CLIMATE CHANGE:
A CHALLENGE TO THE MEANS OF TECHNOLOGY TRANSFER

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1. Introduction

Greenhouse gases originating in large part from the burning of fossil fuels contribute to warming of the atmosphere by trapping the heat that otherwise would radiate out from the earth's warm surface and atmosphere into the cold of outer space. As a result, the earth's climate is expected to change as energy use increases, creating severe problems that can range from total loss of certain land areas as a result of rising sea level to profound changes in agriculture, fisheries, human habitations, and health.

These prospects require an examination of two broad policy alternatives: adaptation to climate change or prevention of large shifts in climate. Building higher dikes to protect The Netherlands and Bangladesh from higher sea levels and more intense storms would be one step toward adaptation. Prevention, by contrast, depends on measures that limit greenhouse gas emissions. In the end, both adaptive and preventive measures must be employed in a ratio that minimizes overall cost. This paper places emphasis on limiting emissions because, in many cases, reducing emissions can be economically as well as environmentally beneficial, whereas adaptation generally burdens the economy.

As the data in the Appendix illustrates, emissions from the industrialized world today dominate atmospheric change. These countries must lead in reducing emissions if a preventive strategy is employed. However, projections such as those developed by the United Nations Intergovernmental Panel on Climate Change (IPCC) [1] indicate that the developing countries' share of emissions will increase substantially over the next 40 years to become a significant portion of the world total. Slowing the growth of emissions from developing countries while accelerating the pace of economic development poses a daunting task for the world community.

A workable abatement strategy depends on clear understanding of the sources of greenhouse gases. In terms of their greenhouse warming potential, the following activities dominate: energy production and use (about 57 percent), chlorofluorocarbon (CFC) use (17 percent), agriculture (14 percent), deforestation (9 percent), and other industrial production (3 percent) [2]. While there are large uncertainties in the estimated percentages, particularly for deforestation, the above figures clearly make the case for limiting the production of carbon dioxide from the burning of fossil fuel and restricting the production of CFCs. In fact, international agreement has been reached on limiting CFCs, which are produced primarily by the industrialized world [3].

There are two main methods by which the emissions of carbon dioxide could be limited in the future. The carbon intensity of fossil fuel energy can be reduced by substituting a non-fossil fuel, such as solar or renewable energy, or by replacing it with a low-carbon intensive fuel, such as natural gas. An even greater potential for reducing greenhouse gas emissions lies in increasing the energy efficiency of the world economy by improved conservation in the industrial, commercial, and household sectors, and by higher fuel efficiency in vehicles and industrial processes. Since the developing nations will, in percentage terms, grow more rapidly than industrialized countries, they have a significant opportunity to meet sharply increased demand and at the same time reduce future emissions through both fuel switching and higher energy efficiency.

The World Bank [4] makes a persuasive case for the development community to focus on energy efficiency:

> The development community needs to outline a policy and research program for sustainable economic development which addresses the implications of possible climatic effects of greenhouse gases. The greatest opportunity lies in the energy sector, which should be the primary focus of attention, notwithstanding that the energy efficiency options are substantial in sectors such as agriculture and urban systems. Indeed, the opportunities for public and private energy efficiency gains are compelling and suggest that the threat of global warming can be reduced primarily by concentrating present efforts on improving energy efficiency of the global economy.

Many, though not necessarily all, of the technologies that can reduce the emissions of these gases will probably be developed in the industrialized world. The effective transfer of these technologies to the developing countries presents a major challenge, both in terms of the technologies to be shared and of the process by which this sharing can be accomplished.

Governments recognize the importance of technology transfer in dealing with problems of climate change. The final ministerial declaration from the second World Climate Conference in December 1990 [5] stated that:

> ...developing countries must within the limits feasible, taking into account the problems regarding the burden of external debt and their economic circumstances, commit themselves to appropriate action [to address climate change]. To this end there is a need, to meet the requirements of developing countries, that adequate and additional financial resources be mobilized and the best available environmentally sound technologies be transferred expeditiously on a fair and most favorable basis.

Thus, the technologies that should be transferred and the best means for doing so are critical questions for the future.

In the industrialized world, particularly among academics, the discussion of technology transfer has centered on supposed barriers, such as questions of intellectual property rights. In fact, experience shows that while such problems provide suitable subjects for learned treatises [6], they rarely arise in practice. Patents typically expire after 15 to 20 years; the basic processes and equipment needed to achieve energy efficiency are now largely in the public domain. As the examples described in the following sections will show, the actual availability of technology poses far fewer difficulties than associated issues of appropriateness and price of the technology and the strength of the supporting infrastructure.

Despite the indisputable benefits of using environmentally sound technologies, developing nations have greeted the concept with mixed views and much suspicion. The developing world's primary need is to maintain and increase economic growth, in the attempt to approach living standards now being enjoyed in the industrialized world. From their standpoint, this goal will be put at risk if they respond to calls by the developed world for cooperation in dealing with climate change. As the early negotiating sessions toward a global climate convention have shown, developing nations are convinced that the climate problem was created primarily by profligacy in the developed countries, which are now attempting to transfer the blame for the problem, and therefore the need for solutions, to the developing world. Developing countries resent the emphasis that industrialized countries place on the contribution of tropical deforestation to climate change [7]. While recognizing the importance of improved forest management, the developing countries point out that deforestation contributes far less to greenhouse gas emissions than the industrial activities of rich nations.

Like academics in the richer countries, many in the developing world also believe that the advanced technology needed to limit greenhouse gas emissions, and thus help to slow climate change, is protected by intellectual property rights held by companies resident in developed countries. The cost of acquiring the technology would be exorbitant; therefore, profit is the rich countries' real motivation for pressuring the developing world to participate in curbing greenhouse gas emissions. In the view of the poor nations, climate change, if real, is the responsibility of the industrialized world, and these wealthy countries should pay developing nations to take part in reducing greenhouse gas emissions.

Developed countries do have selfish interests in transferring greenhouse gas-limiting technologies to the poorer countries. Since both developed and developing countries will suffer the damaging effects of global warming, adoption and adaptation of industrialized-world technology benefits all countries through diminishing the risk of climate change. But this does not imply that industrialized countries will reap exorbitant profits, or that recipient nations must sacrifice their long-term economic interests. Adoption of environmentally sound practices is actually not a zero-sum game, with the economy shrinking in proportion to increasing environmental protection. In many cases, technology that provides new services without harming the environment, or reduces greenhouse gas emissions in an existing process, is far more cost-effective than the equipment it replaces. As a result, developing countries can profit both economically and environmentally, and form a large potential market for the technologies developed in the industrialized world. Helping all nations to recognize these advantages could stimulate mutually beneficial technology transfer by prompting industrialized nations not only to make their equipment and processes available to the poorer countries at relatively low prices, but also to examine creative ways in which the transfer could be supported through training, financing, and expanding the recipient nation's infrastructure.

