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THE ECONOMIC COSTS OF RENEWABLE ENERGY

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1. INTRODUCTION and SUMMARY OF FINDINGS

Many developing countries and the donors who assist them have been turning their attention to solar energy, wind power and bioresources as possible alternatives to conventional energy for certain applications. Testing of such technologies as solar water pumps, biogas digestors and solar powered electricity for villages is currently underway in many Third World countries. The donor-funded pilot projects are designed to accelerate the adoption of favorable technologies by improving their performance, testing alternative designs and making them socially acceptable through demonstration.

A number of arguments supporting LDC's investments in renewable energy are popular in the technical literature today. The arguments take the following forms:

Argument #1. While few renewable energy technologies are competitive with conventional energy systems in the developed countries, they are economically competitive in areas away from central grids such as in remote rural areas of LDC's where it is difficult and expensive to import fuel and repair equipment; and

Argument #2 even if renewable energy is not economically competitive today, even in remote areas, it <u>will</u> be shortly, as the price of oil increases and the cost of the renewable energy technologies decline; and

Argument #3 besides, renewable energy has added advantages to make it attractive over conventional energy: first, it conserves scarce foreign currency; second, it provides employment since components can be fabricated locally; third, it has less impact on the environment than the fossil fueled alternatives; fourth, it contributes to a nation's energy independence.

These arguments are thoroughly woven into the fabric of renewable energy programs and literature. The problem is that a number of questions about the

strength of those arguments are emerging; simply stated, are they correct? Are renewable energy technologies now,or in the near future will they be, economically competitive with conventional technologies? Do the additional benefits accrue? Do they outweigh the economic handicap? What are the key variables around which the economics of renewable energy are most sensitive?

The answers to these questions are critical to the development of country and donor investment strategies. The danger of premature investment and demonstration is that high cost or poor performance may permanently close future markets. The second danger is that development resources, which might have found a more productive use, will be wasted.

The first purpose of this preliminary work is to carefully catalogue, examine and critically evaluate the most important assumptions which support renewable energy investments. Among the most common are the following:

- the rapidly rising price of oil will make renewable energy technologies economically competitive with oil-fueled conventional technologies in the near future;
- technological improvements and mass production techniques will significantly reduce the cost of selected renewable energy technologies;
- high reliability, long lives, and low operating costs (i.e., no fossil fuel) make renewable energy technologies, especially attractive in remote areas;
- indigenous manufacture of renewable energy technologies or components can enhance the economic competitiveness of the technologies, provide local employment opportunities and save scarce foreign currency resources;
- other indirect benefits such as a greater independence from supply interruptions and an improved environment accrue to make renewable energy technologies attractive.

In this effort we have examined the first assumption thoroughly by a method involving several case studies. We used a net present cost analysis method for comparing renewable and conventional energy technologies and applied it to three applications: water pumping for irrigation, electrification of a village and supplementing gasoline with alcohol. The comparisons are made several times for each technology during the period 1980 to 1995 in order to see the effect of rising fuel costs and declining renewable technology costs.

It has not been our purpose here to evaluate whether or not these applications make sense in a particular setting or are economically attractive in absolute terms. The local costs and benefits are too site specific for such a statement. Rather, we have compared different technologies in order to determine which one is or will be relatively superior. We have not addressed the issue of whether any applications pass the cost/benefit test.

This analysis is designed to contribute to the discussion of energy investment strategies for those countries and donors considering renewable energy technologies as a viable alternative to fossil fuel. The technical and economic assumptions selected here can also become useful for other analyses by providing a "common ground" for comparison.

In the long run, only the marketplace can provide the true test of the acceptability of renewable energy technologies. What we hope to do here is to compare the economics of competing systems under a reasonable set of assumptions to determine which renewable systems have a relative chance of market penetration and to identify the conditions in which this penetration can occur. The questioning in the analysis does not arise out of skepticism about the technologies involved, but from a hope that this work will reduce

the likelihood of over-enthusiastic and damaging support of clearly unmerited technologies.

The first set of findings deals with the assumption that the increase in the price of oil projected over the next decades and the drop in renewable technology costs will result in improving the relative economic performance of renewable technologies versus conventional fuel systems. To avoid complicating the analysis, such additional variables as foreign exchange issues and fuel availability are not factors in this paper, though they are very real in fact. The three cases investigated refine the oil price and technology cost assumptions and provide a more useful formulation of the assumptions for the purpose of establishing renewable energy programs.

In the case of water pumping, the cost of oil prices represents less than 10 percent of the total net present cost for a small scale of use, a 1 to 5 hectare farm with agricultural products that are not particularly demanding of water. Fuel prices, therefore, influence the decision for small scale pumping very little. Even if the highest scenario for fuel prices was lower than reality, the effect on the decision to choose the gasoline pump would be very small assuming that fuels were available and foreign exchange was not a major issue.

In pumping, other factors are more telling than the price of fuel. Assumptions discussed in the text for the decline in price of photovoltaic modules and other parts of the pumping system have far more impact than the price of fuel. Accordingly, somewhere in the late 1980's, photovoltaic systems for pumping would be financially and economically viable options from the point of view of a farmer and the society, adjusting for their

different discount rates.

