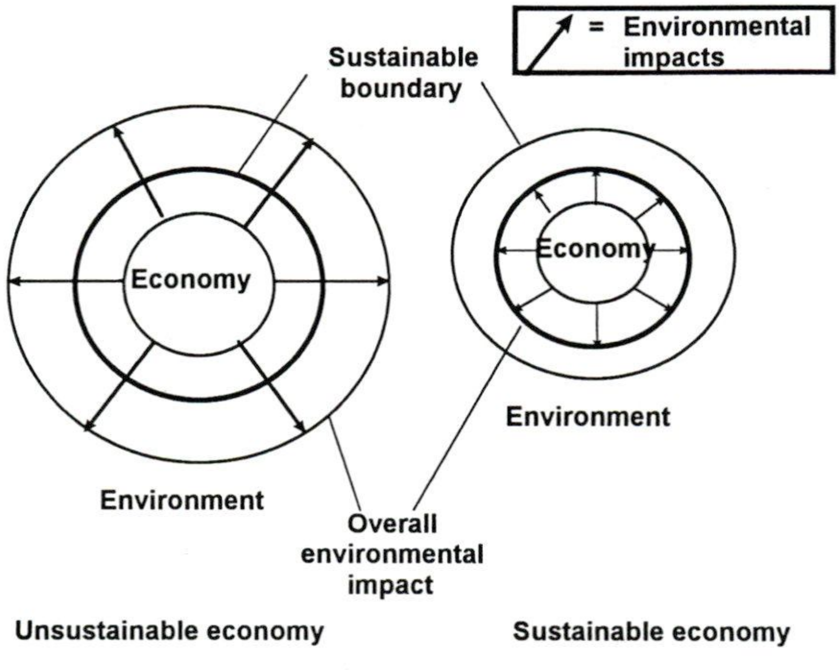
> sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

In recent years, sustainable development has come to represent a more considered approach to the interaction of economic activities with the environment. For instance, Environment Canada interprets the concept of sustainable development to mean the implementation of processes that integrate environmental, economic and social considerations into decision making. Sustainable development, therefore, is generally thought to be reflected by economic activities that are carried out in such a way that people will be able to meet their needs in the future. Thus defined, the goal of sustainable development has received widespread popular acceptance. It provides a positive message that economic development and environmental protection can, and indeed must, go hand in hand.

However, while much has been written about the mutually reinforcing objectives of economic progress and environmental protection, conflicts between environmental protection, economic activity and social development remain prevalent throughout the world. The key to sustainable development, therefore, lies in the elements of its core meaning. One core element is the integration of environmental considerations in economic policy making — in both theory and in practice. Another element is the explicit commitment to equity — which requires some measure of redistribution between developed and developing countries as well as commitment to intergenerational distribution of environmental benefits and costs. Finally, sustainable development requires a commitment to enhanced quality of life for human beings. This final core element embraces the proposition that the preservation and advancement of healthy economies and societies is ultimately dependent upon the maintenance of ecosystem health.

Acceptance of the need for sustainable development requires acceptance of the proposition that ecosystems and the biosphere do have "development" limits. For development to become and remain "sustainable," humankind must come to exist within these limits (see Figure 1). The continuous growth of human societies and economic activities, therefore, cannot go on indefinitely. The equitable improvement of the human condition will eventually require some form of control over flows of energy and materials so that ecosystem and biosphere capacities to maintain human life are not exceeded. Advocates generally acknowledge that humans can come to a collective understanding of their dependency upon ecosystem health, as well as an understanding of the need for development to ensure the maintenance of ecosphere health. Science has a key role to play in helping humans come to a better understanding of the threshold limits or "carrying capacities" of ecosystems and the biosphere as a whole. In addition, scientific knowledge can help redefine these limits over time.

Figure 1: A Conceptualization of Sustainable Limits



Source: Jacobs, 1991.

What Is Science for Sustainable Development?

Attention to sustainable development is inevitably linked to human decision making, since human activities can be mediated through factors such as ethics, knowledge, education, public policy, economic instruments, regulation and law. The cumulative result of decision making by humans will continue to influence and ultimately determine the condition of ecosystems and human society at local, regional and global levels.

It is through its contribution to knowledge used by humans for decision making, innovation and technical change that science can make its most significant contribution to the achievement and maintenance of sustainable development. Science is usually defined as a process of experimentation, observation, description, analysis and communication about natural phenomena that leads to human-based knowledge. The term "science," in this context, must be interpreted broadly to include physical and natural sciences, as well as economic and social sciences.

Some have argued that if the objective of sustainable development is to protect the interests of future generations, then future generations will not only want the same level of "environmental wealth" as the current generation, but will also want the same level of total wealth, including human-made capital, technological expertise and scientific knowledge. Often, these latter forms of wealth have been produced by economic activities that degrade the environment. It has been tempting for some analysts to define sustainable development in terms of maintaining a constant stock of total wealth, including human capital, scientific knowledge and technology.