Preparations for the environmental summit — the United Nations Conference on Environment and Development (UNCED), to be held in Rio de Janeiro in June 1992 — draw attention to the role that technology transfer can play in addressing the conference's dual focus. This paper describes how technology transfer can help developing nations to meet local needs and at the same time slow the potential for climate change. To illustrate the need to control greenhouse gas emissions, the next section and the Appendix will discuss current and future emissions from developing countries. The estimates show that a relatively small number of the poorer nations will contribute a very large percentage of future emissions from the developing world. Section 3 briefly reviews the conditions required for successful transfer of technology. Sections 4–9 provide a concrete picture of what is meant by the often abstract notion of technology transfer through examples drawn from actual experience. They show how technology transfer that is sensitive to local needs and conditions can, in an economically advantageous way, successfully address common problems that contribute both to poverty and to global climate change, and illustrate pitfalls that must be avoided. Section 10 considers the lessons to be drawn for the environmental summit and the role that UNCED might play. The Appendix contains the data on carbon dioxide emissions from the world's nations from 1950 to 1986.

2. Dimensions of the Problem

In the past, the developed countries have been the main source of greenhouse gas emissions. The United States, with only 5 percent of the world's population, currently accounts for about 22 percent of the world's emissions [8]. Other industrialized countries, including Eastern Europe and the Soviet Union, raise the developed world's greenhouse gas emissions to about 68 percent of the total. The remaining 32 percent are due to activities within developing countries (22 percent) and China and centrally planned Asia (10 percent) [9]. However, forecasts [1] indicate that the developing countries' carbon dioxide emissions will rise from approximately one-third today to more than one-half of the global emissions by the year 2030. This relatively higher rate of growth will be spurred both by higher rates of population growth and by a faster rate of economic development. A large fraction of the anticipated rise in carbon dioxide emissions will come from increased burning of fossil fuels, although deforestation in tropical countries contributes to the carbon dioxide burden of the atmosphere.

In terms of carbon dioxide derived from the use of energy, the developing countries' share of the world's energy use increased from about 16 percent to about 25 percent between 1970 and 1986. China, India, Mexico, and Brazil accounted for about 45 percent of the developing countries' consumption of commercial and traditional fuels for 1988, with China alone accounting for 30 percent [10]. Energy use will increase as developing countries expand industrial and transportation infrastructure, continue to electrify cities fully, and begin or continue rural electrification programs. New electrical power generation is likely to be based largely on domestic fuel sources — in many countries, primarily on coal and hydroelectric facilities. Half of the planned electricity generation in China and India, for example, is to be based on coal. Burning coal efficiently is of great importance to slowing global warming, since coal produces significantly more carbon dioxide per unit of delivered heat than does oil or natural gas.

Several organizations, including the World Resources Institute [11], have prepared comprehensive estimates of current contributions of countries to greenhouse gas emissions (also see the Appendix). However, there are no similar estimates for future emission levels; instead, a limited number of country case studies have been prepared. Estimates of future energy use are, perforce, speculative in nature: they depend on projections of population and of overall economic growth as well as on the availability of technology.

2.1 Industry

Sathaye and Ketoff [12] have estimated future emissions for nine developing countries, as shown in Table 1. Their analysis indicates that by 2025 industrial activity will retain its importance in determining energy use and carbon emissions. In their models, based on population growth and estimated economic growth, carbon emissions rise by 300 percent in the industrial sector. China currently dominates the developing world's emissions of carbon dioxide and is projected to continue to do so. However, since opportunities for improving industrial efficiency may be quite high, the proportional increase in emissions from all developing countries could be significantly lessened, as is discussed in the following sections.

Table 1
Carbon Dioxide Emissions from Energy Use by Country
(measured in million tons of carbon. For conversion to million tons of carbon dioxide, multiply by 3.67)

Country	**1986 (%)**	**2025 High (%)**	**2025 Low (%)**
China	554 (58)	1,722 (52)	1,388 (53)
India	144 (15)	709 (21)	623 (24)
Mexico	74 (8)	233 (7)	157 (6)
Brazil	52 (5)	142 (4)	71 (3)
Korea	45 (5)	172 (5)	112 (4)
Indonesia	28 (3)	132 (4)	106 (4)
Venezuela	26 (3)	112 (3)	86 (3)
Argentina	26 (3)	41 (1)	30 (1)
Nigeria	13 (1)	50 (2)	41 (2)
Total	962 (101)	3,313 (99)	2,614 (100)

(see Sathaye and Ketoff [12] and Appendix)

2.2 Transportation

In addition to industrial growth, transportation figures as an important player in carbon emissions. Current levels of car ownership in some developing countries are higher than in the lower-income OECD countries at the time they had similar levels of gross domestic product (GDP) per capita. For example, the current level of ownership in Malaysia is 90 per thousand, while Greece in 1973 had 40 per thousand, even though Malaysia's current per capita income is less than that of Greece at that time. One can expect that much higher ownership of cars and motorcycles will characterize the 2025 transportation scene. Both freight and passenger traffic is expected to rise proportionately with the GDP. As the highway infrastructure develops, road transportation will increase more rapidly than rail transportation. Motor vehicles are the main market for petroleum products, and fuel use from transportation is estimated to rise fivefold in India and sevenfold in China.

In Sathaye's and Ketoff's studies, carbon dioxide emissions from transport will rise, in percentage terms, more than any other source of developing country emissions. The level of increase will depend largely on the fuel efficiency of the vehicles, which varies greatly among individual countries (see Section 9). In general, cars in developing countries are less fuel-efficient than comparable cars in Europe and Japan, but the globalization of car manufacturing is likely to lead to more rapid international transfer of automotive technologies, and transportation fuel efficiencies can be expected to increase in the developing world as old, inefficient fleets are replaced with newer vehicles.

2.3 Residential Use

In the residential sector, cooking is the primary user of energy. In the future, the major change will be the substitution of alternative fuels for wood. Fuel switching in itself may lead to some reduction in emissions, but the most important feature will be increased fuel efficiency as new cooking technologies are adopted, as is discussed in Section 5. Kerosene, a much used but highly inefficient source of lighting, will be largely replaced as urban and rural electrification proceeds.

2.4 Power Generation

Developing countries tend to have inefficient electricity production, transmission, distribution, and consumption systems. For example, steam power plants in many developing countries may use 20 to 45 percent more fuel per kWh of electricity than typical U.S. steam plants. Many plants are operational only 50 to 60 percent of the time, compared with over 80 percent in most developed countries, because of frequent power outages resulting from the lack of spare parts and proper maintenance [13]. Electricity losses during transmission and distribution are also high: 30 percent in countries such as the Dominican Republic and Bangladesh, and over 20 percent in Pakistan, India, and Egypt. Often, the losses can be attributed to illegal tap-ins, but lack of adequate transformers, junction boxes, and transmission lines also contributes.

Developing countries face major technical and institutional obstacles to increased energy efficiency. Many of these countries cannot use efficient motor compressors in refrigeration because of voltage fluctuations due to poor operating and maintenance conditions at the power plant. Moreover, almost all developing countries grant monopolies to government-owned utilities for electricity generation and distribution, and many subsidize the price of energy supplied to consumers. Many developing countries strongly adhere to the belief that cheap energy is a prerequisite for economic growth; as a result, utilities and industries often operate inefficiently, and there are few incentives for end users to conserve or for utilities to improve operating efficiencies.

These trends could be counteracted by adapting advanced technologies to local needs for power generation.. According to USAID [13], these technologies could include, for example, variable-speed drivers for industrial motors, electric arc furnaces for steel production, energy-efficient lighting, water pumping, heating, and refrigeration systems, and capacitors in electricity lines to reduce transmission and distribution losses. Cogeneration might also increase effective electricity generation, primarily in the industrial sector. As the examples described below illustrate, a primary deterrent to the use of up-to-date technologies is the lack of information about the technology and its availability, as well as the lack of infrastructure to support and maintain the technology.

