TECHNOLOGY AND THE INTERNATIONAL ENVIRONMENTAL AGENDA:

LESSONS FOR UNCED AND BEYOND

A Report Prepared for the Social Sciences Division
of the International Development Research Centre
Ottawa, Canada

IDRC

CANADA

TECHNOLOGY AND THE INTERNATIONAL ENVIRONMENTAL AGENDA:

LESSONS FOR UNCED AND BEYOND

A Report Prepared for the Social Sciences Division
of the International Development Research Centre
Ottawa, Canada

by

Amitav Rath and Brent Herbert-Copley

February 1992

TABLE OF CONTENTS

Acknowledgements v

Preface: Poverty, Environment and Technology vii

Section I: Context

A. The Current Environmental Agenda 1
   1. The Global Issues 3
      a) CFCs and Ozone Depletion 3
      b) Greenhouse Gases and Climate Change 5
      c) Forests and Deforestation 5
      d) Biodiversity 6
   2. The Local Issues 6
   3. The Need for International Action 7
B. The Lessons of Previous International Negotiations 9
C. UNCED and Beyond: The Context for Action 14

Section II: Issues and Concepts

A. Environmentally Sound Technologies 21
B. The Lessons of Past Research 24
   1. The Sources of Technological Change 24
      a) Creation of New Knowledge 25
      b) Technology Transfer 27
      c) Incremental Technical Change 29
   2. The International Market for Technology 30
      a) From the Technology Supermarket to the Market for Technology 31
      b) Costs and Benefits to Technology Suppliers 33
      c) The Market for Environmentally Sound Technology 36
   3. Technology Transfer and Technological Capabilities 36

Section III: Options

A. The Bases for Action 41
   1. Ensuring a Plurality of Initiatives 41

2. Pursuing Areas of Mutual Interest 42
3. Building Long-Term Capabilities 44

B. Options for Action 45
1. Clarifying the Rules of the Game 45
2. Increasing the Supply of Technology from Abroad 47
3. Promoting Adoption and Assimilation of Technologies 50
a) Technology Adoption 50
b) Technology Assimilation 53
4. Strengthening Developing Countries' Technological Capabilities 54
a) Needs Assessment 54
b) Technology Assessment and Choice 55
c) Strengthening Innovative Capabilities 56

References 59

ACKNOWLEDGEMENTS

In June 1991, the Social Sciences Division of the International Development Research Centre (IDRC) was asked by the National Round Table on the Environment and the Economy (NRTEE) to prepare a background paper on technology transfer as part of Canada's preparations for the United Nations Conference on Environment and Development (UNCED). This document is a revised and expanded version of that paper. A shorter paper, outlining more specific directions for Canadian policy, is also available (**Technology Environment and Development: Options for Canada at UNCED and Beyond,** September 1991).

As in any undertaking of this sort, this report is the product of the hard work and insights of a number of individuals. Gratitude is due in the first place to the many officials at IDRC and the NRTEE who supported and encouraged the work on which this document is based. Within IDRC, special thanks are due to Anne V. Whyte, Keith Bezanson, James Mullin, Chris Smart and David Brooks. Within the NRTEE secretariat, a note of gratitude is due to Anne Fouillard, Nonita Yap and Anne Dale. Responsibility for the views expressed in this document, of course, rests with the authors.

In addition, a number of individuals from outside IDRC participated as an informal steering group, reviewing and commenting on previous outlines and drafts: Victor Bradley, Theodora Carroll-Foster, Bob Fraser, James Gilmour, Margaret Kerr, Jorge Niosi, Jane Pratt, Grant Ross, and Francisco Sagasti. Additional comments on an earlier draft were received from Ashok Desai (India) and Henrique Rattner (Brazil).

The authors are also grateful for the support of a number of individuals involved in the production of this report. Special thanks must go to Derrick Poon-Young for his dedicated and able assistance with the background research for the report, in particular regarding previous international negotiations. In addition, Elizabeth Michalski helped to process the various drafts of the text, Bill Carman edited the final draft, and Brenda Wilson assisted in the production of the graphics.

Finally, the authors are grateful to the many developing country researchers who over the past two decades have been associated with IDRC's support to science and technology policy research. This report draws heavily upon IDRC's experience in this field. Ultimately, it is to this group of researchers that the report is dedicated.

PREFACE: POVERTY, ENVIRONMENT, AND TECHNOLOGY

The debates leading up to the United Nations Conference on Environment and Development (UNCED) have given new life to the subject of North-South technology transfer. Once at centre stage in development debates, by the mid-1980s it had been shunted aside by concerns over debt, macroeconomic adjustment, trade liberalization, and -- more recently -- sustainable development. But **as awareness has dawned that efforts to involve developing countries in environmental action must provide them with the financial and technical resources to achieve desired environmental goals, a variety of actors in both North and South have begun to reexamine the technology issue.**

To a large extent, unfortunately, this reexamination has been narrowly bounded, focusing on the "supply side", and in particular on the financial, institutional, and legal mechanisms by which technologies currently applied in the North can be transferred to developing countries. As a result, a whole range of "demand side" questions regarding the nature of developing country technology needs, the role of developing country research systems, and the factors affecting the adoption of technology have been downplayed. **This report attempts to provide a somewhat wider perspective, by looking at the role of technology in combatting environmental degradation and the potential of international cooperation in fostering this role.**

The starting point for the report is a recognition of the linkages between poverty, population, and sustainable development. As Sridath Ramphal has remarked: in developing countries, poverty, rapid population growth, and environmental degradation are closely interrelated, through feedback cycles absent in richer societies:

> Poor people often destroy their own environment - not because they are ignorant, but to survive. They over-exploit thin soils, over graze fragile grass lands, and cut down dwindling forest stocks for fire wood. In the context of short term needs of survival each decision is rational; in the longer term and wider context, the effects are disastrous ... Poverty is both a cause and an effect of environmental degradation (Ramphal, 1990, 39).

This is not to suggest that the blame for environmental degradation should fall on the poor. Misguided development paths and the rates and patterns of consumption in the industrialized countries bear far more responsibility for current damages and threats. But **concern for intergenerational equity cannot be ethically or practically maintained without a simultaneous pursuit of equity in the present. Efforts by the world community to tackle current environmental threats must confront the realities of poverty and the vast disparities in resources and opportunities within and among nations.**

What role can technology play in a poverty-focused approach to environmental protection? Technology -- understood here as the mix of knowledge, organizations, procedures, machinery, equipment, and human skills that are combined to produce socially desired products -- is not desired products -- is not simply a tool of social engineering. Economic and social structures shape the definition of social problems and hence the directions of technological change: in turn, changing technologies reshape social and production organizations. As such, **there is need for considerable skepticism about the role of technology in overcoming problems that are, at their roots, social and political -- and about the ease with which technological solutions developed in one socioeconomic context can be transferred to another.**

In both North and South, there is a growing awareness that technology does not on its own provide the answers to the challenge of development. Convenient assumptions linking technological advance with increased productivity and improvements in living standards are challenged by the realities of vast disparities in income and wealth between rich and poor, by the enclave nature of much industrial production, and by problems of indebtedness and capital flight. The link between technology and **sustainable** development is even more suspect, eroded by public perception of the disastrous environmental impacts of past industrial development and the ways in which presumably "benign" technologies -- chlorofluorocarbons, for example -- have in practice had unforeseen and damaging effects on the biosphere. More generally, it is now recognized that the environment is more than a set of biophysical indicators: attention must be directed to the human dimensions of environmental degradation, incorporating insights from the social as well as the natural sciences.

Nonetheless, any strategy to promote more sustainable patterns of development must draw upon technology. Environmental damage need not be an inevitable consequence of industrialization, technological advance and economic growth. New technologies already available provide a wide range of solutions to the recognized problems of the environment, and potential future technologies hold out the prospect of even more radical changes. **What has until now been lacking is international agreement that the local and global environments need to be protected and sustained, and a commitment to pursue the host of social, legal, and economic reforms needed to enable economic development, environmental protection, and technological change to work toward this end.**

This is beginning to change. Many developing countries now recognize the urgency of international efforts to address global environmental threats -- although they remain concerned about possible conflicts between environmental and developmental goals, about the overwhelming emphasis on global as opposed to local environmental issues, and about the ways in which the burdens of environmental adjustment will be shared between North and South. In the North, meanwhile, global environmental threats have provided a renewed and compelling illustration of the mutual interests of industrialized and developing countries and of the necessity of international cooperation. Images of rain forest destruction, the extinction of species, or the threat of climatic disruptions, have been the symbols around which a global environmental constituency has coalesced.

There is thus some hope for international action in the application of science and technology to environmental concerns -- a hope born of the urgency of current environmental problems, of the new-found recognition of mutual environmental interests between North and South, and of the fundamental role of science and technology in assessing and responding to environmental threats. To the extent that this does indeed come to pass, it may also offer a possibility to revisit some of the old but as yet unresolved issues regarding North-South technology transfer and the international economic order more generally.

This report is organized in three sections. The first section sets the context for current actions, looking at the nature of the current environmental concerns, the lessons of previous international negotiations, and the way the issues have been addressed in the lead-up to UNCED. The second section then discusses some of the concepts and issues upon which action must be based -- looking in turn at the nature of "environmentally sound technologies" and at the lessons of past research on issues of technology and development. The final section outlines a strategy for action and presents a series of more concrete initiatives by which a variety of actors -- North and South, private and public, independent and collective -- can work to enable science and technology to contribute to sustainable development. Priority is given to **four broad sets of actions:**

- **clarifying the "rules of the game" governing the international transfer of environmentally sound technologies;**

- **increasing the supply of such technologies from both local and foreign sources;**

- **promoting the adoption and assimilation of environmentally sound technologies; and**

- **strengthening the technological capabilities of developing countries.**

In each of these areas, the report emphasizes the need to combine a search for longer term, more far-reaching international agreements with a variety of incremental, pragmatic actions which can and should be pursued in the short term.

It is important to stress at the outset some of the limitations of the coverage of this report. Due to constraints of time and space, many important issues are only dealt with in passing. In terms of the "global" environmental issues, the report concentrates primarily upon ozone depletion and climate change; the important issues surrounding forests, the erosion of biodiversity, biotechnology, and the push to extend the scope and duration of intellectual property protection are all given more cursory attention. Similarly, the report does not discuss at length the so-called "local" environmental issues (soil erosion, desertification, protection of marine resources, hazardous and toxic wastes, urban environmental issues, etc.); clearly, however, such issues are at the core of the South's environmental concerns, and must not be brushed aside in attempts to deal with the North's "global" agenda. Finally, crucial aspects of the broader environmental debate -- concerning population, health and employment -- are all beyond the scope of this report. While recognizing the intimate connection between all these issues, the report attempts to concentrate upon a narrower sub-set of concerns surrounding science and technology.

Ultimately, this report is optimistic that UNCED will provide an opportunity for a shift in development directions. This optimism is not based on current negotiating positions of the world's governments, nor on the types of proposals so far being put forward by the donor community, nor on the sustainability of current development trends. Rather, it is based on a belief that there remains in the international community a core of rationality and goodwill, which combined with a recognition of longer term self-interest will provide the necessary stimulus to change. It is hoped that this report will make a small contribution toward this goal.

SECTION I: CONTEXT

A. The Current Environmental Agenda

UNCED represents an important milestone in the increasing global awareness and concern for the environment. Environmental concerns themselves, of course, are not new.

In the 1960s and 1970s, there were a number of warnings regarding the limits of natural resources and the physical environment to sustain life, and the dangers of stepping beyond these limits. Ehrlich (1968) argued that in many countries population had outgrown the capacity of the environment to grow food, and that starvation on a large scale was imminent. Similarly, the Club of Rome's influential The Limits to Growth (Meadows et al, 1972) argued that the rapidly growing world population was consuming nonrenewable resources at an extraordinarily rapid and increasing rate, and that critical shortages loomed in the near future.

At least to a certain degree, the dire warnings of Ehrlich and the Club of Rome have receded in importance. Increased food production -- in large part because of the development and diffusion of Green Revolution technologies -- has displaced at least temporarily the spectre of continent-wide starvation. Improved geophysical knowledge and the search for new resources have increased known resource availability 10-fold; combined with changing consumption patterns and decreasing material use per unit of economic activity (because of a variety of technological innovations), this has allayed fears of depletion of many nonrenewable resources.

During the same period, however, others warned of a different type of threat. As early as 1962, Rachel Carson's Silent Spring pointed to the dangers which DDT and other chemicals posed to human and animal health (Carson, 1962). In the intervening years, the kinds of threats highlighted by Carson have grown in importance as a result of the increasing scale and variety of chemical pollutants in use. The current environmental "crisis" is a result not of scarcity and shortages, but instead of the increased scale and variety of production activities; higher rates of growth of use and dispersal of man-made substances are accompanied by increased evidence of the limits of the environment to absorb, dissipate and render harmless the various wastes from human activities.

The issues confronting UNCED are to that extent of a different order from many earlier threats. **Current environmental issues are characterized by at least four distinctive features:**

- First, there has been **an important change in scale, with a shift from relatively small quantities of pollutants to increasingly large quantities** (Speth, 1988). Many of the pollutants of concern today (carbon dioxide, methane) have existed for a long time but have come to overwhelm the capacity of natural cycles to deal with them. And although some of the earlier fears of resource depletion have receded because of technological innovation, the rapid acceleration of pollution and resource degradation have raised new concerns regarding erosion of agricultural soils, loss of forests, over-use and pollution of fresh water, and loss of species.

- Second, there has been **an almost exponential growth in the number and diversity of impacts as a result of the increasing shift from naturally occurring pollutants to synthetic ones.** Today, there are over 80,000 chemicals in use, with scores of new chemicals added each year.

- Third, there has been a **spread of these problems across geographical boundaries**. Most pollution originates in the currently industrialized countries as a result of the enormous disparity in levels of consumption between North and South. But developing countries are important contributors to some environmental problems and will become even more important in the future as populations expand and industrialization spreads. More generally, we now understand that environmental threats do not respect national boundaries, but instead are often transboundary or global in their effects.

- Finally, there is a growing recognition that **the various environmental threats are inextricably interlinked**, both in their effects and in their causes. As a result, individual environmental problems cannot be studied or acted upon in isolation from each other.

In short, **it is the growing, widely shared conviction that a number of truly global problems now confront the world -- and that these problems are highly interrelated -- which provides the motive behind UNCED and shapes the current environmental agenda.**

This agenda is a broad and potentially divisive one. **It is instructive to separate the issues currently on the table into two categories:**

- **"global" issues (ozone depletion, greenhouse warming, deforestation, and the erosion of biodiversity), which, because of their far-reaching effects, have mobilized public attention and political action in the North; and,**

- **"local" issues, which have important impacts particularly in developing countries, but which have attracted far less international attention (desertification, marine pollution, hazardous wastes, solid waste management, the urban environment, etc.).**

The conflict between global and local environmental threats -- or what one observer has referred to as the "live" and "latent" environmental agendas[1] -- has exposed a significant North-South rift, which has arisen repeatedly in the debates leading up to UNCED.

1. The Global Issues

Northern attention has focused to a large degree on four interrelated global issues: ozone depletion, climate change, biodiversity, and forests, particularly the loss of tropical forests.

a) CFCs and Ozone Depletion

The first observation of reductions in the ozone layer over the Antarctic in 1974 can be said to mark the onset of the new era of global environmental concern. Substances that had been valued because they were colourless, odourless, nontoxic, and apparently non-reactive and stable were suddenly found to be an environmental problem precisely **because** of their stability in the lower atmosphere -- which allowed them to accumulate in the atmosphere and at high altitudes contribute to the depletion of atmospheric ozone.

In terms of the UNCED debates, ozone depletion is principally of interest as a model for action. Reaction to the ozone threat has been relatively swift and has become a **de facto** standard against which other negotiations are now judged -- even though, as will be pointed out, the nature of the debates at UNCED differ in fundamental respects from those concerning chlorofluorocarbons (CFCs). Early scientific evidence regarding CFCs led to action in the USA banning the most frivolous and nonessential use of CFCs as an aerosol propellant. As the larger threat of CFC gases became established, this was followed by international negotiations leading to the Vienna Convention (1985), the Montreal Protocol (1987), and most recently amendments to the Protocol in Helsinki (1989) and London (1990). Within a period of 5 years, the international community had agreed to ban completely the future production and use of CFCs over a specified time period. Even so, most recent observations of atmospheric ozone suggest that because of the overhang of CFCs already present, the destruction of ozone is likely to be much larger than suggested earlier. Before CFCs are eliminated, destruction of the ozone may be significant enough to increase rates of skin cancer.

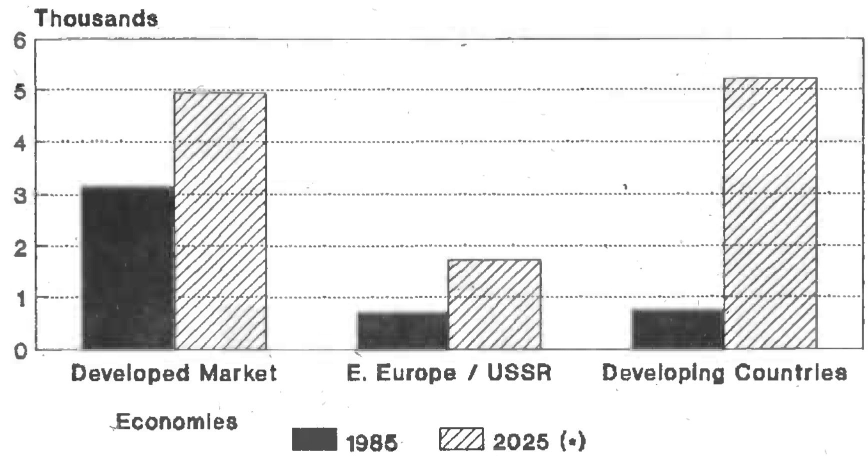
---

[1] The distinction between "live" and "latent" issues was suggested by Ashok Desai; clearly, however, local environmental issues are "latent" only in terms of their impact on Northern public opinion, not in terms of the seriousness of the threats they pose.