However, science for sustainable development cannot be defined in such simple terms, such as a process of replacing natural resources and functions with more productive human-made ones. Many functions of the environment are unique and cannot be replaced by human products and knowledge. Moreover, many natural processes or characteristics changed by human activities are irreversible — despite the possibilities that science and knowledge hold for the future. While scientific progress and potential is undeniable, humans remain largely ignorant about the workings of the biosphere as well as the effects of current economic and social activities on it. Predicting future results of the complex interactions of multiple variables is even more daunting. Advances in theoretical and empirical understanding of complex systems may allow further identification and measurement of parameters that appear to determine the behaviour of complex environmental, social and economic systems. On the other hand, the scale and scope of the parameters influencing these complex systems may continue to limit analysis, and at best permit estimated degrees of progress towards sustainable development.

Science for sustainable development, therefore, must satisfy an extremely diverse range of human needs, values and interests — including the interests of future generations. It must continue to produce new questions, hypotheses, experimental methods, analytical techniques and knowledge. It increasingly must provide feedback about the carrying capacity of ecosystems at different stages of development and about the impacts (real and potential) of numerous interacting influences, and it must communicate complex information in understandable terms so that sustainable decision making and innovation is possible by human beings from all walks of life.

Principles of Sustainable Development

In an effort to further define the roles that science can and should play in support of sustainable development, it is useful to review some of the key principles upon which sustainable development is based as well as the key actions that are felt to be necessary to achieve global sustainability. The following core principles are felt to collectively reflect the overall concept of sustainable development:

1. Respect and concern for ecosystem health

Ecosystems provide a diverse range of environmental goods and services that are necessary to support human life on earth.

2. Respect and concern for humans

Sustainable development is inherently linked to human decision making and the human condition. The cumulative result of decision making by humans will ultimately influence the condition of ecosystems and human society at local, regional and global levels.

3. Policy integration

Decision making in support of sustainable development implies that social, economic and environmental factors should be given equal consideration in policy, program and project development, as well as in the monitoring and evaluation of human activities.

4. Appropriate valuation of environmental resources

The requirement for environmental, economic and social decision making to become mutually reinforcing suggests that the value of natural resources and common environmental goods should reflect full social, environmental and economic costs when used or extracted. Appropriate valuation of environmental resources would encourage renewable resources to be replaced at a rate equivalent to consumption while maintaining constant levels of biodiversity. Non-renewable resources should be valued in a manner that maximizes the efficiency of their use, encourages recycling and substitutions, and ensures conservation of key ecosystems.

5. Equality within and between generations

Sustainable development implies that net environmental, social and economic assets, including natural resources, environmental common goods and human-created capital, will be sustained or enhanced for the use and enjoyment of future generations. This suggests that the costs and benefits of human activity, both current and intergenerational, should be distributed fairly nationally and internationally.

6. Anticipatory and precautionary policy approach

Sustainable development implies that human decision making on the development or use of new technologies, natural resources and environmental common goods should utilize scientific information that demonstrates known or potential social, environmental and economic consequences.

7. Global cooperation

Sustainable development is a global objective and therefore requires significant and broad levels of international cooperation addressing common concerns while accommodating varying responsibilities and capabilities.

8. Community and local participation

Sustainable development can be achieved only if informed decision making and action takes place at the level of communities. Community participation in decision making, therefore, is a vital prerequisite for sustainable development.

9. Interdisciplinarity / Multidisciplinarity

Human decision making in support of sustainable development requires the formation of linkages between traditional science, technology, and social and economic disciplines. These linkages are necessary to promote systemic understanding of complex issues as well as to strengthen the paths through which knowledge is passed to decision-making bodies.

10. Capacity building

In order for sustainable development to be achieved, mechanisms must be found to improve local knowledge and understanding of actions required to move and sustain social and economic activities within the bounds of ecosystem resilience.

Science Policy Implications of Core Principles

The principles upon which the concept of sustainable development is based raise a considerable number of science policy implications. These are summarized in Table 1.