Fuel switching from coal to natural gas would reduce carbon emissions by at least 20 to 60 percent per unit of delivered energy, depending on the end product and the technology that is used [14]. Switching to natural gas, however, might require refitting old facilities or building new ones, including the natural gas distribution infrastructure. Pipelines, pumps, and compressor stations all require heavy initial capital, which is rare in the developing world. Further, in order to bring about a net reduction of greenhouse gases, great attention must be paid to minimizing leaks from the production, distribution, and use of methane, which is a much more powerful greenhouse gas than carbon dioxide [15]. This requirement places a priority on maintenance service and spare parts, both scarce in developing countries. Natural gas is not available everywhere, although, in some cases, the unavailability is due to lack of geologic exploration. For example, China currently is listed as having minimal gas reserves [16], but the geology, the abundance of coal deposits, and the success in finding oil all indicate that China actually possesses considerable (though as yet undiscovered) natural gas resources that could be a significant energy source. Extensive natural gas reserves are just now being developed in a number of countries, including Argentina, Chile, and Thailand.

Renewable and nuclear sources of energy have the lowest greenhouse emissions per unit of delivered energy. However, the high capital cost of installing nuclear power, plus the high technical capabilities required to meet maintenance and safety standards, make it unlikely that nuclear power will play a significant role in providing energy to the developing world in the next decade or two. Widespread use of nuclear energy in the developing world would probably require smaller capacity plants than the 1,000 MW plants typical in industrialized nations. Smaller plants pose additional problems with respect both to safety and to diversion of nuclear materials for weapons purposes. By contrast, many renewable energy sources are small and modular, and hence adaptable to local situations and to decentralized power systems. They tend to be easily maintainable, and are often cost effective, particularly in remote areas. Thousands of photovoltaic and wind systems exist in rural areas for water pumping, drip irrigation, electric power, and lighting. Small hydropower systems are used for milling grain, providing local electric power, and other applications. Biomass systems, based on agricultural residuals, are frequently used. However, aside from traditional wood burning, renewable resources at present account for only a small fraction of the energy used in the developing world.

The use of renewable energy sources is limited by a variety of factors. Indeed, many of the renewable energy projects funded by USAID and other development agencies have not reached commercialization. The reasons include a lack of financing mechanisms, inadequate provision of technical assistance for training in maintenance, the inappropriateness of the technology for the locale, and the lack of understanding of the limitations of such systems. Despite these failures, the examples below will show that the transfer of appropriate technology can meet a range of needs for energy-efficient generation of power and for energy conservation in the industrial, transportation, and residential sectors. Success depends not only upon the particular technology chosen, but on the framework in which the technology will be be used, adapted, and maintained.

3. Conditions for Successful Technology Transfer

The broad objective of economic development is to enable the citizens of developing countries to achieve higher living standards through raising levels of productivity, gross domestic product, and income. Many development assistance agencies identify the acquisition and diffusion of more productive technologies as a major element in achieving this goal. If technology is to be transferred successfully from the industrialized world, however, the process must be highly sensitive to the needs and preconditions of the recipient country [17].

Hitherto, technology transfer has been only a qualified success among developing countries. Technological progress, with concomitant increases in GDP, has been achieved in parts of Latin America in the 1950s and 1960s, in Asia in the 1970s and 1980s, and to a much lesser extent in Africa. However, the living standards for these countries remain well below — in some cases, drastically below — the living standards for the OECD countries. This disparity remains even though many of the technologies used in OECD countries are generally available and could be employed in the developing world. The problem is that developing countries often do not know about the technologies and, even when they do, have not succeeded in using them. The transfer process has not led to the full absorption of technology, techniques, and practice that enhance the ability of a receiving economy to meet the needs of its consumers. Over the longer term, useful transfer requires development of an indigenous capacity for technological adaptation, replication, and innovation by the receiving country. Thus, technology transfer covers a host of activities, commercial and other, involving the international flow of technical research, knowledge, training, studies, processes, and equipment. These activities cut a wide swathe through foreign trade, international economic assistance, and global environmental protection.

In the past, the technology transfer process has been so poorly understood that well-intentioned efforts to install high-technology processes and equipment in poor nations have often resulted in expensive failure, and sometimes in tragedy, as in the case of Bhopal. The primary reason is that "technology" involves both "hard" technology, in the form of plant, machinery, and equipment, and "soft" technology, in the form of training, know-how, and more efficient means of organizing the existing factors of production. Unfortunately, technology transfer is often mistakenly identified solely with the transfer of hard technology. This narrow definition leads to the supposition that economies with a high rate of investment, defined as total capital formation as a proportion of total GDP, will enjoy a more rapid state of productivity growth, since the work force will be operating machinery that is newer and incorporates more recent technology than those of competing economies with lower rates of investment. But this supposition neglects the importance of the role of training and education in upgrading the skill of the work force. In fact, hard technology cannot be successfully absorbed and developed unless complementary soft technologies and the supporting infrastructure are in place. One of the major constraints on successful technological development in developing countries has been the tendency of hard technology to run ahead of the training, institutional capacity, and infrastructure support necessary to sustain the hard technology.

Recognizing the dual components of the process, the International Environmental Technology Transfer Board, established in 1989 by the Administrator of the U.S. Environmental Protection Agency, has identified conditions that seem essential for the successful transfer of technology [18]. These conditions apply generally, but are particularly applicable to transfer of greenhouse gas-limiting technologies, which often require wide acceptance in the receiving country to succeed. These conditions include:

- Local demand. No successful technology transfer can take place unless there is local demand for the technology. This requires the recognition of an existing local deficiency and the potential for overcoming that deficiency through a particular type of process or equipment.

- Availability of information. Local entities must not only recognize the need for a change in technology, but must also know that appropriate technology exists. Thus, accessible information plays a key role in successfully transferring technology.

- Supporting infrastructure. The success of technology transfer depends on the infrastructure for its development. The infrastructure may lie in transportation, communication, or education. This infrastructure must be available to train the operators and maintenance personnel. Development of local manufacturing capabilities is sometimes required for successful transfer.

- Economic viability of the transfer. Overall development will not take place unless the technology transfer strengthens the local economy with at most minor governmental assistance in the form of tax benefits, subsidies, etc.

- Availability of capital. Most technology transfer depends on significant initial capital investment, which requires the availability of financing of the early investment.

- Appropriateness of the technology. In many cases the technology transferred does not meet the underlying need that led to the initiation of the transfer.

Thus, successful technology transfer depends on the framework in which the technology is to be applied, as well as on the technology itself. Donors and recipients must often work together to create the necessary infrastructure and overcome institutional constraints. The initial transfer depends on adequate training programs, while the long-term success of the transfer requires an ongoing maintenance capability, including spare parts. The transfer must make good economic sense. There should be adequate financial incentives and correct price signals. Financing cannot rely on continuing foreign assistance, because, in that case, the project will not generate the foreign currency earnings essential for continued economic development. Nor can it depend on indefinite government subsidy. Beyond this, project financing should not put such a debt burden on the developing country as to inhibit its further economic growth.

