Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized

GLOBAL ENVIRONMENT FACILITY

The Outlook for Renewable Energy Technologies

Robert Williams • Stephen Karakezi • Jyoti Parikh • Chihiro Watanabe

Working Paper Number 14

GEF

The Outlook for Renewable Energy Technologies

Executive Summary
of
Two Reports on Renewable Energy
for Developing Countries

Prepared by the
Scientific and Technical Advisory Panel (STAP)
of the Global Environment Facility (GEF)

Working Paper
Number 14

GEF

Published 1998
Global Environment Facility

ISBN 1-884122-14-0

Contents

Preface

It is a pleasure to present *The Outlook for Renewable Energy Technologies.* This report is the executive summary of two major reports prepared by STAP in response to the request of the GEF Council that STAP review the outlook for renewable energy technologies (RETs).

One of the reports, *Outlook for Renewable Energy Technologies, Strategic Considerations Relating to the GEF Portfolio, and Priorities for Targeted Research,* is a detailed technical assessment of the prospects for a wide range of RETs, with strategic advice to the GEF relating to portfolio development for RETs, and STAP recommendations for targeted research relating to RETs.

The second major report, *International Industrial Collaboration for Accelerated Adoption of Environmentally Sound Energy Technologies in Developing Countries,* discusses international industrial collaboration as a promising instrument for capacity-building aimed at accelerating the adoption of RETs and other environmentally sound energy technologies in developing countries. Much of the analysis in this latter report is based on the major themes that emerged from a workshop convened by STAP in June 1996 in Amsterdam. The workshop is described in more detail in *The STAP Workshop on Stimulating Private-Sector Initiatives for Accelerating the Introduction of Renewable Energy Technologies into the Power Sectors of Developing Countries.*

All of these reports were prepared by the STAP Working Group on Climate and Energy under the chairmanship of Dr. Robert Williams:

Robert Williams (lead author)
Stephen Karekezi
Jyoti Parikh
Chihiro Watanabe

Pier Vellinga
Chairman of STAP

1 Introduction

At its October 1995 meeting the Council of the Global Environment Facility (GEF) asked the Scientific and Technical Advisory Panel (STAP) of the GEF to review for the Council the prospects for renewable energy technologies (RETs).

As part of its response to this request, STAP prepared a technical review of wind, biomass, photovoltaic, solar-thermal, geothermal, and ocean energy technologies, as well as energy systems issues (STAP, 1996a). This review draws heavily on the analysis of RETs presented in Chapter 19 ("Energy Supply Mitigation Options") of the *Second Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 1996). It includes recommendations for priorities for a RET portfolio of projects that the GEF might develop and for new roles for the GEF in supporting targeted research that would enhance the prospects for successfully implementing the GEF Operational Strategy relating to RETs.

In addition, STAP carried out an analysis of public policy issues relating to RETs implementation and capacity building in developing countries. A preliminary version of this RETs policy report identified the mobilization of private sector resources as key to accelerating a transition to an energy future in which RETs are widely adopted throughout the developing world. To understand better how policies might be formulated for so mobilizing private sector resources, STAP convened a workshop on stimulating private sector initiatives for accelerating the introduction of RETs into the power sectors of developing countries (STAP, 1996b). The workshop involved business representatives from both developing and industrialized countries interested in pursuing RET market opportunities in the power sectors of developing countries. STAP solicited participants' views as to the outlook for RETs and the institutional challenges that must be addressed to make widespread adoption of RETs feasible. The insights STAP gained at this workshop shaped to a considerable degree the final version of its report on public policy issues relating to RETs implementation and capacity building in developing countries (STAP, 1996c).

This report summarizes STAP findings of both the technical report on RETs (STAP, 1996a) and the RETs policy report (STAP, 1996c), focusing on strategic planning issues and recommended roles for the GEF in bringing about the widespread adoption of RETs in developing countries.

2 Highlights of Progress Related to Renewable Energy Technologies

Since the early 1980s, there has been considerable worldwide activity aimed at developing and commercializing renewable energy technologies (RETs).

2.1 Wind Power

Largely as a result of government incentives provided to stimulate its development, a global wind power industry was launched in the early 1980s. At the end of 1993, the global installed capacity of high-efficiency wind turbines was 3,100 MWe, about 1,700 MWe of which was in the Americas and about 1,200 MWe was in Europe. Over 600 MWe of wind-turbine capacity was added worldwide in 1994 (one-half in Germany and one-fifth in developing countries), while over 1,100 MWe of new capacity was added in 1995 [780 MWe in Europe (mostly in Germany) and 380 MWe in Asia (mostly in India)], bringing total worldwide installed capacity at the end of 1995 to about 4,800 MWe. Among developing countries, the pace of development has been especially strong in India, where a modern wind energy program was launched in 1989, and installed capacity has risen sharply to 650 MWe as of April 1996.

2.2 Biomass Power

In the United States, Scandinavia, and some other European and developing countries, biomass is used as fuel for steam turbine-based, combined-heat-and-power (CHP) generation in the forest-product and agricultural industries; in these activities the biomass used as fuel consists mainly of the residues of the primary products of these industries. There is also a growing trend to co-firing coal-fired power plants with supplemental biomass inputs. In developing countries, there is a large scope for efficiency improvements in the use of biomass for energy in industry and growing interest in introducing modern steam-turbine CHP technology (e.g., in the cane sugar industry). Moreover, if demonstration projects, such as the GEF-supported biomass-integrated gasifier/gas-turbine (BIG/GT) project in the Brazilian northeast, are successful, biomass might be able to compete in a wide range of stand-alone power applications, as well as CHP applications after the turn of the century, with plantation biomass as well as biomass residues used for fuel.

2.3 Photovoltaic Power

Worldwide sales of photovoltaic (PV) modules increased from 35 peak megawatts (35 MWp) in 1988 to about 90 MWp in 1996. Historically, most applications have been for a variety of consumer electronic products and other niche markets, but both stand-alone and grid-connected electric-power applications are becoming increasingly important applications of PV technology.

Photovoltaic technology is being successfully deployed in small-scale, stand-alone power applications remote from utility grids in many parts of the world. These rural-electric applications — largely for domestic lighting, refrigeration, and educational purposes — make it possible to provide electrical services to rural users while avoiding the economic inefficiencies associated with the alternative of bringing centralized power supplies to these customers, by extending distribution lines that would typically be grossly underutilized.

Present PV prices are still far too high for using PV in central-station power plants. This situation is changing rapidly, however, as advanced PV technologies such as thin-film devices approach commercial readiness for bulk power markets. One vendor won a contract in 1997 to build in Hawaii a 4 MWp power plant based on the use of amorphous silicon PV modules for an announced total plant installed cost of $2,000/kWe; by comparison, the previous least-costly electric utility grid-connected PV installation in the United States cost $7,800/kWe.

2.4 Solar Thermal-Electric Power

Between 1984 and 1991, nine parabolic trough solar thermal-electric power plants with a total installed capacity of 354 MWe were built in southern California. Although the company that built these plants was able to reduce the installed cost for its technology from $6,000/kWe to $3,000/kWe in this period, it went bankrupt in 1991 when government incentives for RETs were suddenly withdrawn. The plants are still operating reliably under new management. Today an improved version of this technology is being resurrected; projects planned in several developing countries could result in several hundred megawatts of new solar thermal-electric capacity by 2000.

3 Assessments of the Global Potential for RETs

Apart from emphasis on improving the efficiency of energy use, which is often more cost-effective in providing a given level of energy services than any energy supply strategy, widespread application of RETs offers some of the best prospects for achieving deep reductions in greenhouse gas (GHG) emissions at the global level over the next century, while providing the energy needed for development and generating many ancillary near-term environmental and economic benefits as well.

The prospects for making a transition to RETs are especially good in developing countries, because most of the world's incremental demand for energy will come from the developing world (see Tables 1 and 2)[1] and because the natural resources needed for supporting RETs are abundant in many developing countries.