Table 1: Principles of Sustainable Development — Science Policy Implications

1. Respect and concern for ecosystem health
- Analysis is required to determine not only the health of individual components of ecosystems, such as air or water quality, but also the health of entire ecosystems
- Science must make use of methodological and analytical approaches that place human decision making within the context of ecosystem processes and boundaries
- Science must make use of time horizons that capture short-term interests and intergenerational equity, as well as the long-term health and integrity of ecosystems

2. Respect and concern for humans
- Science must develop and use criteria for assessing human progress that are based upon alternative and changing development values
- Science must develop and use environmental, economic and social cost and benefit measures that capture and respect the interests of diverse communities within the global ecosystem
- Science must generate and use information on the complete range of stresses (including human health) imposed by human activities on ecosystems at all levels

3. Policy integration
- Priority should be placed on science activities that clearly demonstrate a mutually reinforcing relationship between social, environmental and economic objectives
- Priority should be placed on science activities that allow social, environmental and economic considerations to be effectively integrated and mutually reinforcing in public policy development and implementation
- Science planning, monitoring and evaluation processes need to consider and correlate social, environmental and economic objectives and ramifications
- Social, environmental and economic input is needed for priority setting in science, research and technology development
- Social, environmental and economic input is needed for science and technology monitoring, evaluation and assessment
- Science and technology activities should reflect the shared interest of, and be conducted in partnership with, partners representing social, environmental and economic sectors
- Science and technology activities should provide knowledge and information that allows social, environmental and economic policy concerns to become better integrated and mutually reinforcing
- Science must seek resilience and accept uncertainties inherent in complex systems as an inevitable factor in, rather than an impediment to, sound decision making

4. Appropriate valuation of environmental resources

- Science must develop methodologies and analytical techniques that allow and provide reliable value indicators of natural resources and environmental common goods
- Science assessments supporting resource policy must include methodology and results that allow determination of social, environmental and economic values
- Science assessments supporting resource policy should be designed and implemented by cross-disciplinary teams that include environmental economists and sociologists
- Science activities should be directed at studying and evaluating innovative experiments, projects, policies and programs that attempt full cost valuation of natural resources and common environmental goods
- Science efforts are required to demonstrate unsustainable use of resources and environmental common goods, as well as predict potential local, regional and global effects of continued, accelerated or decelerated degradation
- Science projects and programs underlying policy decisions on non-renewable resources should integrate life-cycle assessment methodologies
- Science assessments are required to demonstrate sustainable resource use in renewable and non-renewable sectors (development of resource substitutions, efficiency improvement, ecosystem assessment to sustain biodiversity and conserve ecosystems, demonstration of renewable resource regeneration etc.)

5. Equality within and between generations

- Science communications should reach all segments of population as well as international populations
- Institutions should maintain and enhance science and technology, human resource and infrastructure capacities, as well as endorse mechanisms to ensure their constant renewal
- Futures assessments should be used to enhance science project and program planning, and set science and technology research priorities
- Environmental science assessments should include international as well as domestic and local perspectives
- Science programs developed to support policy decision making should explicitly develop methodologies sensitive to current inequalities
- Science programs developed to support policy decision making should explicitly develop methodologies that recognize key areas of future concern

6. Anticipatory and precautionary policy approach

- Priority should be directed toward critical areas of uncertainty in the relationship between current trends in economic growth/development and environmental quality
- Priority should be directed toward improved understanding of the relationships between economic growth, technological innovation, liberalized trade and environmental quality
- Science should focus on areas requiring proactive solutions to alter established patterns of development, resource use, and use of locked-in technologies
- Science must develop and use anticipatory approaches, including backcasting, rather than just traditional forecasting methods
- Assessments of future scenarios should be used to enhance project and program planning, and set science and technology research priorities
- Lesson drawing should be used to guide science assessment processes that allow the application and implementation of the precautionary principle
- Science programs should be required to undertake life-cycle assessment of proposed substitutions and alternatives to established development practices

7. Global cooperation

- Science priority setting and planning must accommodate pressures and demands to participate in international research collaboration
- Domestic science activities should be planned and oriented to contribute to international science commitments and obligations
- Domestic science activities that contribute to international information should make use of internationally recognized protocols and methodologies where possible
- Science and technology activities specifically oriented towards international programs should reflect national priorities and strengths or internationally identified knowledge gaps
- Priority setting for international science should identify the areas where greatest potential exists for maximizing transfer of expertise and/or technology, as well as maximizing the sustainable development capabilities of developing economies

8. Community and local participation

- Local and regional science programs should incorporate community-based planning and reporting sessions (town-hall meetings, consultations)
- Community-based science and technology programs should make use of local and traditional knowledge that is available and relevant to research programs
- Local science and technology programs should have local forms of participation and direction
- Community-based science and technology programs should address local concerns and needs but remain relevant to national and international requirements
- Community-based science and technology initiatives should dedicate a reasonable portion of project funding to communications and use a variety of suitable communication strategies to enhance local understanding, interest and support
- Science programs and priorities should reflect external science policy advice
- Science and technology assessments should be conducted informally at a community level, as well as by formal mechanisms such as peer review

9. Interdisciplinarity / Multidisciplinarity

- Multidisciplinary teams should be assembled to plan, conduct and evaluate science and technology programs
- Priority should be assigned to multidisciplinary programs and projects over traditional discipline-based projects and programs
- Economic and social science analysis should be integrated with scientific analysis
- Funding priority should be assigned to integrated, multidisciplinary studies
- Scientists and science managers should be trained to function effectively in multidisciplinary team situations