The following sections provide examples of successful and unsuccessful transfer of technologies with the potential for reducing greenhouse gas emissions. Since better technologies and processes increase efficiency, their successful absorption by a recipient nation will almost always lead to lowering emissions of carbon dioxide and other greenhouse gases. Each case illustrates one particular condition outlined above, although many of them in fact pertain to several of these conditions.

4. Requirement for Local Demand

Without local understanding of the need for an improvement on existing methods and demand for the installation of improved technology, it is highly unlikely that the transfer of any technology will be successful. Because these prerequisites were in place, the introduction of electronic load controllers for small hydro projects in Peru exemplifies a successful transfer of new technology [19].

Hydroelectric projects can provide for community electricity, particularly in mountainous areas, which tend to be inaccessible and have high fuel oil costs. Typically, the hydroelectric power plants consist of a water-driven turbine connected to a generator, with electricity supplied using a powerhouse-control system. Conventional systems are complicated, since the hydro plant must be able to accommodate variable demand while at the same time maintaining a constant frequency. Traditionally, a mechanical governor adjusted the flow of water through the turbine by opening and closing valves to match the turbine speed to the demand of the moment. The mechanical character of these devices required very careful maintenance, as the mechanical linkages make for a complex apparatus.

In the early 1970s, an English inventor developed an electronic device to control electricity load to suit the power available at the turbine. This is achieved by diverting any excess power over and above that demanded into a balance load — for example, heating water. The electronic load controller monitors the frequency of the supply from the generator and diverts the load to maintain balance. The electronic features simplify the turbine design significantly. Since the mechanical features are minimized, the electronic load controller is also far easier to maintain.

A small private company, G.P. Electronics of the United Kingdom, developed a commercial electronic load balancer for hydroelectric plants. The Intermediate Technology Development Group (ITDG), a private not-for-profit United Kingdom entity active in Peru at the time, learned of community requirements for small hydro power. ITDG imported a complete demonstration unit, including turbine, generator, and electronic load controller, and installed it in Cuzco, Peru. A small, family-run company, Hidro Power Fuerza Electrica, saw the demonstration system and approached the ITDG to see whether it could manufacture the electronic load controller locally. Hidro Power Fuerza Electrica and ITDG worked together to test and assemble an electronic load controller in the local company's workshop.

A privately funded small hydro plant on a coffee estate was the first to use the electronic load controller, with all supplies provided by G.P. Electronics and assembled by Hidro Power Fuerza Electrica in Peru. Following this successful demonstration, an electronic load controller was then used to upgrade an existing, but almost defunct, community hydro project. Subsequently, five more sets of the principal parts for the electronic load controller have been supplied to Hidro Power Fuerza Electrica, and the demand is growing. The industry has not yet attained a critical mass in Peru, but the local capability is building up. Since then, a similar experience has followed the introduction of the electronic load controller in Nepal.

The case of the electronic load controller for small hydroelectric projects shows the importance of local demand to spur development. In this case, a very high-technology item could be incorporated into a traditional technology, hydro power — a renewable resource with potential for reducing greenhouse gas emissions. The demonstration project illustrated the technology's value and convinced local users of its applicability. The local capabilities to manufacture and maintain the technology grew with time.

The example also illustrates the fortuitous nature of the whole arrangement. ITDG was on the ground and a small company wanted to manufacture the equipment. Generally, however, there are no current arrangements that would foster the kind of interactions needed to meet local needs and make such technology transfer routine. Indeed, many transfers of technology appear to have succeeded because of a propitious convergence of people and institutions.

By contrast, the attempt by the government of the Philippines to introduce charcoal-fired gasifiers for rural irrigation systems illustrates the failure that results from the absence of local demand [20]. The government had attempted to increase agricultural productivity by installing irrigation systems driven by electrical pumps on rural farms, but had never convinced most of the farmers that irrigated farming would benefit them. The farmers viewed the irrigation systems primarily as an insurance policy against inadequate rainfall; as a result, the systems were used irregularly and many fell into disrepair. Following a fuel price increase in 1980, those farmers who did use the irrigation systems pressured the government to find an alternative energy system to power them. In 1981, with the help of USAID, the Philippine government embarked on an ambitious program, through the Farm Systems Development Corporation (FSDC), to retrofit 1,150 irrigation systems with charcoal-fired gasifiers. FSDC in turn set up a subsidiary company to manufacture the gasifiers, which had been developed and used in a number of other countries. The government reasoned that with lower-cost energy, the irrigation system would be more widely used and agricultural productivity would increase.

The systems installed by FSDC were unable to fulfill the minimal performance requirements in several of the irrigation projects, but the company decided to waive the requirements in order to meet the government's program for installation. The farmers relied on FSDC operating personnel to maintain and repair the installed gasifiers. The operators did not understand the technology and were not properly trained to keep the gasifiers working properly. In addition, the operators lacked financial incentives: they were paid a fixed salary, regardless of the system's operational performance. FSDC, with limited financial and manpower resources, could not supply spare parts or undertake system repair. As a consequence, the farmers did not service the debt incurred from FSDC to install the systems. The low repayment rate affected FSDC's ability to support the program, further undermining its effectiveness. In 1985, FSDC's manufacturing subsidiary stopped production of spare parts and new systems in the face of mounting cash flow problems. By 1987, only 3 of the 248 gasifiers originally installed were still in use, although a further 16 percent were operational but unused.

The program failed not because of any deficiencies in the technology, but because the demand was not there. The farmers had not requested the gasifiers; few of them had used even the old irrigation systems. Those who did use the electrical pumps were concerned about the government's increase in fuel prices, but otherwise were perfectly satisfied with existing arrangements. As a result, even though the farmers could have benefited financially from use of the gasifier technology, they did not. There were no financial incentives to use and maintain the technology, and in any case the farmers were not provided with the training or the spare parts needed to operate and maintain the new technology. The government's predetermined targets were unrealistic, and there was no attempt to proceed step-by-step, using demonstration as a way of encouraging further acceptance of the new technology. The hard technology was available, but the soft technology, in the form of adequate training, supplies, and spare parts, was not.

5. Requirements for Information on Available Technologies

A genuine barrier to technology transfer is the lack of easily accessible information about the range of technologies available and the expertise to apply them in the particular environment of a developing country. The acquisition of information entails costs that may in themselves discourage users of older technology from becoming acquainted with new options. Further, newer technologies carry further costs in the form of training and education necessary to absorb, maintain, and develop them.

Some of these difficulties could be overcome if the industrialized countries provided information about available technologies and their environmental advantages, as well as cost of implementing them. Developing country institutions and business leaders can play a key role in making companies and entrepreneurs aware of the channels and sources of information available to them. Private as well as government -funded international organizations can contribute significantly by coordinating interchanges of relevant information. Certain mechanisms already aid in making information accessible; for instance, the International Chamber of Commerce, through its International Environment Bureau in Geneva, provides such assistance to industries on request. In those cases where an organized effort has been made, companies in developing countries can tap into information that companies in the industrialized nations willingly provide. Wider dissemination of information could stimulate more rapid transfer and diffusion of technology.

An example of how effective information dissemination led to the transfer of useful technology involved distilleries in India [19], which were able to make use of an advanced process to decrease biomass waste and generate some of their own fuel. The residues from processing sugar cane to distill alcohol yield a wastewater stream which, like that in breweries, has a high organic content. If this stream is run into an anaerobic digestion chamber, methane can be produced and used as a fuel to distill further sugar cane residues, thereby lowering the overall fuel cost to the distilleries and reducing net greenhouse gas emissions by using a renewable resource.