In 1993, the World Energy Council (WEC) projected that the contribution of renewable energy to total world commercial energy would grow from 8% in

Table 1: Primary Energy Consumption by Region for Alternative WEC Commission Scenarios[a]
(MTOE per year)

Region	1990	Alternative WEC Commission Scenarios for 2020			
		A (High Growth)	B (Reference)	B_1 (Modified Reference)	C (Ecologically Driven)
North America	2157	2444	2337	2338	1829
Western Europe	1462	1814	1726	1725	1319
Central and Eastern Europe	292	360	319	360	265
CIS	1447	1674	1529	2039	1266
Subtotal	**5358**	**6292**	**5911**	**6462**	**4679**
Latin America	577	2231	1397	2104	1307
Middle East and North Africa	317	1296	864	1134	791
Sub-Saharan Africa	266	1279	690	1053	608
Pacific	1843	4258	3482	3795	2988
(Centrally Planned Asia)	(950)	(2327)	(2009)	(2007)	(1768)
South Asia	446	1852	1015	1460	900
Subtotal	**3449**	**10916**	**7448**	**9546**	**6594**
World	**8807**	**17208**	**13359**	**16008**	**11273**

[a] *Source: WEC Commission (1993)*

1 Situations involving rapid demand growth are inherently more attractive theaters for innovation than where demand growth is slow.

1990 to 12% by 2020 in its "Reference Scenario" and to 20% by 2020 in its "Ecologically Driven Scenario," the latter of which emphasizes both the efficient use of energy and the accelerated development of RETs (WEC Commission, 1993; WEC, 1994). The Shell International Petroleum Company, as part of a long-term energy planning exercise, presented in 1994 a "Sustained Growth Scenario," in which renewable energy sources would provide 20% of total global energy supplies by 2025 and more than 50% by 2050, and fossil fuel consumption would slowly decline after 2030 (Kastler, 1994). The growing role for RETs at the expense of fossil fuels in the Shell scenario was envisioned not as a response to fossil fuel supply shortages in this period but rather as a result of a projected market dynamic in which the rate of innovation in the mature fossil fuel industries would not be able to keep up with that for the new RETs, once the renewables gained footholds in the energy market.

This market dynamic was highlighted in a major international review of RETs (Johansson et al., 1993a; 1993b), which also projected that it would be feasible to meet more than half of global energy needs with RETs by 2050. This study and also a World Bank review of RETs (Ahmed, 1994) pointed out that many RETs have the potential for major cost reductions as a result of both technological improvement and organizational learning (i.e., learning by doing). Many RETs are good candidates for cost-cutting via organizational learning because they are modular and readily amenable to the economies of producing large numbers of identical units. Also, the time from initial product design to operation for these technologies is short, so that needed improvements can be determined in field testing and quickly incorporated into modified designs — making possible many generations of marginally improved products in relatively short periods of time.

For the IPCC's Second Assessment Report, the Energy Supply Mitigation Options Subgroup of the Working Group on Impacts, Adaptation, and Mitigation Options assessed a wide range of energy technologies with regard to their potential for achieving deep reductions in CO_2 emissions from the energy sector (IPCC, 1996; Johansson et al., 1996). To synthesize its findings, the subgroup constructed alternative Low CO_2-Emitting Energy Supply Systems (LESS constructions) for the world to the year 2100, highlighting alternative combinations of energy supply technologies that offered good prospects for achieving deep reductions in CO_2 emissions without large increases in the costs for energy services.[2] The LESS construction exercise showed that if societies should decide to seek deep reductions in CO_2 emissions from the energy sector, this objective could plausibly be accomplished in many alternative ways (with much greater flexibility in choosing among supply options for reducing emissions if emphasis is given to using energy efficiently), without substantially driving up energy costs. The key to this outcome is encouragement of the development of a wide range of low CO_2 emitting energy technologies. All of the LESS constructions involve major contributions from RETs (25% to 30% of total energy by 2025 and 40% to 50+% by 2050), which are generally good candidate technologies for achieving deep reductions in CO_2 emissions without increasing energy costs much or at all.

Table 2: Electricity Consumption by Region for the WEC Reference Scenario[a]
(TWh per year)

Region	1990	2020
North America	3475.5	4650
Western Europe	2468.4	3900
Central and Eastern Europe	362.0	600
CIS	1718.4	2400
Subtotal	**8024.3**	**11550**
Latin America	598.1	2350
Middle East and North Africa	311.4	1350
Sub-Saharan Africa	224.6	700
Pacific	2106.0	5700
(Centrally Planned Asia)	(699.0)	(2650)
South Asia	343.3	1350
Subtotal	**3583.4**	**11450**
World	**11607.7**	**23000**

[a] *Source: WEC Commission (1993)*

2 Annual global CO_2 emissions from fossil-fuel use in the alternative LESS constructions are about 6 GtC/yr in 2025, about 4 1/2 GtC/yr in 2050, and about 2 GtC/yr in 2100. Actual emissions from fossil-fuel burning were 6 GtC/yr in 1990. For comparison, the CO_2 emissions from fossil-fuel burning in 2100 are about 20 GtC/yr in the IPCC's IS92a Scenario (often called the "IPCC Reference Scenario") (IPCC, 1992), and about 11GtC/yr and 2 GtC/yr in the WEC Reference and Ecologically Driven Scenarios, respectively (WEC, 1993).

4 Global Costs for Commercializing RETs

There has been remarkable progress to date toward commercialization of RETs, and some RETs are ready for commercial applications in significant niche markets. Yet RETs are not yet ready for widespread adoption in the energy economy. Renewables intensive energy futures such as those described in the IPCC assessment (IPCC, 1996; Johansson et al., 1996) cannot be realized without a high rate of innovation in the energy sector in both the industrialized and the developing worlds. Such futures can come about only if societies take actions that include providing needed support for research and development on RETs and providing incentives to help launch new industries based on technologies that are successfully developed.

In the private sector, there has been a sharp trend away from long-term energy R&D, in favor of near-term product improvements,[3] as a result of both declining energy prices and, in the power sector, an industrial restructuring that is making power markets increasingly competitive (Williams, 1995). Also, over the last decade, public sector support for energy R&D in International Energy Agency (IEA) countries has declined absolutely by one-third and by half as a percentage of GDP (see Table 3), although there are signs that this downward trend may be ending in some countries. Moreover, government supported R&D has generally focused on nonrenewable energy technologies; less than 10% of IEA member government support is for RETs. Recent declining trends relating to energy innovation have to be reversed to realize energy futures in which RETs play major roles.

Fortunately, many of the promising RETs require relatively modest investments in R&D and commercialization incentives. The need for only relatively modest investments is a reflection largely of the small scale and modularity of these technologies and the fact that they are generally clean and safe (Williams, 1995). After the research phase, the high costs of "scaling up" in the development process can be avoided with small-scale technologies, and progress along learning curves can often be inexpensive relative to learning costs for large-scale technologies (see Figure 1). For technologies that are also characterized by high degrees of inherent safety and cleanliness, R&D resource requirements for improving safety and environmental performance are small.[4] Thus, it should be feasible, even with relatively limited resources for

3 For example, while total expenditures on R&D as a percent of sales have been relatively stable for the major international oil companies, long-term R&D as a percent of total R&D has declined continually, from 28% in 1982 to 11% in 1993 (private communication, Jules Duga, Battelle Columbus Laboratories, January 1995).

4 Enormous R&D resources are sometimes committed to finding effective ways to dispose of harmful residuals of energy systems that are not inherently safe or clean. Especially noteworthy are the billions of dollars that have been spent trying to develop a long-term disposal strategy in the United States for radioactive wastes from civilian nuclear power. In recent years, the U.S. Department of Energy has spent $1.7 billion on scientific and technical studies simply to determine the geological suitability of Nevada's Yucca Mountain as a disposal site for these wastes (Whipple, 1996). For comparison, total U.S. federal government support for photovoltaic R&D, 1972-1994, was $1.8 billion in constant 1992 dollars (Williams and Terzian, 1993).

R&D, to support a diversified portfolio of RET options. The World Energy Council has estimated that the R&D expenditures needed worldwide over the next 20 years to advance a range of solar energy technologies is on the order of $8 billion (WEC, 1994).