This finding is sensitive to the scale of activity, that is, the amount of water and the pumping rates required to provide adequate irrigation. However, site specific characteristics, which may vary within the established range, do not greatly upset the finding that oil prices aren't the key issue. Rather, future technology development, associated cost reductions and good matching of the technology to the need are the major determinants of economic viability.

Windmills are also discussed in the pumping case and aside from the obvious fact that local wind speed is critical in determining the comparative viability of wind versus petroleum, an equally important issue is the relative efficiency of technologies. In the test case, a home-made windmill was compared to a factory manufactured product. The home-made "appropriate" technology is selected for its appeal as a local industry, but it is economically competitive in only very limited circumstances when compared to the manufactured product. The manufactured machine is also only relatively economic vis-a-vis petroleum after 1990, and then only for the highest fuel price scenario and high wind speeds. The way to make the local technology compete economically with either petroleum or imported products is to apply it for limited use or where skilled labor costs are very low.

In sum, the pumping case illustrates the relative importance of factors other than fuel prices (e.g. the renewable energy resource and level of technology development) in making the decision to support renewable energy for that use. It also suggests limits of applicability of some "appropriate" technologies. The early assumption with reference to pumping

is, therefore, essentially correct, renewable energy forms will compete with conventional systems, but the conclusion relates more to technology design and cost reductions than to oil prices.

In the case of electification of a village, the comparative technology findings are very sensitive to the scale of the project. At low levels of power generation, diesel generators will go underutilized where photovoltaics will be used to full capacity. However, even accounting for this feature and assuming no technological improvement in diesel power, it is only after 1990 that rapidly declining photovoltaic system costs will make this new technology economically attractive. In the case of village electrification at the level of 4 Kw, the fuel cost is a much larger component than in pumping and the cost of diesel fuel therefore impacts on the decision to electrify a village. Even so, as a relative contributor to the decision, fuel price is less determinant than technological and design changes in photovoltaic systems. Thus, the factor which drives renewables toward price competitiveness is once again essentially as in the former case: technology development is more critical than oil prices.

In the case comparing wind with alternatives, in areas where wind is prevalent at better than 12 mph average annual wind speed, wind generated power is economic today and will continue to be in the future. Of course, as will be discussed below, the intermittent quality of sun and wind makes considerable storage necessary to provide services similar to those of diesel engines. But, diesel in rural settings have reliability problems. Long lasting power loss can be from the lack of fuel, inadequate spare parts or skilled labor to service the engine.

In sum, the finding for electrification of a small village is that

wind machines work well, where there is adequate wind; that diesel power will be more economic until the early 1990's, even with high fuel costs; and that technological improvements and design changes as noted will make photovoltaic systems relatively attractive sometime in the early 1990's. If the price of photovoltaic declines as shown in our most optimistic case, it will be very attractive for all rural electricity functions by the turn of the century.

It should be emphasized that this study does not comment on the absolute affordability of pumping or electrification, only of the relative cost of technological alternatives to provide a desired service. One of the significant secondary results of the analysis is that in the 1990's new technologies will look economically attractive on a comparative basis, but there will have to be economic growth to pay for the absolute costs. Future costs of renewable energy may be relatively favorable and still be beyond the means of most rural populations.

In the case of gasohol, the various costs are compared with different scenarios for the cost of gasoline. Even though the report (Table 2.2) shows the vastly varying prices which consumers pay for fuel around the world, the unsubsidized or taxed cost makes some ethanol processes and feedstocks attractive even now. However, the significant finding is that as time and price progress toward 1990, more and more feedstocks become economic and ethanol substitution makes increasing sense. The limiting factor is often the availability of a feedstock and the extensive land required to grow sufficient quantities. The price of oil is not sufficient as a determining variable in many cases where current crops or waste are not suited to known processes, but as the key assumption states, increases

in oil prices brings more feedstocks into consideration.

It should be noted, the price of fuel is so sensitive to taxation policy (variations to 50 percent of fuel costs are common) that ethanol use is related to that factor very closely. However, no taxes or subsidies are charged on any fuel or technology for this analysis because of the international variation. Solar technologies are currently subject to taxes as well and the analysis eliminates these costs to facilitate constant comparison.

The key assumption relative to the increase in oil prices and the attractiveness of renewable energy can now be understood more precisely as a result of our findings. A key factor in making renewable energy forms relatively attractive is the scale of the job to be done, the smaller the job, the more suitable is a renewable technology in pumping and in electrification of a village. While the price of oil is a factor, its importance is frequently overshadowed by design choices such as the amount of storage and technological improvements now almost certain to intervene in the last part of the 1980's. Thus, there is nothing automatic about rising oil prices creating a situation where one day oil will price itself beyond renewable energy.