FIGURE 1

Production and Use of CFCs

(Million Tonnes on a CO_2 equivalent)



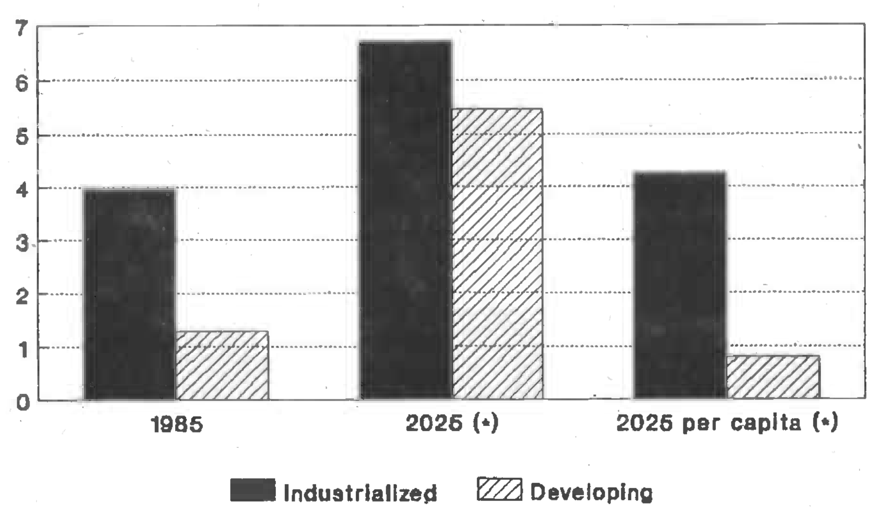
(•)Estimated levels in absence of action to reduce or eliminate CFC use.

Source: EPA

FIGURE 2

Global Carbon Dioxide Emissions

(Billion tonnes of carbon)



(•) Projections based on current trends with no international agreements to reduce emissions.

Source: USAID, 1990.

b) Greenhouse Gases and Climate Change

Climate change is of course the "star" of the current environmental agenda. At least in the North, it has become the dominant symbol of global environmental problems, and the prime mover of international environmental diplomacy.[2]

While many important uncertainties regarding climate change remain, the report of the scientists forming the Intergovernmental Panel on Climate Change (IPCC, 1990) has established that

- Emissions resulting from human activities are substantially increasing the global atmospheric concentration of so-called greenhouse gases: carbon dioxide (CO_2), CFCs, methane, and nitrous oxide;

- These gases enhance the natural greenhouse effect, which maintains the temperature of the earth required for currently existing life;

- The enhanced greenhouse effect **will** cause additional warning of the earth's surface, which in turn will increase the formation of water vapour, further enhancing the warming trend.

The IPCC further **predicts** that current trends are **likely** to cause average global warming of approximately 1 Celsius degree in the next 35 years and 3 celsius degrees in the next 100 years. Such a change in temperatures would be larger than seen in the past 10,000 years, and could result in a rise in global sea levels by 20 cm in the next 35 years and 65 cm over 100 years. This in turn would lead to the inundation of low-lying coastal areas, migration, and, in some cases, extinction of species, significant alterations in rainfall patterns, and substantial disruption of agriculture and forestry. As is the case for ozone depletion, a number of the gases responsible for the greenhouse effect are long lived in the atmosphere, so that their atmospheric concentrations will adjust slowly to changes in emissions.

c) Forests and Deforestation

Concern over forests has sprung in the first instance from the important role of deforestation as a source of CO_2 emissions, and, secondly, from the countervailing potential of growing forests to act as "carbon sinks" that lock up or "sequester" CO_2 produced by other activities. It has thus been realized that any attempt to deal with

---

[2] As with the conventions on biodiversity and forests, the proposed climate change convention is not formally part of the preparatory process for UNCED, but instead is negotiated in a parallel process. It is expected, however, that the convention (or framework agreement) on climate change will be signed in Rio.

climate change will have to address the use of global forest resources and provide guidelines for both afforestation and reforestation.

At the same time, however, there is also a growing recognition of the environmental significance of forests beyond their role in global warming. Forests are important as repositories of biological diversity, sources of productive employment, and contributors to water management and erosion control. As a result, there have been calls for a more far-reaching "forests" convention, rather than simply the inclusion of a forestry protocol in a possible convention on climate change.

d) Biodiversity

The rapid loss of plant and animal species has emerged as a compelling illustration of the global costs of environmental degradation, and has begun to rival climate change in its impact on Northern public opinion. There is also a dawning awareness of the direct economic costs of the erosion of the planet's genetic diversity, and the dependence of agriculture and medicine on genetic material originating largely in the South. This has been spurred in part by growing doubts about the effectiveness of Northern gene banks and a corresponding recognition of the importance of **in situ** preservation of native species.

Developing countries have insisted that any discussion of biodiversity must also touch on issues of direct economic significance to them. In practice, this has lead to discussions on two issues:

- A demand -- now gaining international acceptance -- for a system of "farmers' rights" that would compensate developing-country producers of the genetic material on which improved varieties are based; and

- A much more contentious demand that developing countries be guaranteed preferential access to the outputs of biotechnology research in the North as compensation for Northern access to Southern germplasm.

2. The Local Issues

Public debate in the North has been dominated by the preceding global issues, but it is crucial to remember that these are not the only issues of significance. There are also a series of other environmental issues that form a second and largely latent agenda. In some cases (e.g., marine pollution), these issues have significant transboundary impacts; but, in most cases, their impacts are more localized and are felt overwhelmingly in developing countries. Nonetheless, the combined significance of these "local" phenomena is as great as the so-called "global" issues. They have received comparatively little public attention to date -- either because they do not directly affect industrialized countries (e.g., desertification) or because industrialized countries have already taken action to deal with them, however imperfectly (e.g., hazardous wastes, solid waste management, urban environment).

For most developing countries, such local problems are at the core of their environmental priorities. Southern countries admit the importance of global environmental threats, but they argue with considerable justification that these threats have resulted largely from the effects of pollution and overconsumption in the North, and that the North should thus bear the brunt of the costs of dealing with such problems. According to this view, the debates to date have had two particularly perverse consequences. First, attention has centred to a large degree on the potential future contribution of Southern countries to global issues such as climate change or biodiversity, stressing projected rates of loss of tropical forest cover, or the potential growth of energy demand in developing countries. The greater current contribution of Northern countries is correspondingly downplayed, as is the scope for immediate improvements as a result of unilateral action by the North. Second, concern for global issues has deflected attention from consideration of the equally serious local problems affecting developing countries.

Such local issues, the developing countries maintain, are the key to the environment-development linkage. All too often, they argue, the "D" in UNCED has been silent -- concern for environmental improvement has overshadowed the need to address the problems of underdevelopment and poverty that are at the root of the South's environmental agenda. Issues of poverty, population growth, and employment are, in this sense, central to the UNCED debates.

Developing countries have been successful in ensuring that local environmental issues **are** on the table at UNCED. But public and policy making attention in the North remains squarely fixed on the broader global issues and on environment rather than development. In the realm of technology, the bulk of scientific research -- as well as funding for technology transfer -- is directed at the global issues, particularly climate change. As a result, there is a significant danger that these local issues will be downplayed in the discussions at UNCED and in the ensuing period. Yet, **any comprehensive attempt to mobilize international scientific and technological resources must deal with these issues. This means broadening the conception of Northern self-interest to highlight industrialized countries' stake not only in battling global environmental threats but also in promoting more sustainable patterns of development worldwide. Issues such as sustainable agricultural production or urban environmental problems should be every bit as much a "global" concern as are ozone depletion and climate change.**

3. The Need for International Action

Even a cursory review of this environmental agenda illustrates the pressing need for international action. At the very least, the following conclusions can be drawn.

First, the scope of current environmental threats, and their inherently transboundary or international impacts, means that any effective strategy to tackle them must involve cooperative efforts by North and South.

Second, although uncertainties remain, they are not sufficient to warrant postponing action. There are, of course, significant areas in which current scientific knowledge is deficient. In the case of global warming, for example, the state of knowledge regarding production of methane and nitrous oxide is far weaker than in the cases of CO_2 and CFCs. Similarly, more needs to be known about possible sinks for CO_2, particularly the behaviour of oceans. Current models of the global climate are also weak regarding interactions between clouds, ice sheets, and oceans. These deficiencies in the knowledge base affect estimation of the magnitude, timing, and distribution of warming, the determination of the impacts of warming, and as a result, the calculation of precise costs and benefits of alternative policy prescriptions. Similar gaps in knowledge exist regarding other global environmental issues (e.g., biodiversity), as well as regarding many of the more localized issues.

UNEQUAL UNCERTAINTIES: THE METHANE DEBATE

In debates over actions to combat global climate change, much emphasis has been placed on reducing emissions of methane. Like carbon dioxide, methane's concentration is increasing rapidly (nearly one percent per year) in the earth's atmosphere. Unlike carbon dioxide, methane has a relatively short-lived impact. Its atmospheric lifetime is only about 10 years, compared to 100 years or more for other greenhouse gases. This short atmospheric lifetime makes methane relatively easy to control, and reducing its emission is economically efficient in comparison with other greenhouse gases.

On the other hand, however, there is considerable uncertainty regarding the actual contribution of methane to global warming -- and about the way in which methane figures are being used and reported. Methane is produced in three principal ways: stomach gas from livestock; fermentation in irrigated rice fields; and leakages from coal mining, and oil and gas exploration and transportation, urban landfills and sewage plants. While the last of these three sources accounts for some 40 percent of total methane emissions, much of the emphasis has been placed on the first two, where the contribution of developing countries is relatively large. As Agarwal and Narain (1991) note, however, estimates of methane production from livestock and paddies are open to a wide margin of error, and are based on extremely patchy data. When atmospheric sinks for methane are figured in, total excess production of methane may in fact be quite small.

This suggests the need for considerable skepticism about the contribution of methane to global climate change. More broadly, it underlines the extreme asymmetry between North and South in terms of our understanding of the factors contributing to climate change: while our knowledge of Northern CFC and CO_2 production is relatively well-advanced, Southern contributions from sources like methane are much less certain. This in turn reinforces the importance of increasing scientific capability in developing countries, in order that they can effectively participate in debates over global environmental threats.

But although it is commonly agreed that we must accelerate scientific studies to reduce uncertainties and gaps in our knowledge, we cannot wait to act until all the uncertainties have been resolved. Time alone will not make the problems go away, and in the absence of significant efforts from an early stage, both the scale of impacts and the demands of any amelioration program are likely to be much larger.

Third, there are significant asymmetries between North and South that must be taken into account in designing any strategy of action. In the first place, the imbalance in **responsibility** for current threats is clear: although the potential future contribution of developing countries to global warming and other threats is startling, the inescapable fact remains, that historically, the bulk of environmental degradation has resulted from activities undertaken by, in, and for industrialized countries. Second, the imbalance in **resources** between North and South -- technical, financial, managerial, and institutional -- is undeniable. Finally, and in part because of the imbalance in scientific and technical resources, the very **uncertainty** surrounding current environmental threats is asymmetric (see Box: The Methane Debate). As a result of all these factors, **industrialized countries will have to take the lead in responding to current environmental threats, both by action to reduce their own contributions and by international cooperation to assist developing countries.**

Finally, any strategy to deal with current environmental problems must broach the issue of science and technology. Although technology is by no means a panacea to environmental degradation, scientific and technological capabilities are essential to the diagnosis of environmental threats and to the design of strategies to counter these threats. Yet, it is precisely in this area that the disparity between North and South is most daunting. Given this disparity, efforts must be made to transfer relevant technologies from industrialized countries to developing countries and to strengthen the capabilities of developing countries to select, adapt, and create the technology necessary to deal with environmental threats.

B. The Lessons of Previous International Negotiations

What are the prospects for international agreement on the technology issue at UNCED? Several previous sets of international negotiations have attempted to broach the contentious subject of North-South technology transfer, with varying degrees of success. The most obvious of these are the ongoing negotiations on a proposed international code of conduct on transfer of technology, which have been carried out under the auspices of the United Nations Conference on Trade and Development (UNCTAD) since 1972. In addition, the 1982 Law of the Sea Convention contains several provisions on the transfer of technology to developing countries. More specifically, in the area of environmentally sound technologies, there are three international agreements of relevance: the 1979 Long-Range Transboundary Air Pollution (LRTAP) Convention dealing with acid precipitation in Europe; the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer; and the

1989 Basel Convention on the Transboundary Movements of Hazardous Wastes and their Disposal.

A review of these negotiations yields four broad lessons for the current debates.

(a) First, there is a **trend toward increasingly detailed, concrete technology-transfer provisions** in the relevant conventions.

In fact, the evolution of the language employed is quite striking. The original LRTAP convention included a general call for technical cooperation among signatories, but no specific obligations regarding transfer of technology. The same was true of the first protocol to the Convention, dealing with sulphur oxide (SOx) in 1985. But, by the time of the 1988 nitrous oxide (NOx) protocol, much more specific language was adopted -- setting as a standard the use of the "best available technologies which are economically feasible" and requiring the parties to "facilitate the exchange of technology to reduce emissions of nitrogen oxides." It should be noted, however, that the protocol only requires **commercial** (i.e., nonconcessional) transfers, although it does call on the parties to "commence consideration of procedures to create more favourable conditions for the exchange of technology."

The Basel Convention (1989) made some progress in recognizing the special situation of developing-country signatories. The preamble to the convention states that the signatories have taken into account "the limited capabilities of the developing countries to manage hazardous wastes and other wastes" and recognize "the need to promote the transfer of technology for the sound management of hazardous waste and other wastes." More specifically, the Convention obliges signatories to "employ appropriate means to cooperate in order to assist developing countries in the implementation" of the Convention and to "cooperate in developing the technical capacity among Parties, especially those which may need and request technical assistance in this field." On the other hand, the Convention does not elaborate on specific mechanisms to facilitate such actions -- although it is expected that such an amendment will be on the table during the first meeting of the parties, expected to take place in early 1992.

The real break-through in technology-transfer provisions, however, came with the Montreal Protocol. The preamble to the 1987 Convention states that "special provision is required to meet the needs of developing countries" for CFC substitutes; more specifically, the Convention stresses the importance of ensuring developing country-access to "environmentally safe alternative substances and technology" and provides for the creation of a financial mechanism to assist developing countries in obtaining the relevant technologies. The Helsinki Declaration (1989) strengthened the wording of the preamble, by stating that the parties would "seek to develop appropriate funding mechanisms to facilitate the transfer of technology and replacement of equipment at minimum cost to developing countries". The 1990 London Agreement went even further, making three fundamental -- and unprecedented -- amendments. First, it included a strongly worded obligation on signatories to take all possible steps to transfer the best available technologies on fair and favourable terms to developing country parties. Second, it provided for the creation of a multilateral fund to finance the incremental costs to developing countries of compliance with the terms of the Convention. And, third, it stated clearly that the ability of the developing countries to fulfil their obligations under the Convention was dependent upon the implementation of the provisions regarding financial cooperation and technology transfer (see Box: The Montreal Protocol: Technology Transfer Provisions).

THE MONTREAL PROTOCOL: TECHNOLOGY TRANSFER PROVISIONS

The latest amendments to the Montreal Protocol on Substances that Deplete the Ozone Layer, approved in London in June 1990, included unprecedented language with regard to the transfer of technology.

Article 10A, 'Transfer of Technology', states the following:

> "Each party shall take every practicable step, consistent with the programmes supported by the financial mechanism, to ensure:
> a. that the best available, environmentally safe substitutes and related technologies are expeditiously transferred to [developing country] Parties ... ; and,
> b. that the transfers referred to in subparagraph (a) occur under fair and most favourable conditions."

Meanwhile, Article 10 provides for the creation of a multilateral fund to "meet, on a grant or concessional basis as appropriate, and according to criteria decided upon by the Parties, the agreed incremental costs" of developing country compliance, and to "finance clearing-house functions". This article also states that the financial mechanism will operate "without prejudice to any other future arrangements that may be developed with respect to other environmental issues".

Perhaps most crucially, Article 5 provides the following recognition of the special situation of developing countries:

> "Developing the capacity to fulfil obligations of the [developing country] Parties ... to comply with the control measures set out in Article 2A to 2E and their implementation by those same Parties will depend upon the effective implementation of the financial cooperation as provided by Article 10 and the transfer of technology as provided by Article 10A."

(b) Second, **two factors stand out as particularly important to successful international negotiations** in this field.

The first of these is the existence of clearly defined, scientifically established basis for action. In the LRTAP negotiations, initial opposition from several Western European countries to emissions standards and technology-transfer provisions was eroded over the 1980s by the mounting evidence of the impacts of acid precipitation. In the case of the Montreal Protocol, initial evidence regarding potential ozone depletion had, by the late 1980s, been confirmed by more thorough investigations, such that there was a substantial scientific consensus on the need to limit CFC use. Additional scientific confirmation that emerged during the course of negotiations -- notably the 1988 report of the Ozone Trends Panel -- had a galvanizing effect on reluctant participants such as the United Kingdom. The lack of scientific consensus on some of the issues before UNCED (e.g., climate change) may be one factor that will limit the potential to reach an agreement between North and South.

The second clear factor contributing to success has been the existence of a unifying interest bridging the gap between Northern and Southern negotiators. In the case of the UNCTAD Code of Conduct, it is this failure to find some mutual interest that more than anything else explains the continuing deadlock in the negotiations -- a situation that has also emerged in GATT negotiations regarding trade-related intellectual property measures (TRIPs). In the Law of the Seas negotiations, negotiators were able to forge an agreement on the issue of seabed mining, but the lack of demonstrable threats to Northern interests has weakened the willingness of key signatories such as the United States to accept the technology-transfer provisions and ratify the Convention. In the LRTAP and Montreal agreements, on the other hand, it was the inherently transboundary nature of the problem that served to force action in the area of technology transfer. This same factor -- the inability to halt environmental problems at national borders -- is perhaps the most important "carrot" available to those who hope to make significant progress on technology-transfer issues at UNCED.

(c) Third, the experience of previous negotiations illustrates the **long-term nature of action** to promote international transfer of technology.

Even under the most favourable conditions, of course, negotiating international agreements is a long and time-consuming process. With regard to both the Law of the Seas and Basel Conventions, implementation of technology-transfer provisions has been further stalled by the failure to secure the necessary level of ratification by signatories -- although in the latter case there is optimism that the necessary ratifications will be secured by early 1992.