10. Capacity building

- International lesson drawing should be used to replicate successful science and technology capacity building
- Science and technology programs should develop improved links with local and community-based sectors
- Science and technology projects and programs should emphasize exchange of training, data, information, knowledge, equipment, etc.
- Local and regional science programs should incorporate community-based planning and reporting sessions (town-hall meetings, consultations)
- Community-based science and technology programs should address local concerns and needs but remain relevant to national and international requirements
- Community-based science and technology initiatives should dedicate a reasonable portion of project funding to communications and use a variety of suitable communication strategies to enhance local understanding, interest and support

Science Activities in Support of Sustainable Development

The above set of principles generated a number of implications about the ways in which science activities should be planned, conducted and assessed in order to support sustainable development. There are also a wide range of science activities that can support sustainable development. These activities generate outputs in the form of knowledge, which in turn serves as an input to the achievement of sustainable development. A non-exhaustive list of science activities that can support sustainable development includes:

- research and development (R&D) directed towards detection of emerging problems or issues in ecosystem, social and economic health;
- research that allows systems analysis of local, regional and global ecosystems to identify carrying capacity thresholds and indicators of ecosystem health (including human social and economic health);
- research and data analysis that provides information to humans about past health of local and regional ecosystems, including economic and social health;
- research that analyses assumptions and the effects of public policy and other human (including institutional) decisions on local and regional ecosystems, including social and economic systems;
- research that provides information about and permits analysis of existing and past public policies and human development choices with respect to local and regional ecosystem health, including social and economic health;
- research that provides comparative information on the effects that development decisions and policies are having upon ecosystems, as well as social and economic health;
- research that provides information suggesting alternative approaches for management of economic, social and environmental systems in local, regional and international contexts;
- research leading to the development of new technologies, innovations or technical changes that enable the restoration and stabilization of ecosystem health (including social and economic health) in communities and regions where human development has surpassed environmental carrying capacity;

- research leading to the development of new technologies, innovations or technical changes that enable the maintenance of ecosystem health (including social and economic health) in communities and regions where human development has not yet exceeded carrying capacity;

- research leading to the development of new products, processes or knowledge that reduce and stabilize per capita use of natural resources and energy;

- research leading to the replacement, substitution or recycling of non-renewable resources without overall reduction of economic and ecosystem health;

- research leading to the increased renewal and use of renewable resources without overall reduction of economic and ecosystem health; and

- research and knowledge production that leads to the alteration of existing (and development of new) technologies and industries that reduce and stabilize per capita resource use and pollution generation.

Science Outputs Needed to Support Sustainable Development

In his book *The Green Economy*, Michael Jacobs argues that actions are required in six key areas in order for economies, societies and the environment to shift onto sustainable development trajectories. Building on his list, it can be deduced that science activities need to generate knowledge outputs that serve the following areas:

1. Renewable Resources

With respect to the use of renewable resources, humans must learn to increase sustainable output rates — the ability to obtain higher rates of harvest — without causing long-term depletion of the resource or other forms of associated environmental degradation. Science needs to provide knowledge and information that can be used to:

- increase the size of resource stocks, while respecting ecological implications such as the need to protect habitat and maintain genetic diversity;
- increase the productivity of renewable resource species (e.g. faster-growing, higher-yielding crops); and
- increase the sustainable harvest of crops and forests.

2. Non-Renewable Resources

The sustainable use of non-renewable resources requires achieving an output rate that maintains the size of stock relative to demand. Science needs to provide knowledge that is used to:

- discover and exploit new reserves, thereby increasing the size of economically available stock;
- recycle extracted resources, thereby replenishing the stock; and
- achieve depletion rates that equal the rate at which sustained income or renewable substitutes are developed by human intervention and investment.

3. Pollution Reduction

To reduce pollution caused by a given unit of environmental output, science needs to provide knowledge and information required to:

- produce biodegradable products that break down into harmless organic substances on disposal;
- increase treatment of wastes before their discharge into the environment, thereby converting toxic and polluting substances into inert and harmless ones;
- increase the volume of waste recycling to prevent wastes from reaching the environment;
- increase the assimilative capacity of recipient media without causing detrimental ecological change; and
- discover new and safe recipient media that would allow wastes to be assimilated or stored in new ways.

4. Economic Production Processes

To reduce and reverse the negative impacts of current economic production trajectories, science needs to provide knowledge that supports:

- reducing wastes generated in economic production through better use of materials, recycling and the use of low-waste and clean technologies;
- increasing the volume of materials recycling by reusing a given volume of environmental output;
- reducing energy consumption in production through conservation and through efficient process and technology design;
- switching to the use of renewable energy sources such as solar, wind, tidal, hydroelectric and geothermal energy;
- developing new technologies that alter human work and settlement patterns in ways that reduce environmental impacts;

- substituting human labour for machine production; and
- reducing the resources used in distribution of goods and services.