The International Environment Bureau had alerted the Secretary General of each of the national committees of the International Chamber of Commerce to make them aware of the services it provided. The Secretary General in India saw the potential value of the distillation scheme, and drew this to the attention of the President of the Indian National Committee. The President, in turn, wrote to all local chapters of the Chamber of Commerce in the country, urging them to take advantage of the Bureau's services. As a result, several small distilleries in India, which knew of a potential gap that technology might fill, independently approached the International Environment Bureau for information on how to generate methane from the waste from sugar cane processing. The Bureau supplied the distillers with details of eight different systems for the use of anaerobic chamber digestion, including processes from the Netherlands and Sweden. There was sufficient information for the distilleries to introduce the technology for themselves. In some cases, companies that produced the digestion chamber simply sold the technology at affordable prices.

Firms in industrialized countries may also provide information directly to enterprises in developing countries at little or no cost. For example, a company in a small Persian Gulf state did not know how to deal with the trace metals left in the waste water from electroplating designs onto aluminum cans. Because of the general high cost of water, this imposed an economic burden on the company. Through the United Nations network, the firm approached the International Environment Bureau. The U.S. company Alcoa, an International Environment Bureau member, had faced the same problem, and had designed and built a system to handle the trace metals. Alcoa saw no competitive interest in the area, and sent the full blueprint, plans, and cost estimates to allow the Middle Eastern company to duplicate its system. Fortunately, the company had the engineering talent required to install the process. It should therefore be noted that, while it may be relatively rare for a company not to have a commercial interest in a particular area, these instances do arise.

The Alcoa case, like the case of the Indian distillers, demonstrates that international organizations can serve as effective clearinghouses for information. But currently there is no central overall clearinghouse that identifies energy-efficient technologies to which developing countries can turn. Following the issuance of the report prepared by the International Environmental Technology Transfer Board, the U.S. Environmental Protection Agency has taken steps towards constructing a database containing information on U.S. technologies that have beneficial environmental consequences. There is no similar move afoot at the international level. Thus, acquiring information continues to be largely a hit-or-miss proposition.

6. Availability of Adequate Local Infrastructure

The success of technology transfer projects depends critically on the availability of the supporting infrastructure. Often this infrastructure takes the form of actual hard technologies, such as adequate communications or transportation systems. But it can also take the form of soft technology, in the sense of having an adequate technical work force to implement and maintain that technology. A case in point is the development of the Indonesian electricity sector [19].

Since the early 1970s, Ewbank Preece, a United Kingdom engineering consulting firm, has provided advice and project management services to the Indonesian electrical utility, Perusahaan Umum Listrik Negara (PLN), on the extension of its electrical supply network in West Java. The program has been financially supported by the World Bank. Ewbank Preece's initial involvement included preparing the specifications and evaluating bids for 27 new substations, 11 extensions to the substations, and associated cables, lines, and specialized services. Contracts for the equipment were placed in 1978, and the project was largely completed by 1984. In 1986, further transmission and substation projects were designed for use in Jakarta and West Java, involving 30 new and existing 150 kv and 70 kv substations, with associated 150 kv and 70 kv overhead transmission lines.

The project introduced the latest technological standards in power generation and transmission, in particular gas-insulated substation technology, to Indonesia. The key to its success was that Ewbank Preece had for years worked closely with PLN engineers and managers, with the active participation of the local universities, resulting in the creation of a talented technical staff. The program structure enabled Indonesian engineers to acquire the skills to maintain, operate, and develop the system. The strong manpower base in engineering allowed the best available hard technology to be absorbed smoothly. As a result, the electricity network is technically efficient, and the network is growing. These technical efficiencies will lead to lower greenhouse emissions per unit of energy delivered, in addition to securing economic benefits for the PLN.

There are many cases of unsuccessful attempts at technology transfer when the local infrastructure did not provide an adequate soft technology base. For example, during the 1980s the People's Republic of China imported generating plants from a number of western firms, including General Electric and Westinghouse, in order to augment their generating capacity [19]. In determining the level of technology to export, the western firms examined the existing hardware in Shanghai and Harbin (the destination cities), including buildings, equipment, and machine tools, to ensure that the new plants would be technically compatible. But the initial examination failed to analyze the social and environmental factors, including work practices and management skills, that would determine whether the technology would be successfully absorbed and efficiently used.

The project has achieved mixed results. A 300 MW unit at Shanghai has been operated successfully, but there have been major problems with the 600 MW plant at Harbin. The principal reasons for the problems at Harbin has been the lack of management and work force training to operate the plant, although the difference in scale between the plants contributed to the difficulties. Because the plant, is far larger than existing plants, it stresses the indigenous capability in technical management and operation. The lack of technical skills has led to difficulties in maintaining plant equipment. A further factor that hindered the successful completion of the project was the lack of financial motivation: workers were paid a standard rate, with no bonus element related to productivity. Thus, the lack of adequate management and technological skills in one city led to failure to absorb the latest in hard technology, even though a similar technology has succeeded in a different part of the country.

Universities can play a key role in the successful transfer of technology, as the development of the Indonesian power grid illustrates. A further example is provided by a project in which a group of engineers from McGill University worked with their counterparts in Khon Kaen University, located in an impoverished region of Thailand some 400 km northeast of Bangkok [21] to develop an extensive system for the use of renewable resources for energy.

The project started when a group from Khon Kaen University, sponsored by the Canadian International Development Agency, visited McGill in 1985 and described problems common in northeast Thailand. Historically, wood has been used as the fuel for cooking and small industry. As a result, the region was rapidly using up its forest resources, soil fertility was decreasing, and widespread poverty was driving young people to migrate to Bangkok. The combined McGill-Khon Kaen group put forth a series of proposals for better use of existing energy resources. The team developed a simple solar steamer for domestic rice cooking, rice husk and charcoal gasifiers, improved wood stoves, and solar-based grain dryers. As the technologies evolved, public interest was generated by workshops, videos, brochures, open houses, and a request by a princess of the Thai royal family to have a meal cooked on a solar stove.

Local industry has shown interest in manufacturing some of the equipment, and the World Bank is moving to fund further development and extension of the work through a continuing agreement. Further exchanges are planned for McGill and Khon Kaen University faculty. In this case the early success of the program depended heavily on the close involvement of the local university, both in devising the technology and in providing the technical training required for its adoption.

7. Economic Viability of the Project

For any transfer to a private enterprise to succeed, the commercial entity in the developing country must be able to turn a profit. This will depend, to varying degrees, on the types of financial arrangements made to obtain the technology. The buyer must act upon accurate information about the availability and price of the technology, but in the end, the gain from the technology must exceed the purchase price plus additional costs of training and providing the infrastructure.