After agreements have entered into force, concrete action in implementing the technology-transfer provisions has often been slow. Only two agreements have so far been signed as a result of the provisions of the 1988 NOx protocol to LRTAP -- between Finland and Poland and between Sweden and Poland. In part, however, this is due to the fact that many of the west European signatories have been able to meet LRTAP targets with existing technologies, thus reducing demand for development and transfer of new technologies -- and to the financial constraints facing potential purchasers in eastern and central Europe. It is expected that these issues will be addressed in negotiations later this year on an additional protocol dealing with volatile organic compounds (VOCs).

Pressures for action have been strongest in the case of the Montreal Protocol; but, even in this case, action has been somewhat slower than expected. The Multilateral Fund provided for in the Protocol has now been established under the joint auspices of the United Nations Development Program (UNDP), the United Nations Environment Program

(UNEP), and the World Bank. The fund, based in Montreal, is still in the process of appointing staff, organizing its day-to-day operations, and formulating its selection criteria. Contributions from sponsoring nations have been slow in materializing, and at least partially as a result of this, project disbursements have been far slower than expected.

(d) Finally, close examination suggests that **none of the previous agreements provides a firm precedent for the debates at UNCED.**

The closest parallel, of course, is the Montreal Protocol, and there has been considerable optimism that these negotiations have yielded a new model for international environmental diplomacy (Benedick, 1989) that will form the basis for action in Rio and beyond.

There is little doubt that the Montreal Protocol experience will form at least an implicit backdrop to the UNCED debates, particularly those on climate change. The type of agreements reached in the ozone accord on technology transfer and financial cooperation have set a benchmark against which developing-country participants will now judge subsequent agreements in other fields. There are also some clear lessons in terms of the conduct of the negotiations. Both the Montreal and LRTAP experiences demonstrate the utility of a flexible, incremental approach to negotiations, in which an initial agreement is quickly established in international law, but in which the treaty is deliberately designed to be reopened and adjusted as needed, on the basis of periodically scheduled scientific, economic, environmental, and technological assessments. The climate change negotiations may well follow a similar pattern, with the signing of an initial framework convention in Rio -- although there are also those who would prefer to accelerate the timetable, and push action in setting targets and establishing mechanisms for financial and technological cooperation.

At the same time, there are several factors that limit the relevance of the Montreal Protocol as a model for the debates at UNCED. To begin with, as previously noted, while the scientific evidence regarding climate change is strong, it has not yet attained the level of consensus that persuaded the parties to the Montreal Protocol to take dramatic action on ozone depletion. Second, and equally crucially, the Montreal Protocol succeeded in large part because of the limited nature of the problem under consideration, the limited range of alternative technologies to replace CFCs, and the resultant ability to predict and limit the financial obligations resulting from the treaty. Indeed, the 1990 London agreement prefaces its statements on technology transfer and financing with just these sorts of observations. In the case of the climate change and other debates at UNCED, the sheer scope of the problems and the uncertainty regarding costs may stall attempts to reach binding, comprehensive agreements on issues of financial and technological cooperation. Instead, UNCED is more likely to result in a set of framework agreements and a series of more piecemeal technical assistance and capacity-building efforts to address various aspects of the technology-transfer agenda.

C. UNCED and Beyond: The Context for Action

In the end, UNCED is the product, not the cause, of the increasing global concern over the links between environment and development. **Even though the "Earth Summit" may catalyze action at the national and international level, it is best seen as one of a number of steps toward desired goals, rather than the forum for achieving those goals.** And although failure to achieve concrete progress at the Conference would be a devastating blow to the global ecosystem, few if any of the issues facing the Conference will be resolved in their entirety at Rio. **This is certainly true in the field of technology transfer, where any agreements reached at UNCED will need to be followed up with ongoing initiatives by a variety of actors.**

Nonetheless, the Conference remains the key focal point for current political and diplomatic initiatives on environmental issues. Its importance derives from two factors.

First, expectations surrounding UNCED are high. At the time of the 1972 Stockholm Conference, developing countries were generally suspicious of calls for action on environmental concerns, viewing these as another barrier to development being thrust upon them by a developed world that, having prospered as a result of profligate resource use, was now asking the South to forego such benefits in the interests of a cleaner planet. On the Northern side, the nascent environmental movement succeeded in publicizing the linkage between environment and development, but lacked the political clout to convince Northern governments of the need for large-scale financial transfers, far-reaching institutional reform, or fundamental changes in patterns of resource use at home.

The situation facing the 1992 Earth Summit is appreciably different. Although many of the Third World's worries of environmental conditionality and environmental protectionism remain, their attitude toward the Summit is far less defensive than was the case in Stockholm. In part, this is due to the mounting evidence that certain aspects of global environmental change -- e.g., sea level rise because of climate change -- will affect some developing countries far more seriously than their Northern counterparts. But it also reflects a growing sense that the increasing political weight of the environmental movement in the North has made the environment "card" the strongest one in a generally weak Southern "hand", and one that must be played adroitly if the South is to link environmental concerns with its own development priorities. In the North, meanwhile, the prospects for action have been raised by a variety of factors: the increasing recognition that environmental protection and enhanced competitiveness may be complementary rather than contradictory goals; the growing strength of the domestic environmental movement, which has moved to the mainstream of political opinion; and the realization that the global nature of environmental threats makes defensive, "not in my backyard" responses untenable. These shifts of opinion have raised hopes that UNCED will result in a far more extensive and concrete "bargain" between North and South than has been possible in earlier negotiations.

WHAT'S ON THE TABLE AT UNCED?

The Earth Charter

The proposed Earth Charter will essentially be a moral document -- a statement of principles by which people and nations should conduct themselves in relation to each other and to their common environment. Among other things, it will affirm the right of all citizens to a clean environment, and the right of all countries to develop sustainably.

Agenda 21

This is the key document to be debated at the Summit, a 'programme of action' for implementation of the principles enshrined in the Earth Charter. Early indications are that the document will consist of three 'clusters' of issues. The first cluster would deal with the basis for action, profiling the opportunities and constraints facing the international community, outlining a set of principles underlying sustainable development, and setting out a series of broad developmental and environmental goals. The second cluster would present an action agenda, by defining concrete areas of action, and setting the parameters (objectives, targets, time frames, actors and institutions) for programmes of action, particularly within the UN system. The final cluster would then deal with the instruments for action, describing both the 'tool kit' required, and the types of supporting institutions and mechanisms needed to put it into action.

Conventions

The international conventions are being negotiated in processes separate from the preparatory committees for UNCED, but it is expected that at least some of these may be ready for signature in Rio. The climate change convention is the most likely candidate, although it now appears that this may take the shape of a framework convention (without specific commitments on CO_2 emissions, forestry or funding) rather than a more comprehensive agreement. Conventions on biodiversity and forests are at a more preliminary stage.

Cross-Cutting Issues

Finally, there will be pressures for some form of commitment to the types of cross-cutting actions necessary to implement any of the above actions -- principally institutional reform, financial transfers from North to South, and support to the transfer and development of environmentally-sound technologies.

Second, whereas other international fora have made progress on limited aspects of the global environmental agenda (most notably ozone depletion), UNCED stands out for its determined emphasis on the totality of global (and local) environmental threats. The Summit is aiming at four concrete outputs (see Box: What's on the Table at UNCED):

- An "Earth Charter" setting out the basic principles that must govern the environmental conduct of peoples and nations;
- An agenda for action, labelled "Agenda 21," which will translate these general principles into more concrete goals and strategies;

- Possible international conventions on issues such as climate change, biodiversity, and forests; and
- Agreement among the parties on the means to implement these measures, covering institutional reform and access for developing countries to necessary financial and technological resources.

In addition, it is likely that the Rio Conference will serve as the forum for the announcement of a number of national and regional initiatives on a variety of topics.

Where and how does technology enter this agenda? The most obvious and most frequently mentioned point of entry is the proposed climate change convention. It is widely agreed that any climate change convention will have to include a commitment to provide developing countries with the necessary financial resources and the appropriate technology and technical expertise to comply with the terms of the convention. This in turn would demand at least the following actions: agreement on an approach to be followed to assess developing countries' technology needs and inventory available technological resources; examination of the possible channels by which necessary technologies and technical expertise can be provided to developing countries; and agreement on the resources required to implement the necessary technology-transfer provisions.

This is not, however, the only area in which issues of technology transfer will be addressed. Both the Earth Charter and Agenda 21 will probably make general reference to the need to ensure access to relevant technologies, and technology-related issues will form an important part of the "tool-box" proposed in Agenda 21. Technology-related issues also are of clear relevance to debates over the conventions on forests and on biological diversity. Without underestimating the intractability of the issues facing the proposed climate change convention, some of the other technology-related issues before UNCED may prove even more formidable. In the first place, attempts to enshrine a general commitment to provide access to environmentally sound technologies within the Earth Charter continue to run into opposition from industrialized countries, fearing future financial obligations above and beyond the climate change convention. Meanwhile, the proposed biodiversity convention raises a host of even more contentious issues related to developing-country access to the fruits of biotechnology research in North as a quid pro quo for access to Southern germplasm -- which may, in the end, frustrate attempts to reach agreement on a convention.

Even though both industrialized and developing countries have accepted the need for some form of action on technology transfer, there is a wide gap between the two positions. At the risk of oversimplification, it is fair to state that **Northern countries have stressed the following four points:**

- **The need to ensure adequate financial compensation to inventors via developing-country recognition of intellectual property rights;**

- **A conviction that, as far as possible, technology should be provided on nonconcessional (commercial) terms, with no across-the-board guarantee of concessional access;**
- **A desire to limit the range of technologies under consideration, in particular by delinking the climate change convention from other issues under discussion at the Summit; and**
- **A preference for working through existing institutions to channel funds to support technology transfer activities, particularly the World Bank's Global Environmental Facility (GEF).**

Even within the Northern "camp" however, there are some important differences of opinion. The United States has tended to take the hardest line in terms of intellectual property rights and nonconcessional access. Other countries, notably Japan and western Germany, have taken a softer line. At least in part, this reflects their leading positions as suppliers of environmentally sound products, and the related perception that the principal economic benefits lie not in protecting rents associated with patents, but rather in aggressively promoting emerging environmental industries.

THE VIEW FROM THE SOUTH

Two recent ministerial-level meetings of developing country representatives have given greater insights into the likely Southern position on technology transfer issues at UNCED.

The **Tlatelolco Platform on Environment and Development** was adopted by the member countries of the UN's Economic Commission for Latin America and the Caribbean at a meeting in Mexico City in March 1991. Among other points, the Platform argues that "the promotion of sustainable development is incompatible ... with restricted access to technology", and that developing countries should be guaranteed access to environmentally sound technologies "on a non-commercial basis", with the largest share of the costs of transfer borne by the industrialized countries. The document further recommends that "a special international fund should be set up to ensure that the developing countries receive access to and transfer of environmentally sound technologies and to strengthen their endogenous capacity". In the area of biotechnology, the Platform argues that "developing countries should have access to advances in biotechnology, on concessional terms".

Even more recently, the **Beijing Ministerial Declaration on Environment and Development** was endorsed by representatives of forty-one developing countries at a meeting in June 1991. The Declaration stresses the need "to ensure the transfer of environmentally sound technologies to the developing countries on preferential, most favourable, concessional and non-commercial terms", and argues that such transfer should be seen as "a contribution to the common interests of humankind". The Declaration calls for the establishment of a special Green Fund to address problems not covered by other international agreements; such a Fund "would be managed on the basis of equitable representation from developing and developed countries". Finally, the document stresses that the biodiversity convention now under negotiation "must clearly recognize, inter alia, the linkage between access to genetic material and transfer of biotechnology".

The Southern position, conversely, has tended to stress the following points (see Box: The View from the South):

- **The need to secure access to the latest available technology, including proprietary technology, without conditionality in terms of reform of Southern patent legislation;**
- **The importance of concessional transfers, with the North bearing the brunt of the costs of providing the relevant technologies;**
- **The need to consider the entire range of environmentally sound technologies, not just those of relevance to global warming; and**
- **The importance of channelling funding through new institutions that would ensure an adequate voice for the developing countries in their constitution and operation.**

The emerging Southern position also emphasizes the need to negotiate a trade-off between Northern access to Southern plant varieties and Southern access to the results of biotechnology research being carried out in the North.

To a large degree, then, the discussion to date on transfer of "environmentally sound" technology has tended to mirror earlier debates about North-South technology transfer more generally, both in the gulf separating the Northern and Southern positions and in the nature of the issues addressed. As Martin Bell has pointed out with respect to the climate change negotiations, much of the debate regarding technology transfer has centred on "top-down" issues -- that is, the broad legal, institutional and financial arrangements governing developing country access to technologies developed in the industrialized world (Bell, 1990). At the other extreme, attention has focused on the specific mechanisms by which existing technologies now employed in the North could be transferred to the South. As a result, a whole range of questions regarding the nature of developing-country technology needs, the generation of more appropriate technologies to meet those needs, the expertise needed to ensure effective transfer, and the factors affecting adoption, assimilation, and adaptation of imported technology have been downplayed or ignored.

At the same time, there are **a few emerging signs of a movement away from this situation, and even of partial consensus between North and South.** In the first place, there is **a somewhat tentative consensus emerging that intellectual property issues are not the key constraint to effective action.** This is not so much the result of any softening of positions on the issue, but rather a recognition that many of the relevant technologies are not patent protected -- but instead involve public-domain technologies or "soft" technologies (e.g., managerial expertise). Second, there is an **increased recognition in both North and South that any effective strategy must involve not only the transfer of technologies from North to South but also the strengthening of indigenous Southern technological capabilities, through a variety of training and capacity building measures.** In general, this is a positive sign, although developing countries also worry that industrialized country support for capacity building and "technology cooperation" may serve to detract attention from the crucial issues of financing and concessionality. On these latter issues, as well as on the issue of the scope of technology-transfer provisions and on broader questions of financial and institutional reform, there is as yet no indication of a narrowing of the North-South gap.

SECTION II: ISSUES AND CONCEPTS

A. Environmentally Sound Technologies

Any discussion of the application of technology to global environmental problems must begin by examining the nature of technology needs. At the narrowest, these can be defined as the technology required to modify or improve upon specific products and processes that cause environmental damage. This is the kind of approach adopted by the Montreal Protocol, for example, in relation to ozone-depleting substances. For many observers (particularly in the South), however, such a definition is far too narrow, and should be broadened to include the transfer of all "environmentally sound" technologies.

But what are "environmentally sound" technologies and how can we go about identifying them? Three points are of particular importance in this regard. First, **there are a number of criteria of environmental soundness**. Full environmental soundness, of course, would mean "better" than any other technologies on all environmental and economic considerations. In practice, however, some types of technologies will be sound on multiple criteria, many will be sound on some criteria and less sound on others, and some will solve one problem only to create others. Second, **environmental soundness can only be a relative concept**. At a given time, one technology may be environmentally sound; but, at a later time, new technologies that are environmentally "sounder" are likely to emerge. As well, a technology that is initially considered environmentally sound may turn out to be very unsound (e.g., CFCs) because of increased knowledge regarding long-term effects or increased scale of use. Third, **environmental soundness is in many cases situation specific**. The mix of environmental and economic criteria to be met, and the relative weight attached to each of these, will vary widely from place to place. Moreover, the environmental soundness of a particular technology will in practice depend crucially upon the conditions under which it operates.

Despite these caveats, it is possible to define in general terms the characteristics of more environmentally sound technologies, provided there is agreement on the major environmental threats. As discussed earlier, the major threats today appear to emerge from limits to waste disposal capacity, and from the excessive loading on the environment of toxic products and by-products. Further, to the extent that environmental degradation is a result of poverty, environmentally sound technologies must increase wealth-creation and employment opportunities in the South. In generic terms, then, the technologies needed for a transition to a more sustainable development path would have to address the following goals:

- increased rates of economic growth and expanded employment opportunities in developing countries, and greater sensitivity to the resource endowments of these countries.

- increased efficiency in the use of raw materials and energy.

- elimination or reduction of the amounts of harmful wastes generated in production, and where such wastes are produced, ensuring minimum hazards to human health.

- promoting the reuse or recycling of inputs and final products.

Beyond such general considerations, **is it possible to meet the demand of the North to define a set of environmentally sound technologies in such a way as to limit the range of technologies under consideration and, more to the point, limit any concessionary financing to the defined set?** We believe there is no rational basis by which such a set can be predefined. It would instead have to evolve over time, through the assessment and application of various technologies, in terms of both their potential to improve a particular problem, and the likelihood that they will not create other subsequent environmental problems. Identification of such technologies will be an ongoing process, which will itself demand significant effort. As will be discussed, one of the crucial areas for action is the strengthening of the capabilities of developing countries to define their technology needs and to assess and select among alternative technologies.

These comments also suggest two other important observations. First, the range of potentially environmentally sound technologies is extremely broad. If we look at the problem of greenhouse warming, for example, environmentally sound technologies might include the following:

- Technologies to limit the use of CFCs. These form a relatively well-defined group of technologies, and are already targeted for transfer under the Montreal Protocol. These would include technologies to manufacture CFC substitutes products such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs); new processes to replace CFCs, in particular industrial processes, such as its use as a solvent in the semiconductor industry; technologies for substitute products (e.g., CFC-free refrigerators) as well the process technologies needed to use the new product; and technologies to recapture/recycle CFCs already in existing products such as air conditioners and refrigerators.

- Technologies that reduce the amount of primary energy required for a given end use. Approximately a third of the $C0_2$ produced in the industrialized countries (and more in the developing countries) is generated by electricity production. There is tremendous scope to increase the energy efficiency of domestic appliances, residential and commercial heating, cooking, lighting, and in industrial electric motors -- and thereby reduce the need for primary energy.

- Technologies to improve the efficiency of energy production. Increasing energy efficiency in end use provides the most immediate potential to slow the growth of CO_2 emissions (as well as potential benefits for economic growth). But developing countries will still need additional power generation capacity, much of which will continue to come from coal. Improved technologies such as combustion turbines, combined cycle systems, and cogeneration can increase fuel efficiency by more than 25 percent. Further reductions of CO_2 are possible by switching from coal to oil and natural gas: oil and gas exploration, exploitation, and utilization technologies thus should be considered environmentally "sound" at least in the near term for countries that would otherwise use coal.