5. Products

To reduce and reverse the negative impacts of products used and consumed by human economies and societies, science activities need to be oriented to provide knowledge that supports:

- reducing the size of goods;
- increasing the durability of goods;
- reducing the energy required in using goods;
- producing more biodegradable products that break down into harmless substances upon disposal; and
- improving the quality of products.

6. Demand

To reduce and reverse the negative impacts of human demand on ecosystems and quality of life, science activities need to provide knowledge support and technological changes that:

- shift the composition of demand to products with a lower material content;
- achieve absolute reductions in per capita demand; and
- achieve absolute reductions in population.

Technological Change and Sustainable Development

An important facet of science for sustainable development concerns the potential and real influence it exerts upon technological change. Evolutionary economists have discussed the need to shift existing technological systems towards more environmentally benign forms (Heaton et al., 1991; Freeman, 1992; Kemp, 1994). In 1991, the World Resources Institute produced a report entitled *Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century.*[1] This study emphasized that many emerging technologies offer exciting opportunities to achieve an "ecological modernization" of industry and agriculture, and provided a comprehensive examination of the types of public policy change needed to realize this potential (Table 2).

The guiding philosophy underlying this transformation of technological society has become *pollution prevention*. Until now, most environmental technologies

[1] See Heaton et al., 1991.

have been designed as end-of-pipe controls, as well as for the clean-up of existing pollution. However, it is increasingly recognized that products, processes and systems can also be designed to prevent pollution, and to generate positive long-term economic benefits (Hirschorn and Oldenberg, 1991). Policies that support pollution prevention through technological advancement are clearly necessary for sustainable development.

It is now recognized that technical change is not a random process, but is somewhat deterministic (Nelson and Winter, 1977; Dosi, 1982). It has also been found that the rate and direction of technological change is shaped into distinct patterns because of the beliefs and actions of key actors, scientists, entrepreneurs and industrialists. According to Kemp (1994), an important characteristic of a techno-economic paradigm is the existence of a core technological framework, shared by entire communities of technological and economic actors, that acts as a base from which improvements in process efficiency and product development are made. The term *selection environment* has been used to illustrate the importance of historical socio-economic context in technological trajectory pathways and the establishment of technological patterns.

Table 2: Key Policy Recommendations Necessary for Transforming Technology to Support Sustainable Development

Recommendation	Required Action
Environmental regulation should be reformed to encourage technological change	• Move away from standards based on "best available technology" towards performance-based standards • Integrate environmental regulatory statutes • Increase use of public disclosure requirements
Economic incentives should be employed in tandem with regulation	• Ensure that pollution charges reflect the full social and economic costs of production, consumption and waste
Economic indicators should fully estimate the value of the environment	• Integrate the full cost of the use of the environment into national economic indicators
Technology policies should embrace environmental objectives	• Integrate environmental objectives into technology policies • Assess long-term consequences of technologies more thoroughly at an early stage
Educational policies emphasizing the role of technology in a sustainable future need to be directed at private sector managment and the general public	• Convince those who design and control technology in private firms that environmental protection complements competitiveness • Change management's focus away from end-of-pipe pollution control towards pollution prevention • Ensure that public school and university curricula fully integrate environmental factors

Source: Based on recommendations in Heaton et al., 1991.

Freeman (1992) has argued that a sustainable future requires the evolution of technological systems that are shaped primarily by environmental considerations — material and input reductions, achievement of production efficiency and alleviation of pollution. In his view, technological innovation offers the best potential to make a sustainable transition from "worn out" paths of industrial development to new trajectories. Such a vision immediately suggests an important role for government policy along the lines presented by the World Resources Institute (Heaton et al., 1991), even though many would argue that government policy continues to support the dominance of existing (and polluting) technological trajectories.[2] Kemp (1994, p. 1032) reinforces the idea that governments can play a key role in the shifting of technological systems towards environmental sustainability:

> Through its science and technology policy, the government is involved in the generation of knowledge and through its education policy in education and skill formation. Public authorities are often heavily involved in the provision of infrastructure which is so important for the growth of new technological systems. As a last point, the government's tax policy, industrial policy, procurement and regulation all affect the economic process in important ways.

If governments are to influence the rate and direction of technical change in society, therefore, they should be able to provide commitment to the promotion of an environmentally sustainable future through explicit and implicit forms of technology policy. Schot (1992, p. 42) suggests that a quasi-evolutionary model of sustainable technological development allows three types of actors to be distinguished:

1. actors who are directly involved in the formulation of objectives and heuristics. By doing this they determine the content of variation generation. Good examples of this are company research and development departments and technological institutes funded by the government.