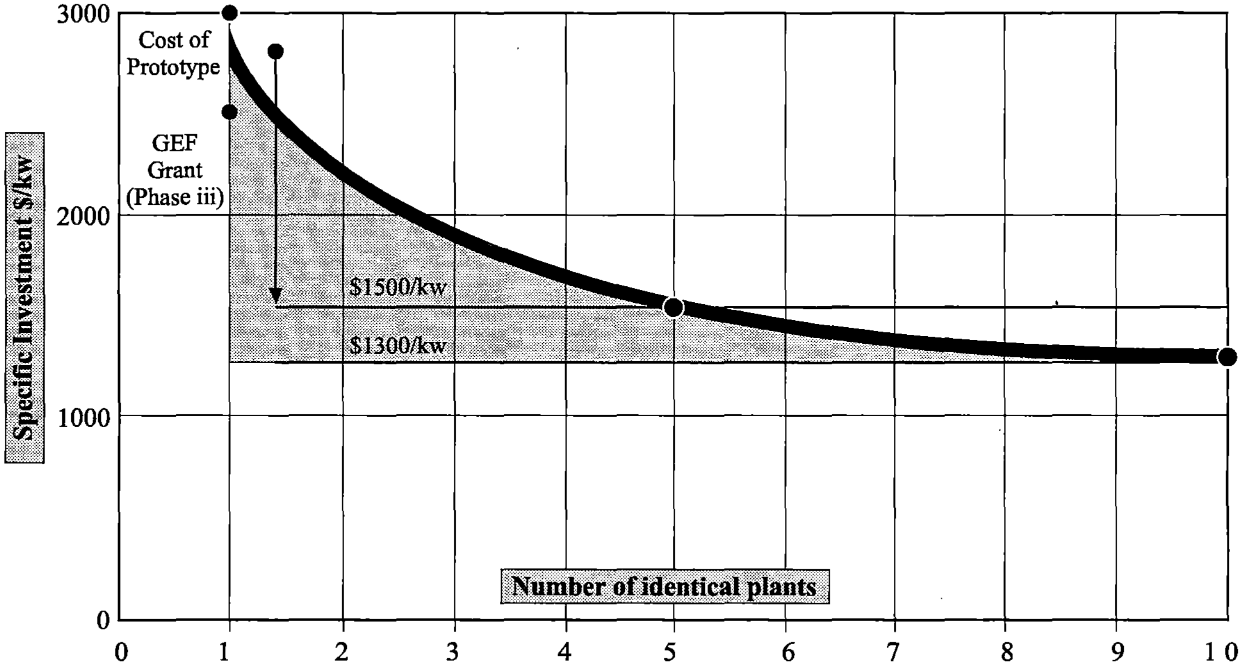
R&D programs are necessary but not sufficient to establish new technologies in the marketplace. Commercial demonstration projects and programs to stimulate markets for new technologies also are needed. The World Energy Council estimates that subsidies on the order of $7-12 billion are needed to support initial deployment of various solar energy technologies until manufacturing economies of scale are achieved, to compete with conventional options (WEC, 1994). Thus, the World Energy Council estimates that the total investment needed for R&D on and support for initial deployment of RETs to be $15-20 billion. This is 0.1% of the annual global gross national product at the turn of the century. Of course, in any particular year, these expenditures as a percent of global gross national product would be far less, as these expenditures would be distributed over a couple of decades (WEC, 1994).

Table 3: Total Reported IEA Government R&D Budgets[a] (Columns 1-7) **and GDP**[b] (Column 8)

Year	(1) Fossil Energy	(2) Nuclear Fission	(3) Nuclear Fusion	(4) Energy Conservation	(5) Renewable Energy	(6) Other	(7) Total	(8) GDP	(9) % of GDP
1983	1.70	6.38	1.43	0.79	1.05	1.08	12.40	10.68	0.12
1984	1.60	6.12	1.44	0.70	1.02	0.99	11.88	11.20	0.11
1985	1.51	6.26	1.42	0.70	0.85	1.04	11.77	11.58	0.10
1986	1.51	5.72	1.31	0.59	0.66	0.94	10.74	11.90	0.09
1987	1.37	4.36	1.23	0.65	0.62	1.04	9.27	12.29	0.08
1988	1.46	3.64	1.13	0.53	0.62	1.19	8.58	12.82	0.07
1989	1.30	4.42	1.07	0.45	0.57	1.33	9.13	13.23	0.07
1990	1.75	4.48	1.09	0.55	0.61	1.15	9.62	13.52	0.07
1991	1.52	4.45	0.99	0.59	0.64	1.39	9.57	13.58	0.07
1992	1.07	3.90	0.96	0.56	0.70	1.28	8.48	13.82	0.06
1993	1.07	3.81	1.05	0.65	0.71	1.38	8.66		
1994	0.98	3.74	1.05	0.94	0.70	1.30	8.72		

[a] *U.S.$ billion at 1994 prices and exchange rates (IEA, 1995).*
[b] *U.S.$ trillion at 1993 prices (OECD, 1994)*

Figure 1: Learning Curve for Biomass-Integrated Gasifier/Combined Cycle Technology



This learning curve indicates the expected trend in unit costs for biomass integrated gasifier/combined cycle (BIG/CC) technology based on a 25,000 kWe demonstration plant that is scheduled to commence operation in the late 1990s in the northeast of Brazil. Shell researchers (Elliott and Booth, 1993) involved in the project expect that the costs for the first 10 units will follow a learning curve characterized by an 80 percent progress ratio (i.e., the installed cost is expected to decline 20 percent for each cumulative doubling of production), based on the expectations that: (i) most plant assembly would take place in the factory; (ii) there would be minimal site preparation and foundation requirements; (iii) onsite construction would consist mainly of integration of standard factory-built modules; and (iv) there would be short time lapses between ground breaking and plant start-up.

For modular technologies like this, the "cost of learning" is far less than for large-scale fossil or nuclear technologies. Note that:

Cost of BIG/CC learning = (shaded area)*(25,000 kWe) = $0.12 billion.

This can be compared to the cost of learning for an advanced nuclear fission technology, such as a "passively safe" design for which the size target for commercial plants is 600,000 kWe. If this technology were to follow exactly the same learning curve for unit capital cost, then:

Cost of nuclear learning = (shaded area)*(600,000 kWe) = $2.9 billion.

Also, it is much more difficult to obtain the benefits of "learning-by-doing" with large-scale technologies such as nuclear power. Fisher (1974) pointed out that in building a large power plant instead of a small one, much of the construction that would have been carried out in the factory is shifted to the field, where labor costs are much higher. Moreover, the construction of a large plant takes many years, so that it is usually not possible to cut costs via the replication of a large number of identical units by the same construction team (learning-by-doing). Building a large nuclear power plant is like building a "widget factory" that produces only one widget.

5 RETs vs. Fossil Fuels

Unlike the situation in the 1970s, when the oil crises first sparked wide public interest in renewable energy development, the world oil price is now low and is not expected to rise sharply in the decades immediately ahead. Perhaps the greatest challenges to the evolution of a renewables intensive energy future are the present low prices for oil and other fossil fuels.

Low fossil fuel prices underscore the importance of pursuing through R&D and technology commercialization incentives the development of innovative RETs that offer the potential for being competitive without sharp increases in fossil fuel prices. They also highlight the importance of better appreciating how RETs can help cope with the social costs of fossil fuel dependence that are not yet reflected in market energy prices.

In addition to the climate change benefits offered by RETs, which will benefit the global community mainly over the longer term, RETs also offer immediate benefits to the populations they serve directly via the reduced air pollution and other local environmental benefits arising from their replacement of fossil fuels. There are already high levels of concern about the environment in developing countries (Bloom, 1995), and these concerns will increase with continued income growth and expanded use of fossil fuels. Moreover, in many developing countries, it will be difficult to meet environmental cleanup goals by mandating that pollution-control technologies be retrofitted onto energy technologies originally designed without consideration for environmental problems — owing to weak regulatory enforcement infrastructures and/or weak operation and maintenance infrastructures for supporting environmental regulations. The adoption of RETs can be helpful in such circumstances because they offer a high degree of inherent cleanliness, without the need for ancillary pollution control equipment.

RETs can also be important options for reducing convertible currency expenditures on energy imports. Because of reduced export prices for their principal export commodities, many developing countries are still spending significant portions of their convertible currency earnings on energy imports — ranging in 1993 from 26% for Bangladesh to 61% for Nicaragua (World Bank, 1995).