- Non carbon-based energy resource technologies. Among these, hydroelectric power already provides considerable amounts of non-CO_2 based energy. Wind energy, solar thermal, and solar photovoltaic technologies have already established themselves as viable technologies in commercial systems. Their costs are close to thermal power and there is considerable potential for cost reductions through technical change and scale efficiencies. Nuclear power is also included by many as an environmentally sound technology, since the nuclear power cycle contributes only 5 percent of the CO_2 produced by thermal power plants (although the CO_2 generated over its total life cycle is higher); on the other hand, problems of radioactive waste, decommissioning and the generally higher cost of nuclear energy make it economically and environmentally less sound. Many environmentalists have similar reservations regarding large hydroelectric projects.

- Agricultural and forest-related technologies. This is potentially a very wide field. Improvements in energy efficiency in agriculture (both directly and by reducing applications of fertilizers, pesticides and other chemicals) can contribute to controlling CO_2 emissions; use of new rice varieties, improved irrigation management techniques, or alternative livestock feeding practices may contribute to reducing methane emissions; better forest management practices, afforestation techniques, and the development of agroforestry practices can help to slow the rates of deforestation and increase potential carbon sinks; and, most generally, technologies to increase agricultural output per unit of land can reduce pressures on forests.

This list is by no means exhaustive, and similar inventories could be made for other areas of environmental concern. What it illustrates, however, is **the extremely wide range of technologies potentially at issue, the interrelations among the various technical solutions, and the impossibility of establishing any firm dividing line between technologies with potential for environmental improvement and those that are important for development reasons. Decisions about the soundness of particular technologies must of necessity mix environmental and developmental criteria; where environmentally sound technologies are**

also cost reducing or employment enhancing, they should form the core of technologies to be developed and transferred to developing countries.

The second observation has to do with the nature of technological responses to environmental problems. There is now fairly widespread agreement that efforts to reduce environmental degradation must call upon not only "hard" technologies (machinery, tools, equipment) but also so-called "soft" technologies (management practices, know-how). What is less routinely acknowledged, however, is that **much of the scope for environmental improvement will come not simply from the application of existing technologies, but rather from the development of new technologies and practices suited to local conditions and from the efforts to improve the efficiency with which technologies are operated** (see Section B.1.c).

Together, these two observations suggest the need to broaden the discussion considerably from the focus to date on the availability of environmentally sound technologies and the legal, financial and institutional barriers to their use. Although such considerations are of undeniable importance, the **debate must tackle not only the transfer of environmentally sound technologies but also the ways in which the entire vector of technological change (in both North and South) can be altered in the direction of greater environmental sustainability. Given the difficulty of distinguishing between environmental and developmental technologies, the search for specific environmentally sound technologies must be balanced with efforts to improve the "generic" technological capabilities of developing countries.**

B. The Lessons of Past Research

These comments suggest that the scope of required actions is far broader than currently portrayed. At the same time, however, the nature of the challenges facing the international community is perhaps less novel than often realized. Earlier research into the relationship between science, technology, and development can yield important insights for current debates; at the same time, the greater urgency of current environmental threats and the wider recognition of mutual interests between North and South may provide a fresh -- and constructive -- outlook on earlier debates and disagreements. The following discussion attempts to distil some key lessons from earlier research on North-South technology issues and to suggest the relevance of these debates to the current environmental problematique. More specifically, the discussion below looks in turn at the sources of technological change in developing countries, the nature of the international market for technology, and the relationship between technology transfer and the development of indigenous technological capabilities.

1. The Sources of Technological Change

It is widely agreed that technological factors (and the capacity of a country to use these factors efficiently toward national development objectives) are among the key determinants of successful growth and development. Technological change may be induced in three different ways:

- The **generation of new knowledge** through basic and applied research;

- The **diffusion or transfer of new technologies both within and across national boundaries and their incorporation in productive activities**; and

- The **process of incremental improvements to production systems over time.**

These three sources, it should be noted, are not isolated. For science and technology to realize their potential contributions to development, factors spanning all three of these sources must be met simultaneously. It is nonetheless instructive to look at each of the three in more detail.

a) Creation of New Knowledge

Productive knowledge has traditionally been created by people as they attended to their normal economic activities. They recognize, for example, particular characteristics of certain seeds, patterns of crop rotations, or intermixing different plants to increase yields. More systematic processes for increasing the knowledge base are of more recent origin and have generally been the preserve of universities and educational systems. Finally, we have in recent decades the newly devised structures of public and private research laboratories that work on issues of basic knowledge and its application; it is this last category that is normally captured in national R&D statistics.

We know that scientific knowledge is not directly translated into technological innovation and that, too often, developing-country policies and international cooperation are biased toward the support and promotion of basic scientific capacities. But, to foster the increased use of environmentally sound technologies, there is a tremendous need for increased scientific and technical skills and increased research capacity in the developing counties. This is true for three reasons.

- **First**, even when technologies are transferred from abroad, it is increasingly evident that domestic scientific and technological capacity is the most important factor determining the success or failure of effective transfer.

- **Second**, increased scientific capacity and research in the developing countries is needed so that these countries can participate to a larger extent in debates over issues of global change, and contribute to their solution.

- **Finally**, increased capacity is essential for these countries to select among the most appropriate solutions and to modify and adapt these solutions to their own needs.

In addition to knowledge-creation **capacity**, attention must also be addressed to the efficiency of knowledge creation in developing countries. Similar to the poor economic efficiency of many production activities, the efficiency of utilization of skilled personnel and scientific resources in developing countries is often low. This is due to many factors: inadequate physical facilities, low pay and lack of incentives for applied, problem-solving research, lack of linkages to users and to larger groups of scientists in other parts of the world, poor access to information, and, lack of experience in problem definition and management. Tackling these problems requires not only increased financial resources but also increased scientific cooperation both between developing and industrialized countries and among developing countries themselves, and internal reform of scientific research institutions.

One of the key factors in the utilization of scientific and technological knowledge is the nature and extent of linkages between producers and users of knowledge. In the late 1970s, the STPI (Science and Technology Policy Instruments) study commented on the intimate connection between production activities, related financial and economic decisions, and the "technology variable." **Ideally, production and technology generation should be closely coupled, so that user problems drive research and development efforts; as solutions are proposed they are continually tested and adapted, providing new problems to be tackled and, hence, new directions for research.** Unfortunately, the results of the STPI work showed that such links were often weak or non-existent (Sagasti, 1978). More recent studies have confirmed this general finding, and suggest that a number of innovative efforts to link public sector research institutions with private sector research users can be undertaken (Ayiku, 1991; Azucena, 1988; Waissbluth et al, 1988).

Strategies to strengthen knowledge-creation capacities in developing countries must also contend with important changes in the nature of technological advance. Among these are the increasing "science-based" nature of technological change in many fields, and the fact that innovations now often call on inputs from a variety of disciplines and fields of research; the trends toward privatization of research, through both private funding of university-based research and the growing importance of in-house research capabilities; and the growing internationalization of the research and development process, not only in the public sector but also in the private sector, where the past decade has seen the growth of strategic alliances for precommercial research that often span national boundaries. The implications of such trends for developing countries are far from clear, but they will certainly affect the costs and risks of basic scientific research in developing countries, the need for collaborative efforts both within and among countries, and the balance between "producer" and "user" level efforts.

Finally, it must be remembered that knowledge creation may also involve an important element of recovery and reintegration of "traditional" knowledge. This may be particularly important in some areas of environmental concern (e.g., low-input agriculture) and raises a host of other challenges for developing countries (on the issue of "blending" new and traditional technologies, see Rosenberg, 1986).

b) Technology Transfer

Transfer of technology is said to take place when an existing technique is moved from one location to another. This movement may be from a research laboratory to a production location or entity or from one production location to another. Transfers can take place within a single firm, where a technology used in one plant or location is transferred to another; within a country, where a technology is diffused from one producer to another; or across international boundaries.

As previously stated, it is a mistake to reduce the debate over the linkages between technology and sustainable development to a much more narrowly bounded discussion of North-South technology transfer. Nonetheless, technology transfer remains a crucial element of any effort to deal with current environmental threats.

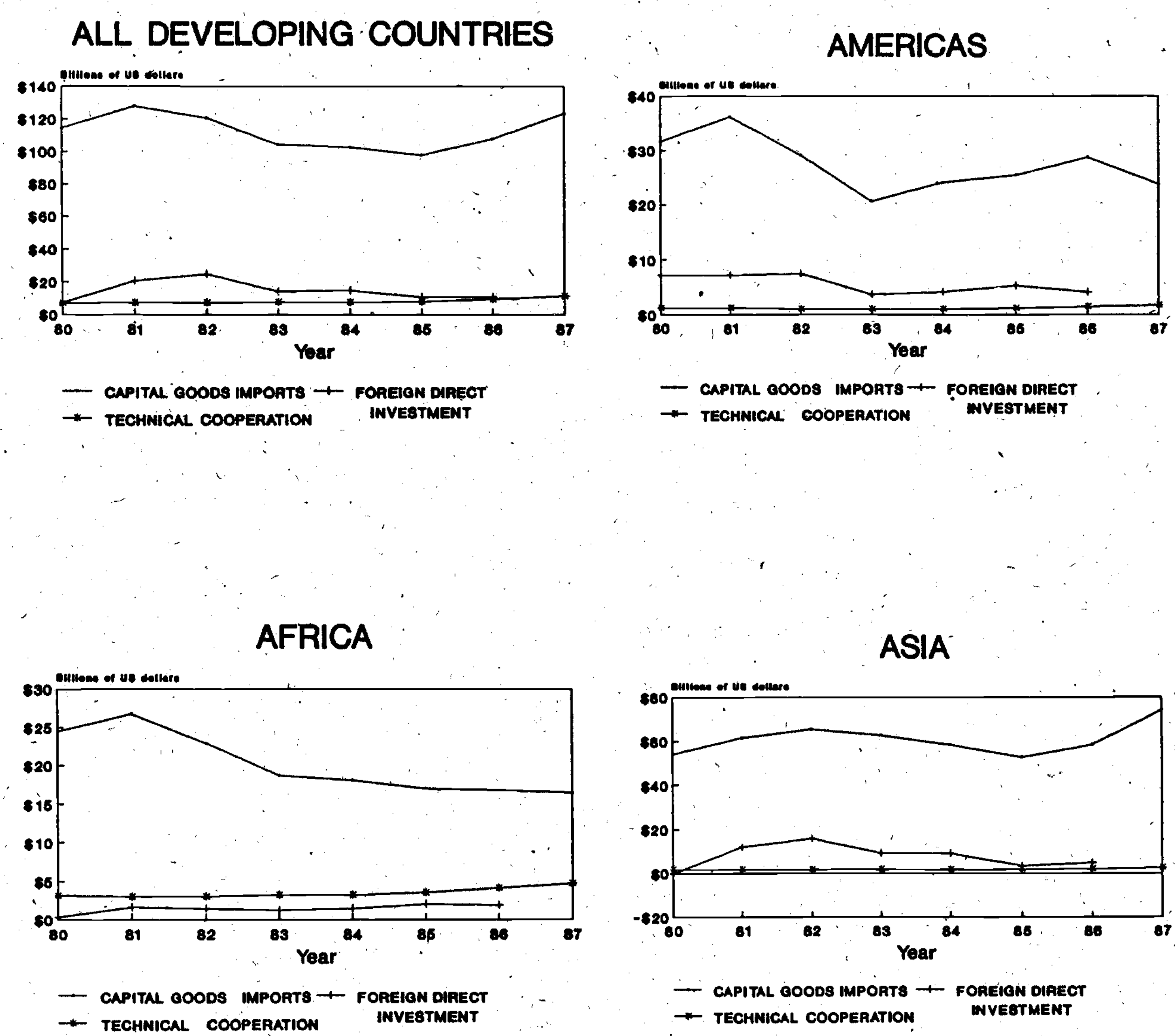
Of all the disparities between North and South, the disparity in scientific and technological resources is most acute. No matter how much effort is made to develop local capacities in the developing countries, in the medium term there will be continuing need for technology transfer. This is particularly true in the context of current environmental debates, where the challenges facing the international community are urgent and immediate. Technologies to meet many developing country needs do exist, and efforts to strengthen local innovative capabilities are in no way a substitute for their transfer. Indeed, it is increasingly recognized that technology transfer and innovation are not polar opposites; instead, technology transfer can under appropriate circumstances contribute to the strengthening of indigenous technological capabilities (see Section B.3).

Perhaps even more crucially, efforts to increase the supply of technology from abroad are important as a means of counteracting, however partially, current trends in the environment for international technology flows. **At least in Africa and Latin America, low growth rates and high debts have reduced capital flows and made foreign exchange increasingly scarce. The result has been a reduction or stagnation of capital goods imports, foreign direct investment, technical assistance and foreign training, all of which are important channels for technology transfer (see Figure 3). In this scenario, it is not surprising that many developing countries look to the UNCED debates as an opportunity not only to tackle crucial environmental problems but also to jump-start stagnant flows of technology and capital from North to South.**

Meanwhile, increasing competition, increasing rates of technical change in some sectors, the need for access to wider elements of knowledge for successful product and process innovation, and the resultant increase in the costs and risks of innovation have forced many industrialized country firms to increase cooperative activities in technology

FIGURE 3

INDICATORS OF TECHNOLOGY FLOWS TO DEVELOPING COUNTRIES, 1980-87



Source: Chudnovsky, 1990.

development and production (cross-licensing of patents, joint R&D activities, new forms of product and process development partnerships). There may be some benefits to developing countries in these trends: larger numbers of technology suppliers and heightened competition among them should allow developing countries to increase their options and obtain better terms. On the other hand, however, there is a very real danger that increasing collaboration among industrialized country firms may leave developing countries on the periphery of an increasingly important source of technological advance.

c) Incremental Technical Change

For many people, science and technology imply only the major and radical breakthroughs, undertaken at increasingly large expense in formal research facilities. As a result, discussions of technological innovation and transfer often do not distinguish between "radical" technological innovations (microelectronics, biotechnology, advanced industrial materials) and the equally significant role of "incremental" technical change. Incremental technical changes are those being developed and incorporated everyday at the level of the production unit, be it farm, factory, or service unit, as technology users continually improve initial innovations, develop new applications, reduce input costs, and adapt the original innovation to local demands and conditions.

Since the late 1970s, a number of firm- and sector-level studies in developing countries have highlighted the importance of incremental technical change. Earlier questions -- whether to import technology or develop it locally; labour-intensive versus capital-intensive technologies; and others posed in a framework of static comparisons -- have given way to a recognition of the essentially dynamic nature of technology. Technology decisions are no longer seen as a one-off choice but an ongoing series of decisions that must focus on continuous improvements.

This literature has yielded a number of conclusions of relevance to debates over environment and technology (see also Herbert-Copley, 1990). The impact of incremental technical change on productivity can be astounding and, at times, outweighs the effects of the introduction of new, capital-embodied innovations. Yet there is nothing automatic about this process (as the simplest formulations of "learning by doing" -- in which learning is a function of time or cumulative output -- would suggest). "Learning" does not occur in all firms, but rather depends on a conscious decision by management to invest resources in training, organizational changes, and technical assistance. And since many of the stimuli responsible for incremental technical change are internal to the firm, developing-country manufacturing installations tend to be highly "idiosyncratic" in their structure and operating parameters -- which, in turn, may limit the extent to which technologies currently in use in the North can be easily transferred.

Whereas attention has usually been focused on the role of incremental technical change in improving capital or labour productivity, other studies show similarly impressive rates of increase in the efficiency of energy and other natural resource use. One of the bestdocumented studies is Enos' path-breaking 1962 study of the experience of US oil refineries over a 30-year period. He found that small, ongoing processes of technical change not only increased labour and capital productivity but also resulted in a more than 50% saving in energy and other material inputs per unit of output. More recently, de Larderel (in UNCSTD, 1991) cites evidence from a survey of Dutch firms, in which as many as 30 percent of the prospects for "cleaner" production involved relatively simple "housekeeping" measures (fixing leaks, separating waste streams to allow recovery, etc.). This suggests that there is significant scope for relatively low-cost, incremental improvements in the environmental costs of production.

Similar evidence exists for developing countries. Bell (1990) argues that although developing-country installations tend to operate at low levels of energy efficiency, there is scope for substantial improvements in energy efficiency through more efficient use of -- and minor technical changes to -- existing facilities. In fact, Bell argues that the most important source of productivity improvements for developing countries will continue to be incremental changes within existing production facilities, rather than entirely new generations of technology -- and that in the absence of sustained efforts to build the types of capabilities needed to create and sustain productivity improvements, transfer of novel technological systems may result in only limited and short-term improvements in efficiency (Bell, 1990, p.32). Perhaps even more crucially, he notes that improvements in resource use are likely to go hand in hand with increased productivity of capital and labour. As a result, in many cases reductions in levels of CO_2 emissions and other pollutants can be achieved as part of a strategy to improve the **economic** efficiency of production in developing countries (see also ERG, 1986).

2. The International Market for Technology

In debates about science, technology, and development in the 1950s and 1960s, it was commonly assumed that science and technology were public goods. Once created, everyone benefitted from new scientific and technological knowledge, there were no losses to one individual because another acquired it, and the cost of diffusion and transfer of knowledge was close to zero. As a result, it was assumed that the vast body of world knowledge was waiting as in supermarket shelves to be picked by the developing countries to meet their needs. This would provide the developing countries with an advantage over the countries that had industrialized earlier, allowing them to "leapfrog" to reduce the gaps between themselves and the industrialized countries.

It is instructive to explore in more detail the nature of the technology market -- particularly since many suggest today that technology transfer will allow developing countries to leapfrog the energy-, material-, and pollution-intensive phase of development experienced by the currently industrialized countries. The following discussion looks at changing perspectives on the nature of the market facing developing-country purchasers of technology, at the costs and benefits of transfer to technology suppliers and at some of the specific features of the market for environmentally sound technologies.

a) From the Technology Supermarket to the Market for Technology

By the mid-1960s, developing countries had begun to complain that insufficient technology was available to them to meet their development objectives and, further, that technology supplies were largely controlled by multinational corporations (MNCs) that were able to enforce unequal partnerships with developing-country governments and firms. The earlier view, in which technology was equated with knowledge and in which "firms can produce and use innovations by dipping freely into a general stock or pool of technological knowledge" (Pavitt, 1985, 7), was increasingly seen to be mistaken. Instead, researchers began to emphasize the process of "technology commercialization" (Vaitsos, 1974) or technology trade and to examine the nature of the market in which technology is transferred to developing countries.