2. actors who attempt selectively to influence the variations from outside in order to obtain desired effects. These are the actors who do not formulate the objectives of technology development themselves. Good examples are government bodies that try to force technological change by way of environmental regulations and certain environmentalists who attempt to do the same by political action.

[2] In his discussion of technological paradigms, Giovanni Dosi distinguished between the role of public policies related to the search for new technological paths from those aimed at promoting technological advances along established technological trajectories. See Dosi, 1982.

3. actors who couple variation and selection: the technological nexus. These are institutions or individuals who, on one hand, translate demands made from within the selection environment into recommendations or objectives for technological development, and who, on the other hand, impose the demands made by certain technological variations on the selection environment. An example could be environment departments in firms.

In Schot's (1992, p. 43) model of technical change, moreover, three general government strategies are distinguished as being particularly important for moving technological systems towards an environmentally sustainable future. These are:

1. *Development of alternative variations.* Governments can try to stimulate technologies that are not developed in the marketplace.

2. *Modification of the selection environment* through regulation and other instruments. Stringent regulation is seen as being important for the creation of new expectations about viable technological futures.

3. *Creation or utilization of institutional links*, called the technological nexus, between places that produce variations and their selection environments. Such a nexus helps translate selection pressure into criteria and specifications used in the design process. Networks need to develop around new technological options and effectively serve nexus functions.

A broad range of actors can be envisaged as playing a role in a technological nexus, including government actors. Schot (1992, p. 51) argues that as governments develop the nexus strategy, a fourth actor "type" will emerge — those who monitor the "technology game" by "creating suitable conditions for interaction and feedback" amongst various social, economic and political actors.

Challenges in Orienting Science for Sustainable Development

The above discussion has emphasized the attractiveness of "technological shifts" as an approach for moving towards sustainable development. The role of government science and technology policy in motivating these shifts has been emphasized. It should be clear, however, that government, industry and social actors and institutions are all responsible for helping shift technological systems towards sustainability. Moreover, it should be recognized that the addition of an environmental dimension into the sectoral technology policy making complicates decision making for government. The foremost problem is that responsibility for environmental and science and technology policies is usually divided between government departments.[3] Therefore, it is essential for science and technology policy and environmental policy to integrate in a manner that supports a redirection of technological systems towards sustainable development objectives.

The science and technology capacity to support sustainable development is located in a broad range of institutions — industry, governments, colleges and universities, non-government organizations, and individual communities. In each of these sectors, science priorities and directions are shaped by different values, perceptions, philosophies, missions and needs. The orientation of scientific activities, therefore, reflects sectoral values and philosophies. Another challenge is the uneven geographic distribution of scientific human resource and physical infrastructure capacity worldwide. Geographic areas having little domestic science human resources and infrastructure are dependent upon external suppliers of scientific support. These external science resources (human and physical) may again be driven by different values, perceptions, philosophies, missions and needs from those in the receiving environment.

While science capacities in different institutional sectors and geopolitical regions can be oriented to support the principles of sustainable development, a key challenge is the coordination, integration and communication of currently disconnected research and science efforts. Integrating distinct science activities and actors to provide the types of information that would allow the systemic analysis necessary for evaluating progress towards sustainable development is and will likely remain a challenge. Breaking the orientation of science away from disciplinary barriers towards multidisciplinary studies is another challenge. Integrating methodologies and analytical approaches used by natural, physical and social sciences requires innovative approaches to project design and management.

Increasing stakeholder participation in science project design is an ongoing challenge for science. Scientists often find it difficult to develop programs and projects using input gained at a local and community level. Local sources of knowledge, moreover, are often shunned or disregarded by scientists, and the level of technical knowledge within communities can serve as a barrier to relevant participation. Communication gaps that still exist between scientists and members of the public must continue to be broken down. Greater effort, moreover, must be made to use and communicate information that already exists, rather than focusing solely on generating new information that remains known to a select few.

[3] Government agencies involved in these traditionally separate activities are often only imperfectly aware of the implications of their departmentalized policies on policies for innovation elsewhere in the political system (whether at an intra- or intergovernmental level). Even when they are aware of these indirect connections, they often do not attach much significance to them, as they are preoccupied with their primary mission. See Rothwell, 1992.

Finally, managing the complex scientific analyses required to provide useful information on progress towards sustainable development is likely to remain a formidable challenge in the future. Advances in theoretical and empirical understanding of complex systems may allow further identification and measurement of parameters that appear to determine the behaviour of complex environmental, social and economic systems. On the other hand, the scale and scope of parameters influencing these complex systems may continue to limit analysis, and at best permit estimated degrees of progress towards sustainable development.