Moreover, emphasis on the development and commercialization of RETs will help increase energy supply diversity and thus enhance energy supply security in the near term. Such near term efforts will also ensure a smooth transition to climatologically and otherwise environmentally attractive fossil fuel substitutes that will be needed in a few decades time. In the longer term, having such fuels available for direct use, especially for transportation, will become increasingly important – in light of global constraints on remaining petroleum resources and the rapidly growing appetite for liquid fuels, especially in the developing world.[5]

For natural gas, currently the fossil fuel of choice[6] for many applications in those parts of the world where it is available, the future supply outlook is somewhat different. It is generally thought that, in terms of energy content, estimated remaining recoverable conventional resources of natural gas are about as large as remaining conventional oil resources (Masters et al., 1994). However, natural gas is produced at the global level at just half the rate at which oil is produced, on an energy equivalent basis. It is generally expected that natural gas production will increase rapidly in the decades immediately ahead.

Even in regions where natural gas is readily available, emphasis on natural gas in the near term will be helpful to RETs in the long term. In power generation, for example, natural gas-fired combustion turbine and combined cycle power plants are good complements for intermittent renewable electric systems (wind, PV, and solar thermal-electric RETs);[7] and advanced technologies (e.g., advanced gas turbine and fuel cell technologies) that are now being developed for natural gas applications in stationary power and transport systems can be used later with renewable energy sources (STAP, 1996a).

Unlike supplies for oil and natural gas, supplies for coal are not likely to be significantly constrained in the next century. A major problem with the combustion of coal is that it typically gives rise to substantial air pollution emissions unless emission control technologies are employed. It will be difficult for RETs to compete with coal-conversion technologies that do not involve emission controls, but there are good prospects that various mature RETs will be able to compete with coal in many parts of the world if air pollution standards similar to the most stringent in the industrialized world are in place and enforced (STAP, 1996a).

Despite the challenges posed by low fossil fuel prices, there are reasonably good prospects for bringing about a transition to a RETs intensive energy future over a period of several decades, as is indicated by this review and the other major recent studies mentioned earlier. The keys to such a global energy future for the long term in the face of current low fossil fuel prices are actions launched in the near term (i) to break down the institutional barriers to commercializing those RETs that are cost-effective, (ii) to find ways to internalize the external costs of fossil fuels not presently reflected in market energy prices, (iii) to intensify R&D on RETs, and (iv) to develop market reward structures that promote the industrial dynamism of the "virtuous circle" involving market growth and price reductions for technically proven advanced RETs, as these technologies progress along their learning curves. A concerted global effort along these lines offers good prospects for convergence of costs for RETs and costs for fossil fuel energy.

---

5 To appreciate the significance of these constraints, consider recent estimates of global remaining recoverable conventional crude oil and natural gas liquids (identified reserves plus estimated undiscovered resources) made by the U.S. Geological Survey (Masters et al., 1994). Suppose, hypothetically, that these remaining resources will be entirely consumed at a constant annual rate in the period to the year 2100. Under this assumption remaining global oil supplies would be adequate to provide oil at less than 61%, 68%, or 89% of the actual global rate of oil consumption in 1992, with probabilities of 5%, 50%, or 95%, respectively, for the U.S. Geological Survey's three alternative estimates of remaining recoverable conventional oil resources.

In the real world, conventional petroleum resources will be more constrained over time than is suggested by this simple exercise, since the global demand for liquid fuels is likely to rise sharply in the decades immediately ahead, especially in developing countries. For example, the WEC Commission's Reference Scenario projects that between 1990 and 2020 the demand for petroleum in developing countries will increase by an amount equal to one-third of total global oil use in 1990 (WEC Commission, 1993).

6 The burning of natural gas leads to low local air pollutant emissions levels. Also the CO_2 emissions index (kg C per GJ) for natural gas is about 55% of that for coal and about 70% of that for oil. The market price of natural gas is also typically lower than that for oil in many parts of the world where it is readily available.

7 Combustion turbines and combined cycles can change their output levels quickly in response to changes in output levels of intermittent renewables. Also, their low specific capital costs (in $ per kWe) makes them good candidates for backing up intermittent renewables. In contrast, the output levels of baseload coal or nuclear plants cannot be changed quickly, and their high specific capital costs make it costly for the utility to shut them down when intermittent renewable electricity is available; thus baseload coal or nuclear plants are poor candidates for backing up intermittent renewables.

6 Other Benefits of RETs for Developing Countries

Aside from the global and local environmental benefits, the energy supply security benefits, and the foreign exchange benefits they offer, RETs would also bring a number of other potential benefits to the developing world that arise largely from the small scales and modularity that are characteristic of many RETs.

RETs make it possible to bring modern energy technologies in the near term more quickly and at lower cost to many of the millions of people who do not yet enjoy their benefits. About 63% of the population of the developing world live in rural areas (WRI, 1994), 67% of whom do not have grid connection (Clement-Jones and Mercier, 1995). Where the population density is less than two people per km^2, the cost of the electricity cable will be more than $5,000 per hookup. In such remote areas, there are often good opportunities for using RETs at competitive costs in meeting small-scale mechanical or electric power needs at levels of the individual household, farm, or village.

A closely related benefit is that even the poorest developing countries, with limited access to capital, can plan and implement energy investment programs based on RETs. Unlike conventional energy technologies, RETs do not require large installations to realize lower costs. This is particularly important for heavily indebted developing countries that either have great difficulty in attracting capital or do not wish to increase their debt fractions.

RETs — in contrast to conventional energy technologies that are mature and require relatively large resources on the part of developing countries for acquiring and developing know-how — are still in the early stages of their technological development and tend to have fairly low technology acquisition/development costs. Consequently, well-targeted R&D and training could enable any developing country to develop cutting-edge capabilities for one or more RETs and become well positioned to reap the benefits that rapid growth in the use of RETs is likely to bring.

There are good prospects that many RET components can be manufactured in developing countries, with locally manufactured product content increasing over time; some RET products can be entirely manufactured locally at competitive costs at the present time. Local manufacture implies not only local job creation opportunities but also often potentially lower costs than for RETs imported from the industrialized world, leading to large domestic markets for RETs and opportunities for export growth.

7 Institutional Challenges Posed by RETs

RETs pose a variety of institutional challenges relating to technology transfer and dissemination. If RETs are to be widely adopted in the power sectors of the developing world, technology management skills quite different from those required for conventional power-generation technology will have to be cultivated, and the institutional environment of the energy sector will have to be modified, in many instances.

Operation of intermittent RETs, for example, requires the skills of integrating nondispatchable intermittents with dispatchable conventional power sources in ways that provide, on demand, reliable electric power cost-effectively. Over the last decade, there has been some experience with the integration of intermittent renewables into electric grids (mostly in industrialized countries), but managers at most utilities in the developing world are not familiar with the needed management techniques.

Some RETs, most notably photovoltaic (PV) systems, will often be installed not in central station power plants but close to users in small distributed configurations — in both stand-alone applications remote from utility grids and in grid-connected applications. As the skills needed for managing such systems are only beginning to be developed in the industrialized world, the needed skills must be largely developed in the field in developing countries.

Some RET applications will require large central station power plant configurations. For example, central station arrays of 50-150 MWe offer some of the best opportunities for rapidly bringing down the costs of photovoltaic power (STAP, 1996a). And large 100-200 MWe plants are likely to dominate applications of solar thermal-electric power (De Laquil et al., 1993). Moreover, while nearly all wind power development has focused on establishing wind farms (clusters of wind turbines) at scales of at most a few tens of megawatts, in those parts of the world where the best wind resources are remote from major electricity demand centers (e.g., the United States, Morocco, China), large (> 1 GWe) wind farms integrated with long-distance transmission lines and possibly also large-scale electrical storage technologies (e.g., compressed air energy storage) will be needed to exploit these resources cost-effectively (Cavallo, 1995; Lew et al., 1996). In such instances, the skills of large-scale project development are key. Yet the management skills needed for large-scale RET projects are not well established anywhere in the world.

Many initial biomass power projects will be for combined-heat-and-power (CHP) applications based on the use of biomass residues of industrial or agricultural activities. Many of the management skills needed for biomass CHP plants are similar to those needed for CHP applications based on the use of fossil fuels. Fossil fuel-based CHP projects have typically involved industrial or third-party operators, who sell the electricity produced in excess of onsite needs to electric utilities. To effectively exploit biomass CHP opportunities, the technological skills for managing such operations must be developed, and public policies must be enacted that eliminate unfair constraints on such electricity sales.