Thus, the key assumption that oil price increases and renewable energy technology cost declines will make renewable energy economically attractive is true with operational caveats. First, it takes engineering judgement to size the units to scale; end use analysis to design the most suitable system to satisfy the need; and new manufacturing techniques and materials to improve fuller exploitation of the solar resource potential. Second, at the level of costs under consideration, quality engineering and clearly articulated

service objectives are essential to any project design for renewable energy. The case analyses provide a basis to bound these general statements and provide some understanding of contributing factors to economic competitiveness.

A further boundary of the general statement limits extrapolation from the few technologies that have been carefully examined in this paper. There are many more renewable technologies than the windmills, ethanol plants, and photovoltaic systems described. Furthermore, there are many more applications and characteristics of the resources than those enumerated here. Varying assumptions will vary the findings. We are confident that more can be said from this analysis than a general statement about the price of oil making or not making a difference or an equally general statement that everything is site specific. However, we do not wish to invite interpretations of this work that extrapolate to technologies of significant difference in scale or kind. We are, however, reasonably sure that escalating oil prices will not dramatically change the results. Even as the paper was in progress, oil prices increased such that the highest scenario in the paper, S3, looks possible. If the oil prices go even beyond our highest projection in real terms, the only difference in our results is that except for ethanol, cost competitiveness in the early 1990's may be achieved a year or two earlier. The primary results are not significantly impacted by a somewhat erroneous assumption in this area.

A further statement is not empirically derived from the data, but is interpretive of some of the basic relationships among the variables. In order to be competitive with oil, renewable energy forms have to be provided at a level of service that avoids expensive modes to deal with the intermittent

quality of the renewable resource. In spite of reductions in prices of windmills, which are expected to be small, and in photovoltaic modules which are expected to be large, the electrification programs based on solar energy will still have to avoid large battery systems and some of the engineering which characterizes today's demonstration systems. Compromises will have to be made. Power shortages will have to be as acceptable for renewable systems as they are for conventional systems, if electricity is to be afforded. If a decision maker seeks the so called "soft path" of meeting energy demand, he must also have "soft" expectations. However, we continually find energy ministers who have a desire for the "soft" path, but keep their "hard" expectations. Decision makers will have to be realistic in their expectations of the level of service to be offered to rural populations. Full back up systems are too expensive and usually are only needed for a very few critical uses where a little storage or a small back up engine would suffice to meet critical needs. If the decision makers inform the engineers that they will accept a level of service that represents major strides for a village, but may not meet the design specifications of the home city of the designer, then the conclusions in this paper are valid. If the soft path is ill matched to hard expectations then the findings which project cost competitiveness of renewable energy in this decade could be delayed.

The paper has no findings on two other central matters that would influence the decision makers desire to introduce renewable energy. For a number of reasons, including balance of trade problems or national security matters, decision makers might favor renewables over conventional energy. These considerations have not been factored into our economic analysis,

leaving room for other interpretations, usually favorable to renewable energy.

Another matter which affects decisions is how soon a donor agency should demonstrate a technology before it is economically competitive. In conventional technologies, the planning cycle for even a known power technology is in the neighborhood of ten years. If the same timing is applied to the systems in this paper, then the early 1990's will provide a favorable economic setting for the commercialization of renewable energy facilities. That means that demonstrations should begin in the early eighties.

The risks behind this decision will be better understood because this study details the areas where vulnerable assumptions are made. A start up program in renewable energy will have to address the issues of scale, level of service, indigenous manufacturing, and other design considerations in order to replace conventional technologies and remain relatively economical.

In sum, the general assumption that as the increase of oil prices and the decline in technology costs proceed, renewable energy will be cost competitive is essentially true. Despite many factors, the very basic conclusion is that technical forces are leading to the economic viability of renewable energy for important applications in national development.

2. CATALOGUE OF ASSUMPTIONS

The purpose of this chapter is to identify the dominant assumptions which concern the economic competitiveness of renewable energy resources, state them clearly and subject them to close scrutiny. The result of this will be a useable set of common assumptions for the case studies presented in Section III of this report. The assumptions may also be useful in preparing other comparisons of conventional and renewable technologies. The assumptions which will be considered here involve the future price of fuel, increases in the cost of photovoltaic and other renewable systems, reliability and life expectancy of various systems, methods of comparison used in various cost comparisons and discount factors. Other assumptions which affect the economic value of systems, but do not directly enter the costing calculus, will also be noted. They include: employment, indigenous manufacture of components and environmental impact of systems.

We initially reviewed a broad range of literature of renewable energy technologies. The review included examining reports prepared by NASA and others (on photovoltaic cells), the DOE and manufacturers of conventional and renewable technologies and various economic comparisons of renewable technologies with conventional ones. References are noted in the text. The next step was to extract the key assumptions upon which these reports were based. These assumptions were then examined and, where appropriate, compared with actual field experience of US AID and other donor and country programs. A major verification effort was made to obtain current technology costs through telephone and personal interviews with manufacturers of off-the-shelf technology. Unless specifically noted, "cost" refers to cost to the consumer, or the price paid. Thus cost and price are used interchangeably.

