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Financing Solar Energy Development

Financement du développement de l'énergie solaire

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Financement du développement de l'énergie solaire

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FINANCING SOLAR AND RENEWABLE ENERGY DEVELOPMENT

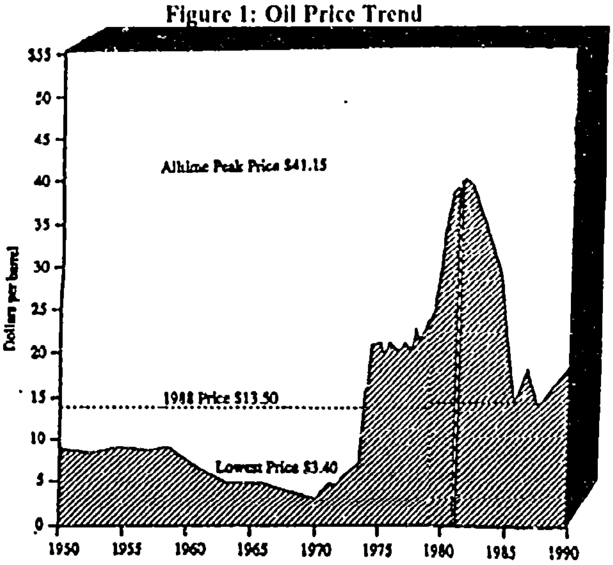
by Ernesto N. Terrado

Introduction

Twenty years after the first UNESCO conference in Paris on new and renewable sources of energy (NRSE) development, the mobilization of financial resources for this field remains a difficult problem worldwide. A large part of the problem stems from the very meager achievements realized during the period. It is important to understand this experience before any discussion of financing approaches can be made.

In 1973, global fears of an energy supply crisis caused by the sudden jump in oil prices mobilized substantial international funding for renewable energy development. For several years after that, various research, development and demonstration activities were conducted under national programs in NRSE financed mainly by bilateral and other external sources of funds. But the situation changed rapidly in the 80s, as international interest in NRSE rapidly waned.

Figure 1: Oil Price Trend



Source: Odell (1991)

The change of heart was brought on by a number of factors, the most important being the unexpected decline in oil prices. After a fivefold increase between 1972-83, international oil prices dropped precipituously so that by 1987, they were again roughly at about the *same level, in real terms*, as in 1972 (See Figure 1). The softening of oil prices had two major effects on renewables. Firstly, it made uneconomic various NRSE options then being developed that could compete directly in the modern sector as relatively large-scale petroleum substitutes. These included, among others, fuel alcohol projects, dendrothermal power plants, "wind farms" for electriciy generation and industrial-scale solar water heating systems.[1] The World Bank's first loan to the Brazilian alcohol program, for example, was made when oil price was over US$30 a barrel. The second loan made in 1983 was when oil price was about $29 a barrel and projected in the appraisal report to rise to $38 by 1995. At present international oil prices of about $18 a

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[1] Terrado, *et al* "Impact of Lower Oil Prices on Renewables", Energy Dept Working Paper No. 5, The World Bank (1988). Note that since the economics of NRSE applications are extremely site-specific, some projects in this list may still be viable in their particular context.

barrel, the Brazilian fuel alcohol program could only be marginally justified, at best. The Government, in fact, has suspended further expansion in fuel alcohol distilling capacity.

The second negative impact on NRSE by the drop in oil prices was that it gave the *perception* that oil was again cheap and plentiful and that there was no need to examine other less familiar fuel options. This perception was reinforced by unfulfilled expectations about NRSE technologies. The rush to commercialize NRSE applications during the period raised public expectations to unrealistic levels. Technologies which were not commercially ready, by reason of economics or technical status, were prematurely deployed in large national programs and propped up with subsidies. Notable examples include the "dendrothermal" power program in the Philippines and the biomass gasifier programs in Thailand and Indonesia[2]. Today, with very few exceptions, "national NRSE programs" in developing countries are little more than token gestures. Political support has waned. In the Philippines, for example, the nonconventional energy development program had a gross appropriation of 10 million pesos (for Grants-in-Aid projects) when it was created in 1978. By1992 the budget had declined to only 2.4 million pesos[3].

Data on annual financial expenditures for NRSE worldwide are not easy to monitor, partly because of disgreements on what to include[4]. Indications of the downward trend for NRSE funding, however, can be gleaned from the energy research, development and demonstration (RD &D) budgets of International Energy Agency (IEA) countries from 1979-90.

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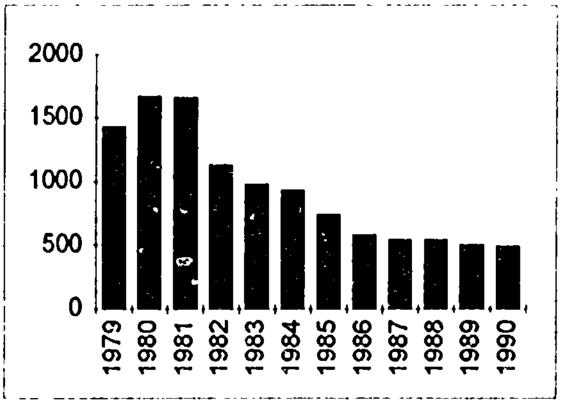
[2] The Philippines' dendrothermal power program launched in 1979 was based on the integration of a wood-burning power plant with managed plantations of fast-growing trees. While the concept was sound, political considerations rushed large-scale deployment too quickly. System failures mainly on the biomass production side doomed the program. In Thailand in the 1980s, a biomass gasifier program aimed to deploy 4000 units to supplement rural electrification. Only 140 of the 15 kW systems were actually built and none operated satisfactorily.

[3] Philippines Office of Energy Affairs data (1992)

[4] The UN's official definition of NRSE includes, among others, large hydro, fuelwood and charcoal. Large hydro has been a commercial technology since decades ago and does not require further development attention. Fuelwood and charcoal, while important in most developing countries, are associated with issues that are entirely different from "regular" solar or wind technologies.

Figure 2. RD&D Budget Allocations for NRSE of IEA Countries, 1979-90
US$ Million



Source: OECD(1991) as reported in UN A/AC.218/1992/5/Rev.1

Some Gains

The few real gains during the period were probably in technology development in theWest. In the United States, tax incentives extended during the late seventies enabled the commercial operation of large windfarms and solar thermal power plants in California. These led to substantial technology improvements in both systems and components, and to valuable operational experience by the utilities[5]. Competition on photovoltaics gave rise to new manufacturing techniques and caused a dramatic drop in PV prices, from a high of US$30-70 per peak watt in the early 70s to only about $5-7 (retail) today.[6]. Related to this were significant advances in the design of cheaper, more efficient PV-driven pumps, lights and refrigerators. Wind machines were developed that could start operating at lower wind speeds and therefore were more economical. Unfortunately, these reductions in technology costs, while significant, still have not reached levels that would make them immediately competitive in the marketplace. For instance, at current energy prices, PV costs would have to drop further to the order of $1 per peak watt before they can offer competition to conventional fuels in average situations[7].

For the developing countries, some gains were made in identifying "niche" applications, i.e., those that are already economic and practical. However, the niches were

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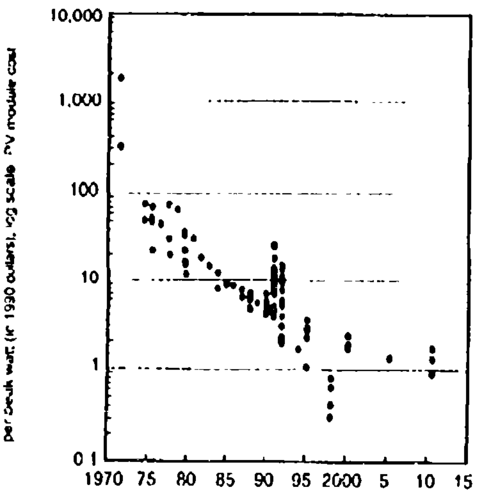
[5] In 1991, however, Luz, the major solar thermal power company, declared bankruptcy. This was caused by a combination of factors, the most important being the reduction or withdrawal of Federal and local tax incentives, and the drop in the price of natural gas to which solar energy sales were linked (Lotker, 1991).

[6] Reliabilities were also significantly improved. In early 1993, Solarex announced extension of the warranty on PV modules to 20 years or double the previous industry standard.

[7] The discussion excludes already commercial PV use in calculators, watches and telecommunication devices.

small. For example, PV for lighting is already least cost in many remote area applications, as the availability and cost of conventional alternatives become prohibitive with distance from central supply sources. The problem is that most developing countries, for lack of investment resources, do not have a *policy* of electrifying remote areas. There is not even adequate funds to electrify many towns and villages close to the grid. Thus almost all PV electrification projects that have been implemented in the developing countries were financed almost entirely by external donors.

Figure 3
Photovoltaic module costs



Source: Kulsum Ahmed (1993)

In the last decade or so, valuable insights have also been obtained on the non-technical prerequisites of NRSE operations, including the institutional, financing and after-sales service arrangements must be in place for projects to have any chance of success. The lessons learned, however, were sometimes not universally applicable. In the Pacific islands, for example, several years of trying out various institutional approaches to implementation of PV electrification projects found that the most successful ones are those in which the PV systems are owned, installed and periodically maintained by a cooperative, which also handles fee collection[8]. A similar arrangement is being tried in some islands in the Philippines but, so far, success by way of a self-sustaining operation of a PV cooperative has been elusive. Perhaps the most notable accomplishment in developing countries has been in manpower resources development : clearly there are now more people with NRSE expertise both in Government and in the private sector in these countries than two decades ago.

Global Environment Concerns

The most important "break" for renewable energy development, in the view of many, are the recent global agreements to protect the global environment. The agreements have set aside substantial funds to finance projects that would massively reduce greenhouse gas emissions. There would be more conscious accounting of the environmental costs of conventional energy projects, even as more active efforts are mounted to develop backstop technologies, primarily NRSE. Although investments in more conventional activities such as energy conservation can also reduce greenhouse gases, carbon accumulation considerations under a global warming scenario imply that the long term goal should be to replace *all* fossil fuel burning. The Global Environment Facility (GEF), established under these agreements and administered by the World Bank, is now financing investment projects in pursuit of this goal. But GEF resources, while large, are at present still only a fraction of total official development assistance funds.

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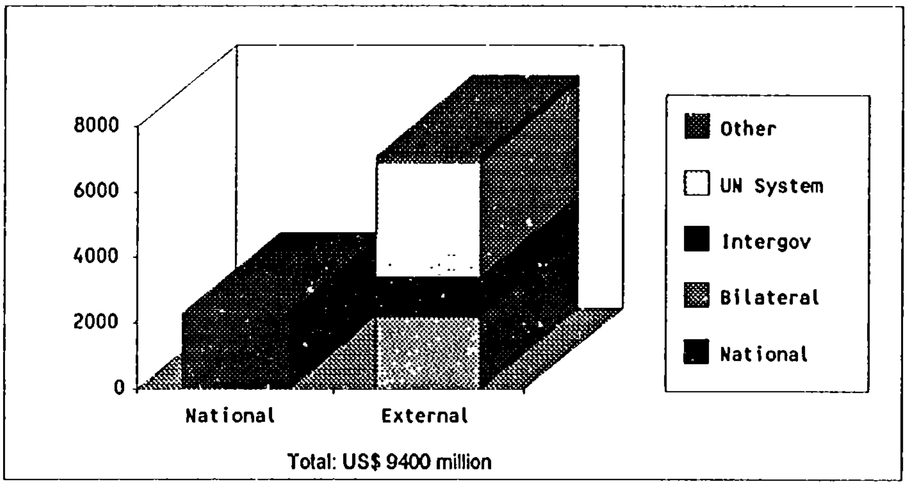
[8] Wade, H., "Photovoltaic Project Development", South Pacific Institute for Renewable Energy, Tahiti (1990)

Therefore, the argument is being made that GEF funds should be primarily allocated to investments in clean technology projects that are presently uneconomic by conventional criteria.[9] It is clear that these considerations effectively enhance the availability of financing resources for NRSE.

Financing Issues

Financing of NRSE activities in developing countries has always been largely provided by external sources. Data collected by the UN show that for the period 1980 to 1987 about three quarters of the total $9.4 billion expenditures in NRSE research, development and demonstration were obtained from bilateral agencies, intergovernmental agencies and the United Nations system.

Figure 4. Funding Sources for NRSE in Developing Countries 1980-87



Source: UN A/AC.218/1992/5/Rev.1
Note: Excludes large hydro but includes geothermal, fuelwood and energy conservation

Of the $ 3.5 billion provided by the UN system in that period, the bulk is due to World bank lending. However, although lending for large hydropower projects were already subtracted from the figures, they include a variety of other areas, such as geothermal energy, fuelwood, energy conservation and energy planning. It is clear that compared to these more "mainstream" areas, the resources expended for solar, wind and biomass technologies have been small.

It is useful to distinguish between financing issues for RD&D and for commercialization projects in developing countries. Lending institutions such as the World Bank rarely provide financial support for RD &D. In any case, most developing country

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[9] Anderson, D. and Williams, R., Background Paper for the GEF, World Bank (1993)

governments are not keen on borrowing money for RD &D purposes, relying instead on grant funds from bilaterals and UNDP.