Briefly stated, Vaitsos and later researchers argued that technology transfer is governed by a bargaining relationship between suppliers and recipients. In this bargain, purchasers are at an inherent disadvantage, due to two factors:

- **The nature of technology itself**, which is largely codified and cannot be thoroughly evaluated by buyers in advance of a particular transaction. As Arrow (1962) said, in any commercial transaction of knowledge and information there is an inherent asymmetry between the seller who knows what he is selling and the buyer who, to some degree, must remain ignorant of what will be purchased. The asymmetry is even more pronounced in the case of developing-country firms, which are typically smaller, less experienced, and technologically weaker than technology suppliers. These weaknesses limit the purchaser's search among possible technology suppliers, and may mean that transfer has to be undertaken through an intermediary who packages the elements of required technology. The buyer suffers a further information disadvantage in that there are no easily available figures of the price paid for similar transactions in the past.

- **The oligopolistic or even monopolistic nature of the international market for technology**. New explanations of the multinational firm put its command over technology and the objective of maximizing profits from its technological assets at the core of its behaviour. Technology suppliers were thus able to combine ownership of technology, dominant market power, access to financial resources, and skilled personnel to extract agreements from developing-country firms and governments that resulted in high costs to the recipients -- not only directly but also through a variety of restrictive clauses (restrictions on the right of recipient firm to make any changes in product, process or inputs without approval; requirements to transfer to the supplier knowledge of all improvements made in the technology with no reciprocal obligation on the supplier; tied purchases of capital goods and inputs; and imposed production or export restrictions).

SMALL ENTERPRISES AS TECHNOLOGY SUPPLIERS

Are developing countries able to secure a 'better deal' from small and medium enterprises (SMEs) than is the case with larger firms? There has been some speculation that the increasing role of SMEs as technology suppliers may hold benefits for developing country firms and governments, in terms of greater flexibility in sources of supply, greater equality in bargaining power, and (to some degree) expectations that technology developed by SMEs may be more 'appropriate' to developing country markets.

These sorts of questions formed the background for an international collaborative research project on SMEs as technology suppliers, carried out between 1987 and 1990 by a network of researchers from six developing countries (Argentina, Brazil, Mexico, India, South Korea and Singapore) and seven industrialized countries (Canada, the United States, the United Kingdom, France, Germany, Italy and Japan). In total, researchers studied 114 examples of technology transfer, involving 106 supplier firms.

The picture which emerges is mixed. On the one hand, the bargaining position of recipient firms vis-a-vis SMEs may be relatively strong. The majority of supplier firms in the sample had no previous international experience, whereas recipient firms generally had at least some previous experience with technology imports. In many cases, in fact, the initiative for transfer came not from the supplier, but rather from the technology search activities of the recipient firm. On the other hand, however, most of the SMEs were best characterized as 'small oligopolists', occupying large parts of the domestic (and in some cases international) market in narrow product niches. As a result they enjoyed a strong bargaining position despite their small size, due to their monopoly over technical information on the technology and product in question. And far from being an alternative to large multinational enterprises, the narrow range of SME activities means that they are at best complementary to multinationals as suppliers of technology (Niosi and Rivard, 1990, 1540-1541).

The research also suggests some interesting conclusions about the nature of technology transfer by SMEs. Not surprisingly, most of the supplier firms showed a preference for arms-length transactions, presumably because of the greater transaction costs involved in direct investment. Yet in a significant minority of cases, supplier SMEs opted for 100 percent equity investments rather than licensing or joint ventures -- a factor which the researchers attribute to the highly research intensive of many fields of SME activity, and the consequent need to protect key technological assets. In a somewhat similar fashion, the researchers found that on average transfers were 'deeper' than anticipated, in that they often involved the transfer of an entire range of product, process and organizational technology, and that there was a much higher involvement of SMEs in training activities than expected. Finally, while early expectations suggested that SMEs would primarily be involved in one-off transactions, in fact the relation between supplier and recipient firms was quite stable.

All this suggests that stereotypic arguments about SMEs as technology suppliers should be viewed with considerable scepticism. While some of the purported advantages of relying on SMEs may have been over-stated, it also appears that there is scope for much more ongoing, intensive knowledge transfer by SMEs than often expected.

More recent research has led to the revision of some aspects of the 1970s view of the technology market. In the first place, the decades since 1970 have seen emergence of larger numbers of technology suppliers -- both from industrialized countries and, in some cases, from developing countries themselves. In many sectors, the increasing costs of R&D and the need for large markets to recover these costs has made large firms take increased interest in technology-transfer activities. Larger numbers of supplier countries and supplier firms should increase competition among suppliers, thereby lowering the prices and improving the terms under which technology becomes available -- a contention which is at least partially supported by the evidence. Studies have also demonstrated that contrary to the earlier view, in many cases it is the developing country firm -- not the technology supplier -- that takes the lead in initiating the transaction, often searching out a number of alternative suppliers and using its greater knowledge of the local market to extract a more favourable "bargain" (Bell and Scott-Kemmis, 1988).

Evidence also suggests that the importance of small and medium-sized firms as technology suppliers is increasing (Niosi and Rivard, 1990). Such firms suffer from some of the same financial, informational, and human resource constraints as their developing-country counterparts; as a result, the bargaining relationship between small technology suppliers and developing-country purchasers should be more equal than is the case with larger, integrated MNCs -- and (so the argument goes) the terms of the bargain more favourable to developing countries. Smaller firms may also be less concerned with protecting property rights and more prepared to sell their technology outright or on a fee basis to avoid the costs of operating in a large number of countries. Of course, smaller companies do not have the resources for many large investment projects and as a result are not substitutes for large MNCs. But in a number of sectors of environmental interest (waste treatment, energy conservation systems and management, some areas of biotechnology), smaller firms are likely to be important suppliers. (see Box: Small Enterprises as Technology Suppliers).

Despite this reappraisal, it is still clear that the nature of technology results in an information asymmetry that will, other things being equal, shift the balance of bargaining power in favour of technology suppliers. As a result, one of the key constraints facing developing countries is the difficulty of matching their needs with appropriate technological solutions and identifying alternative sources of technology supply. These constraints are all the more binding in "new and emerging" fields, where future trends in technology development are uncertain, where corporate secrecy is the norm, and where sources of supply may span several industrial branches.

b) Costs and Benefits to Technology Suppliers

As previously stated, initial research on technology transfer tended to assume that transferring technology was relatively costless for the supplier firm. More recent studies, however, have confirmed that there are in fact substantial costs involved -- and that these costs have a crucial impact upon the willingness of suppliers to transfer technology, the channels of transfer employed, and the elements of technological knowledge transferred.

In a study of 26 technology transfer projects, Teece (1977) found that costs were higher the more complex the technology to be transferred and the larger the gap between the technological level of supplier and recipient. Costs were also significantly higher when the technology was transferred for the first time, but declined with experience. Contractor (1981) detailed three types of costs: direct costs of the transfer (travel, training, personnel, documentation, and related costs), opportunity costs, and sunk development costs. Niosi and Rivard (1990) further suggest that opportunity cost is of two types. One is the potential cost of market loss and competition by the recipient -- which is not a major worry for many transactions. The second, which is often more important for smaller technology suppliers, is the opportunity cost of the skilled personnel used in the transfer process who could have been used more profitably in other activities.

The evidence also suggests that the direct costs of transfer vary according to the elements being transferred (Lall, 1985; Desai, 1988). They are lowest when existing designs, drawings, and specifications are copied and shipped to the recipient. Transfer costs increase as more uncodified, human-embodied knowledge and skills ("know-how") are transferred. Costs also increase the more training is provided to recipient firms and are even higher if process or product technologies have to be modified for small market size in the recipient countries or for different demand patterns and resource endowments. Opportunity costs increase if skilled personnel are used to effect the transfer and if the transfer affects negatively potential or existing export markets. The potential loss is also larger in cases where more exclusive and recent vintage technological assets are to be transferred.

Although transferring technology thus cannot be seen as a costless activity, it is also true that technology suppliers may reap substantial long-term benefits, quite apart from direct payments for technology transfer. Such benefits may take several forms and, in many cases, are not limited to the firm in question, but instead accrue more broadly to the supplier country.

- **Expansion of export opportunities** for spare parts, auxiliary equipment, and related products or technology. In emerging fields, early entry as a technology supplier may result in substantial advantages over competitors -- not only because of the need for recipients to ensure standardization of supply, but also because of the imperfect information on alternative sources of supply. The benefits of recognition as a world leader may accrue not only to individual firms but also to entire branches of industry, as national origin becomes an identifiable "mark of excellence."

- **Increased efficiency of the transfer process itself.** There are substantial "learning" effects associated with international technology-transfer operations for supplier firms -- as they gradually learn to master the legal, managerial, and technical challenges involved in successful transfer of process or product technology to a different competitive environment. Learning effects will be particularly important for smaller firms with little or no international experience that dominate in at least some sectors of the market for environmental technologies.

- **Enhanced competitive position of supplier firms vis-à-vis international competitors.** In cases where the domestic market is small or the upstream costs of technology development are high (e.g., in research-intensive fields like biotechnology or advanced industrial materials, or fields like pharmaceutical where regulatory hurdles increase development costs), international technology-transfer operations may be an important means of reaping scale and scope economies and a precondition to bringing down unit production costs.

- **Improving the productivity of input and component suppliers**, whether these are affiliated firms or arms-length contractors. Particularly in final assembly industries (electronics, automobiles), the profitability of the "core" firm depends crucially on the efficiency of input suppliers. Moreover, many industries are moving away from hierarchical, equity-based networks of suppliers, toward more flexible, arms-length relationships as a means of providing the flexibility necessary to adjust to shifts in demand and consumer preferences (Hoffman and Kaplinsky, 1988). In many cases, suppliers are not limited to firms in the "home" country (the Mexican **maquiladoras** are the most obvious example).

- **Two-way flows of knowledge.** There may well be substantial scope for supplier firms to benefit from process or product adaptations pioneered by recipient firms. Such reverse transfers are more likely to result from transactions that involve active and ongoing contact among the parties, rather than relatively passive sale of equipment or licensing of design information. This type of ongoing technology cooperation between industrialized and developing-country firms is not common, but may hold significant promise for the future (Wynne-Edwards, 1991).

The balance between costs and benefits of transferring technology will vary from company to company and from transaction to transaction. Other things being equal, however, the financial returns to technology suppliers will have to be greater the more intensive and ongoing is the interaction between supplier and recipient (i.e., the greater the "costs" of transfer) and the closer the technology in question is to the "core" technological assets of the supplier firm.

Firms' calculations of costs and benefits will be affected by two additional factors. First, many of the "dynamic" benefits outlined above will only materialize over time. Whereas larger firms with greater international experience may be able to internalize the short-term costs of transfer while longer-term benefits take hold, the same is not likely to be true for smaller, more specialized firms with limited overseas experience. In such cases, considerable "up-front" financing may well be required to induce firms to become involved in transfer operations -- particularly if there is pressure for longer term, more intensive interaction with recipients (training and technical service agreements, as opposed to straightforward licensing or equipment sales). Second, many of the benefits of technology transfer to the supplier firm are only partly appropriable by that firm. Once again, smaller more specialized firms may not be able to capture the downstream benefits of transfer in terms of its effects on future export markets. To the extent that the involvement of supplier country firms yields such externalities, there may be scope for compensation outside formal contractual channels (via tax incentives for international technology-transfer operations, for example, or government funding of export development missions by small firms).

c) The Market for Environmentally Sound Technologies

What sort of preliminary observations can we make regarding the "market" for environmentally sound technologies facing developing countries?

In the first place, as the points previously raised make clear, a range of relevant technologies already exists. Available technologies can be grouped in several different ways. A recent report by Touche Ross (1991) for the UK Department of Trade and Industry, for example, groups the relevant technologies to combat global warming in terms of ownership and availability, distinguishing potential future technologies, "high" technologies currently available, widely available "public-domain" technologies, and disembodied know-how. Others suggest categorizing the relevant technologies in terms of their technical characteristics, distinguishing among "end-of-the-pipe" pollution-control technologies, process modifications that may be integrated into existing technologies to limit or eliminate harmful environmental impacts, and new product or process design.

Second, while the range of available technologies is impressive, it is not exhaustive. In many cases, technologies to meet specific developing-country needs either do not exist, are in the early stages of development, or will require substantial adaptation. In other words, developing countries cannot simply pull the necessary technologies "off the shelf."

Finally, the market facing developing countries is extremely diverse. As a general rule, there appear to be a wide range of alternative technologies available and a substantial diversity of potential suppliers, many of which are small and lack overseas experience. This may complicate problems of technology assessment and choice, but also suggests a relatively competitive market, in which developing countries should enjoy relatively strong bargaining power with suppliers. At the same time, however, conditions vary widely among sectors and applications -- in terms of both the availability of off-the-shelf technologies and the degree of concentration of supply. Just as it is impossible to predefine an exhaustive list of environmentally sound technologies, so our knowledge of the market for particular technologies will have to develop in a gradual, iterative fashion.

3. Technology Transfer and Technological Capabilities

In their critiques of technology transfer, developing countries initially focused largely on the (excessive) costs of technology transactions and the many "unfair" and restrictive clauses imposed on the recipient by the supplier. Such concerns formed the basis of a number of interventions by developing-country governments to increase the information available to recipients, to strengthen the bargaining capacity of recipient firms, and to outlaw practices that were deemed to violate national interests.

A second and somewhat more recent set of criticisms centred on the inappropriateness of imported technology -- in terms of its capital- and skill-intensity, its reliance on imported rather than locally available inputs, and its orientation to the needs of higher income consumers in industrialized countries. Production using these technologies reduces employment, heightens foreign exchange constraints, and limits backward linkages to the local economy. It may replace "appropriate" products with new ones that can be purchased only by a small number of relatively affluent customers -- thus creating welfare losses and limiting scale economies and competition, placing further limits on possibilities for growth and technical efficiency (Stewart, 1978, 1987). In addition, the more productive imported technology sector may lead to a "dual" economy, with one sector using modern technologies, higher skills, and providing high wages side by side with growing poverty and unemployment in the rest of the economy.

These points are of undeniable importance. Debates about environmentally sound technology cannot be divorced from earlier concerns about the economic, social, and cultural appropriateness of imported technology. Neither can the rush to stave off environmental degradation detract attention from the terms and conditions under which technology is supplied.

Increasingly, however, attention is being focused not on the static questions of the costs or characteristics of imported technologies, but rather on the factors affecting the creation and maintenance of technological capabilities in developing countries. In part, this is due to a recognition that many of the problems just outlined (limited bargaining capability of developing-country firms, inappropriate technology choice, insufficient linkages with the local economy) can only be overcome by efforts to increase the endogenous capabilities of developing countries to select, adapt, and develop technologies appropriate to their unique needs and circumstances. It also results from a reappraisal of the linkage between technology imports and technological capability. Much of the dependency literature argued that importing knowledge, production know-how, and capital goods could be cost minimizing for individual transactions but would in the long term have negative effects on local problem solving and innovative capacity. More recent case-study research, as well as observation of the experience of countries such as South Korea and Taiwan, however, suggest that **at least under certain circumstances, transfer of technology can be a potent force in strengthening technological capabilities in developing countries.** In the context of the UNCED debates, one of the most important issues is how to ensure that badly needed technology imports contribute to, rather than frustrate, efforts to build up such endogenous capabilities.

In essence, technological capability refers to the skills, abilities, and experience needed to select, use, adapt, and create technology. Mytelka (1989), for example, argues that technological capabilities can be split into four "phases," corresponding to acquisition, utilization, absorption, and innovation. Indicators of technological capability would include capacity of the recipient firm to define its technology needs and negotiate with suppliers; the ability to efficiently operate imported technology; the capacity to undertake routine repairs and maintenance; the ability to analyze the production facilities and to undertake modifications and additions to equipment to increase capacity and reduce costs; the ability to plan, design, and execute expansions of capacity; and, finally, the ability to generate a series of technological innovations to improve production.

It is clear that in many cases technology transfer has not allowed recipient enterprises to accumulate such technological capabilities. In a study of transfer of petrochemical technology to the Middle East, for example, researchers concluded that although the volume of technology transactions has increased, "technology transfers (whereby recipient gains improved capability to operate an industrial facility) have been limited" (OTA, 1984). In a study of fertilizer plants in Bangladesh, Quazi (1984) found that over a period of 25 years, there were no changes in the responsibility for technological elements between foreign suppliers and local participants. Hill (1988) states that "technology transfer in Indonesia rarely moved beyond production." A series of other studies (Chantramonklasri, 1984, 1985; Fong, 1987; Santikarn, 1987; Bell and Scott-Kemmis, 1988) provide further illustrations of cases where technology transfer, as measured by the additional problem-solving skills created in the recipient, was severely deficient.

ENERGY EFFICIENCY IN THE FERTILIZER INDUSTRY, BANGLADESH

A study of the fertilizer industry in Bangladesh (Quazi, 1984) provides some interesting insights into both the low levels of energy efficiency often achieved in developing country installations, and the reasons for poor performance in this regard.

Quazi's detailed study of plant-level performance in two urea fertilizer plants showed poor performance in terms of both levels of energy efficiency, and trends in efficiency over time. On the first count, levels of energy efficiency remained below initial design levels for both plants -- in direct contrast to the situation noted for similar plants in industrialized countries. In terms of changes over time, the evidence indicated only very slow rates of improvements in energy efficiency and no significant plant adaptations over the eight-year period of study.

This poor performance in turn reflects the strategy adopted by plant managers with respect to acquisition and strengthening of indigenous technological capabilities. While some effort was made to develop the capabilities needed to operate the plants, improvements and modernization of the plants was dependent almost entirely upon outside managerial and technical expertise. Rather than engendering an ongoing process of technical change, this situation led to a piecemeal, "stop-and-go" trend in productivity: while efficiency (including energy efficiency) rose as a result of the application of imported expertise, levels of efficiency began to fall shortly after outside engineers and managers were withdrawn.

In other cases, however, the results are far more encouraging. A number of case studies carried out in Latin America and Asia in the late 1970s and early 1980s emphasized that the creation of domestic technological capability can be enhanced by complementary inputs of domestic effort and imported technology. Perhaps the archetypal example is that of the USIMINAS steel plant in Brazil, which not only successfully assimilated and adapted imported technology, but then used the knowledge gained to move on to the creation and eventual commercialization of technology (Dahlman and Fonseca, 1987).