Different financial arrangements suit different circumstances. A company can sell or license patented technology to the customer. Joint venture agreements and partnership arrangements between companies, or between government agencies and commercial enterprises, provide an alternative mechanism. In multinational corporations, one national division can transfer the technology to another. Still another mechanism is through contracts for buying, transporting, and setting up plant and equipment, including "turnkey" arrangements, whereby the contractor hands over to the client a fully commissioned and operational plant for a fixed price or some other financial arrangement. Such arrangements, however superficially attractive, have a high rate of failure because of inadequate provisions for training and maintenance. Buy-back agreements can also be negotiated, where the contractor is paid from a percentage of the sale revenues or profits generated by the process. The customer can also enter into contracts for obtaining technical assistance, training programs, and management help from service companies or from manufacturers. In some cases, a hybrid of these mechanisms might be arranged through a development assistance corporation, either private or governmental, which puts together a package covering the right to patented technologies, technical assistance to apply them commercially, and financing to meet the capital cost of their implementation.

The multinational chemical company ICI prefers conventional technology transfer through licensing arrangements in sharing its low-pressure process for manufacturing methanol [19]. The history of this process provides an interesting insight into the mechanisms of technology transfer, as well illustrating the importance of the economic viability of the project.

About 25 years ago, ICI developed a low-pressure process for the manufacture of methanol. This process is approximately 15 percent more energy efficient than the old high-pressure process, because it relies on a specially formulated catalyst that is effective at lower temperatures and pressures than the catalyst that had previously been used. Furthermore, there is a saving on equipment, since the process operates at less demanding conditions. ICI has licensed the technology to about two dozen plants in OECD countries, and 15 plants in developing countries, including Brazil, India, and China.

Once ICI had established the commercial viability of the process in England, it began to enter into long-term licensing agreements with a small number of international engineering contractors, who then had the right to offer the technology to foreign customers wishing to manufacture methanol. ICI provides the contractors with the necessary process design information and computer programs to enable them to tailor the design to individual customers.

The ICI-provided packages allow all activities from feasibility studies through design, procurement, and construction, to commissioning of the plant. An attempt is made to meet local requirements. For example, ICI redesigned the reactor for one customer in Brazil to maximize the participation of local engineers, even though this led to a higher cost to the customer.

ICI provides technical advice, as well as staff training, throughout the installation and even after the commissioning of the plants. ICI representatives visit the plants on a regular basis for on-site discussion of performance. The initial license fee for each new plant includes these support services. ICI maintains an interest in the operation of the plant, since it is a source — although not the only source — for the catalyst. Local manufacture of the equipment is possible, although the reactor and compressor require a reasonably advanced manufacturing technology.

Today, some two dozen plants around the world are manufacturing methanol using ICI's low-pressure process. Most are owned by local companies. In all cases, the initiative for the projects was locally generated by companies who saw the market opportunity. The projects were economically viable in large part because of the lower fuel cost associated with the process and the lower initial capital equipment cost and maintenance. Developing nations often sell the methanol produced in bulk to industrialized countries, thereby generating hard currency.

The methanol example illustrates technology transfer by a large multinational corporation whose international reach enabled it to contact potential customers throughout the world. Information on the process and its price were readily available. The lower cost of the process and its equipment, plus the international demand for methanol, provide the basis for a profitable enterprise.

By contrast, the Brazilian government's effort to spur reliance on ethanol-powered vehicles [22] illustrates the futility of distorting market mechanisms in order to promote use of an inappropriate technology, regardless of its environmental benefits. In the early 1970s, following the oil price rise, the Brazilian government encouraged the development of vehicles fueled with the alcohol produced from sugar cane. The alcohol-fueled vehicles were advocated, in part, because they were thought to be environmentally less polluting; the policy was also prompted by the declining international sugar market, which adversely affected the Brazilian sugar industry. In addition, the use of domestically produced ethanol would bring down Brazil's growing trade imbalance by reducing oil imports.

Although ethanol vehicles were less efficient than gasoline-powered vehicles, the growth of the ethanol car market was stimulated by a government commitment to hold the price of ethanol to 65 percent or less of the price of gasoline. The Brazilian government maintained the price differential both by subsidies for ethanol and taxes on gasoline.

The initial response to the introduction of ethanol-powered vehicles was positive. By the end of the 1980s, some 4.5 million vehicles — a third of Brazil's total vehicle fleet — ran exclusively on ethanol, and the remaining two-thirds ran on a mixture of ethanol and gasoline. Then, advances in gasoline-powered vehicles, resulting in much higher efficiency, together with several years of lower crude oil prices, raised the relative cost of ethanol: by the end of the 1980s, ethanol was approximately three times as expensive as gasoline. This increasing cost differential placed a growing burden on the Brazilian government: between 1975 and 1989, Brazil spent the equivalent of U.S. $6 billion subsidizing ethanol. In an effort to reduce the cost of the subsidy, the government held down the domestic price of sugar, which encouraged farmers to switch to other crops, or attempt to sell their sugar on the export market. These moves caused shortages in the supply of ethanol. Finally, in 1989, the government allowed the price of ethanol to rise to 75 percent of that of gasoline. The reduction in the subsidy diminished the attractiveness of ethanol to car owners, and in 1990 the production of ethanol vehicles virtually halted in Brazil.

The ready availability of technology for ethanol-powered vehicles was a necessary, but insufficient, condition for successful introduction of the new technology. In order for a technology to be accepted, it must offer an economic advantage, or at least no significant disadvantage to the buyer. Stimulating an economic advantage by taxes and subsidies can be successful, but not if the underlying price differential is too wide. If the price differential is great, then, over the longer term, the cost of maintaining the subsidy imposes an intolerable burden on government, and consequently lowers country-wide economic productivity.

8. Availability of Financing

Given that new technology often requires major investments in equipment and facilities, successful technology transfer requires that up-front financing be available. In optimal circumstances, local capital would suffice, but in many cases, the financing must be drawn from assistance agencies. Even when the capital costs are not great, the supporting soft technologies may demand extra financing.

A case in point is the introduction of fuel-efficient cooking stoves in Sri Lanka [19]. These stoves met a perceived local need, provided immediate economic benefits, and could be designed for local manufacture. The major problem was financing, both in the early design stages and later in the dissemination of information.

The residential sector in Sri Lanka is a significant consumer of energy, principally for cooking. Traditionally, stoves were composed of three stones or bricks in a horseshoe formation, covered in mud to form a wood-burning cooking stove that could accommodate only one pot at a time. In the early 1980s, Sarvodaya, a Sri Lankan non-governmental organization with special interest in improving living circumstances, recognized the need for more efficient stoves and pioneered the design of a two-pot mud stove. A U.S. volunteer working for Sarvodaya at the time approached the ITDG, the non-profit UK group, which was also working at the time on cooking stove designs in Indonesia, Thailand, and India. Some ashrams in India had very successfully introduced ceramic linings in their stoves. ITDG took up the idea of using ceramics, and developed Sarvodaya's two-pot mud stove into a ceramic version in which three sections — two chambers and a linking tunnel — were made separately and then the three pieces were assembled using mud. The design effort was funded by the British foreign assistance agency, the Overseas Development Agency (ODA). This early funding maintained and built the enthusiasm for the program; without it, the project would have collapsed.

At about this time, a Sri Lankan working for the World Bank was sent for a tour of duty assisting the Sri Lankan Ministry of Power and Lighting. (Officially, he was the chief energy advisor to the President of Sri Lanka.) He was impressed by Sarvodaya's new stove, and wrote an influential paper to the government, which, in turn, led the Ministry of Power and Lighting to ask the Ceylon Electricity Board to promote a rural stoves program. The program used money from the government of The Netherlands to subsidize both the purchase of the ceramic components from local potters and the distribution to the rural households. This aid from The Netherlands was essential in demonstrating the viability of the technology. The householders, however, paid for the installation.