Prior to GEF, if one excludes lending for fuelwood/forestry and large hydro projects, the World Bank had only one free-standing loan in renewable energy, the $500 million loan to Brazil described earlier for its power alcohol program in the 1980s. For "other renewables", the Bank did finance a few small hydro projects, including some financing to the private sector for manufacture of renewable energy equipment in the eighties by the Bank's affiliate, the International Financing Corporation (IFC). Bank financial support for solar, wind and biomass technologies other than fuel alcohol took the form mainly of financing pilot activities that borrower governments requested to be included as *components* of larger energy or agriculture projects. Several factors account for this situation. First, for intended commercial NRSE projects, the technologies often did not meet standard Bank criteria for economic and financial feasibility. Even in the few cases where the feasibility figures looked adequate, because of the newness of the applications, performance track records for the technologies in question were not available Finally, it was difficult to design NRSE projects large enough for conventional Bank operations work. Aggregating or "bundling" a large number of small decentralized NRSE subprojects to create the desired scale simply raised the problem of carrying out too many subproject appraisals that Bank project staff could not handle.

It is instructive to discuss briefly the structure of the most recent free-standing Bank lending for NRSE, the $430 million India Renewable Energy Project approved in 1992. The three specific renewable energy applications in that project were first identified in a Bank review of India's nonconventional energy program[10]. The small hydro and wind farms investment possibilities were then separately studied to bring the data and information as close as possible to appraisal stage[11]. The resulting overall project consists of three NRSE subprojects--small hydro, wind farms and solar PV-- and one subproject for a paper mill expansion to use bagasse. The small hydro component, at a total cost of $94 million, would develop 40-50 of grid-interconnected small hydro schemes totaling 100 MW in existing irrigation canals and dams in 4 states. The schemes would install turbo-generators of 500kW to 5 MW capacity for a maximum capacity of 15 MW per station, taking advantage of existing patterns of irrigation discharges and therefore reducing civil works cost. The economic internal rates of return (EIRR) for each of the schemes range from 12% to 41%, all above the discount rate, reflecting the maturity of this technology.

The wind farms component, costing $105 million, would finance private sector proposals up to an aggregate of 70 MW in 4 states confirmed as having good wind regimes. The individual wind farm sizes, locations and feasibility assessment would be the responsibility of the private investor who would own and operate the machines. The major incentive for the private investor, who is expected to provide at least 25% of the project

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[10] India: Opportunities for Commercialization of Nonconventional Energy Systems, ESMAP Report 091/88(1988)

[11] India: Minihydro Development on Irrigation Dams and Canal Drops, ESMAP report 139/91 (1991); India: Windfarms Preinvestment Study, ESMAP Report 150/92(1992).

costs as equity, is the income tax relief from accelerated deprecation allowed for his investment. The EIRR is estimated to be between 5-10% depending on whether the comparator is coal-based power or captive diesel generation.

The solar photovoltaic component would establish a marketing and financing program to support the delivery of solar lighting systems in 4 states estimated to have a total market potential of 80 MWp. The main demand is expected to be for two- and four-light syatems in the commercial sector and for 100-households village electrification schemes. Although the PV module costs are assumed to be U$5 per peak watt in 1992 and US$3.50 by 1997 (in 1992 dollars), the EIRR for this component ranges from only 1.3 to 3.3%.

The project illustrates the powerful catalytic role that GEF can play in pushing high risk, large-scale renewable energy projects into the investment stage. Table 1 below shows the financing plan for the project:

Table 1. Financing Plan for India Renewable Energy Project, US$ million

	IBRD	IDA	GEF	Bilateral	Investor	IREDA	IDBI	Total
Small Hydro		70			24			94
Wind farms			13	50	26	16		105
Solar PV		30	8	4	13			55
Paper mill	75				67		28	170
TA			5			1		6
TOTAL	75	100	26	54	130	17	28	430

Source: Staff Appraisal Report, World Bank (1992)
Note: 1) Bilateral donors are DANIDA ($50 m) and Switzerland ($4 million).
2) IREDA: Indian Renewable Energy Development Agency

It is seen that the wind farms and solar PV components benefit from substantial grant co-financing from GEF, $13 million and $8 million, respectively[12]. This subsidy has the effect of raising the EIRRs of the wind farms and solar PV subprojects to over 12%. The subsidy was justified in the appraisal report in terms of the projects demonstration benefits and the displacement of greenhouse gases at relatively low cost per ton. Several other selected NRSE projects designed in a similar vein are in the current portfolio of the GEF, including a commercial solar water heating project in Tunisia and a bagasse cogeneration project in Mauritius.

Conclusions

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[12] While the bilateral grant contribution for the windfarms project is even larger than the GEF contribution, it is likely this would not have been extended without the World Bank/GEF involvement.

Conclusions

The technology advances achieved in the last 15-20 years, while important, have not yet reduced costs to levels that would enable NRSE to compete in the energy markets; these achievements do not in themselves constitute a strong argument for renewed efforts in this field. Except for "niche" applications, there is not much to show for the expenditures of the last twenty years. It is the recent emergence of strong global consensus to protect the environment that provides a new and powerful impetus to renewable energy development. The plea to support RD&D to reduce technology costs, gain operational experience and achieve widespread commercialization has been heard before: these *were* the justifications for most failed NRSE work in the past. While they are still the goals for renewable energy development work today, there is an important difference that needs to be pointed out. What *are* new today are the recognition of the threat of global warming *and* a resolve to address that threat, as evidenced by the contribution of substantial resources to the GEF. NRSE technologies emerge almost by default as the most desirable energy options for the future. It is abundantly clear that there is need not only to continue but to accelerate their development .

Aside from opening up a new source of funding for NRSE, the entry of GEF into the picture has other important advantages for renewable energy development. First, it enables the attainment of a "critical mass" to NRSE projects that previously were carried out as small dispersed activities, not only by virtue of the GEF funds themselves but by the leveraging effect with bilateral and multilateral investment funds. Second, when executed as part of the lending process of multilateral agencies such as the World Bank, the NRSE project receives the same systematic preparatory attention and appraisal as conventional projects, including putting in place the prerequisite policy and institutional framework in the client countries. Third, as a result of this arrangement, an increasing number of conservative task managers used to handling only conventional energy projects become educated (even if reluctantly at first) in the difficult and novel area of renewable energy project design and implementation.

With this new opportunity must be sounded a call for prudence. The availability of grant co-financing for investment projects that otherwise would not have been economic does not guarantee the attainment of project objectives and it is important to be highly selective in project choices. While demonstration projects can lead to significant reductions in capital costs of renewable energy equipment in the future, whether and when this will actually occur is difficult to predict to any degree of certainty. Capital subsidies from grant funds justified on environmental grounds could be used to "kick start" an NRSE project but *sustainability* must be a major consideration when designing such projects. This means ensuring, to the extent possible, that, to begin with, the technical feasibility of the project is real and that the project can continue practical operation even if the expected spin-off benefits do not materialize.

The role of funding from bilateral and UN agencies remain crucial, even though they are generally not investment oriented. Bilateral funds, however, should become less tied to the needs of the donor countries (e.g., the need to market certain solar energy equipment) and more to the priorities of the recepient countries. Many "donor-driven" projects in the past have contributed to the proliferation of inoperational, inappropriate technologies littering the landscape of developing countries. One of the important findings by NRSE donors during the past two decades was that the institutional and policy framework for the implementation of renewable energy projects is generally weak in developing countries; the need in most cases has been for more intensive preinvestment work rather than investments. Technical assistance to developing countries for training, institution building and preinvestment studies must continue to be carried out in parallel with the larger investment activities. In addition, as was shown in the World Bank's India renewable energy project, bilaterals now have new opportunities to leverage their assistance funds into large co-financed investment schemes with GEF and regular loan funds.

For the developing countries who would certainly benefit from early commercialization of NRSE applications, there are a number of important supporting actions to implement. Firstly, they should make a greater effort to adopt rational energy pricing policies that enables a fairer assessment of the near term possibilities for NRSE. For example, a World Bank review of tariff levels in 63 developing countries for the period 1979-1988 showed a marked deterioration in tariff levels such that by 1988 they averaged only about half of the estimated economic cost[13]. Such distorted pricing policies reduce opportunities for NRSE alternatives by discouraging private investments. (There is need, in fact, to do similar studies on the true costs in developing countries of diesel, fuel oil and other conventional fuels that renewables normally must compete with). Secondly, they should review and revitalize their ongoing national NRSE programs that, in most cases, now have obsolete goals, are excluded from regular energy planning exercises and are given little budget support. GEF and other externally financed NRSE projects will undoubtedly multiply in the coming years. Their successful execution will be highly dependent on the absorptive capacity of developing countries for this type of work.

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[13] World Bank, "Review of Electricity Tariffs in Developing Countries during the 1980s", Energy Dept Series Paper No. 32 (1990).

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FINANCING RENEWABLE SOURCES OF ENERGY: DO ENVIRONMENTAL REASONS JUSTIFY THE ECONOMIC COSTS OF DOING SO?

By

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I. Introduction

With increased attention in recent years to the environmental consequences of energy use arising from global warming concerns, the role of renewable energy sources of energy (RSE) in reducing climate impacts has revived discussions to promote RSE consumption.[2] And yet most of these revivals appear to emanate from quarters that have traditionally promoted RSE rather than from a more global spectrum. An example of the cool reaction from non-traditional RSE analysts is the set of papers presented at the 1992 International Conference of the International Association for Energy Economists in Tours, France (IAEE, 1992). No special session was devoted to the topic, only four papers specifically addressed problems related to a renewable resource, two were on hydropower, and all papers dealt with developing countries.

While it is true that a case may be made for refocusing on the increased role that renewable energy sources may play in addressing global climate problems, RSE projects are not necessarily environmentally benign (see Appendix A). Furthermore, when viewed from an overall resource allocation perspective, financing RSE projects may face both microeconomic and macroeconomic drawbacks that environmental issues alone may not justify. At issue are the opportunity costs not only to the private investor where financing is concerned, but also to a country where the allocation of the national economy's resources are evaluated. The linkages of decisions taken with respect to any spending must be evaluated with respect to their impacts on the rest of the energy sector as well as to the rest of the economy of providing financial incentives to promote RSE projects. In other words, even if it may be the "least cost" option, it may not be economically justified (see Figure 1) in a capital-short economy.

In this paper we will raise these resource allocation issues without attempting to provide answers -- since these questions may only be answered in most cases on a case-by-case basis. These questions will also be raised in the context of the capital resources available to developing countries. Nuclear power issues will be referred to but not included in most discussions. Because hydropower

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[1] The views expressed in this paper are those of the author and may not be taken to represent those of the World Bank.

[2] A most recent example is the article of Anderson and Ahmed (1993).

(which is not a new source of energy) is included in the discussion, we use the term "renewable sources of energy" (RSE).

Section II of this paper will discuss issues related to financing RSE projects. It will distinguish between financial analysis and economic analysis, identify likely sources of financing RSE, and summarize issues and problems related to enhancing prospects of financing RSE. Section III focuses on environmental and economic policy issues and draws conclusions. Section IV summarizes the arguments presented.

II. Financing Renewable Sources of Energy

Financial vs. economic viability: definition of terms

In light of the importance of addressing the issue of financing in the proper context,it will be useful to define conceptual boundaries and state the basics that distinguish financial vs. economic viability of RSE projects.

In project analysis, a method is used to evaluate the choice between competing uses of resources. Its elements consists of: (1) a recognition of the existence of several levels of objectives (national, societal, private) and (2) the evaluation of possible alternatives to financing a specific project. It allows assessment of the benefits and costs of using a common denominator. Benefits are defined relative to their effects on fundamental objectives, whether this be at a private investor level (financial valuation) or at a societal level (economic valuation). Costs are defined relative to opportunity costs or foregone benefits.

Financial analysis, also called private cost or commercial market analysis, considers only the private opportunity costs of the investor in a project. Its objective is to maximize private profits or minimize private costs subject to constraints (internal or external to the investor or company). Economic analysis is concerned with the full societal opportunity costs of a project. Its objective is the maximization of social economic welfare gains subject to meeting social goals. It attempts to internalize social values or costs that are not equal to the private or market valuation. Hence, the use of shadow prices.

Since the consideration of RSE for environmental reasons involves the social domain rather than the private or market sphere, analysis of an RSE project from a policy perspective will be based on the economic analysis of the viability of these projects.

Financial vs. economically viable projects

Renewable energy sources range from solar energy to biomass and various methods of harnessing geothermal, wind, and tidal energy. Their uses may be in the household and transportation sector in direct (e.g., wood burning) as well as indirect ways (e.g., ethanol or methanol, electricity). Figure 2 provides a graphic illustration of solar energy systems. The categories usually seen in the literature are shown in Table 1; this system links technologies to four stages of "economic" feasibility, i.e., commercial or financial viability: "economic", commercial-with-incentives (i.e., with help), under development, and future technologies. To discuss issues in financing, however, Feinstein

(1988) identifies three categories of renewable energy: (i) high-capital intensity but low (stable) levels of technology, (ii) high capital combined with high (and changing) technology; and (iii) low capital intensity with low level technologies. These are summarized in Figure 3. We will return to these groupings as the discussion progress.

How are energy projects financed?