A. Cost of Fuel

Shortly after the 1973-74 OPEC mandated oil price leap, the Ford Foundation in its ground breaking examination of alternative energy strategies' for the U. S. developed estimates for future oil prices. It stated:

> "While we believe prices will stay in the range of $7.00 a barrel, an investor cannot ignore the risk of price cuts large enough to ruin investments in domestic oil production that actually cost $7.00 a barrel."[1]

Since then many other scholarly attempts have been made to predict the future price of oil. The Workshop on Alternative Energy Strategies[2] (WAES) in late 1975 based its analysis on three oil price scenarios shown in Figure 2.1. The rising price scenario shows a $17.50 barrel (in 1975 dollars) of oil for 1985. This would be about $28 in 1980 dollars; a mark which was surpassed last year.

Thus it appears that the environment in which oil price projections are made is too unstable to expect great accuracy. Without the benefit of a crystal ball, it is most useful to bound future oil prices based on alternative scenarios of world economic growth and OPEC behavior. The past seven years have provided several lessons unknown by the Ford Foundation and WAES at the time of their reports. These lessons have been incorporated in the projections of oil prices developed by the U. S. Department of Energy in its Annual Report to Congress. We have used these projections as the basis for our estimates of the delivered cost of fuel to the consumer, with modifications as noted (Figure 2.2).

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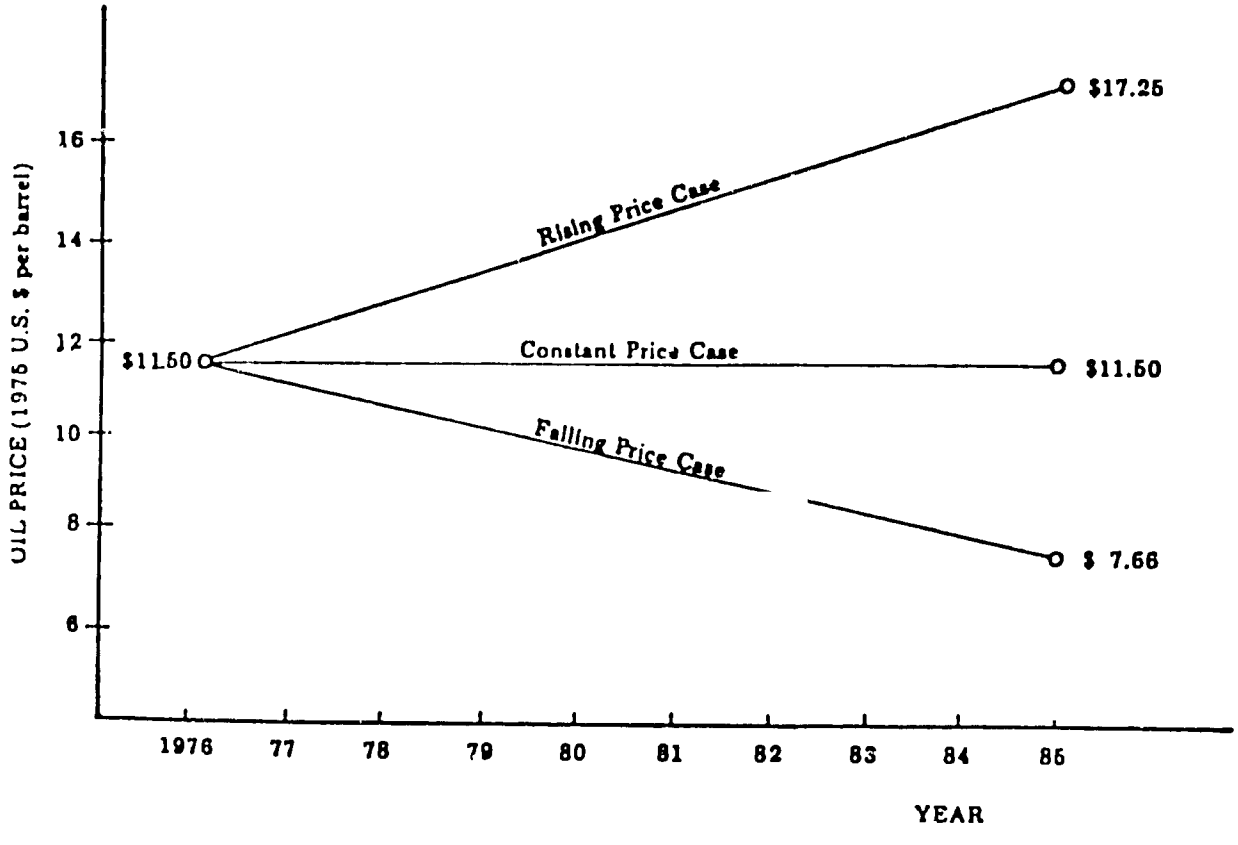
1. A Time To Choose, America's Energy Future, Energy Policy Project of the Ford Foundation, 1974.