Science Policy in Support of Sustainable Development

Since the primary function of science for sustainable development is to provide knowledge for human (including institutional) decision making, technical change and innovation, it is reasonable to expect that policy can help shape the orientation of scientific activities in the desired direction. Evolutionary economists have coined the term *selection environment* to describe the market as well as the various institutional, social and geographical factors that influence choices made by firms. By thinking in a similar way about the role of science policy for sustainable development, it is possible to contemplate the ways in which science might be oriented to provide knowledge to influence the decision-making selection environment of individuals and institution in ways that support sustainable development.

Two primary policy approaches are felt to offer particular relevance for orienting science activities towards sustainable development. The first is through the use of explicit and implicit science policy instruments. The second is through the use of novel policy development and implementation approaches reflected by cooperative institutional arrangements, stakeholder participation, and collaborative/integrated styles of governance.

Providing a basis that will enable planning of science for sustainable development can be primarily accomplished by two tasks — the setting of targets for sustainable development (ecosystem health, social quality of life, economic success) and the establishment of indicators to monitor sustainable development progress. These indicators are required not only to monitor key ecosystem health features that must remain constant, but also to monitor economic and social activities affecting ecosystems. While these tasks can assist in providing a planning foundation to shape future science activities, science can also provide guidance leading to their establishment. Science-based knowledge, for instance, can provide guidance about the types of targets that are required at local, regional and global levels. Scientific knowledge, moreover, can help produce reliable indicators that can be used to monitor the state of ecosystem health, as well as the impacts of economic and social activities on ecosystems.

Science Policy Instruments in Support of Sustainable Development

Science policy instruments in support of sustainable development can be drawn from across a wide range of policy areas (economic, finance, trade, environmental, education, social, health, etc.). They can also vary in their specificity — the degree to which they focus on specific environmental, economic or social issues — as well as the degree to which they focus explicitly on sustainable development objectives. Finally, science policy instrument choices can attempt to elicit a variety of behavioural responses from targeted and non-targeted individuals and institutions. As a result, it is possible for the cumulative effect of science policy instrument choice to present a multistrategic approach to provide support for sustainable development. A characteristic that these policy instruments have in common is that they directly or indirectly affect the decision-making selection environment of human societies in ways that help sustain economic and environmental systems.

Schneider and Ingram (1990) argue that policy instruments almost always attempt to get people (or institutions) to do things that they might not have done otherwise. They identify five broad categories of instruments — authority, incentives, capacity-building, symbolic and hortatory, and learning — each of which makes different assumptions about how policy-relevant behaviour can be fostered. Table 3 shows how this approach can be used to create a typology of explicit and implicit science policy instruments for sustainable development.

Table 3: Typology of Science Policy Instruments in Support of Sustainable Development

Authority	Incentives	Capacity	Symbolic	Learning
Regulatory standards	Subsidies for research and technical change	Funding R&D and technology development programs	Strategies	Committee hearings
Impact assessment requirements	Cost sharing of research and development	Information provision, surveys, policy research	Reorientation of research expenditures	Science and technology networks
Monitoring and evaluation requirements	R&D tax credits	Conference support	Awards	Educational centres and programs
Performance bond requirements	Repayability of performance bonds	Educational centres and programs	Voluntary agreements	Policy issue networks
Rehabilitation requirements	Technology demonstrations	Support of policy forums	Intergovernmental agreements	Support of policy forums
Performance requirements	Procurement	Collaborative research and technology development	Best practice benchmarking and showcasing	Communication strategies and programs
Guidelines	Patent protection	Research and development grants	Persuasion campaigns	Technology transfer
Threat of liability	Threat of liability action	Technology transfer, technical assistance	International agreements	International policy activity
Taxes for environmental clean-up	Tax incentives, concessions and funds	School programs	Establishing conservation areas	Comparative lesson drawing
Voluntary agreements	Threat of criminal actions	International assistance	Clean-up funds	Media campaigns

In order for science to support sustainable development, policy instruments that affect the orientation of science and technology activities in various institutions must come to occupy a common *policy space* (the term *policy space* is used to refer to a set of policies or policy areas that are so closely interrelated that it is not possible to make useful statements about one of them without taking other elements of the set into account). Moreover, patterns of policy instrument choice affecting the orientation of scientific activities must represent multistrategic approaches for focusing attention on integrated analyses of environmental, economic and social issues.

Placing emphasis on the policy approaches required to reorient science attention towards sustainable development has created scope for policy innovation. The integration of environmental, social and economic policy objectives provides an opportunity, therefore, for institutions to "retool" old science policy instruments to serve broader objectives, as well as invent new types of instruments. The trend towards science policy instrument retooling and innovation is likely to be a process of trial and error, as well as learning from mistakes and past experiences. It can be influenced, however, by the evolving discussion of the possible roles of science for sustainable development.

Governance of Science for Sustainable Development

The principles associated with sustainable development have a number of implications for the governance of science and science policy. In particular, it appears that novel science policy approaches need to be reflected by cooperative institutional arrangements, multistakeholder participation and collaborative/integrated governance styles.