There are two main ways of financing any project, including RSE: with equity capital or through borrowing. Equity may be externally generated private capital, supplemented by internally generated cash flow domestically or through transfers in transnational vertically integrated operations. "Project financing" involves relatively high debt-to-equity ratios. Figure 4 lists several possible sources of financing renewable energy projects.

Whether funded through equity or borrowing, the commercial viability of a project will depend on the investor's estimates of returns to investment, i.e., its economics or profitability. The economic assessment of a privately financed project includes the incorporation of risk as a discount factor in net profit calculations.[3] Although distinguishable in the the degree of opportunity of loss, for current purposes the concepts of risk and uncertainty will be used interchangeably.[4] By affecting the discounting process and the time frame for recovering investments, perceptions of risk affect the net benefit/cost relationships for the private investor. This is usually referred to in the comparisons of applicable cost curves, whether short-term or long-term marginal cost curves are used.[5] RSE projects are viewed in terms of the short-term cost curve in light of the shorter investment recovery periods associated with them.[6]

In the case of RSE, commercial risks are perceived to be higher in Feinstein's Categories 2 (hi-capital, hi-tech) than in Category 1 (hi-capital, low tech); see Figure 3 again. The problem of commercialization and the absence of large market for renewable energies seriously affects perceptions of risks. Hence, manufacturers or RSE technology focus on a shorter payback period. By doing so, they are viewed as calculating net returns on the basis of short-run marginal cost (which is higher than short-run average cost) whereas power utilities, by virtue of calculating investments over a longer time frame, calculate net returns on the basis of long-run marginal costs (see footnote 5). It also means that many of the technologies shown in Figure 2 -- which rely heavily on the traditional forms of project financing (i.e., equity or private borrowing) -- would face financing

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[3] The risk-adjusted discount rate of an investor may be expressed as follows: $i = r + k$, where i = the risk-adjusted rate of interest facing the invetor; r = the risk-free discount rate; and k = a constant related to the investor's degree of risk preference or aversion and to uncertainty related to commerical or non-commercial risks. See Siddayao (1980).

[4] "Risk" is distinguished from "uncertainty" in the degree of the opportunity for loss; the term "risk" refers to an opportunity for loss, wheeas the term "uncertainty" may be applied to "factors where the outcome is not certain but where the opportunity for loss is not as apparent as in risk". See Megill (1988).

[5] Some authors refer to the relevant cost curve facing the utility as the average cost curve (AC), rather than the long-run marginal cost curve (LRMC) (e.g., Foell et al. in Siddayao (1993)). This is conceptually correct under restrictive conditions. The long run marginal cost curve is equal to the long-run average cost curve in a competitive economy.

[6] See, for example, Foell et al. (1993) and Anderson and Ahmed (1993).

problems that are sensitive to the prices of conventional energy and the fiscal incentive regimes. In Figure 5 Feinstein (1988) conceptualizes graphically how differences in valuation (i.e., private market vs. social valuation) affect financing of projects; a broad association is shown between the private vs. social worth of projects and the type of institutions that will finance them.

Although the sources for renewable energy financing continue to be basically those listed in Figure 4, two new sources of financing energy sources are worth mentioning.[7] The first is the Global Environment Facility (GEF) is a three-year pilot program aimed primarily at assisting developing countries in reducing greenhouse gas emissions, among others (see Figure 6). It was set up to provide the opportunity to test and develop renewable technologies in the developing countries by financing the incremental costs on projects with global environmental benefits. The US$1.5 billion facility is a cooperative venture between the national governments of developing countries, the World Bank, the United Nations Environment Programme (UNEP), and the United Nations Development Programme (UNDP). Some of the renewable projects included within the Global Warming allocation are: gasification of wood chips and sugarcane bagasse for power generation in modern gas turbines in Brazil, photovoltaics for household and community use in India and Zimbabwe, wind and photovoltaic power projects in Costa Rica and India, and optimizing the development of small hydro resources in the hills of India. In a recent speech to the U.S. Congress, former World Bank Vice President for Development, Lawrence Summers noted that, "in less than two years, the GEF has become the most important international mechanism for funding global environmental programs in developing countries" (Summers, 1993).

FINESSE (Financing of Energy Services for Small-Scale Energy-Users) is another new initiative. It is sponsored by the World Bank, the U.S. Department of Energy and the Netherlands DG for International Cooperation. Among its objectives are the promotion of "technologically efficient and cost-effective energy systems in developing countries" and the focus is specifically on small-scale users in the ASEAN countries. Among the projects for renewable energy development is a small hydropower project in the Philippines.

Multilateral agencies are instrumental in combining the transfer of capital and technical assistance. Bilateral agencies have instituted new programs to develop renewable energy sources. These programs have generally ben designed to develop, test, and disseminate new technologies for application in developing countries. In the case of RSE projects, variants of the "Hi-capital, Lo-tech" projects will tend to get financed, including small hydro (1-5 MW) projects. Mini-hydro (1000kW to 1MW) and solar water heating will tend to be marginal cases. In general, however, most forms of international transfer are directed to conventional energy projects for reasons that will be dealt with in Section III.

Nonetheless, as Feinstein (1988) notes: "Good" renewable energy projects get financed. These projects generally arise out of coherent national energy plans that: (i) incorporate realistic assumptions and resource assessments; (ii) are solidly based on economic principles of resource allocation and cost-benefit analysis; and (iii) contain investment and follow-up action priorities.

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[7] This paragraph draws from SHP News, No. 1 (1993) and from Anderson and Ahmed (1993).

III. Resource Allocation Issues, Environmental Sustainability, and Providing Financing Incentives for RSE

Ignoring issues under the rubric of "sustainable development"[8] to keep the discussion within the topic chosen, and addressing the more obvious environmental issues, we are faced with energy sources that are not necessarily environmentally benign. Adding to this the fact that most technologies are not cost-competitive with conventional sources of fuel brings us to the issue of financing incentives and their allocative implications. A summary discussion of the major sources of renewable energy, including key economic and environmental issues, is given in Appendix A; a brief presentation of the environmental impacts of RSE from a slightly different perspective is summarized in Appendix B.

Environmental issues

Hydropower is a renewable source of energy that has been with us long before the early 1970s when dramatic increases in oil prices jolted the world and encouraged the search for alternative sources of energy. It is a well proven source of power, its technology is known, and large scale plants are common throughout the world. As will be noted in both Appendices A and B, and more explicitly outlined in Figure 7, hydropower development can have serious environmental consequences. The main environmental impacts are the disruption of river ecologies and theinundation of land under the power reservoirs. Downstream areas are also impacted in various ways, including disruption of lives, established patterns of wildlife, agriculture, fishing, etc.

Biomass, another traditional form of energy, is a renewable source whose development and use require concomittant policies that address related environmental issues. Its environmental disadvantages are generally associated with production and harvesting practices. The continued rapid loss of forests have serious ecological and economic consequences for regions affected by these types of activities as well as on a global scale. Deforestation causes soil degradation, erosion, siltation of reservoirs, flooding, and through a reduced capacity for natural absorption of carbon dioxide could contribute to global warming. Some crops, such as corn as it is currently produced in the United States, require large inputs of energy in the form of fertilizers, operation of equipment, herbicides, etc.; distillation and transportation of ethanol requires other energy inputs, most likely from fossil fuels. After accounting for all energy inputs, the energy balance has been shown to be poor. (See Foell et al. in Appendix A.)

Finizza (1991) observes that mandating large scale sale or use of alternatives to petroleum could result in significant additional costs to the consumer, would degrade the environment more than if reformulated gasoline were used, and would undermine any national ethic that might have developed toward energy conservation as a result of both economic and non-economic factors. Figure 8, which shows the relative levels of greenhouse gas emissions from alternative transportation fuels, demonstrates this point.

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[8] For example, NGOs have reportedly complained that the GEF, as it currently operates, perpetuates current patterns of unsustainable development, e.g., failing to consult local communities or national NGOs so that projects fail to reflect the priorities of the group of people affected. See SHP (1993), p. 33.

The negative environmental impacts of solar photovoltaic cells occurs during the manufacturing process. The exotic inputs required in PV cell fabrication, including toxic and explosive gases, pose a danger to plant workers and the surrounding community if released. Other RSE have either similarly more localized effects and on the whole less serious impacts.

Other forms of renewable energy have more benign, although not negligible impacts on the environment. The ultimate criterion, therefore, for any policy to promote the financing of RSE must lie in an overall evaluation of the relative contribution of RSE to the economic and social development of a country, that is, the net benefit or costs to the society of allocating some of its capital resources to promoting this form of energy, given a particular economy's capital and other resource constraints.

RSE Economics and Project Financing Incentives

Several factors are usually identified as contributing to the failure of RSEs to make their mark in the energy system. This discussion will focus on two economic factors: (1) the pricing structure for energy supplies, including the taxation system, and (2) subsidization of RSE technologies.

To discuss these two factors, we must put RSE in its economic context relative to other energy sources.

Standard hydropower requires large capital investments upfront. Although electricity generated from these projects may be priced economically at rates competitive with other fuel sources, the major commitment of capital for the development of these projects -- which are often located at great distances from the consuming centers -- is unforgiving of errors that may be made in forecasting demand and supply. Once committed, the capital funds invested are "sunk". This does not include consideration of the associated environmental issues already noted. What are the alternatives, given that, as a major alternative to fossil fuels for power generation, hydropower suffers from environmental problems of its own? One can sight several. In many cases, however, the response may be a combination of systems, including both other RSEs and fossil fuels. Net societal costs may not allow ruling out fossil fuels in power generation, with proper environmental controls. (See Schramm, 1993.)

Even with advances and reductions in the per-kilowatt costs of photovoltaic energy, they are still too high for large-scale power generation. Anderson and Ahmed (1993) cite a cost of close to $10,000 "per kilowatt peak" for complete systems (structure, dc/ac converters, etc.). A long-standing problem is the cost of storage, especially in off-grid applications. Photovoltaic systems have a market in remote and "off grid" applications, however, as well as in providing supplementary power on distribution networks of standard power installations.

The problem with biomass may be discussed at two levels: (i) in its traditional use as fuelwood in developing countries; and (ii) in its converted forms for cogeneration in agro-industrial areas, or as liquid and gaseous fuels. The case of the first is usually economically efficient from the user's perspective (private valuation) when the user has no economic alternative; it is inefficient at the societal level for reasons with which most of us are familiar (see Appendices A and B again). We are aware of the arguments associated with fuelwood being a "free good" at worst, or where both suppliers and consumers do not pay the true costs of supply because no formal market exists. We have already raised the issue of the environmental problems associated with indiscriminate practices that lead to deforestation, floods, siltation, etc. Both technical and economic efficiency as well as health arguments have also been raised against fuelwood use for cooking (see, for example, Smith, 1989). There are arguments for seeking alternative fuels to improve energy efficiency as well as economic efficiency in this sector.

Conversion of biomass to liquid and gaseous fuels raises a totally different set of economic issues. Where these fuels have been heavily used, they have been heavily subsidized; Brazil is a well-known case. On the whole, it is not competitive in the oil and gas markets, and the societal costs of a large-scale development of this fuel source would be very high (see Anderson and Ahmed (1993) and Foell et al. (1993) in Appendix A).

Breton and Fitzgibbon (1991) analyze the fuel-cycle costs for each of four alternative transportation fuels. These are shown in Table 2 on a per-unit volume and on a per-MMBTU basis. In the United States, gasoline reformulated to meet the standards of the 1990 Amendments to the Clean Air Act still remains comparable to methanol and gasohol. It would be difficult to provide a widely different cost analysis for any developing country. Put simply, the costs of alternatives are generally very high relative to petroleum products.

One can continue but it appears a picture emerges that makes us conclude that RSEs are not necessarily the economic fuel alternative.

The argument is often made that RSEs are disadvantaged by pricing structures that favor fossil fuels. It is true that petroleum products and electricity are priced below their true marginal costs in many countries. But it would be unwise to perpetuate a distorted pricing structure by adding another distortion in the form of subsidizing RSEs. The answer would lie in correcting what is distorted. It may also be necessary to re-evaluate priorities.

The call for more government subsidization that favors RSEs because it is environmentally benign would need to be addressed at the R&D level but each subsidy will need to be evaluated periodically to prevent it from becoming a permanent crutch for an economically efficient system. Any strategy to make energy production and use more efficient must rely more extensively on markets which are allowed to function properly rather than on government intervention.

Allocative issues in providing financing incentives

It appears that certain questions we once asked as part of energy planning may be asked again in this context:

o At what cost to a country is providing financing incentives to RSEs possible?

o Is capital available to promote the technology? What are the sources? Does the institutional framework exist to attract private capital? What type of investment risks are involved. If public funds are used, should they be allocated for risky projects? Can the supply of funds be sustained throughout the technology development program?

- What is the cost of the economy of controlling environmental impacts generated by technologies, in addition to the costs of financial incentives?

- What is the proper share of public resources that should be allocated to energy activities in general? How much should be allocated to promoting RSE, given other societal needs?

Concluding Remarks

Policy actions, including financing incentives, directed towards encouraging renewables as alternatives to fossil fuels should be guided by the following criteria: energy efficiency, cost effectiveness, and potential for environmental improvement. The foregoing discussion suggests that environmental reasons alone do not automatically justify the promotion of financing incentives for renewable sources of energy, given the potentially high allocative costs involved.