2. Carroll L. Wilson, Energy Demand Studies: Major Consuming Countries, Workshop in Alternative Energy Strategies, 1976.

Figure 2.1

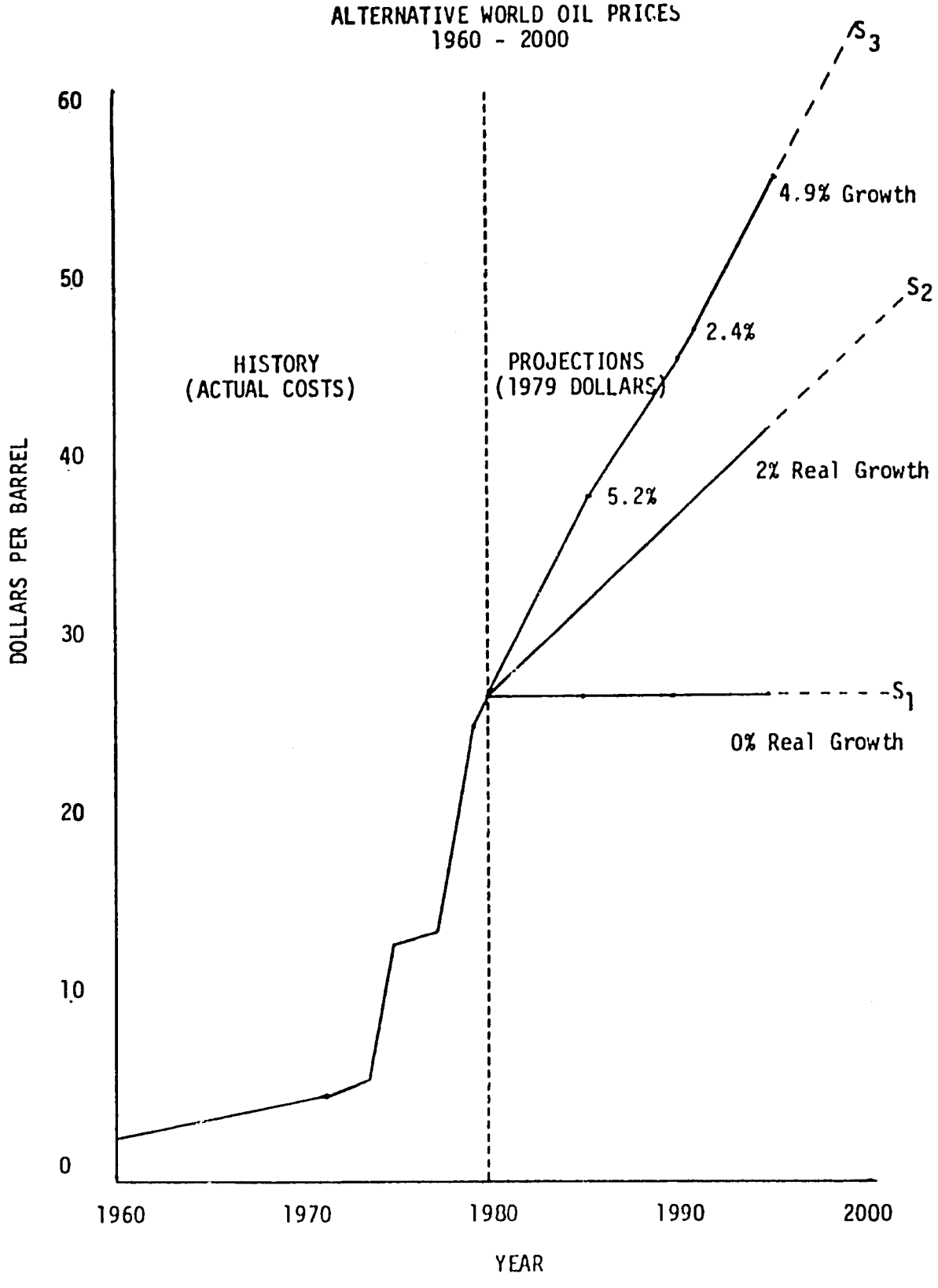
THREE ALTERNATIVE OIL PRICE ASSUMPTIONS TO 1985,
WAES REPORT



Source: A Time To Choose, America's Energy Future, Energy Policy Project of the Ford Foundation, 1974

Figure 2.2

ALTERNATIVE WORLD OIL PRICES
1960 - 2000



SOURCE: DOE ANNUAL REPORT TO CONGRESS - 1979

Figure 2.2 presents the projections of world oil prices for three alternative scenarios, S_1, S_2, S_3. The methodology behind these price forecasts reflects the historical OPEC pricing strategy within the pricing procedure rather than the strict forecasts of market clearing prices from previous DOE analyses. The high price scenario implies that by 1985, real oil prices rise 5.2 percent annually from the April 1980 level, 2.4 percent annually between 1985 and 1990 and 4.9 percent annually between 1990 and 1995. The average rise in the real price of oil for the 1980-95 period is 4.2 percent annually. This scenario reflects the effect of three oil supply descriptions consisting of a cutback in OPEC production of two million barrels per day.