Clearly, then, there is no automatic link between technology imports and the development of technological capability. As Bell (1990) notes, technology transfers can be distinguished in terms of their "technological content" -- that is, the knowledge, skills, and capabilities imparted to the recipient. In some cases, this technological content is relatively low, consisting largely of capital goods, engineering and managerial services, and product designs. In other cases, additional skills and know-how for operation and maintenance of imported technology may be included. In both these instances, only **production** capacity is transferred to the recipient. Only where there is a much more thorough-going transfer of the knowledge, expertise, and experience needed to generate and manage technical change, Bell contends, can we speak of the accumulation of **technological** capacity by a recipient.

The available evidence suggests that two factors are crucial in determining the extent to which technology transfer contributes to the building of endogenous technological capabilities.

The first is the intensity of contact between the supplier and the recipient. Active, ongoing contact between recipient and supplier is crucial to the effective transfer of disembodied skills and knowledge. This does not mean, however, that direct equity involvement of suppliers is essential. Although foreign equity participation may help to guarantee efficient **production** capability (Fong, 1987; Santikarn, 1987; Desai, 1988; Kim, 1988), other types of capability related to investment, expansion, and innovation can be stunted with excessive foreign control. Far more important than the contractual form of a transfer is the extent of knowledge acquisition and, in this regard, training is crucial. Unfortunately, recipient firms and countries have all too often underemphasized or ignored the issue of training. For instance, in an analysis of over 600 petroleum-exploration contracts, Turner (1982) found that only 14 percent made any provisions regarding training, employment of nationals, and local technical services, and concluded that the contracts displayed little concern over acquisition of critical skills. In an analysis of 79 contracts in the Caribbean, Odle (1986) similarly found that provisions for training and for skills transfer in design and engineering provisions were rare.

A recent study of the mining industry (Warhurst, 1991) confirms the importance of training links. Warhurst argues that Northern mining companies are beginning to apply their latest, "cleanest" technologies to developing-country operations in a bid to offset high development costs, improve their public image, and avoid future regulatory barriers -- rather than simply transferring obsolete technologies to pollution "havens" in the developing world. Yet, as she notes, the ability of developing countries to profit from such a change in corporate practices will depend in large measure on the way in which technology-transfer agreements are structured -- and, in particular, on the ability of recipient firms and countries to build adequate knowledge transfer and training components into licensing agreements and joint ventures.

The second factor, somewhat related to the first, is the skills and strategic orientation of the recipient enterprise. In a study in India, Nath (1987) concludes that "the main issue as it emerges is not what is contractually agreed or what is the supplier's stake but rather the subsequent update or activities undertaken by the host country enterprise." Santikarn (1987) similarly concludes from her study in Thailand that successful technology transfer hinges on the ability and awareness of management of technological factors; on investment in human resources; and on appropriate choice of technology and supplier. These require sound knowledge before transfer, a rigorous search for sources and intensive participation at all stages of project planning and implementation. Enos and Park (1987) confirm that local efforts have been the most significant factor in the Korean success in technology transfer. The technical sophistication of the Korean firms permitted them to search and select technologies effectively, allowed them to negotiate better terms, and made them aware of the importance of large-scale training program and human-embodied knowledge in the transfer of arrangements.

On the other hand -- and in contrast to the earlier enthusiasm for government intervention to offset the disadvantages facing developing-country purchasers of technology -- many studies suggest that where the capacities to search, select, and negotiate for technologies are absent, government regulation has been of little value for technology transactions. The evidence from Desai (1988) and Mihyo (1988) suggests that, in many cases, formal institutional structures based on superficial understanding of the technology-acquisition decisions confronting the country and unconnected to existing implementation capacities are in fact an obstacle to the effective transfer and use of technology.

This does not mean that government policy is unimportant. But it does suggest several notes of caution about the role of government in helping to build technological capabilities. In the first place, many of the required actions involve not so much direct intervention, but rather efforts to build an environment conducive to local entrepreneurship and innovation -- by ensuring adequate levels of savings and investment capital or improving the quality of education. Second, even though there remains a role for more direct intervention, this should emphasize the building of technological capabilities, rather than simply the regulation of the terms and conditions of technology agreements -- through support to training, for example, or provision of incentives to firm-level technical effort. Finally, and perhaps most importantly, to the extent that there is a role for government, public sector agencies must themselves be a target of capacity-building efforts.

SECTION III: OPTIONS

A. The Bases for Action

Any attempt by the international community to deal with global environmental threats must confront the need to make difficult choices among the possible avenues of action. In the end, this will require detailed plans of action, setting out targets, specifying the types of initiatives to be undertaken, and outlining the financial, technical, and institutional requirements of the chosen courses of action.

What is true of the general response to global environmental degradation is equally applicable to the more narrowly defined question of North-South technology transfer and cooperation. There are now many proposals on the table from various sources; however, there is a need to go beyond outlining "menus" of options and, instead, begin to map out strategies for action. This task is obviously beyond the scope of the current report. As a first step, however, it is possible to identify three broad criteria that should form the bases of future action.

1. Ensuring a Plurality of Initiatives

Effective action in the area of technology transfer and cooperation must of necessity involve a number of different actors -- national governments, private sector firms, international institutions, non-governmental organizations, etc. The costs of securing consensus among the various actors' issues are likely to be prohibitive, and should not detract attention from the opportunities for immediate action by individual actors or smaller groups of actors.

Moreover, the global environmental debate is still characterized by a considerable level of uncertainty, not only regarding the severity of the threats but also regarding the appropriateness of various responses: How should "polluter pays" principles be determined? What levels of penalties, types of standards, and market incentives are required for different problems and countries? Which technologies are most appropriate in given situations? What are the most effective mechanisms for their transfer? What is the appropriate balance between short-term technology transfer and longer term capacity-building measures? This uncertainty is compounded by the rapid changes occurring in many of the relevant fields of technical knowledge, and the fact that the effectiveness of given technological solutions will be dramatically affected by the conditions in which they must operate.

Under conditions of such uncertainty, the most appropriate response may be to hedge your bets. Although there may be efficiency losses because of insufficient coordination -- or even contradictory actions -- these are likely to be less important than the transaction costs of negotiating more broadly based solutions without sufficient information, or the danger of investing too many resources in what may turn out to be a false lead. A plurality of initiatives also recommends itself on grounds of efficiency. Given the broad range of actions required, no single actor or group of actors can address them all. Pursuing a number of actions will allow for the participation of different actors, and increase the potential for contribution of specialized knowledge available to particular groups.

This in turn suggests a "two-track" approach, in which efforts to reach a broad consensus among the relevant actors (e.g., with regard to international conventions) are balanced with more immediate and independent actions.

2. Pursuing Areas of Mutual Interest

The rise to prominence of global environmental concerns has given new life to notions of global interdependence. There are, of course, limits to this mutuality of interests: debates about sustainable development of necessity touch upon the unequal distribution of resources -- natural, economic, political, and technological -- within and among nations and, hence, involve considerations of economic and political power. They arouse fears in the South that the sacrifices and burdens will fall unfairly on the poor, and intensify existing inequalities. But **the notion of mutual interests does provide at least a partial road forward, in that it can direct our attention toward possible "win-win-win" solutions -- that is, initiatives that meet the developmental needs of the Third World, the commercial needs of technology suppliers, and the environmental needs of the planetary ecosystem.**

There are increasing indications that the perceived trade-off between protecting the environment and encouraging economic growth and development is not as rigid as often assumed, and that the application of environmentally sound technologies can also result in increases in **economic** efficiency. A recent report by the World Resources Institute (WRI) argues that advances in the fields of biotechnology, information systems, and advanced materials hold out the process of a technological "transformation," in which pollution and materials consumption per unit of output decline in step with increases in economic output (WRI, 1991, pp.1-3). Reductions in pesticide use as a result of the introduction of bioengineered plant varieties, waste reduction as a result of computerized control of manufacturing processes, or decreases in energy consumption as a result of miniaturization are all examples of such a process. As was argued in the previous section, it is not only through such radical innovations that economic and environmental objectives can be linked: in both industrialized and developing countries, incremental improvements to existing facilities can yield simultaneous economic and environmental benefits.

There is also growing recognition that technology transfer can yield important benefits to technology suppliers and that, as argued in the previous section, these go far beyond the direct financial compensation involved in a given transaction.

At least partially as a result of these factors, the United States and some other industrialized countries have supported what has come to be known as a "no regrets" approach to limiting greenhouse gas emissions (White, 1990; Gray and Rivkin, 1991). According to this rationale, even in the absence of a complete scientific consensus on the effects of global warming; steps should be taken to limit emissions in cases where such actions also hold out other economic benefits. In other words, acting in areas of common environmental and economic benefit is seen as a "hedge" against an uncertain future. But the attraction of building on areas of common interest is not limited to such considerations. Initial actions in such areas can also help to increase the likelihood of longer term, more comprehensive, and more costly measures -- both by demonstrating the potential for reversing current trends toward environmental degradation and by generating the income stream necessary to finance more far-reaching initiatives.

At least in theory, then, it should be possible to arrive at initial courses of action that will respond to environmental imperatives without sacrificing the developmental aspirations of the South, and without expecting technology suppliers to forego commercial benefits. Yet, there are also formidable barriers to the realization of these solutions in practice.

To begin with, **financial constraints** may be particularly important for two reasons, both of which were alluded to in Section II. First, many of the potential benefits of technology transfer -- to both recipients and suppliers -- are long term in nature. As a result, financial support may be crucial to allow suppliers and recipients to overcome short-term costs and to permit longer term benefits to materialize. Second, the benefits of technology transfer are often not entirely appropriated by supplier or recipient firms: expansion of export opportunities may benefit firms other than the technology supplier, whereas the "public good" characteristics of many environmental technologies mean that recipient firms cannot hope to capture the benefits resulting from their application. In such situations, additional compensation (tax incentives, government funding of export development missions) may be necessary to increase the returns to technology transfer for both supplier and recipient.

On the other hand, financial considerations are not a binding constraint in all situations. Much technology appropriate to the environmental needs of developing countries is not the state of the art, but rather more readily available, standardized technology; in such cases, the opportunity costs of transfer to the supplier firm are likely to be relatively low (although there are still direct costs involved, such that the total cost is not zero). Even in the case of more novel technologies, a rapidly changing technology frontier, combined with intense competition among suppliers, may make transfer of relatively recent vintage technology an attractive option.

There are also important **informational obstacles** to negotiating "win-win-win" solutions. As was pointed out earlier, technology purchasers in developing countries typically face extreme disadvantages vis-à-vis suppliers, in terms of their inadequate knowledge regarding domestic technology needs and the range of technologies potentially available to meet those needs. There are also informational constraints on the supplier side. In new and emerging fields of endeavour, the nature of future applications may not be immediately apparent, such that estimation of potential markets is difficult, particularly for newcomer firms that lack the overseas experience necessary to adequately assess market opportunities. In addition, technology suppliers may in some cases face a situation in which, despite an obvious need for a particular technology, there are few if any buyers -- either because the field is still new, because the benefits of the technology have the character of a public good, with few individual buyers willing to become involved, or because the firm lacks experience in overseas markets.

Finally, there are a range of **institutional constraints** that must be considered. This includes the variety of ways in which the domestic policy environment in both recipient and supplier countries militates against successful technology transfer -- including such factors as intellectual property regimes, pricing policies, and taxation measures. Also of note would be the need to reform existing research and research policy institutions, which in many cases have failed to strengthen local capabilities to import, adapt or create technology (e.g., see Juma, 1990; Goka et al., 1990). At least as important, however, are situations in which the relevant institutions simply do not exist. There may be crucial intermediation roles that are not effectively played by existing institutions, and, as a result, new institutions may be required to match developing-country technology needs with appropriate expertise in Northern countries.

3. Building Long-Term Capabilities

As Joly and Bandelier (1988, 14-16) note, short-term application of existing technologies may alter the scope for longer term development and application of new technological solutions. Thus, for example, the application of scrubbers in thermal power plants may slow the introduction of environmentally preferable technologies, such as fluidized bed combustion, because of the lower investment costs implied by the first option; similarly, improved energy efficiency could conceivably allow traditional agricultural fertilizers, pesticides, and herbicides to compete with newly developed biological control systems. In addition, writers such as Arthur (1990) have pointed out that initial technological solutions may in many cases become "locked in" with the result that costs of switching to new standards becomes prohibitive, even if they hold out the potential of efficiency gains (e.g., the barriers to switching to fibre optic cable in telecommunications systems). This suggests a note of caution in terms of latching on to emerging technological solutions -- particularly for developing countries where resource constraints may make the problems of "lock in" even more insurmountable.

It is clearly impossible to predict **ex ante** the nature of the interrelations among various technologies, or to second-guess future patterns of technological advance. What the above examples illustrate, however, is the crucial importance of capacity-building. **The ultimate goal of any international action in the field of environmentally sound technology should not be to apply particular technological solutions, but rather to enhance the capabilities of developing countries to select, import, assimilate, adapt, and create the relevant technologies. In large measure, moreover, this is a matter of enhancing "generic" technological capabilities rather than pursuing actions related specifically to environmental technologies.**

This by no means implies that short-term action is not required or that technology transfer is unimportant. But it reinforces once again that transfer of "clean" technologies is only part of the solution -- and that concern with the economic and environmental efficiency of a given technological solution needs to be matched with a concern for its integration into the local productive structure, the conditions by which it is acquired, and the extent to which "hardware" imports are accompanied by effective transfers of knowledge and capabilities.

B. Options for Action

The pages that follow set out some more concrete avenues for action, grouped around four broad objectives:

- **Clarifying the "rules of the game" with regard to international coöperation in the transfer and development of environmentally sound technologies;**
- **Increasing the supply of environmentally sound technologies from abroad;**
- **Promoting the adoption and assimilation of imported technologies; and**
- **Strengthening the technological capabilities of developing countries in the field of environmentally sound technology.**

In each of these areas, priority is given to the three criteria outlined earlier: ensuring a plurality of actions, overcoming the barriers to "win-win-win" solutions, and building long-term capabilities

1. Clarifying the Rules of the Game

In the first instance, attention must be given to clarifying the "rules of the game" -- the broad principles that should govern cooperation between North and South in their efforts to facilitate technology transfer and strengthen the technological capabilities of developing countries. It is likely that these sort of principles will form an important part both of the conventions on climate change and biodiversity, and of the Agenda 21 document to be debated at UNCED. The most important and contentious points are likely to be intellectual property rights and concessionality.

The issue of **intellectual property rights** is perhaps the most intractable facing the transfer of technology debate, bringing to the fore differing perspectives on the nature of scientific and technological research, and the appropriate distribution of the benefits flowing from such research (Belcher and Hawtin, 1991). On the basis of recent public pronouncements from Northern and Southern representatives, there seems to be little scope for a compromise. Yet, there are some signs of hope -- notably the progress that has been made in the past few years on the issue of "farmers rights" (Keystone Center, 1991) -- which suggest that what were once seen as intractable issues can in some cases be resolved. There are also indications of important changes in the attitudes of some Third World governments (most recently Mexico) toward intellectual property rights, which may lead to equally important shifts in North-South negotiations. On the Northern side, however, positions have been far more uncompromising, with the United States in particular exerting pressure on developing countries to dramatically extend the scope and duration of patent protection.

There is little doubt that at least in some fields of activity, adequate recognition of intellectual property rights is essential to the continued development of much-needed technologies. At the same time, however, **developing countries should resist pressures to unilaterally extend property rights, particularly into new and controversial areas like the patenting of living organisms**. Instead, priority should be given to ongoing multilateral efforts to find a compromise between Northern and Southern positions on this issue -- while recognizing that this issue, like so many others, will not be resolved in time for the Rio conference.

In any case, the fact that much of the relevant technology is not patent protected means that failure to reach a comprehensive agreement on this issue need not stall actions on other fronts. While developed and developing countries should continue to search for an across-the-board consensus on intellectual property rights, more limited actions to transfer patent-protected technologies may also be possible, and may be an important means of ensuring the flow of proprietary technologies in the short to medium term (see section B.2). Such actions may also serve as important "confidence-building measures," helping to overcome the mutual suspicion between North and South on this issue.

On the issue of **concessionality**, the challenge is to marry Northern concerns to recognize the commercial nature of most technology transfer, with Southern demands for favourable access. **A compromise position may be possible, resting on a distinction between the terms upon which technology is purchased from a commercial supplier, and the terms upon which financing is made available to developing country purchasers. Such an agreement would reaffirm that in the case of privately-owned technologies, market rates should form the basis for compensation to owners of technology. On the other hand, however, developing countries would be provided with concessional financing to allow them to make such purchases, and assured that such financing would be additional to existing commitments for development assistance.**

In essence, this is a recognition of the broader principle that Northern countries (but not necessarily individual technology suppliers) should shoulder the larger part of the burden of countering global environmental problems -- both by taking immediate action to reduce their own contributions, and by assisting developing countries to make the necessary adjustments. If developing countries are to compromise on the issues of concessionality and intellectual property rights, this sort of strong commitment by industrialized countries in the area of burden-sharing is essential.

It is also important to recognize that the imperfect nature of some segments of the technology market means that "market rates" may be excessive, and may be accompanied by excessively restrictive conditions of transfers. As a result, there is a need for renewed discussions on some form of code of conduct on technology transfer to guard against abuses of strong market positions.

2. Increasing the Supply of Technology from Abroad

This is the area that has received greatest attention to date. As has been argued throughout this report, the problem of applying environmentally sound technologies in developing countries cannot be limited to the much narrower issue of increasing the flow of existing technologies from North to South.

Nonetheless, a commitment to increase the flow of environmentally sound technology may be an important means of countering some of the other trends at work in the international technology market. Problems of indebtedness and the shift of industrialized-country investment away from developing countries have meant that commercial flows of technology from North to South have stagnated or declined over the past decade -- with the exception of flows to some of the newly industrializing countries of East Asia. Cutbacks in aid appropriations have had similar effects on the flow of publicly financed technology and technical assistance. At the same time, "high-technology" sectors with potentially important roles to play in supplying environmentally sound technologies (biotechnology, advanced industrial materials) have been subject to strong trends toward the privatization of research, which has in turn reduced the flow of public domain technology in such fields. Finally, the growth of interfirm collaborative arrangements between Northern firms have accelerated the sharing of precommercial research, but in ways that have largely frozen out developing countries.