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Table 1. Current Status of Renewable Energy Technologies

Economic (In some locations)

Solar water heaters, replacing electricity, or with seasonal storage and for swimming pools
Solar industrial process heat with parabolic trough collectors or large flat-plate collectors
Residential passive solar heating designs and daylighting
Solar agricultural drying
Small remote photovoltaic systems
Small to medium wind systems
Direct biomass combustion
Anaerobic digestion (of some feedstocks)
Conventional geothermal technologies (dry and flashed steam power generation, high temperature hot water and low temperature heat)
Tidal systems

Commercial-With-Incentives

Solar water and space heaters replacing natural gas or oil
Electricity generation with parabolic trough collectors
Non-residential passive solar heating and daylighting
Biomass liquid fuels (ethanol) from sugar and starch feedstocks
Binary cycle hydro-geothermal systems

Under Development

Solar space cooling (active and passive)
Solar thermal power systems (other than parabilic trough collectors)
Photovoltaic power systems
Large-sized wind systems
Biomass gasification
Hot dry rock geothermal
Geothermal total flow prime movers
Wave energy systems

Future Technologies

Photochemical and thermochemical conversion
Fast pyrolysis or direct liquefaction of biomass
Biochemical biomass conversion processes
Ocean thermal energy conversion systems
Geopressured geothermal
Geothermal magma

Definition of Categories

Economic. Technologies are well developed and economically viable at least in some markets and locations, for which further market penetration will require technology refinements, mass production and/or economies of scale.

Commercial-with-Incentives. Technologies are available in some markets, but are competitive with the conventional technologies only with preferential treatments, so that they still need further development to be economically competitive.

Under Development. Technologies need more R & D to improve efficiency, reliability or cost to become commercial.

Future. Technologies have not yet been technically proven, even though they are scientifically feasible.

Source: IEA, Renewable Sources of Energy, Paris, 1987

TABLE 2. FUEL CYCLE COSTS
(1989 Dollars)

Cost Component	Reformulated Gasoline		Methanol (M85)		CNG		Gasohol (E10)	
	¢/Gallon	¢/MMBtu	¢/Gallon	¢/MMBtu	¢/MCF	¢/MMBtu	¢/Gallon	¢/MMBtu
Plant Input Fuel Cost*	66.60	532.8	10.44	141.8	369.00	358.3	10.13	83.7
Capital	7.42	59.4	20.89	283.6	0.00	0.0	2.82	23.3
O&M	10.37	82.9	6.28	85.3	0.00	0.0	4.89	40.5
Fuel Consumption	5.33	42.6	0.00	0.0	0.00	0.0	0.00	0.0
Plant Output Price	89.71	717.7	37.61	510.6	369.00	358.3	17.84	147.5
Transport to U.S.	0.00	0.0	4.43	60.1	0.00	0.0	0.00	0.00
U.S. Landed Price	89.71	717.7	42.04	570.7	369.00	358.3	17.84	147.5
Blending	0.00	0.00	13.94	189.2	0.00	0.0	81.11	670.5
Pre-Distribution Price	89.71	717.7	55.98	760.0	369.00	358.3	98.95	818.0
Distribution Capital	0.37	3.0	1.16	15.8	5.00	4.9	0.37	3.0
Distribution O&M	2.83	22.7	2.83	38.4	144.73	140.5	4.92	40.6
Delivered Price to Station	92.91	743.3	59.97	814.1	518.73	503.6	104.23	861.7
Station Capital	4.84	38.7	6.03	81.9	47.40	46.0	4.84	40.0
Station O&M	5.87	47.0	3.98	54.0	123.61	120.0	5.68	47.0
Delivered Price to Vehicle	103.62	828.9	69.98	950.0	689.73	669.6	114.75	948.7

* Based on a crude oil price of $27.97/BBL.
ICF Resources, Inc.

Source: Breton and Fitzgibbon (1991).

Figure 1: Least Cost vs. Economic Justifications for NRSE

		Least Cost? (Financial - Micro)	
		Yes	No
Economic (Socioecon - macro)	Yes	Fully justified	Technology promotion
	No	Economic, Social, Environmental criteria	Research & development

Source: Adapted from Feinstein (1988).

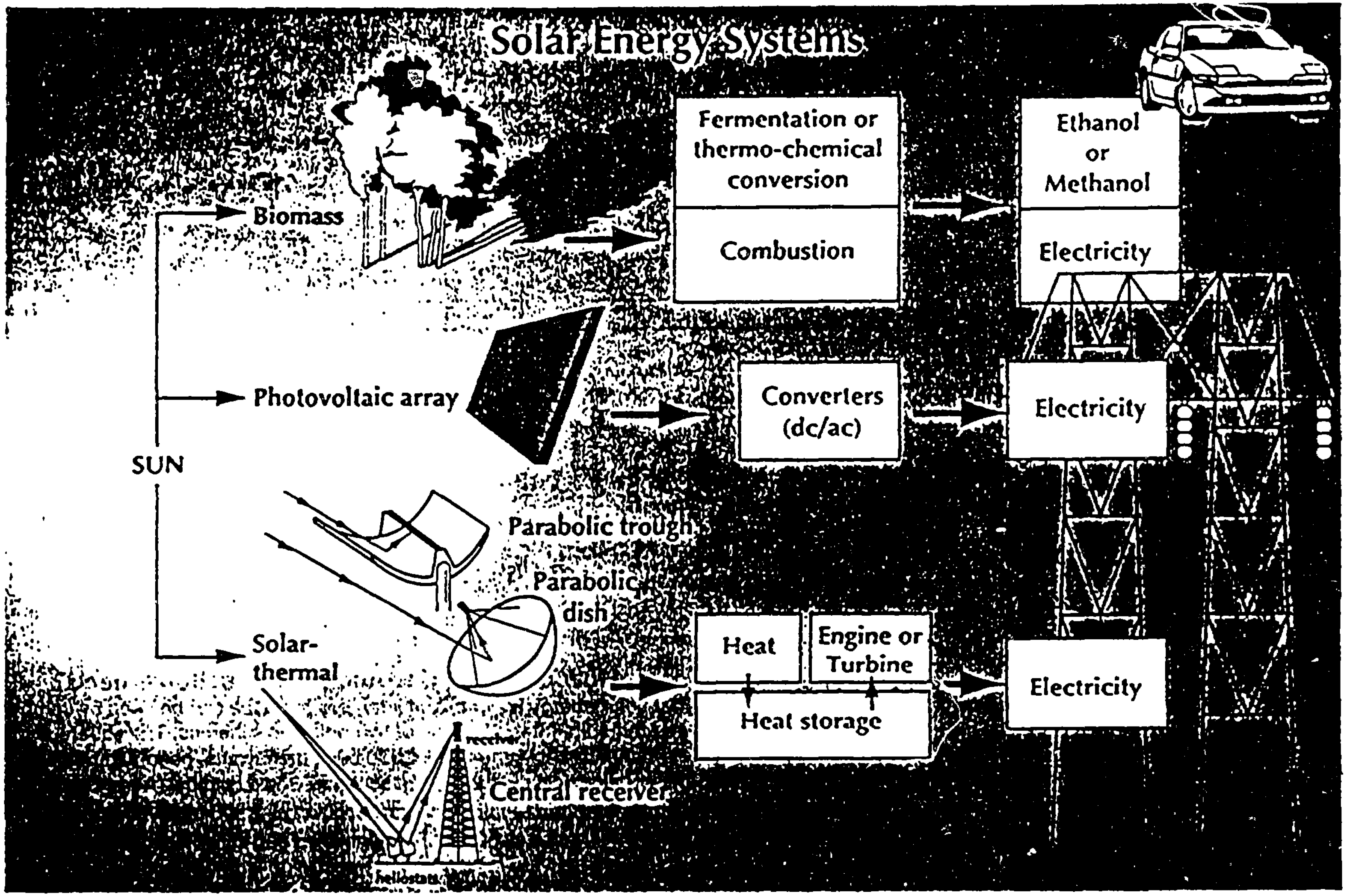


Figure 2: Solar Energy Systems: An Illustration

Source: Anderson and Ahmed (1993).

FIGURE 3

THREE WORLDS OF RENEWABLE ENERGY
(Extracted from Feinstein, 1988)

Some useful generalizations can be drawn from the foregoing discussion on the problems of financing renewable development. With the caveat that there are exceptions to every classification, I would like to advance that there appear to be not one, but three worlds of renewable energy insofar as financing is concerned. These are projects involving:

(a) **High capital intensity but low (stable) levels of technology;**
(b) **High capital intensity combined with high (and changing) technology; and**
(c) **Low capital intensity with low level technologies.**

Hydroelectric and wet rock geothermal power belong to the first category and raise no special problems; they are well established electric power system components familiar to many financing institutions. Renewable energy systems in the "hi-capital/lo-tech" group are characterized by high levels of technological maturity, commercialization, monetization and financial/economic returns. Multilateral development bank funding of these developments has historically been large, and co-financing opportunities are substantial. Mini-hydro, solar water heating, and agro-industrial waste-fired cogeneration cycles probably orbit on the fringe of this group.

The "hi-capital/hi-tech" grouping is highly diversified but would certainly include many solar electric, solar thermal, wind, biomass gasifier-electric and biomass to bio-fuel technologies. The techniques tend to be new and rapidly evolving and have not yet won widespread commercial acceptance. While the energy outputs can usually be monetized, issues of decentralization, scale economies and lack of economic competitiveness have generally limited this second group's applications to "niche" project opportunities. Flow of finance to this category is therefore particularly sensitive to conventional energy prices and fiscal incentive regimes.

The "lo-capital/Lo-tech" category includes renewable energy in its traditional role as a source of cooking fuel and is, in human terms, by far the most important one. Such biomass resources as firewood, charcoal, crop residues and animal dung, account for virtually all of the fuel used in many rural areas and for about 20-25% of total energy consumption in the developing world. In much of sub-Saharan Africa, fuelwood use represents 75% of national primary energy consumption and charcoal purchases absorb 20-25% of urban household budgets. It is estimated that more than two billion people depend wholly on such fuels to meet their most basic energy needs. However, their fuel supplies are threatened by the deforestation which is taking place in much of the developing world with grave environmental, economic and human consequences.

FIGURE 4

Possible Sources of Renewable Energy Finance

DOMESTIC

Public

- Direct government expenditure
- Government grants
- National development bank loans (may be an on-lending arrangement for international credit)

Private

- Borrowing on the domestic credit market
- Share subscription on the domestic equity market
- Utility-assisted financing (e.g. shared savings and lease-back arrangements)

INTERNATIONAL

Public

- Government-to-government borrowing and soft loans
- Bilateral grants
- Direct government borrowing from the international capital market
- Official export credits (e.g. U.S. Ex-Im Bank)
- Barter and counter-trade
- IBRD loans and IDA credits
- Regional development bank loans
- UNDP sources and funds of the specialized UN agencies (e.g. GEF)
- OPEC Fund for Development
- Other international agency combinations (e.g., FINESSE)

Private

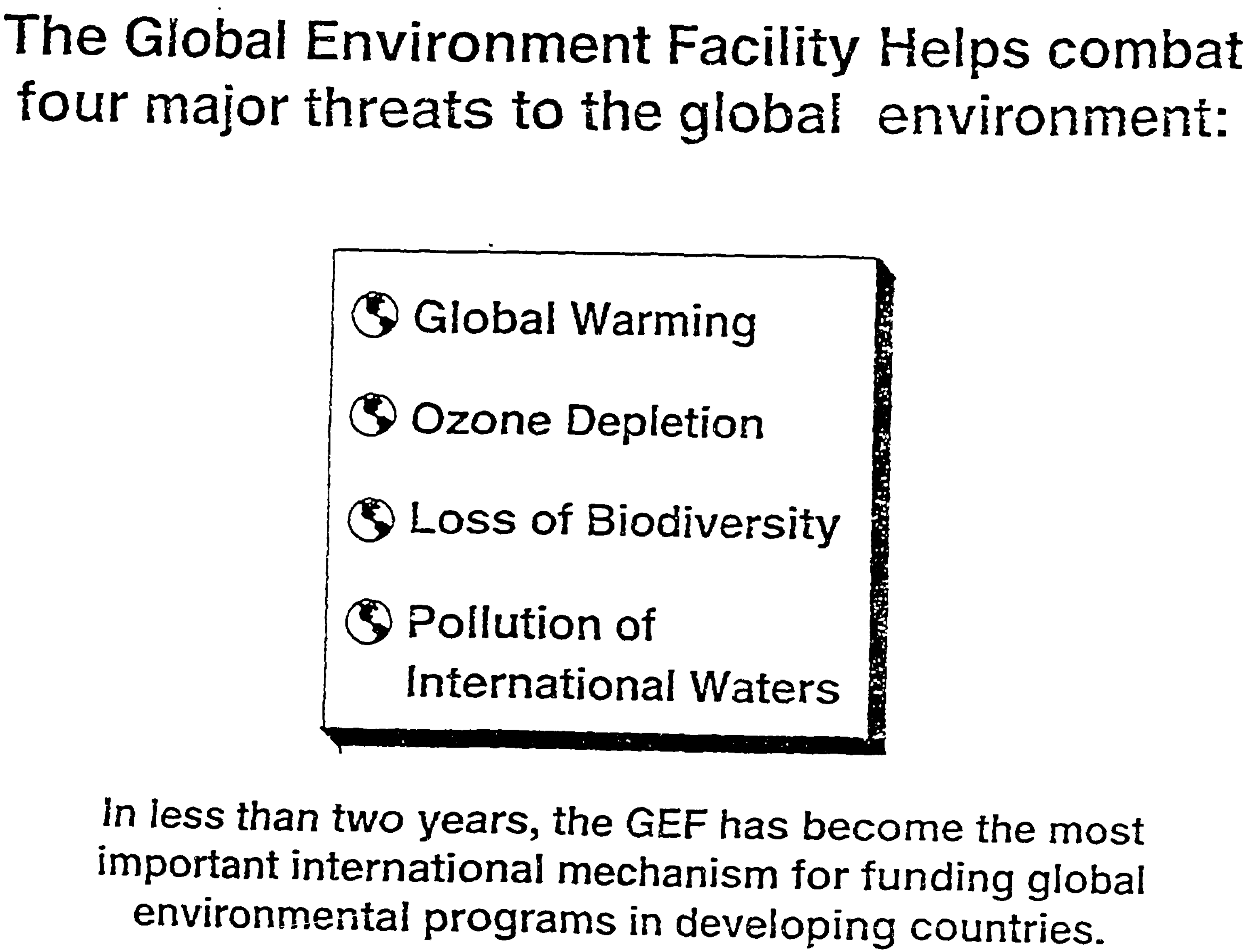
- Private borrowings from the international capital market
- Supplier's credits
- Debt/equity investments by the international private sector (including joint venture, non-recourse project financing, leasing and energy service contract arrangements)
- Private foundation grants

Source: Adapted from Feinstein (1988).