In the midprice scenario, S_2, the average growth in real price is 2.0 percent annually from 1980 to 1995. This is similar to the historic increase between 1974 and 1979. The low price scenario, S_1, is that oil prices will remain level in real terms throughout the forecast period, recognizing that the possibility of oil price increases only compensate for inflation. It is recognized that in many remote areas, prices of fuel can be significantly higher. During periods of temporary fuel shortage, prices typically also rise very steeply. However, these costs are based on expected average, long-term costs for a great majority of areas in developing countries.

The world price of crude oil is only the first component of the total price of the fuel to the consumer. The other price components are transport costs, refinery costs, transport of refined products, taxes and profit. Each of these costs is highly country and site specific. Rather than provide a single cost, we provide a range of costs for transport, refining and handling. These are shown on the next page.

	Dollars per gallon (1979 Dollars)	
Transport to refinery		
Transport to refinery	1980[1]	2000[2]
Bulk Transport	$0.10	$0.13
Small Transport	.40	.50
Refining		
World Scale Refinery[3]	.25	.31
Regional Refinery[4]	.50	.63
Transport and Handling		
High Access[5]	.10	.13
Low Access[6]	.80	1.00

---

1)Derived from World Bank, Energy in the Developing Countries.

2)Assume 25% real increase in transport and refining costs between 1980 and 2000.

3)120,000 BBL/Day capacity

4)10-30,000 BBL/Day Capacity

5)High Access - to coastal depot or capital city.

6)Low Access - to remote inland village
100 Km from capital.

The range of delivered fuel prices is shown in Table 2.1. On the low end is the cost of fuel based on bulk transport of crude oil, a world scale refinery and a good road and/or pipeline system for delivery of products. This reflects situations found in the U. S. and other OECD countries. The high cost estimate is based on transport of crude in small tankers, a small refinery and low access requiring small tank trucks, four wheel trucks or carts to remote areas. No taxes or local profits are included because they vary greatly in each country and reflect local pricing policies. In our analysis we will use untaxed fuel costs. The cost to the consumer, or oil price, is, therefore, higher or lower than shown by the amount of tax or subsidy in a country.

Since the actual prices of petroleum that are familiar to the consumer at the gas pump vary widely from our untaxed fuel costs, Table 2.2 lists typical consumer prices, taxes and duties for a number of countries throughout the world in July 1978 and 1979 as a basis for comparison with the Fuel Cost Schedule in Table 2.1.

Table 2.1

FUEL COST SCHEDULE 1965-2000
(Constant 1979 dollars)*

	Unrefined World Oil Prices	Delivered Bulk Transport World Scale Refinery High Access	Fuel Small Transport Small Refinery Low Access
1980	27.00	1.09	2.34
1985			
S_2	32.00	1.21	2.53
S_3	39.00	1.38	2.63
1990			
S_2	37.00	1.33	2.75
S_3	44.00	1.50	2.95
1995			
S_2	41.00	1.43	2.98
S_3	56.00	1.78	3.32
2000			
S_2	46.00	1.67	3.23
S_3	67.00	2.17	3.73

*Based on real price increase of 2% and 5% annually.

Appendix A, Table 1 shows annual price rise.

Table 2.2
WORLD SURVEY OF PETROLEUM PRODUCT PRICES (US$ PER U.S. GALLON*)

Country and Products	July 31, 1978				July 31, 1979			
		INCLUDES				INCLUDES		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty
NORTH AMERICA:								
Canada, Ottawa								
Premium gasoline	.73	.26	x	none	.78	.24	x	none
Regular gasoline	.67	.25	x	none	.71	.23	x	none
Auto diesel fuel	.68	x	x	none	.76	.23	x	none
Mexico, Mexico City								
Premium gasoline	.67	.22	x	none	.67	.22	x	none
Regular gasoline	.47	.16	x	none	.47	.16	x	none
Auto diesel fuel	.11	x	x	none	.15	x	x	none
United States (national average)								
Premium gasoline (leaded full serve)	.71	.13	none	none	.97	.14	none	none
Regular gasoline (leaded full serve)	.65	.13	none	none	.91	.14	none	none
Auto diesel fuel	.53	.13	none	none	.82	.14	none	none
CENTRAL AMERICA AND CARIBBEAN:								
Jamaica, Kingston								
Premium gasoline	1.56	.95	x	x	1.79	.79	x	.16
Regular gasoline	1.48	.88	x	x	1.75	.79	x	.15
Auto diesel fuel	x	x	x	x	.79	x	x	.11

* Source: International Petroleum Annual 1978, US DOE

Table 2.2 (cont'd)