Ultimately, ensuring an adequate flow of technology depends on the efforts of North and South to create a market for environmentally sound products and services. A long-term response to the problem of technology flows to developing countries must deal with the structural factors that limit demand for imported technology in these countries, such as small effective market size, foreign exchange constraints, and lack of infrastructure. Ultimately, this must involve action to resolve the underlying problems (debt burdens, protectionism, stagnant aid flows, ineffective macroeconomic stabilization) that limit both foreign and domestic investment.

There are also many more specific actions that can and should be taken. The appropriate actions depend crucially upon the type of technology in question. As a start, it is instructive to consider four categories: proprietary technologies, public domain technologies, "emerging" technologies and precommercial research, and "soft" technologies or know-how.

REDUCING CFC USE IN MEXICO'S ELECTRONICS INDUSTRY

With its burgeoning electronics assembly industry, Mexico has become a significant user of CFC solvents, currently estimated at some 400 metric tons annually. Efforts to reduce CFC use have led to an innovative partnership involving Mexican electronics enterprises, the state environmental agency (SEDUE), the U.S. Environmental Protection Agency, and Canadian-based electronics manufacturer Northern Telecom.

As part of its efforts to eliminate CFC use from its operations, Northern Telecom developed a spray misting technology which eliminates the need for CFC solvents to clean synthetic flux residue from printed circuit boards. This process is not only environmentally sound but has also proven to be economically feasible and efficient.

In March 1991, Northern Telecom joined with SEDUE and the EPA in launching a training and demonstration project on CFC solvent conservation and elimination in the Mexican electronics industry. Under the project, Northern Telecom will share its experience in the implementation of CFC-reducing process technology, and coordinate a series of custom-designed training programs for Mexican companies. The project will involve diagnostic missions, demonstrations of improved process technologies, on-site work to install and/or retrofit technology, and evaluation and monitoring meetings.

While multilateral financing plays a key role in the project (the Multilateral Fund established under the Montreal Protocol has financed some of the capital costs of conversion to the new process), the project also illustrates how long-term corporate interest can itself be a potent force for North-South technology transfer. The project also highlights the potential for collaboration **among** private sector technology suppliers. One of the key aspects of the project is the involvement of the Industry Cooperative for Ozone Layer Protection (ICOLP), an association of industrial users of CFCs founded in 1989 to coordinate the worldwide exchange of information on CFC alternatives. In addition to the involvement of Northern Telecom (a founding member of ICOLP), the project will involve demonstrations at ICOLP member facilities, and the use of ICOLP's on-line data base, OZONET.

In the case of **proprietary technologies**, intellectual property (IP) issues remain the most frequently mentioned barrier to transfer. As noted above, it is doubtful that any across-the-board agreement on IP issues can be reached at UNCED. Even in the absence of such an agreement, however, there may be considerable scope to increase the transfer of certain types of proprietary technologies.

- In the first place, companies may be willing to transfer recently developed technologies in cases where these do not represent part of their "core" technological capabilities, and where the spread of such technologies to subsidiaries and nonaffiliated suppliers improves long-term profitability. In industries such as electronics and automobiles, the wide network of equipment and component suppliers involved (many without equity links) means that "sharing" technologies may be an essential part of a competitive strategy.

- Second, there may be considerable scope for technology cooperation among noncompeting users. This is the case, for example, with a proposed network of utility companies in North America, Europe, India, Brazil and China, which would sponsor collaborative research and technology development related to climate change (USAID, 1990).

- Third, in some fields (e.g, selected biotechnology applications) it may be possible to use public interest provisions in existing legislation as a vehicle to encourage the diffusion of proprietary technologies (for details, see UNCED, 1991)

- Finally, there may be scope for the creation of specialized brokering services to mediate between the owners of proprietary technology and potential users in developing countries (see Box: Brokering in Biotechnology).

BROKERING IN BIOTECHNOLOGY

Recent advances in agricultural biotechnology could potentially play a crucial role in meeting the food supply needs of an expanding global population -- for example, through the development of pest-resistant plant varieties which would reduce the need for pesticide use, or by the increasing use of biopesticides and biological control systems. Similarly, tissue culture applications may be an important tool in reforestation efforts, contributing to the modulation of global warming.

But advanced biotechnology applications -- unlike many other types of environmentally sound technologies -- are increasingly proprietary, the result of a gradual process by which control over biotechnology research has passed into the hands of large industrialized country firms. This is a stark contrast to the earlier development of 'Green Revolution' high-yielding varieties, which were largely under the control of national and international public sector research institutes. Combined with the infrastructural and investment-related constraints to developing country entry into the world biotechnology industry, this has given rise to serious doubts about the ability of developing countries to secure access to biotechnology applications.

One response to this situation has been the recent formation of the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), a not-for-profit international organization dedicated to facilitating the transfer of proprietary agricultural biotechnology applications from industrialized to developing countries. Still in its infancy, the ISAAA's goals are to assist developing countries in assessing their biotechnology needs, to monitor the availability of appropriate proprietary technology in industrialized countries, to provide 'brokering' services to match developing country needs with appropriate technological solutions, to mobilize funding from donor agencies to implement brokered proposals, and to counsel developing countries on biosafety and regulatory procedures.

Early examples of ISAAA's early work include an arrangement by which Monsanto Corp. will transfer coat protein genes to a Mexican research institute to control potato viruses, and a project to transfer a cold DNA diagnostic probe for detection of black rot, developed by researchers at Washington State University, to the Asian Vegetable Research and Development Centre (AVRDC) and its client countries in the Third World.

For **more widely available, public-domain technologies**, the barriers are likely to be less legal and financial than informational -- although there may be scope to provide seed financing to firms with little or no international experience to overcome some of the up-front costs of such involvement. Possible mechanisms to increase the flow of such technologies might include donor government funding of export development missions, particularly for small, specialized firms; improved provision of market information to smaller and less experienced suppliers; or support to brokering services to match local technology needs with appropriate suppliers.

In the case of **emerging technologies and precommercial research**, much depends upon whether research is primarily based in the public or private sector. In the latter case, significant progress can be made by donor countries in funding research partnerships between developing countries and Northern researchers in university or public sector institutions. IDRC's cooperative research grants, involving Canadian and developing-country scientists, represent a key model in this regard. At a more ambitious level, multilateral efforts might be taken to fund precommercial research in specific areas, along the lines of the CGIAR (Consultative Group on International Agricultural Research) system in the field of agricultural research. In cases where basic and precommercial research has been largely or completely privatized, the barriers to transfer are much higher. As noted, strategic partnerships in the fields of semiconductors, telecommunications and the like have in recent years begun to span national boundaries, facilitating the international flow of precommercial research; but this has not involved Southern countries. In the future, there may be scope for the participation of some Southern enterprises in such schemes, but the limited scientific capabilities of most Southern countries makes this a remote possibility at best.

Finally, in the area of **"soft" technologies and know-how**, there are a wide variety of mechanisms to facilitate transfer. Such know-how tends to be fairly widely dispersed in most fields, although information on the availability of particular types of expertise is often poorly distributed. This is one area where there may be considerable scope for South-South transfers, and for various forms of "twinning" between Northern and Southern institutions (see Box: Strengthening Environmental Management Capabilities: The EMDI Project). In addition, action to reverse the South-North flow of trained professionals -- for example, via increased international funding of scientific research institutions in developing countries -- may be crucial in this area.

3. Promoting Adoption and Assimilation of Technologies

Barriers to adoption and assimilation of more environmentally sound technologies affect both imported and locally developed technological solutions.

a) Technology Adoption

In the area of technology adoption, the key problem is the frequent lack of incentives for the application of more environmentally sound techniques; as a result, existing and readily available solutions, whether imported or locally developed, may not be applied as widely as is desirable.

STRENGTHENING ENVIRONMENTAL MANAGEMENT CAPABILITIES: THE EMDI PROJECT

Discussions of technology transfer inevitably focus on the transfer of "hard" technologies (machinery and equipment), and to a lesser extent on design information, and on the skills and abilities necessary to operate, maintain and adapt imported equipment. At least as important, however, is the transfer of less tangible skills and know-how, or what is often referred to as "soft" technology. For most developing countries, efforts to upgrade environmental management skills are every bit as crucial as imports of "cleaner" technology -- and just as deserving of international support.

One attempt to tackle this issue is the Environmental Management Development in Indonesia (EMDI) project, a joint effort of the Indonesian Ministry of State for Population and Environment (KLH) and the School of Resource and Environmental Studies at Dalhousie University in Halifax, Canada. The project is designed to strengthen the institutional and human resource base for environmental planning in Indonesia. Currently in its third phase, the project is supported by the Canadian International Development Agency (CIDA), which will contribute CAD $31.1 million to the project between 1989 and 1994.

The project involves a variety of technical cooperation and training activities, spanning the following areas:

- spatial planning and regional environmental management (particularly the application of geographic information systems)
- management of environmentally negative impacts of development (environmental impact assessment, environmental standards, hazardous and toxic substance management)
- marine and coastal environmental management
- environmental management support systems (environmental information systems, environmental law)

The EMDI project also proceeds from a conviction that responsibility for environmental management must be shared among a variety of institutions. In addition to the lead role played by KLH, the project is also intended to strengthen the environmental management capabilities of central, sectoral and regional governmental agencies, universities, non-governmental organizations (NGOs), and private sector institutions. Linkages and exchanges with Canadian counterparts are designed to support the development of relevant skills and expertise in all these spheres.

For the most part, recent debate has viewed this problem through the optic of "market forces," focusing on distortions in factor prices (especially energy), on poorly developed capital markets and on trade restrictions that militate against the import of environmentally sound products and processes (Touche Ross, 1991). Clearly, reorienting prices to redress the most glaring problems (particularly regarding energy prices) is urgently required. This, for example, is the intent behind discussions of possible "carbon taxes" on fossil fuel use, or more general taxes on energy use: in both cases, taxation would force energy users to "internalize" the social and environmental costs of energy use, and thus would alter the relatively profitability of "clean" technologies. Studies of the diffusion of rural energy technologies (Barnett, 1990) have similarly confirmed the importance of a "macro policy environment" that supports rather than frustrates micro-level interventions.

It is also increasingly being recognized, however, that market-based reforms on their own may be insufficient to alter prevailing patterns of technology use. In addition, a variety of nonmarket measures may be needed:

- More traditional "command and control" type regulations (pollution standards, regulatory practices) may be essential in at least some fields, particularly where price mechanisms do not function adequately. Because of the technical and administrative requirements of regulatory action, they should be used selectively, and one potentially important area of cooperation between North and South is in the design of regulatory systems appropriate to the conditions and administrative capabilities of individual developing countries (for a discussion, see Turnham and O'Connor, 1992, or Winpenny, 1990).

- There may be important financial or technical bottlenecks to shifting to cleaner technologies -- for example, because of the up-front investment costs of switching to new process technology or the need for ancillary technological expertise. In such cases, public sector financial assistance, or publicly funded R&D, may play an important role (on the technological bottlenecks facing CFC reduction in Southeast Asian electronics production, see O'Connor, 1991).

- As a recent report by the UNCED Secretariat notes, developing-country governments can also have a considerable effect on technology adoption by the reform of investment criteria for private-sector investments and by the judicious use of procurement provisions in public sector investment (UNCED, 1991).

Donor countries can assist developing countries to undertake the kinds of reforms outlined above through both the provision of financial assistance and the furnishing of technical assistance for specific aspects of policy reform (e.g., regarding investment criteria). In addition, there are also several more concrete areas where donor involvement might help to improve adoption of clean technologies:

- The funding of demonstration projects illustrating the technical and economic efficiency of environmentally sound technologies might help to overcome some of the nonfinancial barriers to technology adoption;

- Financial and technical assistance could be provided to promote technology-sharing arrangements among developing country firms, as a means of overcoming the high capital costs of many of the relevant technologies

- Assistance could be provided to improve the technical expertise of local and regional lending institutions in developing countries. Development banks and similar institutions play a key role in providing local funding for technology-transfer projects (as well as providing assistance to local private sector R&D efforts in many cases). Yet, such institutions frequently lack the necessary expertise to adequately assess the technical feasibility of investments.

b) Technology Assimilation

It is now widely accepted that ensuring effective use is at least as important as promoting the initial adoption of technologies. In particular, research has established that efficient operation of a given technology is not a trivial matter, because of the noncodified and tacit nature of much technological knowledge; as a result, considerable effort must be expended to reach the operating parameters of a given technology -- if, indeed, these are ever reached. Moreover, it now almost a truism that imported technology may be inappropriate to domestic conditions, in terms of its capital intensity, resource use, etc.; as a result, effective use of imported technologies may demand a series of minor or major adaptations to those technologies so that they can function effectively in developing country markets.

Assimilation of imported technology is dependent upon the broad conditions facing local firms: degree of local competition, trade, monetary and fiscal policy, and the availability of trained personnel (Herbert-Copley, 1990). As a result, effective action to promote the assimilation of technology at the level of productive enterprises depends on a fairly thorough-going process of policy reform. At the same time, however, there are a variety of more limited, concrete measures which can be undertaken:

- First, the feasibility of effective assimilation is also determined by the conditions under which technology is transferred, particularly the provision of long-term training and technical assistance services by the technology supplier. Incentives can be offered to promote such involvement, and in cases where such long-term involvement is not feasible (e.g., small supplier firms without the capacity to mount such after-sales efforts), alternative sources of technical assistance could be developed

- Second, there is almost universal agreement among the writers on learning and technical change that an adequate supply of trained human resources is essential to effectively assimilating new technology and engendering ongoing performance improvements. As a result, attention should be given to both incentives for on-the-job training, and more effective training of engineers, scientists, and technicians.

- Finally, the "learning" literature emphasizes that the development of technological capabilities is often the result of idiosyncratic firm-level factors, usually related to the personality and interests of management. As a result, management training and demonstration projects may have a decisive effect on firm-level technical effort.

4. Strengthening Developing Countries' Technological Capabilities

This is potentially the broadest avenue of action, encompassing efforts to strengthen local research and training institutes, develop long-term partnerships between Northern and Southern institutions, and promote more effective technological decisions within productive enterprises. Three areas are of particular importance: strengthening the scientific capabilities needed to adequately assess technology needs in developing countries; improving technology assessment and choice; and strengthening innovative capabilities of key institutions.

a) Needs Assessment

An adequate basis in "the science of the environment" is crucial if developing countries are to make adequate assessments of technological needs. As such, the acquisition by developing countries of relevant scientific knowledge regarding environmental issues should be seen as an essential counterpart to any action on technology transfer.

One possible point of entry in this area may be via the needs assessments which will have to be carried out as part of both the specific conventions signed at Rio and the broader Agenda 21 document. A US document prepared for the June 1991 meeting of the Intergovernmental Negotiating Committee (INC) for the proposed climate change convention argues that if properly designed, country level needs assessments can themselves be an effective way of "transferring data, expertise, and analytical capabilities to host countries." The paper goes on to argue that the experience of the Montreal Protocol may offer important lessons in this regard. Under the Montreal process, industrialized countries volunteered to assist one or more developing countries in undertaking joint needs assessments, subject to a common framework developed at a workshop of participating countries. According to the US document, the key factor in successful assessments was the active involvement of target countries in designing and conducting the studies. The US Environmental Protection Agency (EPA) has already taken independent action in proposing a study with Brazil that will develop a comprehensive inventory of net greenhouse gas emissions.

For many developing countries, the financial, technical and logistical burden of country-level assessments may be overwhelming. While the Montreal Protocol experience is thus an interesting experiment, there will also be a need to explore more decentralized approaches, working from the regional or local level. Moreover, any needs assessment procedure must given careful to the methodology to be followed, and the type of training provided to local counterparts. Ultimately, there will also be need for coordination of efforts in this field. In the area of climate change, this is most likely to take place via the Intergovernmental Panel on Climate Change (IPCC), which has endorsed a work plan to develop draft guidelines for national emissions inventories by mid-1992, and which (via its coastal zone management subgroup) has proposed the development of a common approach to country studies of vulnerability to sea-level rise.

THE IMPORTANCE OF NEEDS ASSESSMENT: SOLAR DRYERS IN AFRICA

A study of solar drying technologies in Africa (Wereko-Brobby, 1987) illustrates the way in which a combination of donor preferences and disciplinary biases can steer well-meaning efforts at the development and diffusion of 'appropriate' technologies away from the felt needs of beneficiary populations.

As a result of the oil supply and price problems of the 1970s, "governments in many developing countries, international funding agencies, and researchers operated on the single assumption that any activity that increased, or diversified, energy supply options would be good for the country in the long run" (Wereko-Brobby, 1987, 276). The result was that research was directed to the development and diffusion of particular renewable energy technologies, in this case solar dryers. This technology-push bias has been exacerbated by the fact that research and development has been overwhelmingly defined and executed by technologists, with little or no input from social scientists.

While the ensuing effort has resulted in the development of a number of improved dryers which are technologically superior to traditional sun drying, success in the application of the improved designs has been much more limited. The root cause, argues Wereko-Brobby, is the failure to adequately identify beneficiaries and assess their felt needs. "Especially when dealing with subsistence farming communities in the informal economic environment", he argues, "the technological innovation option can only really be considered as the last stage in the process of research problem definition" (Wereko-Brobby, 1987, 276).

One final point must be stressed. Needs assessment should not be focused exclusively on identifying possible technological solutions. As decades of experience in supporting research for development have shown, a successful intervention must start by identifying the felt needs of the local population to ensure that chosen solutions are effectively implemented. Even though inventories of potentially useful technologies are urgently required, it is crucial that needs assessment exercises not assume that solutions will be technological (see Box: The Importance of Needs Assessment: Solar Dryers in Africa).

b) Technology Assessment and Choice

Sound technology choice is the sine qua non of any strategy for international technology transfer. Unless developing countries are able to make informed choices among the various technological options open to them, efforts to promote international technology transfer risk becoming overwhelmingly supplier driven, geared more to transferring available technological solutions than to responding to the needs of developing countries. Yet, at the same time, developing countries typically face severe disadvantages in terms of the information available to them and their technical capacities to evaluate particular technologies.