Figure 5: Financial vs. Economic Valuation and Project Financing

		Financially Attractive?	
		Yes	No
Economically Attractive?	Yes	Commercial credit Equity financing User fees (privatized finance)	Multilaterals Bilaterals Taxation (public finance)
	No	? ? ?	Demonstration/ R & D grants (Specialized agencies, bilaterals, government subsidies)

Source: Feinstein (1988).



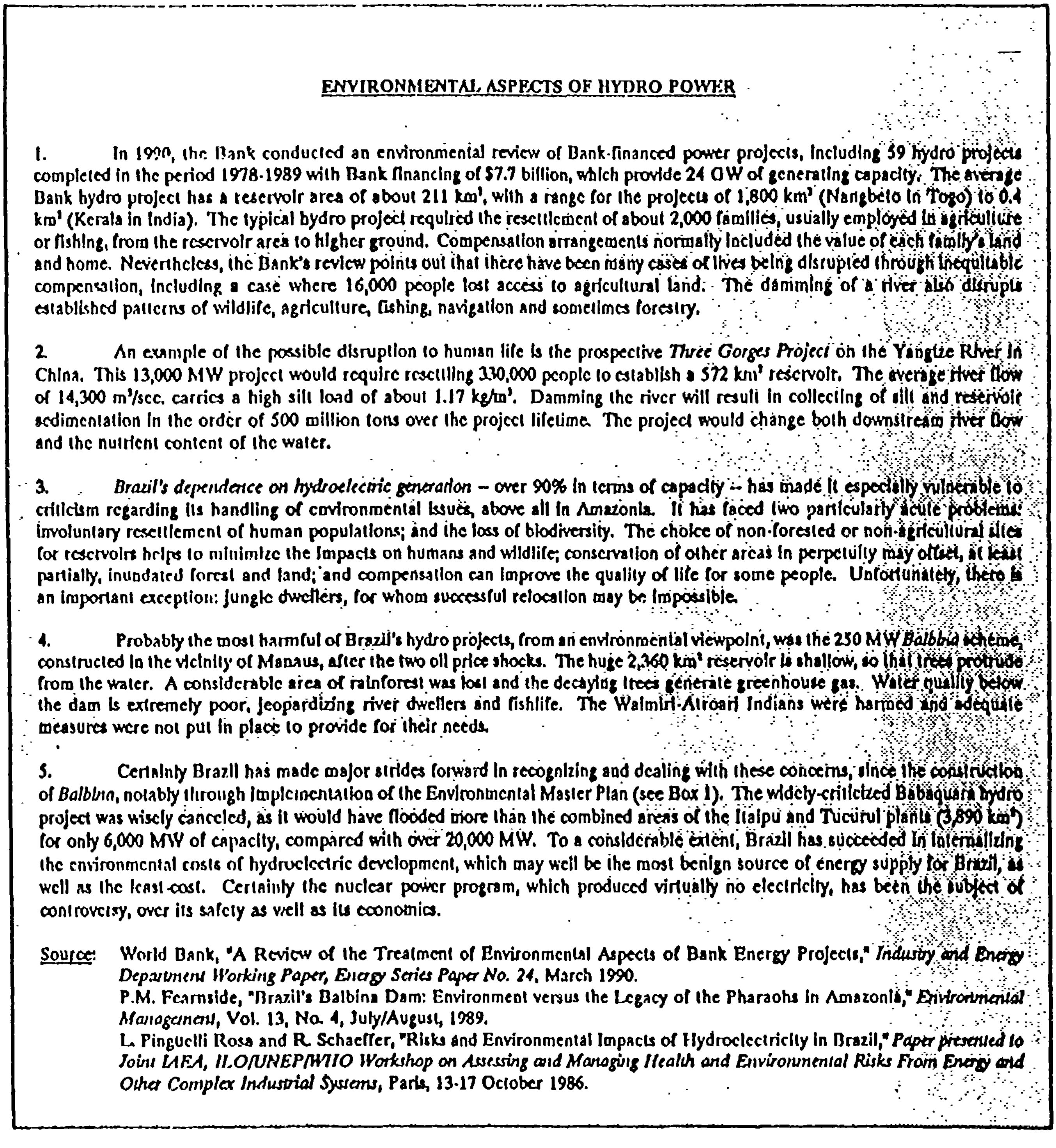
The Global Environment Facility Helps combat four major threats to the global environment:

- Global Warming
- Ozone Depletion
- Loss of Biodiversity
- Pollution of International Waters

In less than two years, the GEF has become the most important international mechanism for funding global environmental programs in developing countries.

Figure 6. GLOBAL ENVIRONMENT FACILITY

Source: Summers (1993).



ENVIRONMENTAL ASPECTS OF HYDRO POWER

1. In 1990, the Bank conducted an environmental review of Bank-financed power projects, including 59 hydro projects completed in the period 1978-1989 with Bank financing of $7.7 billion, which provide 24 GW of generating capacity. The average Bank hydro project has a reservoir area of about 211 km^2, with a range for the projects of 1,800 km^2 (Nangbelo in Togo) to 0.4 km^2 (Kerala in India). The typical hydro project required the resettlement of about 2,000 families, usually employed in agriculture or fishing, from the reservoir area to higher ground. Compensation arrangements normally included the value of each family's land and home. Nevertheless, the Bank's review points out that there have been many cases of lives being disrupted through inequitable compensation, including a case where 16,000 people lost access to agricultural land. The damming of a river also disrupts established patterns of wildlife, agriculture, fishing, navigation and sometimes forestry.

2. An example of the possible disruption to human life is the prospective *Three Gorges Project* on the Yangtze River in China. This 13,000 MW project would require resettling 330,000 people to establish a 572 km^2 reservoir. The average river flow of 14,300 m^3/sec. carries a high silt load of about 1.17 kg/m^3. Damming the river will result in collecting of silt and reservoir sedimentation in the order of 500 million tons over the project lifetime. The project would change both downstream river flow and the nutrient content of the water.

3. *Brazil's dependence on hydroelectric generation* – over 90% in terms of capacity -- has made it especially vulnerable to criticism regarding its handling of environmental issues, above all in Amazonia. It has faced two particularly acute problems: involuntary resettlement of human populations; and the loss of biodiversity. The choice of non-forested or non-agricultural sites for reservoirs helps to minimize the impacts on humans and wildlife; conservation of other areas in perpetuity may offset, at least partially, inundated forest and land; and compensation can improve the quality of life for some people. Unfortunately, there is an important exception: jungle dwellers, for whom successful relocation may be impossible.

4. Probably the most harmful of Brazil's hydro projects, from an environmental viewpoint, was the 250 MW *Balbina* scheme, constructed in the vicinity of Manaus, after the two oil price shocks. The huge 2,360 km^2 reservoir is shallow, so that trees protrude from the water. A considerable area of rainforest was lost and the decaying trees generate greenhouse gas. Water quality below the dam is extremely poor, jeopardizing river dwellers and fishlife. The Waimiri-Atroari Indians were harmed and adequate measures were not put in place to provide for their needs.

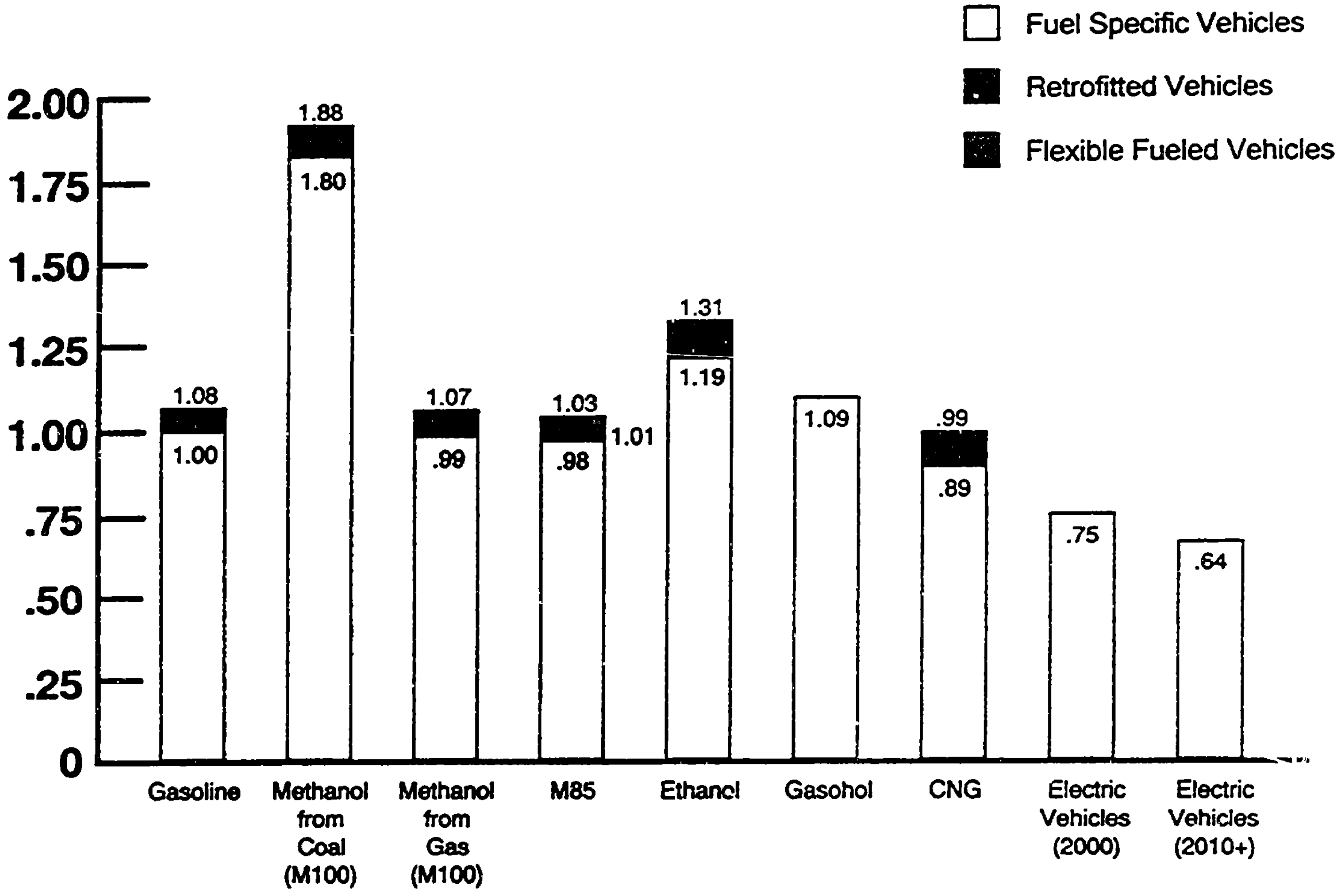
5. Certainly Brazil has made major strides forward in recognizing and dealing with these concerns, since the construction of *Balbina*, notably through implementation of the Environmental Master Plan (see Box 1). The widely-criticized Babaquara hydro project was wisely canceled, as it would have flooded more than the combined areas of the Itaipu and Tucurui plants (3,890 km^2) for only 6,000 MW of capacity, compared with over 20,000 MW. To a considerable extent, Brazil has succeeded in internalizing the environmental costs of hydroelectric development, which may well be the most benign source of energy supply for Brazil, as well as the least-cost. Certainly the nuclear power program, which produced virtually no electricity, has been the subject of controversy, over its safety as well as its economics.