Country and Products	July 31, 1978 Consumer Price	July 31, 1978 INCLUDES Tax	July 31, 1978 INCLUDES VAT 1/	July 31, 1978 INCLUDES Import Duty	July 31, 1979 Consumer Price	July 31, 1979 INCLUDES Tax	July 31, 1979 INCLUDES VAT 1/	July 31, 1979 INCLUDES Import Duty
CENTRAL AMERICA AND CARIBBEAN (Cont'd)								
Panama Republic, Panama								
Premium gasoline	1.10	.10	x	.41	1.56	.10	x	.41
Regular gasoline	1.00	.10	x	.33	1.45	.10	x	.33
Auto diesel fuel	.55	x	x	.02	.89	x	x	.02
SOUTH AMERICA:								
Chile, Santiago 8/								
Premium gasoline	1.02	.51	x	10%	1.98	.39	+20%	10%
Regular gasoline	.83	.33	x	10%	1.52	.28	+20%	10%
Auto diesel fuel	.64	.14	x	10%	1.31	x	20%	10%
Ecuador, Quito								
Premium gasoline	.18	.07	x	none	.18	.07	x	none
Regular gasoline	.16	.07	x	none	.16	.07	x	none
Auto diesel fuel	x	x	x	x	x	x	x	x
Peru, Lima								
Premium gasoline	.86	.30	x	x	.89	.24	x	x
Regular gasoline	.74	.29	x	x	.78	.23	x	x
Auto diesel fuel	x	x	x	x	x	x	x	x

Table 2.2 (cont'd)

Country and Products	July 31, 1978 Consumer Price	July 31, 1978 INCLUDES Tax	July 31, 1978 INCLUDES VAT 1/	July 31, 1978 INCLUDES Import Duty	July 31, 1979 Consumer Price	July 31, 1979 INCLUDES Tax	July 31, 1979 INCLUDES VAT 1/	July 31, 1979 INCLUDES Import Duty
WESTERN EUROPE:								
Austria, Vienna 10/								
Premium gasoline	1.80	.66	+18%	.06	2.22	.79	+18%	.07
Regular gasoline	1.70	.66	+18%	.06	2.02	.79	+18%	.07
Auto diesel fuel	1.57	.56	+18%	.04	2.11	.69	+18%	.04
Denmark, Copenhagen 11/								
Premium gasoline	1.94	.90	x	.30	2.84	1.30	x	.48
Regular gasoline	1.90	.90	x	.29	2.80	1.30	x	.47
Auto diesel fuel	x	x	x	x	1.45	.21	x	.24
W. Germany, Bonn								
Premium gasoline	1.76	.81	+12%	6%	2.19	.94	+12%	6%
Regular gasoline	1.68	.81	+12%	6%	2.09	.94	+12%	6%
Auto diesel fuel	1.70	.77	+12%	6%	2.21	.88	+12%	6%
Italy, Rome 11/								
Premium gasoline	2.25	1.36	+12%	6%	2.53	1.39	+14%	6%
Regular gasoline	2.16	1.32	+12%	6%	2.44	1.35	+14%	6%
Auto diesel fuel	.75	.20	+14%	6%	1.11	.12	+14%	3.5%
Netherlands, The Hague 11/								
Premium gasoline	1.89	x	18%	.85	2.25	x	18%	.92
Regular gasoline	1.83	x	18%	.85	2.18	x	18%	.92
Auto diesel fuel	1.11	x	18%	.32	1.43	x	18%	.35

Table 2.2 (cont'd)

Country and Products	July 31, 1978				July 31, 1979			
		I N C L U D E S				I N C L U D E S		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty
WESTERN EUROPE: (Cont'd)								
Portugal, Lisbon 13/								
Premium gasoline	2.18	1.17	x	.37	2.41	1.30	x	.34
Regular gasoline	1.93	1.01	x	.35	2.17	1.14	x	.33
Auto diesel fuel	x	x	x	x	x	x	x	x
Sweden, Stockholm								
Premium gasoline	1.54	.93	x	x	2.04	.95	x	x
Regular gasoline	1.51	.93	x	x	1.97	.95	x	x
Auto diesel fuel	.62	.04	x	x	.98	.04	x	x
Yugoslavia, Belgrade								
Premium gasoline	1.47	.95	x	x	2.67	1.62	x	x
Regular gasoline	1.41	.92	x	x	2.47	1.56	x	x
Auto diesel fuel	x	x	x	x	1.88	.91	x	x
MIDDLE EAST:								
Israel, Tel Aviv								
Premium gasoline	1.47	.37	x	.32	2.48	1.02	x	.51
Regular gasoline	1.36	.42	x	.22	2.32	1.03	x	.41
Auto diesel fuel	x	x	x	x	x	x	x	x

Table 2.2 (cont'd)

Country and Products	July 31, 1978				July 31, 1979			
		I N C L U D E S				I N C L U D E S		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty
MIDDLE EAST: (Cont'd)								
Lebanon, Beirut								
Premium gasoline	.90	.24	x	.02	.94	.22	x	.02
Regular gasoline	.78	.24	x	.02	x	x	x	x
Auto diesel fuel	x	x	x	x	x	x	x	x
Turkey, Ankara								
Premium gasoline	1.59	.31	x	.02	1.55	.23	x	.79
Regular gasoline	1.31	.24	x	.02	1.32	.20	x	.78
Auto diesel fuel	.76	.21	x	.01	.70	.13	x	.03
AFRICA:								
Ethiopia, Addis Ababa 17/								
Premium gasoline	1.42	.28	x	x	1.65	.28	x	x
Regular gasoline	1.22	.23	x	x	1.38	.23	x	x
Auto diesel fuel	x	x	x	x	x	x	x	x
Ghana, Accra								
Premium gasoline	1.13	none	x	.49	1.05	none	x	.31
Regular gasoline	.95	none	x	.20	.90	none	x	.21
Auto diesel fuel	.57	none	x	.12	.60	none	x	.08