It is important to emphasize that scientific information, even if it could be perfect, is only one input to institutional and individual decision-making processes related to sustainable development. The challenge for research planners and scientists, moreover, is to plan and conduct research that can provide relevant scientific information that is useful and timely for decision makers. It probably will remain the case that complete scientific consensus will be difficult to reach on most complex issues associated with sustainable development. Scientists, however, are routinely expected to reach such consensus in the face of considerable uncertainty. While reaching a reasonable level of scientific consensus in support of environmental and resource decision making is a laudable objective, science for sustainable development should also aim to provide decision makers with an understanding of the uncertainty associated with complex systems. The real challenge for science is to develop methods that determine the potential costs of this uncertainty, and to adjust human incentive systems to reduce its detrimental effects. Moreover, scientists need to develop better methods of communicating uncertainty, justify the use of the precautionary principle with respect to sustainable development decision making, and link more effectively with other disciplines and policy processes.

Human motivations and responses should be included as part of science activities in support of sustainable development (Costanza, 1993). As inputs and values other than those provided by scientists will always be part of human decision making, there is a need to include all types of stakeholders in efforts to orient scientific research towards the complex issues associated with sustainable development. While the literature on multistakeholder collaboration has generally developed independently from that on environmental protection and science policy, it is growing in importance as all of these fields undergo a paradigm shift from a mechanistic, linear perspective to a perspective characterized by complex actor relationships and negotiated order. Negotiated order theories use approaches involving interactive processes through which stakeholders gradually come to shared definitions of the situations they collectively face (Perlmutter and Trist, 1986).

Of particular interest to science for sustainable development is the growing literature on networks for social problem solving, although thus far research on these networks has been limited to public-private or community partnerships at the local level (Brooks et al., 1984; Pasquero, 1991). The highest level of network collaboration has been achieved through what Trist (1983, p. 270) has called "referent organizations." These networks have been specifically designed to address supraorganizational tasks — such as conceptualization of large-scale social problems with local implications, institutional direction setting, and development of collectively shared understandings — while leaving operations and implementation to lower-status organizations.

This literature suggests that, in order for science to support sustainable development, the governance of science should foster problem solving across organizations through the multipartite collaboration of different or otherwise conflicting interests. Some scholars have stressed the importance of including multiple perspectives in the search for solutions to environmental problems (Bingham, 1986; Susskind and Cruikshank, 1987). Gray and Hay (1986) found that the key benefit of the collaborative approach to natural resource policy making was the learning about values held by various interests in a policy community or network and the development of a shared perspective on key issues and policy problems.

It was implied earlier that including human motivations in science for sustainable development can be accomplished by developing linkages between the natural and social sciences to develop transdisciplinary syntheses. The existing literature on governance of science for sustainable development goes further by arguing that scientists should be used to recognize problems and issues, but should not act as decision makers.[4] This literature argues that scientists can explain what is known about an issue, and attempt to determine or explain the consequences of different responses or actions. In the arena of human decision making, however, there seems to be consensus that scientists are no more or less qualified to advocate solutions with respect to sustainable development than other well-informed citizens. Moreover, it is these ordinary decision makers (and the parties that stand to gain from the decisions made) who must ultimately be held accountable for the consequences of their decisions and actions.

[4] See multiple articles in Levin, S., ed. "Perspective: Science and Sustainability," *Ecological Applications* 3:4, pp. 545-590.

Conclusions

Science is essential to providing the knowledge for sustainable development. It is science that has enabled understanding of the mutually dependent relationships that exist between human activities and environmental health. Science provides a means of assessing as well as predicting the state of human conditions and environmental factors that sustain human life. Moreover, through its contribution to knowledge used by humans for decision making, innovation and technical change, science enables actions that improve the human condition while respecting the essential role that environmental health plays in sustaining human life.

Canada is a country that has traditionally demonstrated successful leadership in establishing policy and action that supports sustainable development. At the same time, Canada is one of the world's largest per capita consumers of energy, natural resources and water. The country has come under increased international pressure in recent years to reduce and stabilize its per capita consumption and waste generation trends. More significantly, domestic actions to achieve and demonstrate sustainable development are required in order to promote a similar result in other countries.

There are new efforts afoot in Canada to recognize and enhance the role that knowledge plays and will continue to play in Canadian society. An opportunity has been presented, therefore, for Canadians to think about the contributions that a knowledge-based economy and society in Canada could make to the achievement of sustainable development — both at home and abroad. To provide the foundation for an environmentally sustainable, knowledge-based economy and society, however, it is important that Canada reorient its science system to support sustainable development. Many examples have been provided of the ways in which science and science policy can be directed to support sustainable development. Canada, moreover, has an opportunity to orient its science capacity in a way that supports a renewed international role for the country as a "broker" of knowledge for sustainable development.

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