Source: World Bank, "A Review of the Treatment of Environmental Aspects of Bank Energy Projects," *Industry and Energy Department Working Paper, Energy Series Paper No. 24*, March 1990.
P.M. Fearnside, "Brazil's Balbina Dam: Environment versus the Legacy of the Pharaohs in Amazonia," *Environmental Management*, Vol. 13, No. 4, July/August, 1989.
L. Pinguelli Rosa and R. Schaeffer, "Risks and Environmental Impacts of Hydroelectricity in Brazil," *Paper presented to Joint IAEA, ILO/UNEP/WHO Workshop on Assessing and Managing Health and Environmental Risks From Energy and Other Complex Industrial Systems*, Paris, 13-17 October 1986.

Figure 7. ENVIRONMENTAL ASPECTS OF HYDROPOWER

Source: Bates and Moore (1992).

Figure 8
Greenhouse Emissions of
Alternative Transportation Fuels
(Relative to Gasoline)



Source: Finizza (1991).

APPENDIX A

Summary Discussion of Major Renewable Systems

(Extracted from W. K. Foell, M. E. Hanson, and C. W. Green,
"Environmental Considerations in Renewable Energy
Policy Development and Investment Planning,"
in C. M. Siddayao and L. A. Griffin, eds.,
Energy Investments and the Environment: Selected Topics,
World Bank/Economic Development Institute, 1993)

The summary discussions of renewable energy sources in this part provide a brief status report on these systems. These summary discussions provide a synopsis of not only the environmental status of the systems, but commentary on the technical and economic status of the systems. Attempting to provide a summary discussion is difficult due to the variability within each of the systems as well as variability in the success in the use of the systems in different settings, even when the technologies involved have been quite similar. For example, wood-fired power production has been largely a failure to date in the Philippines, while it has been partially successful in areas of northern Europe, the United States, Canada, and Indonesia. Similarly, solar hot water systems for domestic use have been very successful in Cyprus and Israel, while they have hardly made any inroads in Tunisia, a country in the same region with similar climatic conditions.

1. Biomass

a. Wood and Other Biomass Direct Combustion. The energy system for the direct combustion of biomass for power, process heat, or combined heat and power (cogeneration) is quite similar to that for conventional fossil fuel combustion except that the primary resource is biomass rather than a fossil fuel. In the case of wood combustion for cogeneration, specialized harvesting and transportation equipment are utilized in harvesting the fuel and transporting it to the power plant. Because of the high water content and low energy density of biomass, transportation haul lengths will usually be limited. The feed systems, boilers, and generators are fairly standard, although fluidized bed boilers have proven to be particularly appropriate for wood and wood wastes.

The economics of the system are dependent on the cost of the primary energy source. Wood boilers, for example, are common throughout much of the world in the forest products industry because of the availability of wood or waste and scrap wood. The use of wood cut exclusively for direct combustion appears to be limited due to the difficulty in competing with coal, oil, and natural gas at current prices.

b. Liquid and Gaseous Fuels. Liquid and gaseous fuels can be produced from virtually all forms of biomass by a number of processes. The two most common liquid fuels are alcohol-based products ethanol and methanol, while the most important gaseous fuels are syngas and biogas. The type of fuel ultimately produced depends on the type of conversion process. The two main types of biomass transformation processes are biochemical and thermal conversion.

The fermentation of grains, sugar cane, and other woody or herbaceous crops rich in sugar or starch produces grain alcohol or ethanol. Ethanol is a relatively clean burning fuel that can be used as a substitute for gasoline in modified internal combustion engines or as a non-lead, octane-enhancing gasoline additive. The major producers of ethanol include Brazil, the United States, and France.

Biogas is produced by the biochemical process of anaerobic digestion, the same process used to treat sewage wastes and sludge. Biogas is a medium British thermal unit (medium-BTU) mixture of methane and carbon dioxide which can be purified to yield high-BTU methane, the principal component of natural gas. Biogas may also be produced from animal wastes, crop residues, and sewage. Small anaerobic digesters have been relatively successful in developing countries. For example, in China over seven million small digestion systems have been installed to partially meet the cooking, space heating, and lighting demands of a number of small rural communities [Brower, 1990]. In the United States, the majority of biogas plants have been constructed to collect the gaseous emissions produced from decomposition in landfills. As of 1988, 50 plants were in operation and another 40 plants were either in construction or being planned [Brower, 1990].

Methanol can be produced through catalytic reactions from the medium-BTU gaseous products of either gasification or pyrolysis. Methanol is a high-octane fuel that, like ethanol, can be used in automobiles fitted with special combustion engines or as an additive in gasoline. Currently there is little industrial interest in converting biomass to methanol because it is less costly to derive methanol from natural gas.

c. Environmental Aspects. The environmental effects of wide-spread use of biomass resources for energy can be broken down into three categories: biomass resource production, conversion, and end-use. Environmentally, biomass production has some distinct advantages and disadvantages. The advantages are that if the feedstock is grown on a renewable basis (in a plantation or in a less intensively managed production system such as natural forest), carbon release and carbon uptake balance each other. Some marginal lands may be found to be more economical when supporting energy crops than other agricultural crops, and a greater portion of harvested plant material may be used, increasing the economic value of the harvest.

In the conversion process, solid and liquid wastes can be utilized to reduce water pollution and waste products can provide a benefit as organic fertilizer if they are collected and applied to the land. In the case of biogas production, sanitary conversion of manure and human sewage into energy and slurry fertilizer will reduce the incidence of schistosomiasis. Finally, biomass combustion produces little sulfur and ash, and particulates are readily controlled.

The environmental disadvantages of biomass are generally associated with production and harvesting practices. Careful wood harvesting and avoidance of steep slopes can minimize erosion. Intensive biomass production, on the other hand, often requires the application of fertilizers and other chemicals which are a threat to water bodies. On a broader scale, an important biomass issue is the type of land used for production. For example, reforesting marginal and damaged lands has a very different consequence than harvesting old growth forest (tropical or temperate) or displacing agricultural land. Some crops, such as corn as it is currently produced in the United States, require large inputs of energy in the form of fertilizers, operation of equipment, herbicides etc. After accounting for these energy inputs and others for transportation and distillation of ethanol, the energy balance on premium fuels has been shown to be poor. In other words, the premium energy inputs approximately equal the premium energy produced. The profit derived from corn-based ethanol relies upon subsidies, including the exclusion of gasoline and ethanol mix fuels from some or all motor vehicle fuel taxes. Under these circumstances, biomass fuels are not an economically advantageous option.

Burning methanol and ethanol instead of gasoline would substantially reduce major pollutant emissions in motor vehicle exhaust. This is a particularly important advantage in large cities. There would be an increase in aldehydes yet there is debate over what levels are harmful and how much of the pollutant can be removed with a catalytic converter [Brower, 1990].

2. Geothermal

There are three types of geothermal resources: hydrothermal, dry hot rock, and geo-pressured. The ultimate use of geothermal resources will depend on the type of resource developed. Currently, only hydrothermal resources have been exploited. Geo-pressured and hot dry rock resources are still in the resource definition and experimental stages in the United States. The main producers of power from geothermal energy are the Philippines, New Zealand, Iceland, and the United States. Global installed capacity is more than 4700 megawatts electric (MWe) [World Resources Institute, 1988].

The main features of a geothermal energy system are: geothermal wells, a well head, pipes for transporting energy in liquid or vapor form, a central conversion plant, and wells for reinjecting the spent geothermal fluid or abatement facilities. Energy conversion and use processes depend strongly on whether the geothermal fluid is liquid or vapor-dominated. Steam-turbine technology is in an advanced state of development and equipment used in exploiting hydrothermal geothermal resources is adapted directly from the conventional power industry.

The environmental effects of geothermal energy sources are highly site-dependant and technology-dependant (open system or closed system) as geothermal reservoirs have a wide range of geothermal and chemical properties. For this reason it is not possible to describe a "typical" geothermal energy system. Thus, it is important to note that environmental impacts and the use and effectiveness of mitigation techniques can be constructively considered only on a site-by-site basis.

The major environmental impacts of geothermal resource development are associated with the release of geothermal fluids and their dissolved gases and solids into the environment. Impacts connected with geothermal fluids can be partially ameliorated with the treatment or reinjection of the waste geothermal fluids. In addition, while CO_2 emissions dominate the gaseous emissions from most geothermal wells, overall emissions of CO_2 per unit of energy are still less than levels associated with fossil fuel plants [Organization for Economic Cooperation and Development (OECD), 1988]. Land subsidence and induced seismicity from the removal or forced injection of geothermal fluids are other environmental factors that must be considered.

3. Wind Power

Wind Energy Conversion Systems (WECS) capture solar energy stored in air movements caused by the uneven heating of the earth's surface. Most modern systems use lift across an airfoil surface (a concept similar to that of an airplane propeller) while some systems employ drag forces to turn the blades of the rotor. The rotor is commonly connected to an electric generator to produce direct current, although mechanical pumps are used in some countries. The main features of a Wind Energy Conversion System using three airfoil blades are a rotor, transmission, electrical generator, and control system, all mounted on a tower.

The power output of WECS are determined by wind speed and rotor size. Wind speed is the principal factor governing the power output from WECS and represents a major constraint on their siting requirements. Typical systems will not operate in winds of less than 10 kilometers/hour (km/h). The power output and size of WECS vary significantly. The majority of wind turbines now in operation are intermediate in size, generating approximately 50 to 300 kilowatts (kW) peak capacity. Most WECS are located in industrialized countries such as Denmark, the Netherlands, and the United States.

The levelized cost of electricity generated from WECS can be competitive with intermediate and peak conventional generating costs in regions with favorable wind regimes, generating power for about 7-9 kilowatt-hours (kWh).[1] Since winds are variable over time, extensive use of wind power requires back up or energy storage. The need for storage is reduced somewhat due to the fact that wind speeds often follow consistent daily patterns (see discussion of storage in Section C.4 on direct solar energy).

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[1] All monetary values are in United States dollars unless otherwise noted.

Environmentally, WECS have some very clear advantages and some unique drawbacks. Once in place, these energy systems are essentially benign, producing no air emissions, water emissions, or wastes. The physical land required by a single machine is quite small comprising only the size of the base.

The negative impacts of WECS appear to be local in scale. Wind farms comprised of hundreds of WECS will require relatively large land areas allowing for a moderate distance between individual machines to account for the wake produced by the rotors. Noise generated from the rotors will create siting constraints. Comparatively large distances may be needed between WECS and residential communities [800 to 2500 meters (*m*)], although it may be possible to reduce this distance to between 300 to 500 *m* through suitable amelioration techniques. Finally, there is the combined visual impact of large clusters of WECS and their associated power transmission lines. The degree of impact will be largely subjective on the part of local residents but may also have broader impacts on recreation and tourism when units are located near coastlines.

4. Direct Solar Energy

Solar energy embodies the largest resource potential of any renewable or nonrenewable energy source. The amount of sunlight that can be collected and converted to energy at any time, however, is constrained by the amount of available land and the efficiency of energy conversion. Direct conversion of solar radiation into useful energy can be accomplished in many ways, e.g., solar architecture, solar thermal systems for hot water or electricity, and photovoltaic cells that convert solar energy directly into electricity.

a. Solar Thermal. Solar thermal systems collect heat from sunlight producing temperatures that can be used for industrial processes, electricity generation, or hot water heating. There are five predominant types of collectors: solar ponds, parabolic troughs, parabolic dishes, central receivers, and flat plate collectors. A central receiver system consists of an array of sun-tracking reflectors (heliostats) that focus light onto a receiver mounted on a tower. Solar energy absorbed at the receiver is transferred to a working fluid and converted into electrical energy via a steam turbine generator.

Application of these various technologies depends upon the end-use energy desired. Some sources believe that central receiver electric systems could become competitive for generating peak electric power by the mid-to-late 1990s. A study by Bechtel National and Pacific Gas and Electric predicts that central receivers of 100-200 MW could produce electricity in California for as little as 8-11/kWh by 1997 [Brower, 1990]. In the eastern Mediterranean, over 90% of the homes in Cyprus and 65% of the homes in Israel are equipped with solar hot water heaters. Despite the high initial costs of these systems, solar hot water heating in sunny climates is usually cost effective in comparison with electric water heating [Shea, 1988].

A distinct advantage of solar thermal systems (with the exception of central collectors, which are planned as large facilities of at least 30 MW capacity to take advantage of economies of scale) is that they are comprised of modular units that can be added or removed as demand changes, decreasing the risk in constructing facilities to meet predicted energy demand that may not materialize. Small modular units for the production of electricity may be economically competitive in rural areas which are costly to connect to the existing electricity grid and hot water heating units are even competitive in urban areas.

Environmentally, most solar thermal systems are relatively benign, producing waste only during routine maintenance periods. Solar collectors require large material inputs which is a one-time environmental and economic cost that is repeated at the end of the system's lifetime (currently estimated at 25-30 years). Land use for large station solar electric generation is comparable to the amount needed for electric generation from coal when land disturbances from coal mining are taken into account.

b. Solar Photovoltaic. Photovoltaic (PV) cells convert sunlight into electricity by means of the photovoltaic effect. Photons of light strike the cell dislodging electrons from atoms. The charged electrons travel through the cell towards an oppositely charged contact drawn by a voltage created between two semiconductor materials. When the circuit is closed, an electric current is created.