Local manufacturing of RET components or of entire systems not only could provide local employment but also could potentially lead to lower costs in those countries (e.g., the rapidly industrializing countries) that have strong basic engineering infrastructures and lower wage rates for the needed levels of skills than are found in the industrialized world. It is thus worthwhile to explore the prospects for different degrees of equipment manufacture in developing countries (ranging from assembly of imported parts to full local manufacture of all parts as well as parts assembly), to assess the cost-reduction potential from local manufacture, and to identify the key technology transfer issues associated with such manufacturing for RETs.

RETs are sufficiently different from conventional energy technologies that their successful introduction might require changes in institutions outside the energy sector that affect their prospective economics. For example, a recent study showed that under current U.S. tax laws, the tax loads associated with constructing and owning various kinds of renewable electric facilities are higher than for natural gas-fired power plants of the same size, hours of operation, and technology status, so that public initiatives aimed at tax neutrality would help renewables compete (Jenkins et al., 1994). Moreover, in the United Kingdom, experience has shown that renewable energy projects pay more for their capital and have more onerous terms and conditions of lending than conventional energy sources, thus reducing the competitiveness of renewables (Mitchell, 1993). This problem is partly due to the newness of the technology (which will be overcome to some extent with experience) but is also due to the innate differences or mismatching between the needs of the U.K. financing system and the characteristics of RETs (Mitchell, 1995). This financing problem is well-known for domestic lighting applications of photovoltaic (PV) technologies in rural areas remote from electric utility grids throughout the developing world; for such applications present PV technology is fully competitive with the alternative of extending grid service to rural households, but financing is typically not available for the modest levels of system costs involved (typically ~ $500 per household).

Thus, RETs pose multiple challenges relating to both technology transfer and technology dissemination that must be dealt with if they are to play substantial roles in the energy sectors of the developing world. Creatively designed RET projects could be good candidates for "institutional demonstration projects" in developing countries that can help resolve a wide range of technology transfer and technology dissemination issues and thus can be helpful in understanding better the technology transfer process for environment energy technologies generally.

Furthermore, the nature of these multiple challenges relating to technology transfer in particular highlights the importance of having *a priori* strong basic technological skills in developing countries so as to facilitate the effective acquisition of additional technological capacity via experience in the field (STAP, 1996c).[8] In those regions of the developing world where existing capabilities are weak in specific RET areas, base levels of technological capability might be promoted via the establishment of regional institutes that provide training in the fundamentals of the technology and the basic skills of technology assessment and management.

---

8 Recent research on technology transfer (Chantramonklasri, 1990) shows that the greater the existing stock of technological capabilities within and around the technology importing firms, the greater the increments to that stock which can be acquired in international industrial collaborations (see next section). This research indicates that without active intervention and interaction in the technology transfer process, the increments in technological capability that accrue to firms seeking to acquire technological capacity are likely to be trivial other than for acquiring basic operational techniques. But with active intervention and interaction a "virtuous circle" dynamic can lead to gains in technological capacity and, as a result, gains in industrial productivity. Those firms that fail to carry out efforts to enter the virtuous circle will be left in a "vicious circle" of technological dependence and stagnation.

8 Roles for International Industrial Collaborations in Accelerating Adoption of RETs in Developing Countries

STAP has identified the international industrial collaboration (joint venture, Build-Own-Operate-Transfer project, etc.) as a potentially powerful instrument for accelerating the widespread adoption of RETs and other promising "environmental energy technologies" — defined here as energy technologies characterized by a high degree of inherent cleanliness and safety — in developing countries and for helping build the needed technological infrastructure there for designing, constructing, operating, and marketing such systems (STAP, 1996c). It is desirable for the GEF to find ways to leverage its scarce resources available for RETs projects by helping direct private sector resources to RETs development and dissemination.

Although the financial resources needed to establish viable RET industries in the developing world are relatively modest (see above), the requirements exceed the available resources at the GEF. Moreover, it is likely that adequate additional financial resources will be forthcoming neither from the World Bank and its affiliates nor from the public sectors of the already industrialized world (in light of the increasingly tight fiscal constraints facing those governments).

In contrast, foreign direct investment in developing countries is increasing rapidly. The GEF could gain enormous leverage in allocating its scarce resources available for RETs development if it could identify and pursue, in collaboration with developing country governments, effective strategies for directing some of these enormous private sector resources to industrial development for RETs. Though few of these financial resources are currently committed to the pursuit of RETs, substantial amounts of these resources could be directed to such purposes because: (i) many firms in countries with the needed technological and financial resources are interested in gaining access to developing country energy markets, and (ii) in those developing countries where market forces are effective in the energy sector, governments will have the power to direct these energy investments to the dissemination of RETs and other energy technologies that meet sustainable development objectives.

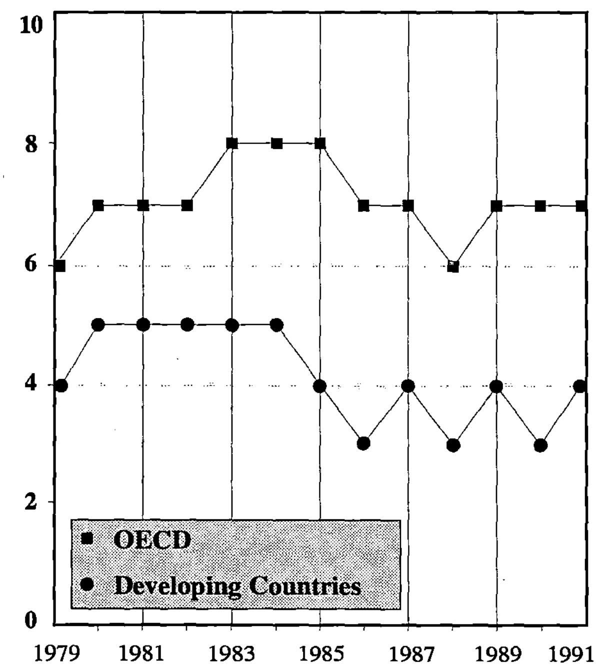
Energy technology firms, mainly from industrialized countries, are eager to gain access to developing country energy markets — which are large and rapidly growing, in contrast to the slow demand growth that characterizes most industrialized country energy markets (see Tables 1 and 2 p. 4, 5). Firms from the industrialized countries with this capacity can efficiently transfer the "tacit knowledge" relating to RETs to firms in developing countries, via international industrial collaborations. These firms will make such technology transfers if agreement can be reached on the protection of intellectual property rights and if they perceive that by so doing they will gain access to developing country markets for these technologies.

Moreover, the governments of those developing countries that are successful in bringing about the energy-sector reforms (e.g., electricity tariff reforms[9]) and other structural reforms of their national economies (e.g., liberalization of markets and prices, encouragement of savings by the household sector, and development of domestic capital markets) long advocated by the World Bank and the International Monetary Fund, will have considerable market power to insist that foreign direct investment be focused on RETs and related environmental energy technologies that conform to sustainable development objectives. In those developing countries where market forces are effective in the energy sector, governments will have the power to stimulate the creation of the large latent markets for RETs and related technologies and to make these markets efficient by: (i) by insisting as conditions for market access that technologies being transferred meet sustainable development criteria and that the foreign firms be committed to transferring these technologies to local industry, and (ii) encouraging competition among international industrial collaborators to compete to provide such technology.

For those developing countries that pursue this strategy, the result could be that state-of-the-art RETs and other environmental energy technologies will migrate to these countries, which could potentially become world leaders in the export of such technologies. This possibility arises from a market dynamic involving a synergism between the cost trend characteristics of RETs and particular conditions in developing countries. Cost reductions for RETs will potentially take place rapidly as a result of both "learning by doing" in these rapidly growing markets and technological innovation. In developing countries, lower production costs would be realized for these technologies than would be feasible in already industrialized countries, because of both the much larger early market potential arising from rapid energy demand growth and the much lower wage rates in developing countries for given levels of skills. Once rapidly growing markets have been established for these technologies, the industrialized country partners in these industrial collaborations will be forced to innovate continually in order to sustain a market position.