ITDG wished to avoid a growing dependence on subsidies, and began to look for a more marketable system that could take advantage of the local commercial network. They evolved the stove into a one-piece ceramic design that could still be made by local potters, but could be sold off the shelf without local installation. In urban areas, where there is a cash economy and fuel wood is purchased rather than collected, the new stove offered immediate economic benefits to householders. The ODA again provided essential help by funding a promotion campaign, including posters, advertisements, and articles in newspapers and magazines, commercials on television, and high-profile visitors' involvement, which led to news coverage. The advertising efforts were key to widespread interest in the stoves in urban areas. The success of the stoves demonstrated the value of the commercial approach in an urban area. The remaining problem is introducing the stove in rural areas, where cash transactions are less common and where wood, which is collected rather than purchased, is not perceived as valuable.

The up-front financing by the Dutch government was essential to the success of the project, as was ODA's funding of the design and of the campaign to disseminate knowledge about the stove. Several other features contributed to the longer-term success of this technology transfer: there was a local recognition of the need, and the technology evolved essentially within the region of interest. This example also illustrates that it is possible to transfer technology among developing countries, since earlier work in Thailand and India contributed to the eventual design adopted by Sri Lanka. But as in many cases of successful transfer, the process was largely fortuitous, depending on having the right people in place at the appropriate time.

9. Availability of Technology

A clear example where developing countries have easy access to the latest in industrialized technology is the case of automobiles in Southeast Asia. The effectiveness and environmental efficiency of these automobiles, however, depend not on the quality of the technology itself, but rather upon the setting in which the technology is used. This case also illustrates the importance of the administrative infrastructure to enforce any regulatory scheme.

In a comprehensive analysis of the use of vehicle technologies in six Southeast Asian countries [23], OECD pointed out that, although most of the major cities in the region have integrated mass transportation systems, private automobile use has risen dramatically with the increasing number of residents with middle incomes. Therefore, the importance of technology to reduce carbon dioxide emissions and other pollutants from motor vehicles has risen sharply. OECD also concluded that patent restrictions have not limited the transfer of automotive technology; all countries have been able to gain access to the same models.

The study found that Hong Kong, Singapore, and Taiwan, which are the most advanced countries in the region in terms of income per capita, have vehicle fleets that to a great extent incorporate up-to-date carbon dioxide-efficient technology. That is, the vehicles used in these countries have a high kilometers-per-liter rating. Thailand and Malaysia have less efficient fleets, and a lower overall technical capacity, while the Philippines, the poorest country in the group, has the least advanced vehicle fleet with the greatest contribution to atmospheric carbon dioxide per motor vehicle kilometer.

Several reasons account for the disparities among the Southeast Asian countries. The wealthier countries have a higher rate of investment in new vehicles that incorporate the most advanced technologies, and thus have built up efficient fleets. The richer countries also have the best infrastructure in the form of well-maintained roads, which help to maximize the fuel efficiency of vehicles. Unleaded and high-octane gasolines are readily available, minimizing the carbon intensity of the fuels. In countries such as Hong Kong, financial incentives in the form of lower taxes on lead-free gasoline encourage the use of that gasoline in preference to leaded gasoline. A very important element is that, in the more advanced countries, high-quality maintenance services were generally available, so that the vehicles kept their efficiency during their lifetime. The wealthier countries also had the capacity to monitor and enforce regulations.

10. Lessons for UNCED

As the above examples indicate, many technologies can play important roles in limiting the emissions of greenhouse gases. Discussions usually center around those processes that involve the conversion of fossil fuel to other forms of energy, such as power plants for electrical utilities. In fact, advanced technologies can assist across all sectors of the economy. In looking at these opportunities for technology transfer, certain generalizations arise that may contribute to a meaningful treatment of the issue within the UNCED framework. The international attention that the conference will attract give it significant influence in focusing attention on the real benefits that would accrue to all nations through effective technology transfer. While UNCED itself would only be a beginning, longer-term results would then be achieved through enduring institutional actions [24].

10.1 Encourage Waste Reduction

So far, the developing countries have tended to follow the developed world in emphasis on end-of-pipe treatment of pollutants. UNCED should emphasize the benefits that would result if developing nations leapfrog this approach and institute waste reduction technologies directly. For example, increasing the efficiency of coal-fired power plants reduces the amount of sulfur that must be disposed of if sulfur controls are required to maintain air quality standards. In the semiconductor manufacturing process, the recovery of key elements reduces the energy required for mining and refining. UNCED should demonstrate that the goals of waste reduction and energy efficiency reinforce each other and together make good economic, as well as environmental, sense.

10.2 Identify Priority Countries

In examining potential solutions to reducing the emissions of greenhouse gases, it is important to recognize that no single view can encompass all nations' problems. However, UNCED may be able to obtain a consensus on those countries in which action will have the greatest global impact, as well as those that are most vulnerable to climate change. The vulnerability might rest with sea-level changes, changes in agricultural productivity, disruption of fishing, added disease burdens, and destruction of tourism. Once these nations have been identified, a permanent organization such as UNEP could undertake studies of the individual countries that would identify priority economic sectors, taking into account the local circumstances and industry structure. Based on these studies, UNEP should assess the gains that might be achieved through limiting greenhouse emissions and then identify the remedies and technologies needed, factoring in the incremental cost associated with them. The international assistance agencies would have to play key parts in all these activities.

10.3 Emphasize the Importance of Soft Technologies

In addition to stimulating research on the needs of individual countries, strong statements at UNCED could help to direct research toward critical aspects of the technology transfer process. As has been illustrated in most of the cases described above, soft technologies, including training and education programs and enhanced maintenance and operating efficiency, can make the difference between success and failure of advanced technology. UNCED should focus attention on initiatives that would improve the mechanisms for transferring technology and for developing the associated infrastructure in the priority countries. The conference should also encourage a greater flow of bilateral and multilateral aid funds into soft technologies and into programs for enhanced maintenance and efficiencies of existing hard technologies. Part of this effort might include developing cost-benefit methodologies to take into account the global impact of greenhouse gas emissions and to use these methodologies in project appraisal. In some cases organizations from industrialized countries or multilateral agencies may provide training to the indigenous staff. In any case, educational and training activities pose a relatively lower cost to the developing nations than investment in capital equipment.

10.4 Examine Costing and Financing Methods

A commonly perceived barrier to technology transfer, and one that poses a genuine difficulty, is cost. As the examples above have illustrated, technology transfer will fail if it does not make economic sense. The Brazilian experience with ethanol shows the distortions that occur when a high-cost technology is forced into the marketplace through government intervention. In many cases funding assistance is required in order to meet capital investments, but both the projects themselves and the form of that assistance must be evaluated very carefully. International and national funding agencies can make an especially critical difference in this area. UNCED can strongly encourage them to focus their attention on such activities, which directly address the core of the conference's dual mission.

A very sensitive subject, but one that must be taken up within the UNCED context, is that of concessional finance. The use of interest rate subsidies for projects in developing countries that incorporate environmentally sound technologies would appear to be an effective way to promote these technologies. However, concessional financing is anathema to much of the developing world, and the whole issue must be approached with great care.