The most dominant material used in photovoltaic construction is silicon. New manufacturing processes involving silicon as well as new exotic semiconducting materials are continuing to be developed. Conversion efficiencies of commercially available PV cells are currently about 15%, and laboratory tests involving single-crystal silicon, concentrating collectors and thin film systems have been demonstrated to have efficiencies in the high 20 percent and low 30 percent range [Brower, 1990].

The price of PV cells has fallen dramatically in just 15 years. In 1976 the cost per peak kilowatt of capacity was $44,000 (1986 dollars) and has fallen to the current estimated price of $4,000-$5,000 [Shea, 1988]. However, at this price, the cost of electricity generated from PV systems is 25-35 cents/kWh, usually beyond the price necessary to compete with current systems generating peak power. Nevertheless, PV systems have proven cost effective in some limited markets. For example, the largest market for PV systems is providing power for machinery and villages in areas far removed from utility grids.

As with solar thermal systems, most of the negative environmental effects of PV systems occurs during the manufacturing process. PV cell fabrication requires exotic inputs and a number of toxic and explosive gases that pose a danger to plant workers and to the surrounding community if released. Land requirements for large scale PV electric generation are comparable to land requirements for coal mining for electric generation. In dispersed applications, individual cells can be placed on roof tops with little or no environmental effects.

c. Storage. An important issue with respect to solar and wind energy systems is energy storage. Because sunlight is variable, energy storage systems or backup systems will be necessary if power is to be provided on an uninterrupted basis. A number of technologies are currently available for providing energy storage for solar energy systems: hydroelectric, electric batteries, compressed air, thermal storage, and hydrogen. Hydroelectric storage is a simple form of storage that is already in wide commercial use.

Thermal storage usually involves heating or cooling a liquid or solid mass. Storage can either be short-term (storing excess energy by day for conversion to electricity at night or cloudy days), or long-term (using large, insulated underground storage to collect summer heat for use during winter months).

Although the need for energy storage in conjunction with renewable energy sources is an important issue, its significance should not be exaggerated. For many renewable utility applications, energy storage will not be necessary in the short-term. Some electric utilities have excess reserve capacity and some plants can be economically relegated to backup. In addition, variations in electricity demand are often matched closely with levels of solar insolation so that the energy will be available during times of high demand. Energy storage will be necessary, as solar and wind energy sources comprise a larger fraction of the total electric generating supply and in remote areas away from existing utility grids where renewable supply is the only means for heating or electricity generation.

5. Hydropower

Hydropower is a well proven source of power. Large scale plants are common throughout the world where river flow and geological conditions are favorable. This [appendix] focuses on small scale micro (up to 100 kW), mini (100 kW to 1000 kW), and small (1000 kW to 20,000 kW) plants [George and Van Schaik, 1988]. Plants are common at these scales. In Burundi, Costa Rica, Guatemala, Guinea, Madagascar, Nepal, Papua New Guinea, and Peru, small-hydro potential exceeds total installed generating capacity from all other energy sources. China is the world leader in small-hydro, with about 90,000 turbines supplying electricity to rural areas in 1988 [Shea, 1988]. The Philippines reported 3.9 MW of mini-hydro in place in 1980. In the United States by 1985, private enterprise had brought almost 1,000 MW of small hydropower on-line and electric utilities had installed twice that amount. Nearly 60 percent of the total 3,200 MW was installed during the 1980s [Shea, 1988].

The *central economic question* with micro-hydro and mini-hydro is whether the plants can be built and connected to grids, or directly to users, at costs competitive with other sources of power. Small scale hydro is particularly interesting in sites which are isolated from central grids, but where power is required, often generated by small diesel generation sets. Because of the finite number of potential sites in any region and the fact that the best sites are developed first, the cost of power from new sites is generally increasing. There is, however, tremendous variability from region to region as is the potential for and the extent of hydropower development.

The main environmental impact of major hydro facilities is the disruption of river ecologies and the inundation of land under the power reservoirs. Besides the ecosystems and often social disruptions caused by inundation, downstream areas are impacted by the change in sediment loads, disruption of fish migration patterns, changes in water temperature, etc. A dramatic example of these effects is represented by the Aswan Dam. The advantage of small scale hydro, including run of the river hydro, is that the areas of inundation are much smaller, and depending on the size of the facility, there may be no significant changes in sediment loads and other river characteristics.

6. Urban Waste

Although urban wastes are made up of an assortment of materials, some of which are not renewable, urban waste can be considered an ongoing and hence renewable source of energy. Renewable components of urban waste include organic material, which accounts for over half of urban wastes. The amount of urban wastes now being generated and landfilled can be considerably reduced by the adoption of recycling and composting, and a growing number of cities around the world are integrating recycling into their waste management plans. The benefits of recycling are the energy and material savings of avoiding the use of virgin materials and reduced pollution. For example, aluminum is an extremely energy- intensive material, however, recycling aluminum requires just 5 percent as much energy as producing it from bauxite [Pollock, 1987].

However, even after recycling, it is anticipated that there will continue to be a waste stream which can be combusted for the production of power or process heat. The facilities required for combusting urban wastes are similar to those for the combustion of biomass described in Section C.1 (Biomass). The main difference is the allowance for separation of combustibles which may take place prior to combustion, yielding refuse derived fuel (RDF) and other materials -- some of which may be recycled -- or the separation (of ferrous materials) after mass burn (i.e. after burning of the mass of materials).

Power generation from urban wastes does not generally compete with coal-based generation if transportation infrastructure is available to economically transport coal and if landfill costs are low. This is due to the high energy content and ease of handling of coal. However, in an increasing number of industrialized countries, landfill costs and environmental impacts, such as ground water pollution, are becoming so great as to make the use of urban wastes economical. Essentially, the higher cost of the fuel is more than offset by the avoided cost of landfilling. Waste to power plants are becoming increasingly popular although problems have been reported [Abert, 1985]. Worldwide, there are more than 1500 operating municipal solid-waste incinerator units built by selected major manufacturers [Penner et al., 1988]. In Switzerland 80% of municipal wastes are disposed of by incineration [Penner et al., 1988] and in West Germany 47 waste incineration plants serve 35% of its population [Barniske, 1989].

The production of power or process heat from municipal waste has a considerable environmental advantage of greatly diminishing solid wastes for landfill. Depending on their location, they may also reduce the distance that municipal wastes have to be hauled. Their environmental disadvantage relates to emissions of CO_2, sulfur oxides, particulates, heavy metals, and other pollutants. Particular attention has been focused on the emissions of dioxins and furans [Barniske, 1989; Penner et al., 1987]. While controversy continues, it appears that these emissions can be reduced to acceptable levels [Barniske, 1989] and that further work in terms of controlling input to the incinerators by prior recycling and source controls is promising. In addition, concern has been mounting over the disposal of the ash residues from incinerators. Because the ash often contains heavy metals from discarded batteries, lighting fixtures, and other sources, Sweden treats it as hazardous waste [Shea, 1988].

In planning disposal options for urban waste (recycling and incineration), program planners should include an assessment of the net energy gains from various materials. Wastes that prove more valuable when recycled should be separated from the waste stream rather than burned. Overbuilding incinerator capacity can result in a desire to meet the designed capacity by increasing the waste stream through the curtailment of recycling, a policy option that could waste more energy than it produces.

Appendix A References

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APPENDIX B

Environmental Impacts of Energy Production from Renewable Sources[1]

(Extracted from T. Vukina (1992),
Energy and the Environment: Some Key Issues
EDI Working Papers Energy Series.
Washington, D.C.: The World Bank)

The general realization of the finite nature of fossil fuel resources has caused re-examination of the possibility of using renewable energy resources. In developed countries, strategies for the exploitation of such sources constitute a part of recent policies which aim at reducing the dependence on fossil fuels and alleviating environmental concerns and problems. In developing countries, particularly those short of fossil fuel resources, development of technologies to harness renewable energy sources in a more efficient way constitutes a promise for meeting future energy needs to accelerate the process of development.

The resource base of renewable energy sources is extremely large, but due to the diffuse nature of most of them, only a fraction can be exploited. With the present state of technology, it is difficult to estimate how much of the resource base can be technically and economically exploited.

a. Energy from Biomass. Biomass is defined as renewable organic matter produced by photosynthesis, directly in the case of plants and indirectly in animals whose ultimate food source is plant material. The biomass resource base consists of trees, grass, agricultural crops, agricultural and agro-industrial residues, aquatic vegetation (fresh water and marine), animal excrement, and urban refuse or municipal solid waste. Biomass is an important source of energy; perhaps the most important in terms of actual users, for it is the principal fuel for the majority of people in most developing countries.

Two main processes are known to convert biomass into energy or synthetic fuel: thermochemical and biochemical. The first includes direct combustion, pyrolysis, and distillation and it is generally applicable to terrestrial biomass with lower moisture content. Biochemical processes include anaerobic digestion and fermentation to produce synthetic fuel.

Biomass has several positive effects on the environment. It acts as renewable energy storage, and as a sink for atmospheric carbon dioxide. Biomass contributes to soil stabilization, and helps reduce water runoff and desertification. It provides a low-sulphur fuel and an inexpensive source of energy, especially for rural areas in developing countries. The conversion of organic waste into fuel reduces the environmental hazards associated with this waste. Conversely, if biomass is not properly managed (excessive cutting of trees, slash and burn practices etc.) various detrimental environmental consequences will occur, such as: soil erosion, desertification, climatic change, etc.

(1) Thermochemical Processes. (a) Direct combustion of biomass provides energy for cooking and heating to the majority of rural populations in the world. The biomass used is mainly wood, crop residues, and manure (dung cakes). The uncontrolled collection of fuelwood has lead to soil erosion and degradation and has enhanced the desertification process. It is estimated that forest areas in developing countries are being destroyed at a rate of 16 million hectares a year [UNEP, 1980]. Since extensive

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[1] For a technical report of environmental impacts of production and use of renewable sources of energy see UNEP [1980].

deforestation reduces the capacity of the world's ecosystems to assimilate carbon dioxide, it is (together with burning of fossil fuels) the major factor contributing to the greenhouse effect. Afforestation programs and proper forest management are therefore the main prerequisites for ensuring an adequate firewood supply without causing ecological degradation.

(b) Charcoal is produced by the pyrolytic conversion of wood. It offers a number of advantages over wood as a fuel. It is easier to transport; it is more efficient in burning and less polluting. Charcoal can also be produced from pyrolytic conversion of agricultural and agro-industrial residues, and urban refuse. Therefore, pyrolysis provides a means for efficient conversion of these residues, which themselves are a major source of pollution, into transporle and clean-burning renewable fuels.

(2) Biochemical Processes. (a) Biogas is the product of anaerobic digestion of biomass. Its composition depends on the type of material fermented, but it is generally in the range of 55-65% methane, 35-45% carbon dioxide, 0-3% nitrogen, and 0-1% of each hydrogen, oxygen and hydrogen sulphide [UNEP, 1980]. The production of biogas provides a means for beneficial management of organic waste and, at the same time, it is an important source of energy for cooking, lighting, production of electricity, and for fuel for internal combustion engines. In addition, the effluent and sludge remaining after digestion is a nutrient-rich fertilizer. It has been found that anaerobic digestion eliminates most of the pathogenic organisms found in manure, and this could lead to a reduction of some parasitic diseases in rural areas.

Environmental problems encountered in large-scale biogas production are substantial when compared with small family-size plants. They include land requirements; collection, storage and handling of organic waste; production, storage, and distribution of biogas; and, handling large quantities of waste water produced.

(b) Another interesting synthetic fuel is ethanol (alcohol). Ethanol can be produced through fermentation of sugarcane, cassava, corn, sweet sorghum, etc. Alcohol can be blended with gasoline which leads to savings in crude oil requirements. The production of alcohol from fuel crops raises a number of important environmental and socio-economic issues: land area and water requirements, fertilizer and pesticide use, pressure on soil productivity, possible competition with food production, and management of large amounts of effluents (mainly stillage).

b. Hydro-Power. Currently the predominant use of hydro-power is for electricity generation. The growth of electricity production from hydro-power has considerably increased in the last 40 years. In 1950 hydro-electricity production was 343 TWh/year and in 1986 it reached 2,027 terawatt-hours/year (TWh/year), which represents an increase of almost six times. On the average, hydro-electricity constitutes about 21% of the total world electricity production.[2]

According to the indicative scenario in "Energy for a Sustainable World,"[3] the share of hydro-electricity production in the total world production of electricity will increase to 25.8% by the year 2020 (from 20.2% in 1986). The total world production of electricity from hydro-power sources will amount to 4,030 TWh/year.[4]

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[2] United Nations (annual). *United Nations Yearbook of Energy Statistics* (New York: United Nations).

[3] "Energy for a Sustainable World" ....

[4] Data used are from Besant-Jones [1989, p. 14].