This strategy for pursuing the RETs via international industrial collaborations defines a new industrial paradigm for energy development. Yet it does not require radical institutional restructuring. Many international industrial collaborations of various kinds are already in place and new ones are being formed continually, at an accelerated pace — collaborations involving "South/South" and "triangular" collaborations (e.g., a collaboration involving firms from a developing country in the early stages of its development, a rapidly industrializing country, and an industrialized country), as well as "North/South" partnerships. Many of the financial and institutional arrangements required to bring about the kinds of industrial collaborations proposed here are already in place or are about to be established, but for conventional energy technologies. Some modification of these arrangements will be required when emphasis is shifted to RETs or to environmental energy technologies generally. This is the case largely because different technological skills will be involved (see above) and a different and broader set of actors will be involved — e.g., more small-and medium-scale enterprises will be involved, from both developing and industrialized countries, and with this broader set of actors, it is to be expected that the scope for industrial collaboration will be widened.

Figure 2: Trends in Electricity Tariffs of OECD and Developing Countries for 1979-91
(1986 U.S. cents/kWh)



OECD = Organization for Economic Cooperation and Development
Source: Heidarian and Wu (1994)

9 Tariff reform is key to converting the current sellers' markets that characterizes many electric- technology purchases in developing countries into buyers' markets.

At the present time, electricity tariffs in many developing countries are typically just over half the tariffs in industrialized countries (see Figure 2) and may represent no more than one-third of costs (Schramm, 1993), because of widespread electricity price subsidies. By keeping tariffs below long-run marginal costs the state-run power companies in developing countries have been unable to generate retained earnings for investment in expanded capacity and have established poor credit ratings in global commercial capital markets. As a result, these companies have become largely dependent on their governments and the various development-assistance agencies for the needed capital. But the potential capital supplies that can be provided by the development- assistance agencies are modest in relation to the demand for capital in these markets (Schramm, 1990), and the governments that have historically provided the bulk of the capital needs of the power sector are operating under increasingly fiscally austere conditions that are creating capital-supply shortfalls for the power sector.

Where these conditions exist today, utilities have very little "technology-forcing power" in dealing with vendors.

9 Framing the Public Policy Issues Relating to RETs

Two important themes relating to energy policy emerged from the STAP workshop on stimulating private sector initiatives to accelerate the introduction of RETs in developing countries (STAP, 1996b):

- Industrial participants generally recognized that RETs will have to be introduced in ways that are compatible with the ongoing structural reforms taking place throughout the energy sectors of the developing world.

- However, industrial participants generally argued that unless these structural reforms are accompanied by measures to assist the early market development of RETs (e.g., temporary incentives aimed at achieving quickly cost convergence between RETs and conventional energy supplies), it will be difficult to establish viable RET industries. Participants felt it was essential to formulate coherent policies aimed at unleashing the industrial dynamism of the "virtuous cycle" involving market growth and price decreases for RETs.

The major policy recommendation that emerged from discussions at the STAP workshop is that public sector encouragement of RETs is needed in three categories:

- Category 1: To help establish innovative delivery systems for RETs that are already both technically proven and fully cost-competitive in targeted markets.

- Category 2: To provide incentives designed to encourage fast progress along learning curves for RETs that are technically proven with good intrinsic prospects for cost reduction but still positioned early on the learning curve.

- Category 3: To provide support for technological demonstrations of RETs that are not yet technically proven but have good intrinsic prospects for being cost competitive if successfully demonstrated and advanced along the learning curve.

For some RETs, only policies in category 1 are needed; for others, policies in both categories 1 and 2 or in all three categories are needed. It was pointed out that a coherent policy framework is needed to ensure a smooth transition from precommercial to fully commercial development of RETs.[10]

The GEF can be helpful with regard to category 1 by supporting "institutional demonstration projects" and with regard to category 3 by supporting "technological demonstration projects."[11] Regarding the latter, industrial workshop participants pointed out that unlike the situation in Europe, Japan, and the United States, there is no mechanism outside of the GEF for supporting technological demonstration projects in the developing world — hence the importance of the GEF role in supporting technological demonstrations. But category 2 requires public policies that extend beyond what is achievable by the GEF acting alone,

10 This same point was stressed in a major review of the renewables Non-Fossil-Fuel Obligation (NFFO) in the United Kingdom (Mitchell, 1995).

11 The STAP review of RETs (STAP, 1996a) highlighted the importance of both institutional and technological demonstration projects in developing countries as key in bringing about a transition to widespread use of RETs in the developing world.

with its limited resources. Workshop participants emphasized the importance of exploring innovative approaches for dealing with the challenges posed by category 2. Addressing the challenges of category 2 will not be easy in light of the fiscally austere conditions facing most national governments. However, workshop participants identified "soft policies" (not necessarily requiring fiscal support) and the catalytic role GEF might provide in facilitating such policies as promising and worthy of close scrutiny for addressing category 2 challenges. Various innovative proposals relating to category 2 were made during the workshop, some of which provide the basis for the discussion that follows.

10 Roles for Developing Country Governments in Promoting the Accelerated Adoption of RETs

Aside from implementing the needed basic economic reforms relating to energy described earlier, governments could implement proactive policies to accelerate the introduction of RETs. Emphasis is given here to category 2 challenges discussed above, in light of their central importance.

Of course, policies to promote the adoption of RETs should have good prospects of being both effective in meeting goals and economically and administratively efficient. Moreover, they should be designed to achieve cost convergence between RET and conventional energy systems — quickly if feasible. In some instances, a developing country might adopt a public policy that has been successful for RETs in an already industrialized country or some other developing country. In other instances, entirely novel approaches would be more appropriate. Three examples of "soft policies" for promoting RETs are given here — two that have been used for promoting renewables in the United States and the United Kingdom, and one proposed for wind energy (by a participant of the STAP workshop on RETs) that has been successfully used for decades in the development of oil and other mineral resources.

A case study of a regulation that was effective in promoting innovation in the power sector is the Public Utilities Regulatory Policy Act passed by the U.S. Congress in 1978, which eventually led to the creation of a competitive, decentralized electricity market in the United States. The law required electric utilities to buy power from independent producers at prices equal to the utilities' long-term avoided costs. This law is largely responsible for the introduction of 8,000 MWe from biomass, 1,500 MWe from wind, 730 MWe from small-scale hydropower, and 350 MWe from solar thermal-electric technology (WEC, 1994).

The United Kingdom's energy policy aims to bring into operation by the year 2000 the baseload equivalent of 1,500 MWe of renewable electric supplies. Renewables are promoted to meet this goal by mandating via a renewables Non-Fossil-Fuel Obligation (NFFO) that public electricity suppliers purchase electricity from renewable energy projects in a series of public orders soliciting proposals. The public electric suppliers pay these generators a premium price for renewable electricity, and the difference between the premium price and the market electricity price is paid for by a tax on fossil fuels consumed by the utilities. The extra cost for the renewables NFFO is paid for ultimately by the ratepayers, but the effect has been small (an increase of 0.1 to 0.5 percent in the electricity price between 1990 and 1996), because the renewable electric capacity accounts for a very small fraction of the total capacity. Over the last several years, the renewables NFFO has made cost convergence an explicit goal, as explained by the Minister of Energy in July 1993 (Mitchell, 1995):

> "...the purpose of the NFFO Orders is to create an initial market so that in the not too distant future the most promising renewables can compete without financial support. This requires a steady convergence under successive Orders between the price paid under the NFFO and the market price. This will only be achieved if there is competition in the allocation of NFFO contracts."

Indeed, there have been substantial price reductions between the NFFO2 renewables contracts (awarded in 1991) and the NFFO3 renewables contracts (awarded in 1994).

At the STAP workshop on RETs (STAP, 1996b), one of the focal points of discussion was how to deal institutionally with the challenge of developing large-scale (> 1 GWe) wind farms necessary to exploit, at acceptable cost, wind resources that are remote from demand centers, since GW-scale long-distance transmission lines are required (Cavallo, 1995). One of the workshop participants, formerly a chairman and CEO of a major oil company, pointed out that a sensible strategy for doing this would be to exploit the wind resource via a "wind energy resource-development concession," in much the same way that oil and other mineral resources have been developed via resource-development concessions (Brennand, 1996).[12]

This concept applied to wind power development might work as follows.[13] In a delineated region of high-quality wind resources, the government would seek bids for concessions to venture company partnerships between local government and private sector entities, to explore and develop wind energy in the region over a specified period of time. Under the agreement, the concessionaire would assume all the upfront technical and financial risks associated with the uncertainties relating to initial developmental activities, in exchange for agreed-upon shares of the benefits that would arise from the development.