To begin with, there is a need for better access to information on the range of technological options available to developing countries and the performance characteristics of given technologies. This is now widely recognized, and there are a number of inventories, information services, data bases and the like either in operation or in the planning stage. This is one area where there may be need for more effective coordination of the various initiatives, and the proposals currently being put forward by the UNCED Secretariat for a single clearing house and information network on environmentally sound technologies are welcome moves in this direction.

In all likelihood, however, access to information will be limited less by the insufficient provision of such information, than by the insufficient capacity of recipient countries to use the information available. Careful thought needs to be given to the design and implementation of information systems to ensure that the appropriate clients are in fact reached, and that the appropriate tools are available to promote diffusion of the information within supplier countries. In addition, there may be considerable room for the involvement of intermediary institutions that form a brokering service -- particularly in fields of rapid technological advance where formal information services may not capture all the relevant information, and where the capacity of developing countries to evaluate various technological options may be limited.

To improve the technology-assessment capabilities of recipient countries, there are obvious needs for provision of training support and personnel exchanges, both on a government-to-government basis and within productive enterprises. There is also a need for the design of improved teaching materials, manuals, and assessment criteria to permit the more effective evaluation of technology alternatives. This latter point is particularly important if developing countries are to resist the temptation toward the automatic application of "best available" technologies developed in Northern countries, and, instead, begin to investigate alternatives more appropriate to their domestic conditions (see Box: Appropriate Technology vs. Best Availabile Technology: Options for CFC Phaseout)

c) Strengthening Innovative Capabilities

Ultimately, an effective response to global environmental threats must allow developing countries not only to access the "pool" of world technology but also to create their own technological solutions. As a result, there is a clear need for support to the structures and institutions that foster innovation in developing countries. Two specific points should be made regarding the types of capacity-building actions which are required.

- First, the past two decades have witnessed a shift in the locus of technological effort away from formal research institutions, and toward the productive unit;

as a result, any strategy to improve the technological capabilities of developing countries must involve action at this level as well as broader based support to national and regional research institutes.

'APPROPRIATE TECHNOLOGY' VS. 'BEST AVAILABLE TECHNOLOGY': OPTIONS FOR CFC PHASEOUT

Since the signing of the Montreal Protocol in 1987, considerable efforts have been devoted to the development and application of alternatives to chlorofluorocarbons (CFCs). Multinational electronic companies have developed new techniques for cleaning electronic components, substituting water-based solvents or reducing the use of soldering flux itself. The switch away from the use of CFCs as aerosol propellants has also been fairly rapid, in part because aside from initial investment costs, non-CFC propellants offer significant cost savings over CFCs. The most difficult and costly change, however, will be the switch to non-CFC refrigeration technology -- which is by far the greatest source of CFC use in developing countries.

To date, most of the emphasis has been placed upon two new chemicals: hydrochlorofluorocarbons (HCFCs), which contain some ozone-destroying chlorine but are less stable than CFCs and thus largely break down before reaching the ozone layer; and, hydrofluorocarbons (HFCs), which contain no chlorine. While the costs of switching to HCFCs or HFCs are relatively high, their use is being promoted both by Northern chemical companies (which see an opportunity to market new, proprietary technologies as a replacement for CFCs which are no longer protected by patents) and by developing country governments (which are justifiably reticent to accept 'second-best' alternatives which might widen the technological gap between them and the North.)

In fact, however, these may not be the only alternatives to CFCs. The New Scientist (30 June 1990, pp. 39-40) has suggested that there are cheaper alternatives to CFCs which may prove appropriate for many uses. These include the use of propane or ammonia as refrigerants, or the development of 'absorption refrigerators', which re-condense the coolant on an absorbent chemical, eliminating the need for a compressor. The latter use water as a coolant (with a chemical such as lithium bromide used as an absorbent) and in addition to replacing CFCs may dramatically improve energy efficiency.

The economic and technical feasibility of such refrigerants remain largely unexplored. But their very existence highlights possible conflicts between 'best available' and 'appropriate' technologies, and between directions of technological change suggested by current commercial interest versus alternate directions. There is a compelling need for research into novel alternatives to CFCs to meet developing country needs, and for diffusion of information regarding such innovations.

- Second, it is now accepted that innovations result not so much from single institutions, but rather from networks of institutions. As a result, considerable emphasis should be placed on efforts to improve the capabilities of technology users and equipment suppliers -- which in industrialized countries are increasingly recognized as an important source of innovation (Bell, 1990, 37; for an interesting discussion of the role of technology users as a stimulus to innovation in both North and South, see Gamser, 1988). In addition, ongoing efforts to provide effective linkages between research institutions and technology users in productive sectors are crucial and should be a key focus of donor efforts to strengthen local systems of innovation.

There are a number of possible actions which can be taken to strengthen developing countries' innovative capabilities. Twinning programs between Northern and Southern institutions; enhanced scholarship support to developing country students; project and/or core support to existing scientific institutions; policy advice regarding the reform of incentives to private-sector research; enterprise level training in improved production design, maintenance and quality control -- these are all examples of incremental, independent actions which can and should be pursued by a variety of actors.

Given the economies of scale associated with scientific research and the limited resources available to most developing countries, however, some form of collaborative effort in this area is essential.

In this regard, there are two broad avenues of action. The first, exemplified by US calls for the establishment of major regional research institutes on global environmental issues, stresses the creation of new institutions charged with the furthering of environmental science, technology and policy. There are, of course, advantages to such an approach -- particularly the ability to transcend the disciplinary boundaries of many existing institutions in order to attack problems from a more integrated perspective. Any such effort must learn from the strengths and weaknesses of existing bodies, such as the CGIAR system in the field of agricultural research. Specifically, there is a need to have greater participation by developing-country scientists, policy makers, and users of the research results in these institutions than has often been the practice.

On the other hand, in a climate of severe resource shortages a new regional initiative is likely to be counterproductive, if it is at the expense of increasing the capacity of existing national institutions. For this reason, others argue for alternatives to the creation of new institutions. The UNCED Secretariat has proposed the establishment of regional capacity-building programs to support sustainable development in developing countries, which it argues would not require the establishment of new central institutions, but would instead involve mechanisms for coordination and cooperation among existing institutions. While remaining open to the possibility of creating new institutions, therefore, the international community should actively pursue ways of improving the effectiveness and efficiency of existing scientific and technical institutions at the national and regional level. The experience of IDRC and other donors active in the support of development research will form an indispensable part of any strategy to reinforce and improve existing capabilities.

REFERENCES

Agarwal, A., and S. Narain, 1991. Global Warming in an Unequal World: A Case of Environmental Colonialism. Centre for Science and Environment, New Delhi.

Arrow, K., 1962. "Economic Welfare and the Allocation of Resources for Information". In National Bureau for Economic Research, The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, NJ.

Arthur, B., 1990. "Positive Feedbacks in the Economy". Scientific American 262 (2), 92-99.

Ayiku, M., 1991. University-Productive Sector Linkages: Review of the State-of-the-Art in Africa. IDRC, Ottawa, MR280e.

Azucena, C., ed., 1988. Universities and Application of Research Results. IDRC, Ottawa.

Barnett, A., 1990. "The Diffusion of Energy Technology in the Rural Areas of Developing Countries: A Synthesis". World Development, 18 (4), 539-553.

Belcher, B. and G. Hawtin, 1991. A Patent on Life: Ownership of Plant and Animal Research. IDRC, Ottawa, IDRC-269e.

Bell, M., 1990. Continuing Industrialisation, Climate Change and International Technology Transfer. Science Policy Research Unit, University of Sussex, UK.

Bell, M. and D. Scott-Kemmis, 1988. "Technology Import Policy: Have the Problems Changed?". In A. Desai, ed., Technology Absorption in Indian Industry. Wiley Eastern, New Delhi, 30-70..

Benedick, R., 1989. "Ozone Diplomacy". Issues in Science and Technology, VI (1), 43-50.

Carson, R., 1962. Silent Spring. Houghton Mifflin, Boston.

Chantramonklasri, N., 1984. Technology Transfer, Technical Change and Technology Accumulation. ESCAP/UNCTC Joint Unit on Transnational Corporations, Bangkok.

Chantramonklasri, N., 1985. Technological Response to Rising Energy Prices: A Study of Technological Capability and Technical Change Efforts in Energy-Intensive Manufacturing Industries in Thailand. DPhil Thesis, University of Sussex, UK.

Chudnovsky, D., 1990. North South Technology Transfer Revisited: Research Issues for the 1990s. Report to the International Development Research Centre, Ottawa (mimeo).

Contractor, F.J. and T. Sagafi-Nejad, 1981. "International Technology Transfer: Major Issues and Policy Responses". Journal of International Business Studies, Fall, 113-135.

Dahlman, C. and F. Fonseca, 1987. "From Technological Dependence to Technological Development: The Case of the USIMINAS Steel Plant in Brazil". In J. Katz, ed., Technology Generation in Latin American Manufacturing Enterprises: Theory and Case-Studies Concerning Its Nature, Magnitude and Consequences. Macmillan, London, UK.

Desai, Ashok, ed., 1988. Technology Absorption in Indian Industry. Wiley Eastern, New Delhi.

Ehrlich, Paul R., 1968. The Population Bomb. Ballantine, New York.

Enos, J., 1962. "Invention and Innovation in the Petroleum Refining Industry". In NBER (National Bureau for Economic Research), The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton University Press, Princeton, NJ.

Enos, J.L. and W.H. Park, 1987. The Adoption and Diffusion of Imported Technology in the Case of Korea. Croom Helm, London.

ERG (Energy Research Group), 1986. Energy Research: Directions and Issues for Developing Countries. IDRC, Ottawa. IDRC-250e.

Fong, C.O., 1987. "Technology Acquisition under Alternative Arrangements with Transnational Corporations: Selected Industrial Case Studies in Malaysia". In United Nations, Technology Transfer under Alternative Arrangements with Transnational Corporations. ESCAP/UNCTC Publications Series B, No. 11, Bangkok.

Fowler, C. and P. Mooney, 1990. Shattering: Food, Politics and the Loss of Genetic Diversity. University of Arizona Press, Tucson, Arizona.

Gamser, M., 1988. "Innovation, Technical Assistance and Development: The Importance of Technology Users". World Development, 16 (6), 711-721.

Goka, A., et al, 1990. Performance Review of Institutions for Technology Policy in Ghana, Nigeria and Tanzania. IDRC, Ottawa, MR-241e.

Gray, C. and D. Rivken, 1991. "A "No Regrets" Environmental Policy". Foreign Policy, 83, 47-65.

Herbert-Copley, B., 1990. "Technical Change in Latin American Manufacturing Firms: Review and Synthesis". World Development, 18 (11), 1457-1469.

Hill, H., 1988. Foreign Investment and Industrialization in Indonesia. Oxford University Press, Singapore.

Hoffman, K. and N. Girvan, 1990. Managing International Technology Transfer: A Strategic Approach for Developing Countries. IDRC, Ottawa, MR-259e.

Hoffman, K., and R. Kaplinsky, 1988. Driving Force: The Global Restructuring of Technology, Labour and Investment in the Automobile and Components Industries. Westview Press, Boulder CO.

IPCC (Intergovernmental Panel on Climate Change), 1991. Climate Change: The IPCC Scientific Assessment. Cambridge University Press, Cambridge UK.

Joly, A. and M. Bandelier, 1988. The Impact of New Technologies on the Environment. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Juma, C., 1990. "Promoting Technological Innovation in Africa: The Case for Institutional and Legal Reform". African Centre for Technology Studies, Nairobi, Kenya (mimeo).

Keystone Center, 1991. Final Consensus Report: Global Initiative for the Security and Sustainable Use of Plant Genetic Resources. Keystone Center, Keystone, Colorado.

Kim, L., 1988. Technology Policy for Industrialization: Conceptual Frameworks and Korea's Experience. World Bank Working Paper, World Bank, Washington, DC.

Lall, S., 1985. "Trade in Technology in a Slowly Industrializing Country". In N. Rosenberg and C. Frischtak, eds., International Technology Transfer: Concepts, Measures and Comparisons. Praeger, New York, pp. 45-76.

Meadows, D.H., et al, 1972. The Limits to Growth. Signet, New York.

Mihyo, P., 1985. Bargaining for Technology: Some Experiences from Tanzania's Public Enterprises. University of Dar Es Salaam, Dar Es Salaam, Tanzania.

Mytelka, L., 1989. "Technology and the Least Developed Countries: A Background Paper" (mimeo).

Nath, N.C.B., 1987. "Technology Acquisition under Alternative Arrangements with Transnational Corporations: Selected Industrial Case Studies in India". In United Nations, Technology Transfer under Alternative Arrangements with Transnational Corporations. ESCAP/UNCTC, Publications Series B, No. 11, Bangkok.

Niosi, J. and J. Rivard, 1990. "Canadian Technology Transfer to Developing Countries through Small and Medium-Size Enterprises". World Development, 18 (11), 1529-1542.

O'Connor, D., 1991. Strategies, Policies and Practices for the Reduction of CFC Usage in the Electronics Industries of Developing Asia. OECD Development Centre, Paris, France.

O'Connor, D. and D. Turnham, 1992. Managing the Environment in Developing Countries. Policy Brief No. 2, OECD Development Centre, Paris, France.

Odle, M., 1986. Commercialization of Technology and Dependence. Institute of Social and Economic Research, University of the West Indies, Mona (Kingston), Jamaica.

OTA (Office of Technology Assessment), 1984. Technology Transfer to the Middle East. United States Office of Technology Assessment, Washington, D.C.

Pavitt, K., 1985. "Technology Transfer among the Industrially Advanced Countries". In N. Rosenberg and C. Frischtak, eds., International Technology Transfer: Concepts, Measures and Comparisons. Praeger, New York, pp. 3-24.

Quazi, A., 1984. Technological Capacity and Production Performance in the Fertilizer and Paper Industries in Bangladesh, University of Dhaka, Dhaka, Bangladesh.

Ramphal, Sir Sridath, 1990. "Third World Grievances". EPA Journal, 16 (4), 39-43.

Rath, A., 1990. "Science, Technology and Policy in the Periphery: A Perspective from the Centre". World Development, 18(11), 1429-1444.

Rosenberg, N., 1986. On Technology Blending. World Employment Programme Working Paper WEP 2-22/WP 189. International Labour Office, Geneva.

Sagasti, F., 1978. Science and Technology for Development: Main Comparative Report of the STPI Project. IDRC, Ottawa, IDRC-109e.

Santikarn, M., 1981. Technology Transfer: A Case Study, Singapore University Press, Singapore.

South Commission, 1990. The Challenge to the South: The Report of the South Commission. Oxford University Press, Oxford, UK.

Speth, J.G., 1988. Environmental Pollution: A Long-Term Perspective. World Resources Institute, Washington, D.C.

Stewart, F., 1978. Technology and Underdevelopment, Macmillan, London, U.K.

Stewart, F., 1987. Macro Policies for Appropriate Technology. Westview Press, Boulder, Colorado.

Teece, D., 1977. "Technology Transfer by Multinational Firms: The Resource Cost of Transferring Technological Know-How". The Economic Journal, 87 (346), 242-261.

Touche Ross Ltd., 1991. Global Climate Change: The Role of Technology Transfer. Report prepared for the UK Secretary of State for Trade and Industry. Touche Ross Ltd., London, UK.

Turner, T., 1982. Petroleum Exploration Contracts and Agreements and the Transfer of Technology. United Nations Conference on Trade and Development (UNCTAD), TD/B/C.6/AC.9/5, Geneva.

UNCSTD (United Nations Centre for Science and Technology for Development), 1991. Environmentally Sound Technology Assessment. UNCSTD, New York.

UNCED (United Nations General Assembly, Preparatory Committee for the United Nations Conference on Environment and Development), 1991. Report on Technology Transfer. A/CONF.151/PC/52. United Nations, Geneva, 8 July 1991.

USAID (United States Agency for International Development), 1990. Greenhouse Gas Emissions and the Developing Countries: Strategic Options and the USAID Response. USAID, Washington, DC.

Vaitsos C., 1974. Intercountry Income Distribution and Transnational Enterprises. Clarendon Press, Oxford, UK.

Waissbluth, M., et al, 1988. "Linking University and Industry: An Organizational Experience in Mexico". Research Policy, 17 (6), 341-347.

Warhurst, A., 1991. "Environmental Management in Mining and Mineral Processing in Developing Countries: Enterprise Behaviour and National Policies". Science Policy Research Unit, University of Sussex, UK (mimeo).

Wereko-Brobby, C., 1987. "Research and Development on Solar Drying: Advancing Energy Supply Options or Meeting Felt Needs?". In IDRC, Solar Drying in Africa: Proceedings of a Workshop Held in Dakar, Sénégal, 21-24 July, 1986. International Development Research Centre, Ottawa.

White, R., 1990. "The Great Climate Debate". Scientific American, 263 (1), 36-43.

Winpenny, J., 1990. "National Environmental Policies: The Scope for Government Intervention". Journal of International Development, 2 (4), 441-448.

WRI (World Resources Institute), 1991. Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century. World Resources Institute, Washington, DC.

Wynne-Edwards, H., 1991. Report on Technology Cooperation. Business Council on Sustainable Development, Geneva (draft).

The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support technical and policy research designed to adapt science and technology to the needs of developing countries. The Centre's five program sectors are Natural Resources, Social Sciences, Health Sciences, Information Sciences and Systems, and Corporate Affairs and Initiatives. The Centre's funds are provided by the Parliament of Canada; IDRC's policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

Head Office
IDRC, PO Box 8500, Ottawa, Ontario, Canada K1G 3H9

Regional Office for Southeast and East Asia
IDRC, Tanglin PO Box 101, Singapore 9124, Republic of Singapore

Regional Office for South Asia
IDRC, 11 Jor Bagh, New Delhi 110003, India

Regional Office for Eastern and Southern Africa
IDRC, PO Box 62084, Nairobi, Kenya

Regional Office for the Middle East and North Africa
IDRC, PO Box 14 Orman, Giza, Cairo, Egypt

Regional Office for West and Central Africa
IDRC, BP 11007, CD Annexe, Dakar, Senegal

Regional Office for Latin America and the Caribbean
IDRC, Casilla de Correos 6379, Montevideo, Uruguay

Please direct requests for information about IDRC and its activities to the IDRC office in your region.

Printed on recycled paper