Conventional hydro-electric developments use dams and water-ways to harness the energy of falling water in streams to produce electric power. A dam becomes a dominant factor in the hydrological regime, and sets in motion a series of impacts on physical, biological, and socio-cultural systems. There are currently 150 major dams with hydro-power in the world; 61 of them are located in developing countries.[5]

The environmental side-effects of dam construction are generally divided into two categories: (i) the local effects within the area of the artificial lake; and (ii) the downstream effects resulting from a change in the hydraulic regime. The typical environmental effects of dams and reservoirs can be summarized as follows [World Bank, 1989a]:

(i) Land losses: Large tracts of agricultural lands, forests, or other wildlands may be inundated.
(ii) Health: Some water-related diseases (e.g., schistosomiasis, malaria) may increase unless precautions or mitigatory measures are implemented.
(iii) Plant and animal life: Plant and animal extinction can be prevented by careful project siting. Loss of wildlife may be mitigated by including elsewhere in the country a wildlands management area equivalent to the inundated tract.
(iv) Fish and other aquatic life: Fish migrations (if any) will be impaired even with passage facilities. A reduced supply of nutrients downstream and to estuaries can impair fishery productivity.
(v) Water weeds: Proliferation of floating weeds can impair water quality. Clogging impairs navigation, recreation, fisheries, and irrigation.
(vi) Water quality: Suitability of water quality for drinking, irrigation, fisheries, etc. should be tested.
(vii) Anaerobic decomposition: Inundated vegetation on the bottom of lakes decomposes consuming large amount of oxygen, and the bottom water may become anaerobic.
(viii) Erosion: Erosion in the catchment area leads to sedimentation or land slips which can impair storage.
(ix) Downstream hydrology: Changes in downstream hydrology can impair ecosystems dependent on seasonal flooding, including areas that may be important for fisheries or for traditional flood-recession agriculture.
(x) Intact rivers: Hydro-power projects should preferably be concentrated on the same rivers, in order to preserve a sample of rivers in their natural state.
(xi) Multiple use: Water management and development of irrigation systems increase agricultural production, and generally accelerate industrialization and development. The lake itself provides opportunities for a number of new economic activities such as fisheries, tourism, recreation, and small industries.

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[5] The dam should meet one of the following criteria to be considered a major one: (i) dam height of at least 150 meters (m); (ii) dam volume of at least 15 million cubic meters (m^3); (iii) reservoir capacity of at least 25 cubic kilometers (km^3); or, (iv) hydro-power plant installation of at least 1000 megawatts (MW) [Besant-Jones, 1989].

Hydro-power development projects cause a lot of socio-economic problems. With the creation of the lake, the members of the lake basin population are displaced, crowded, or supplemented by the new migrants. The most affected are those people who must relocate because their homes and fields will be partially or totally inundated by the reservoir and those among whom relocatees must be resettled. Most displacement situations create several problems for the population involved.

Issues related to the loss of cultural heritage are also very important and should be considered in project evaluation. Special attention should be given to dam safety assessment as well.

c. Geothermal Energy. Geothermal energy is based on the natural heat of the earth. Resources suitable for commercial exploitation may be defined as localized geological deposits of heat concentrated at attainable depths, in confined volumes, and at temperatures sufficient for electric or thermal energy utilization. From the geological point of view, geothermal resources can be classified into: hydrothermal convection systems, hot igneous systems, and conduction-dominated systems [UNEP, 1980].

Subsurface reservoirs of steam or hot water, which may display such surface characteristics as boiling springs, sulphurous mud flats, and fumaroles are categorized as hydrothermal convection systems. Hot igneous systems include both magma and hot impermeable dry rock. The recovery of geothermal energy directly from magma is not yet feasible. The technology to utilize hot dry rock is beginning to be developed. A conduction-dominated system arises where a deep sedimentary basin occurs in a zone of high heat flow. Geopressured reservoirs have been found in many countries while searching for oil and gas.

The utilization of geothermal energy for the production of electricity is the oldest one. The non-electric applications include medical mineral baths, space heating, and agricultural use, especially in greenhouses. There is also a wide range of use in industry: from drying of fish and timber to pulp and paper processing.

Since geothermal energy must be utilized or converted in the vicinity of the source to prevent excessive heat loss, the entire fuel cycle is located at one site. This offers environmental advantages in terms of land area requirements and in terms of effluents management. In addition, geothermal power stations do not generally need an external source of water for cooling, since the condensed steam is recycled for that purpose.

Negative environmental effects are site specific, varying according to geochemical characteristics of the reservoir. Hydrogen sulphide (H_2S) is the main airborne effluent of real concern in geothermal fields. The main problem is its considerable smell, but so far no health problems have been known in communities living near these plants.

Liquid effluents from geothermal power stations contain a variety of chemical elements in different concentrations. Methods for disposing of wastewater include direct release to surface water bodies, evaporation, desalination with subsequent water reuse, and reinjection to the production reservoir. Groundwater contamination is yet another environmental concern.

Because of the low thermal efficiency (about 85-92% of the total heat energy contained in the geothermal fluid is emitted as waste heat), geothermal power plants can be important sources of thermal pollution.

d. Solar Energy. A broader definition of solar energy includes both direct and indirect types. For the design of systems to utilize direct solar energy, the most useful information available is the energy received on a horizontal surface (insolation) at the particular location. Indirect types of solar energy include wind energy and energy from the sea (wave power, tidal power, and sea thermal power).

(1) Direct Solar. The annual amount of solar radiation received at the surface of the earth is about 1 x 1018 kilowatt hours (kWhs), which is equivalent to more than 20,000 times the present annual consumption of energy of the whole world [UNEP, 1980]. However, only a fraction of this energy can be extracted, where the efficiency of extraction depends on the location and the prevailing meteorological conditions. Extensive research and development programs are underway in many countries to harness solar radiation efficiently for a broad number of applications: heating and cooling of houses, water heating, desalination, refrigeration, solar drying, irrigation, electricity generation (solar-thermal-electric conversion systems and photovoltaic conversion), and ovens for high-temperature materials processing.

The use of solar energy for water heating for domestic or industrial purposes is environmentally benign. Solar thermal power plants do not emit gaseous, liquid, or solid effluents like fossil fuel or nuclear power plants. They are relatively neutral as far as excess heat rejection is concerned. Although land requirements for solar power plants are comparable to those of conventional thermal power plants, most of the land can be used for other purposes at the same time.

(2) Indirect Solar. (a) The source of *wind* is in the atmospheric temperature differences generated by the sun, which in turn give rise to pressure differentials. The wind is a mechanism for dissipating, as kinetic energy, the potential energy accumulated in those pressure differences. The development of wind energy is focused on increased use of wind machines in the 5-100 kilowatt (kW) range for water pumping and rural electrical systems. Machines for generating electric power in the 100 kW - 5 MW range are also being developed [UNEP, 1980]. Environmental concern about wind energy involves such factors as the risk of accident, noise, interference with telecommunications, and the possibility of micro-climatic alterations.

(b) The energy of the *sea* falls into three categories: wave, tidal and thermal energy. Today *wave energy* is used only on a small scale. The average power output of these systems range from 70 to 120 W [UNEP, 1980]. Wave power plants produce no thermal discharges or emissions, cause no changes in water salinity, and require no fresh water operation. The most direct environmental impact is to calm the sea, since they will act as efficient wave breakers. The calming of the sea might have adverse biological effects because of the reduced mixing of the upper water layers.

(c) *Tidal power* is derived from the combined kinetic and potential energy of the earth-moon-sun system. To harness the tides for power tidal amplitude must be large and coastal topography must be suitable (bay with narrow inlet, river estuary, or similar). Tidal energy may be pollution free, but it will change the ecology of its tidal basin. Some of the detrimental effects on eco-systems attributable to river hydro-plants, to be discussed later in Part I, would be also applicable to tidal power plants.

(d) The most important location of the *sea thermal resource* is roughly between the Tropic of Capricorn and the Tropic of Cancer. In that area deep sea water may be up to 25 °C colder than surface water. Several prototype systems of ocean thermal energy conversion (OTEC) have been suggested and the environmental problems range from questions dealing with biological and ecological aspects of antifouling agents used in OTEC systems, to those dealing with changes in salinity and thermal redistribution.

4. Nuclear Energy and Environment[6]

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[6] For a very detailed report of environmental and other aspects of nuclear energy see International Atomic Energy Agency (IAEA) and World Health Organization (WHO) [1982].

The environmental aspects of production and use of energy have become an increasingly important factor in the development of national energy policies and strategies, and this has been conspicuously so in the case of nuclear energy. Public concern has focussed on a number of issues, the most important of which are:

(i) Can increased radioactive emissions from nuclear facilities affect the quality of air and water?

(ii) What are the effects of radiation on humans, both somatic and genetic, which may be associated with some stages in the nuclear fuel cycle?

(iii) How likely are nuclear accidents which could have serious consequences on humans and the environment?

(iv) What are the environmental impacts associated with radioactive waste disposal and management?

(v) Can nuclear facilities be decommissioned safely after their useful life?

(vi) What is the risk of plutonium theft and misuse?

(vii) What are socio-economic aspects of nuclear power development?

According to the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) [1982, p. 16], by the end of 1981, 272 nuclear power reactors with 152 gigawatt (electric) [GW(e)] capacity were in operation in 23 countries, providing about 7% of the total installed electrical capacity and generating more than 8% of the world's electricity. An additional 236 power reactors with 220 GW(e) generating capacity were at that time under construction in 26 countries.

Generally the nuclear fuel cycle consists of several important steps: mining and milling of uranium ores, uranium hexafluoride conversion (UF6), uranium enrichment, fuel fabrication processes (UO_2), fission, reprocessing, and waste storage [UNEP, 1979a].

There are a number of possible thermal reactor designs based on different combinations of fuel, moderator, and coolant. Those that have been brought into commercial operation fall into four main classes: gas-cooled graphite-moderated reactors, light-water reactors (LWRs), heavy-water reactors, and light-water cooled graphite-moderated reactors. Light-water reactors are the main type of reactors in use (185 out of 272) and will continue to be the most frequently used at least until the year 2000 (191 out of 236 under construction were LWRs) [IAEA and WHO, 1982, p. 32].

Uranium ores are mined by underground or surface mining. This leads to land disruption, possible changes in hydrological regime, and pollution of nearby ground waters. Exposure to radon daughters is considered to be the most important radiological occupational hazard in uranium mining.

Milling of uranium ores requires considerable land areas, most of which are devoted to ponds for permanent disposal of mill tailings. Dissolved toxic substances may have the potential for percolation into the ground water, or for direct seepage to near-by surface waters. The levels of radon are much lower in uranium mills than in the mines, and the occupational dose from milling is insignificant compared to that from mining. Inactive mill tailing piles present a potential for exposure to radiation.

The uranium hexafluoride conversion, enrichment, and fuel fabrication processes do not have major environmental impacts. The uranium enrichment process is the largest consumer of electricity in the entire nuclear fuel cycle. The enrichment process is also a dominant user of cooling water, next to the nuclear reactor itself.

The thermal efficiency of current LWRs is about 33%, which means that two-thirds of the heat energy generated in the reactor core has to be rejected to the environment. However, thermal discharges have been put into beneficial uses in many countries, and further development prospects are under investigation.

Normal operation of a nuclear power station gives rise to a number of fission and activation products. A small part of the radioactive material produced is released in airborne and liquid effluents and part as solid wastes. The occupational radiation exposure at LWRs is mainly due to gamma radiation and is usually kept below 5 rem/y[7] which is within the limits of internationally recommended standards. The population around a nuclear power plant receives very low doses of radiation and existing studies have been unable to establish a correlation between nuclear facilities and increased mortality in the general public.

The probability of hypothetical reactor accidents of various degrees of severity has been estimated to be very low. Nevertheless, accidents have happened and likely will happen in the future. The worst one happened in 1986 in Chernobyl where 31 people died, 135,000 were evacuated and probably 270 more people will die over the coming 70 years [Boiteux, 1989].

The uranium and plutonium in the spent fuel from LWRs are valuable energy sources. When both are recycled, reductions in uranium ore requirements and in the front-end of the fuel cycle can be achieved. The recycling of plutonium would introduce a traffic in purified plutonium, which may increase the risk of theft and misuse. The most important airborne effluents from reprocessing plants are carbon-14, krypton-85, iodine-129, and tritium. The most important radionuclides released in liquid effluents are caesium-134, caesium-137, strontium-90 and tritium [UNEP, 1979a]. The occupational radiation exposure in recently constructed reprocessing plants is estimated to be well below the dose limit of 5 rem/y.

Radioactive wastes are generated in practically all areas of the nuclear industry and accumulate as either liquids, solids, or gases with ranging radiation levels. The bulk of waste occurs at the front-end of the cycle, while the more radioactive waste occur at the back-end (reactor operation and recycling). The latter is generally considered as low, intermediate, high-level waste, and waste contaminated with transuranic elements. Low-level and intermediate waste are normally disposed of by shallow land burial or by dumping in the deep ocean in specially designed containers. High-level and transuranic waste must be conditioned and subsequently disposed of at a suitable repository. Such materials have sufficiently persistent biological hazards and require special long-term isolation. Several options have been proposed, none of them gain unanimous popular or scientific support.

Decommissioning of nuclear installations is technically feasible, although very complex. Reactors are likely to present the greatest problem because of their large numbers, the high levels of induced radioactivity and the very large volume of radioactive waste which will be produced.

Under normal conditions, shipments of material required for the annual fuel requirements of LWRs expose the general population to very small radiation doses. The probability of an accident occurring in transportation of radioactive material is small because of the different precautions taken.

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[7] A rem is the quantity of ionizing radiation whose biological effect is equal to that produced by one roentgen of X-rays. Rem stands for r(oentgen) e(quivalent) in m(an).

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