If wind energy were developed within the framework of resource-development concessions, it should be possible to attract firms with the financial resources required for developing GW-scale wind farms, under conditions of prospectively favorable economics for wind energy, even though GW-scale wind farms have not been developed to date.[14]

Wind energy might be developed this way only if a well-defined regulatory/legal framework is in place that defines how concessions would be offered and enforced. Such a framework might be put in place relatively quickly, by drawing on the wealth of experience with resource-development concessions for various nonrenewable resources, of course modifying the rules from these other sectors as appropriate to take into account the unique attributes of the wind resource.

---

12 The resource-development concession might also be helpful in accelerating the development of other renewable energy resources (Brennand, 1996).

13 The wind resource in Inner Mongolia is a good candidate for an application of the "wind resource-development concession" concept (Lew et al., 1996).

14 Wind equipment manufacturers will not normally propose GW-scale projects, because such companies are generally averse to project risk; thus, the substantial venture capital needed for major project development has not been forthcoming for wind. Moreover, unlike the situation in the oil industry, in which governments invite companies to risk private venture capital in designated "projects" (oil concessions or licenses), in the wind energy sector there are no such licensing rounds. To make an analogy with the oil industry, up to now the situation in the wind energy industry is rather as though the manufacturers of drilling rigs, the drilling contractors, or local officials were seeking to develop the industry rather than oil companies (Brennand, 1996).

11 Roles for the GEF in Advancing RETS

Technological and institutional demonstration projects relating to RETs warrant high priority within the GEF portfolio, for the reasons articulated above. Such projects could be very helpful in launching new RETs-based energy industries, if bolstered by ancillary supporting measures. Specifically, the GEF should leverage its very limited resources available for promoting RETs as low greenhouse gas (GHG)-emitting energy technologies to bring about a commitment of potentially large private sector resources to the wide scale deployment of RETs in the power sector of the developing world. The GEF could accomplish this objective by complementing GEF support for technological and institutional demonstration projects with:

- Assistance for RET policy development in developing countries, which GEF can provide by indicating the importance of their having public policies to hasten the establishment of RET industries based on successfully demonstrated technologies, as a complement to GEF project activities, and by helping these countries understand better the prospective efficacy and economic efficiency of alternative public policies they might consider for this purpose.

- Support for targeted research aimed at clarifying potential markets for renewables, societal impacts of renewable energy development, potential constraints on RETs development, and the institutional issues relating to the exploitation of potential markets.

- Support for training aimed at strengthening the indigenous technological capacity relating to renewables, both to help developing countries understand better the prospects for and issues relating to the wide use of renewables and to assist local firms in ways that increase the prospects for effective technology transfer via international industrial collaborations.

The GEF could assist developing countries in RET policy development by monitoring and evaluating the strengths and weaknesses of various programs around the world aimed at promoting RETs and widely disseminating this information, supporting RET policy analytic capacity-building in developing countries, and by encouraging dialogue in developing countries between policy leaders and representatives of the industrial sectors of the developing and industrialized countries interested in marketing RETs in the developing world.

Recommendations for targeted research relating to various RETs that the GEF might support are articulated in the STAP technical review of RETs (STAP, 1996a) and are summarized in the Appendix to this paper.

The GEF could also help establish regional training institutes relating to renewable technologies. The purpose of these institutes would be two-fold: (i) to help developing countries acquire a strong indigenous capability for assessing the prospects for RETs, their potential societal impacts, and the institutional issues relating to their dissemination, and (ii) to promote a base level of indigenous technological capability that would enhance the likelihood that the technology transfer process carried out in international industrial collaborations would be effective and efficient. The training should emphasize the fundamentals of the technology, technology assessment, and a wide range of skills required for effective technology management — including both technical skills and business skills relating to manufacturing, project development, marketing, plant operation, etc.

A training institute might be organized to specialize in a particular RET (wind, biomass, PV, or solar thermal-electric technology). Prospective trainees might be drawn from the community of applicants with good basic backgrounds in engineering and/or science who seek new careers relating to RETs but have little or no specialized skills. To be most effective, these institutes should involve local firms that would ultimately benefit from the enhanced technological capabilities of trainees.

These training institutes might be associated with technology training activities for some prospective RET user groups. One candidate set of homes for such institutes is some of the better "internal colleges" that have been established at many utilities in the developing world. (Today such colleges are used by utilities to provide their employees the practical technological management skills relating to conventional electric power systems that are needed for running electric utilities.) Another candidate set of homes for institutes are the industrial consortia organized to promote technological innovation by these industries — such as CTC (*Centro de Technologia Copersucar*), the technology center established by Copersucar, the Brazilian trade organization of sugar/alcohol producers in the State of Sao Paulo.[15]

In very large countries (e.g., China, India) more than one training institute might be established for a particular RET. In regions involving many small countries (e.g., Africa), a single institute might serve several countries.

Much of the needed targeted research relating to RETs might be carried out at these training institutes or in close collaboration with activities at these institutes.

Eventually, these institutes could become fully or largely self-supporting. Support could be solicited both from local industrial firms and from foreign firms involved in industrial collaborations. GEF resources could be very helpful in their establishment, however.

If GEF support for RET technological and institutional demonstration projects is complemented by assistance for RET policy development in developing countries plus support for these ancillary targeted research and training activities, the prospects would be greatly enhanced that successful GEF projects would lead to the growth of new renewable energy industries in the developing world.

15 The CTC is supported by its members, who pay to the CTC 0.2% of the total value of the sugar cane delivered to sugar mills.

Appendix: Stap Recommendations to the GEF for Targeted Research Priorities Relating to RETs

As part of its review of the status of RETs (STAP, 1996a), prepared as a response to an October 1995 request from the GEF Council, STAP recommended the following as priorities for targeted research relating to RETs that would be supportive of the GEF Operational Strategy. The recommendations consist of priorities in three categories: one for generic targeted research that is relevant across operational programs and two for the GEF operational programs that involve RETs.

All STAP recommendations for targeted research relating to RETs can be characterized as activities that would increase understanding of: (i) the opportunities offered by and potentials for reducing GHG emissions via alternative RETs, (ii) secondary benefits and adverse impacts of alternative RETs, (iii) the barriers to introducing RETs, and (iv) how to identify and articulate measures that could be effective in removing those barriers.

The initial GEF operational programs in the climate change focal area involving RETs are:
Operational Program #6 (Promoting the adoption of renewable energy by removing barriers and reducing implementation costs) and Operational Program #7 (Reducing the long-term costs of low GHG-emitting energy technologies).

Recommendations for Generic Targeted Research

For all promising RETs, priority should be given to: (i) studies aimed at redesigning technology packages to adapt to local conditions (e.g. reoptimizing the mix of labor and computer control technologies for imported technologies; assessing the prospects for cost-cutting via local equipment manufacture); (ii) assessments of the prospects for cost-cutting via organization learning, realization of scale economies in production, and technological improvements for each technology; (iii) analyses of alternative institutional mechanisms for inducing involvement of indigenous and foreign industrial firms; (iv) analyses of ancillary benefits and potential adverse impacts of the adoption of these technologies; (v) studies on the economic valuation of intermittent renewable electric renewable supplies at alternative levels of penetration of electric grids, both without and with electricity storage;
(vi) policy analyses aimed at better understanding the barriers to the dissemination of these technologies and the merits of alternative policies for overcoming these barriers; and (vii) lifecycle analyses of the GHG emissions characteristics of the technologies.