For the most part, the implementation of new energy-efficient technologies reduces the overall cost of operation, as is the case of ICI's methanol manufacturing process; in some cases, the choice of environmentally sound technologies poses an additional early cost. Over the long term, the benefits derived from using these technologies are seen in lowered costs for health care and for other difficult-to-define stresses. Although these additional costs are hard to estimate, they cannot be forgotten in the overall equation.

UNCED should urge all nations to examine the impact of the different economic instruments that could be used in their quest to reduce the growth in greenhouse gas emissions, as well as the effectiveness of different command and control methods for reducing greenhouse gas emissions. Such research should focus especially strongly on identifying policy distortions that currently favor older, less energy-efficient technologies. The conference should also direct attention to the use of fiscal instruments, such as carbon taxes, to reduce greenhouse gas emissions in developing countries, an approach that requires judgments on the price elasticity and demand for energy. The effectiveness of tax mechanisms and of regulations depends greatly on the administrative infrastructure. Any follow-up research should identify the effects of institutional capacity, penalties for non-compliance, and efficiency of enforcement on any mechanism chosen.

10.5 Focus Attention on Genuine Problems

UNCED could play a significant role in increasing awareness of the distinction between real and perceived barriers to technology transfer, and then focusing initiatives on solving the actual problems. As noted in the introduction, the barrier most often cited is access, yet in fact most modern technologies can be obtained relatively easily. The technologies that the industrialized countries hold closely generally have a high scientific content, for instance, those associated with biotechnology and certain electronic capabilities. The technologies that limit greenhouse gas emissions are relatively less scientifically intense, and most are in the public domain. Energy-efficient automotive, industrial, and residential technologies — those most likely to contribute to lowering emissions — are readily available. UNCED would be an effective forum for heightening world awareness of the actual availability of suitable, environmentally sound technology.

A genuine limitation results from the lack of an adequate, easily accessible information base. The local demand for technology is its best driver; however, demand cannot develop without information that alternatives exist to current technologies. Despite the efforts of such organizations as the International Environment Bureau of the International Chamber of Commerce, the dissemination of information has remained largely haphazard. This deficiency can easily be remedied, and should be given high priority by both national assistance programs and international agencies, such as the World Bank.

UNCED could make a lasting contribution by encouraging the establishment of a single clearinghouse for information on technologies that reduce greenhouse gas emissions. The clearinghouse could serve as the foundation for an international information network for the dissemination of information on the technologies available, their sources, and broad terms on which they may be acquired. Clearinghouse staff could also conduct research and advise both developed and developing countries on the relevance of different technologies in addressing global warming problems. The clearinghouse should include information on patented or otherwise protected technologies, indicating the terms upon which they might be available to prospective buyers. This information, when aggregated with an assessment of the potential contribution of each technology to reducing greenhouse gas emissions, will no doubt support the view that intellectual property rights are not, in practice, a significant barrier to the transfer of environmentally sound technology.

One option for creating such a clearinghouse might be to place it within the United Nations structure, perhaps using the existing mechanism of UNEP through its Industry and Environment Office, which is located in Paris. But in order to carry out this mission, UNEP's modest budget would have to be increased significantly. Although government agencies and private corporations may create databases of their own products and services, such a step would help to ensure impartiality, and should encourage all nations to avail themselves of the clearinghouse's services. An alternative to UNEP would be the United Nations Development Program. This agency is particularly well suited to facilitating information transfer because of its network of offices in most of the developing countries.

UNCED itself will last for only two weeks, and must deal with a huge and complex agenda. Yet the preparatory work will lay the conceptual framework for activities that will prove crucial to the survival of nations throughout the world. By considering issues related to technology transfer, and creating durable institutions to address the problems and opportunities that such transfer presents, UNCED can leave a lasting legacy in its quest to promote sustainable development in all countries.

Appendix: Estimates of Past Carbon Dioxide Emissions

Burning fossil fuels — coals, oil, and natural gas — results in the production of carbon dioxide (CO2), a major greenhouse gas. The manufacture of cement also releases carbon dioxide to the atmosphere in the calcining of limestone, though the amounts of carbon dioxide generated in this way are only a small fraction of those derived from fuel burning. A further major source of atmospheric carbon dioxide is deforestation, in which carbon stored in trees is released by burning or through the decay of dead trees. The relative proportion of carbon dioxide released by fossil fuel burning and deforestation is uncertain, principally because of poor estimates of carbon fixed in new growth forest. On net, it appears that the combustion of fossil fuels is by far the dominant source of the observed increase of atmospheric carbon dioxide concentrations [1,2].

Keeling [25] first established a systematic methods of estimating the release of carbon dioxide from the burning of fossil fuels using energy statistics maintained by the United Nations Department of International Economic and Social Affairs. Since then, a group at the Oak Ridge National Laboratory has undertaken the task of maintaining a current inventory of carbon dioxide emissions by country [26]. Table A presents a summary of the latest compilation of carbon dioxide emissions [27], using the standard convention of listing emissions in terms of tonnes of carbon rather than of carbon dioxide.

Global emissions of carbon dioxide totaled 1.6 billion tonnes of carbon in 1950, increasing to 5.5 billion tonnes in 1986. Over this period, the most rapid rise has been in the developing countries. Emissions from the industrialized world rose rapidly in the 1950-to-1973 period, but leveled off or decreased in subsequent years. The sharp decline in rate of growth is well correlated with increases in oil prices in the early 1970s and subsequent emphasis in OECD countries on conservation and efficiency in energy use. The developing world, starting at a far lower base than the industrialized world, continued to increase total and per capita energy use after prices rose, with consequent increases in carbon dioxide emissions.

Table A illustrates that there are several groupings of countries in terms of per capita carbon emissions. The highest per capita emissions are found in oil-rich countries with small populations (e.g., Bahrain, Qatar). Among the G-7 countries, the United States has the highest per capita emission rate (5.0 tonnes) with Italy the lowest (1.7 tonnes). The per capita emission rates in former Eastern Bloc countries are all high, with the central command and control system of government paying little attention to energy efficiency. France's per capita and total emission rates have decreased sharply in the past two decades with the conversion of the electricity sector to nuclear power. In the poorest countries in the world, the per capita emission rates are not measured in tonnes, but rather in kilograms of carbon, a disparity that emphasizes the enormous potential contribution to greenhouse gases if these were to countries follow the industrialized world's energy-inefficient pattern of development.

In terms of total emissions, the data in Table A for 1986 shows that only two countries — the USA and the USSR — emit more than a billion tons of carbon per year. Together these two countries alone produce 40 percent of the carbon dioxide resulting from fossil fuel consumption. The emissions of seven other countries exceed 100 million tonnes per year; they are, in order, China, unified Germany, Japan, the United Kingdom, India, Poland, and Canada. These seven countries, together with the USA and USSR, contribute 70 percent of carbon dioxide emissions. Nine other countries have emission totals of 50 million tonnes of carbon or greater: France, Italy, South Africa, Mexico, Czechoslovakia, Australia, Romania, Brazil, and Spain. Together with the nine highest emitters, these additional nine account for 82 percent of carbon emissions. The four largest emitters among the developing world — China, India, Mexico, and Brazil — produce 15 percent of total carbon emissions, but the emissions in these countries are among those growing most rapidly. The G-7 nations are responsible for 40 percent of the emissions, with over half of that total (22 percent) due to the United States.