Recommendations Relating to Operational Program #6

Targeted research priorities that would support the GEF program aimed at promoting the adoption of RETs by removing barriers and reducing implementation costs include: (i) development of standardized atlases for renewable energy resources (wind, solar, biomass) in areas where such resources are suitable for development; (ii) supporting the establishment of a "model" institutional base for continually upgrading these atlases; (iii) development of standardized methodologies for the economic valuation of intermittent renewable electricity at alternative levels of penetration on electric grids; and (iv) regional assessments of prospects for and competition among a wide range of small-scale biomass, hydro, PV, and solar heating technologies for heating, mechanical power, and electric power in domestic, rural industrial, and agricultural applications.

Recommendations Relating to Operational Program #7

Targeted research priorities that would support the GEF program aimed at reducing the long-term costs of RETs include (i) for wind: development of atlases for geographically specific energy storage systems [e.g., compressed air energy storage and pumped hydroelectric storage] for regions where electrical storage is needed to bring large remote wind resources to market cost-effectively, via long-distance transmission lines; (ii) for biomass: development of regional models and analyses to help clarify the potential for land-use competition posed by biomass energy farms (e.g., with food production, set-asides for protecting biological diversity, other uses); development of regional inventories of degraded land areas that are candidates for the establishment of biomass energy farms; and experimental research aimed at restoring degraded land to energy farm quality; (iii) for PV: developing low-cost techniques for measurements on a utility subsystem-by-subsystem basis of the value of photovoltaic systems in distributed grid-connected applications; (iv) for solar thermal: quantification of the market potential as a function of technology cost levels, by region, and over time for solar thermal technologies in all categories — low temperature heat, high temperature process heat, electricity generation, and synthetic fuels production.

References

Ahmed, K., 1994: Renewable Energy Technologies: A Review of the Status and Costs of Selected Technologies. Technical Paper Number 240, Energy Series, World Bank, Washington, DC, 169 pp.

Bloom, D.E., 1995: International public opinion on the environment. Science, 269, 354-358.

Brennand, T., 1996: Concessions for Windfarms: A New Approach to Wind Energy Development. Report prepared for the Energy Strategies and Technologies Working Group of the China Council for International Cooperation on Environment and Development, Beijing, China, August.

Cavallo, A., 1995: High capacity factor wind energy systems. Journal of Solar Engineering, 117, 137-143.

Chantramonklasri, N. 1990: The development of technological and managerial capability in the developing countries. In: Technology Transfer in the Developing Countries [Chatterji, M. (ed.)]. The Macmillan Press, Ltd., Houndsmill, Hampshire, and London, England, pp. 36-50.

Clement-Jones, R., J. R. Mercier, 1995: Towards a Renewable Energy Strategy for Sub-Saharan Africa: Phase 1: Photovoltaics Applications. Paper No. 9. Environmentally Sustainable Development Division, Africa Technical Department, World Bank, Washington, DC.

De Laquil, P., D. Kearney, M. Geyer, and R. Diver, 1993: Solar-thermal electric technology. In: Renewable Energy: Sources for Fuels and Electricity [Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams (eds.)]. Island Press, Washington, DC, pp. 213-295.

Elliott, P., and R. Booth, 1993: Brazilian Biomass Power Demonstration Project. Special Project Brief, Shell International Petroleum Company, Shell Centre, London, England.

Fisher, J., 1974: Energy Crises in Perspective. John Wiley and Sons, New York, NY.

Heidarian, J., and G. Wu, 1994: Power Sector Statistics for Developing Countries (1987-1991). Industry and Energy Department, World Bank, Washington, DC.

IEA (International Energy Agency), 1995: Energy Policies of IEA Countries: 1994 Review. OECD, Paris, France.

IPCC (Intergovernmental Panel on Climate Change), 1966 Working Group II: Impacts, Adaptation and Mitigation Options, Chapter 19: Energy supply mitigation options. In: Second Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T., M.C. Zinyowera, and R.H.Moss, (eds.)]. Cambridge University Press, Cambridge, England, and New York, NY.

Jenkins, A.F, R.A. Chapman, and H.E. Reilly, 1994: Tax Barriers to Four Renewable Electric Generation Technologies.

Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams, 1993a: Renewable fuels and electricity for a growing world economy: defining and achieving the potential. In: Renewable Energy: Sources for Fuels and Electricity [Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams (eds.)]. Island Press, Washington, DC, pp. 1-71.

Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams (eds.), 1993b: Renewable Energy: Sources for Fuels and Electricity. Island Press, Washington, DC, 1160 pp.

Johansson, T. B., R.H. Williams, H. Ishitani, and J. Edmonds, 1996: Options for reducing CO2 emissions from the energy supply sector. Energy Policy (in press).

Kassler, P., 1994: Energy for Development. Shell Selected Paper, Shell International Petroleum Company, London, England, November, 11 pp.

Lew, D.J., R.H. Williams, S. Xie, and S. Zhang, 1996: Industrial-scale wind power for China. Report prepared for the Working Group on Energy Strategies and Technologies of the China Council for International Cooperation on Environment and Development, Beijing, China, August.

Masters, C.D., E.D. Attanasi, and D.H. Root [U.S. Geological Survey, National Center, Reston, VA], 1994: World petroleum assessment and analysis. In: Proceedings of the 14th World Petroleum Congress, Stavanger, Norway, John Wiley and Sons Ltd.

Mitchell, C., 1993: The financing of renewable energy in the UK. Proceedings of the Conference on Energy and the Environment in the South West, Camborne School of Mines, Cornwall, England, 13-15 April.

Mitchell, C., 1995: The renewables NFFO: a review. Energy Policy, 23 (12), 1077-1091.

OECD (Organization for Economic Cooperation and Development), 1994: National Accounts: Main Aggregates. Vol. 1. 1960-1992. Paris, France.

Schramm, G., 1990: Electric power in developing countries: status, problems, prospects. Annual Review of Energy, 15, 307-333.

Schramm, G., 1993: Issues and problems in the power sector of developing countries. Energy Policy, 21 (7), 739-.

STAP (Scientific and Technical Advisory Panel), 1996a: Outlook for Renewable Energy Technologies, Strategic Considerations Relating to the GEF Portfolio and Priorities for Targeted Research. Report prepared by the Scientific and Technical Advisory Panel of the Global Environment Facility, Nairobi, Kenya, September.

STAP (Scientific and Technical Advisory Panel), 1996b: The STAP Workshop on Stimulating Private-Sector Initiatives for Accelerating the Introduction of Renewable Energy Technologies into the Power Sectors of Developing Countries. Report prepared by the Scientific and Technical Advisory Panel of the Global Environment Facility, Nairobi, Kenya, September.

STAP (Scientific and Technical Advisory Panel), 1996c: International Industrial Collaboration for Accelerated Adoption of Environmentally Sound Energy Technologies in Developing Countries. Report prepared by the Scientific and Technical Advisory Panel of the Global Environment Facility, Nairobi, Kenya, September.

WEC (World Energy Council) Commission, 1993: Energy for Tomorrow's World. St. Martin's Press, New York, NY, 320 pp.

WEC (World Energy Council), 1994: New Renewable Energy Resources?A Guide to the Future. Kogan Page, London, England, 391 pp.

Whipple, C.G., 1996: Can nuclear waste be stored safely at Yucca Mountain? Scientific American, 274 (6), 72-79.

Williams, R.H., 1995: Making R&D an Effective and Efficient Instrument for Meeting Long-Term Energy Policy Goals. Directorate General for Energy (DG XVII), European Union, Brussels, Belgium, 19 June, 59 pp.

Williams, R.H. and G. Terzian, 1993: A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology. PU/CEES Report No. 281, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ, 47 pp.

World Bank, 1995: World Development Report 1995, Washington, DC.

WRI (World Resources Institute), 1994: World Resources 1994-95: People and the Environment. Oxford University Press, New York, NY.

Nations Development Programme
xecutive Coordinator
nited Nations Plaza
rk, NY 10017 USA
one: 1-212-906-5044
212-906-6998
first name.last name@undp.org

Nations Environment Programme
nit/UNEP
Kenya
one: 254-2-621-234
4-2-520-825
first name.last name@unep.org

rld Bank
Environment Division
Street, NW
gton, DC 20433 USA
one: 1-202-473-1816
202-522-3256
firstnameinitiallastname@worldbank.org
worldbank.org)

GEF

Global Environment Facility, 1818 H Street, NW Washington, DC 20433 USA
Telephone: 1-202-473-0508 Fax: 1-202-522-3240/3245

Printed on recycled paper