Table 2.2 (Cont'd)

Country and Products	July 31, 1978				July 31, 1979			
		I N C L U D E S				I N C L U D E S		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty
AFRICA: (Cont'd)								
Kenya, Nairobi								
Premium gasoline	1.76	.40	x	.34	1.94	.54	x	.31
Regular gasoline	1.69	.40	x	.34	1.78	.46	x	.31
Auto diesel fuel	1.24	.11	x	.22	1.25	.11	x	.20
Morocco, Rabat								
Premium gasoline	1.98	65.7%	x	none	2.77	65.7%	x	none
Regular gasoline	1.80	64.6%	x	none	2.57	64.6%	x	none
Auto diesel fuel	x	x	x	x	x	x	x	x
South Africa, Pretoria								
Premium gasoline	1.31	.05	x	.45	2.46	.10	x	.47
Regular gasoline	1.28	.05	x	.45	2.43	.10	x	.47
Auto diesel fuel	1.28	.05	x	.44	2.43	.10	x	.46
ASIAN AREA:								
Australia, Canberra								
Premium gasoline	1.01	.22	x	.22	1.30	.22	x	.22
Regular gasoline	.93	.22	x	.22	1.34	.22	x	.22
Auto diesel fuel	1.04	.22	x	.22	1.19	.22	x	.22

Table 2.2 (Cont'd)

Country and Products	July 31, 1978				July 31, 1979			
		I N C L U D E S				I N C L U D E S		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty
ASIAN AREA: (Cont'd)								
India, New Delhi								
Premium gasoline	1.69	7%	x	1.04	2.05	7%	x	1.34
Regular gasoline	1.65	7%	x	1.04	1.97	7%	x	1.34
Auto diesel fuel	.64	7%	x	.07	.72	7%	x	.08
Japan, Tokyo 20/								
Premium gasoline	2.23	.87	x	.04	2.46	.95	x	.04
Regular gasoline	2.07	.87	x	.04	2.27	.95	x	.04
Auto diesel fuel	1.17	.38	x	.04	1.49	.42	x	.04
Pakistan, Islamabad								
Premium gasoline	1.24	.15	x	.34	x	x	x	x
Regular gasoline	1.15	.15	x	.34	x	x	x	x
Auto diesel fuel	.54	.34	x	.10	x	x	x	x
Singapore, Singapore								
Premium gasoline	1.31	.62	x	none	1.40	.63	x	none
Regular gasoline	1.18	.59	x	none	1.29	.59	x	none
Auto diesel fuel	.39	negl.	x	none	.63	negl.	x	none
Thailand, Bangkok								
Premium gasoline	.93	.04	x	.34	1.45	.06	x	.54
Regular gasoline	.88	.04	x	.34	1.38	.06	x	.54
Auto diesel fuel	.49	.02	x	.03	.91	.04	x	.10

Table 2.2 (Cont'd)

Country and Products	July 31, 1978				July 31, 1979			
		I N C L U D E S				I N C L U D E S		
	Consumer Price	Tax	VAT 1/	Import Duty	Consumer Price	Tax	VAT 1/	Import Duty

Negl. = Negligible, less than .005 US$.

x Not reported or unknown.

1/ Value-added tax is noted where the percentage figure is known; otherwise any value added tax is included in the tax column figure.

2/ Wholesale price

Note: "Consumer Price" is defined as the final price at the point of consumption. Whatever tax and duty information that can be identified as included (or for some series excluded) in the final price is tabulated in the "Includes" columns. Prices in U.S. dollars distort to some degree the actual increase or decrease of prices in other countries because of exchange rate fluctuations.

B. Price of Photovoltaics

1. Photovoltaic Cells

In 1978 the American Association for the Advancement of Science published an authoritative book entitled Solar Energy in America by Metz and Hammond[3]. In the chapter dealing with Photovoltaic cells, it stated:

> "Arrays of silicone cells now cost about $10 per watt of generating capacity in full sunlight. Reduction to about $1 per watt -- a cost that is expected to make feasible a broad range of specialized applications -- is widely anticipated as early as 1980, particularly for concentrating systems."

1980 has come and gone and PV cells still hover around the $10 mark according to PV manufacturers.

The U.S. Department of Energy has readjusted its annual goals for the price of PV cells upwards, but maintains the $.50 - $.70 Wp price in 1986. (1980 dollars). The DOE argues that immense room exists for progress in the technology and improved manufacturing techniques for mass production will have an analagous effect as that experienced by silicone chips in the computer industry. Figure 2.3 illustrates the DOE's price goals.

While there is little question that PV costs will decline over the next decade, the level of optimism generally relies on a "technological breakthrough" as well as large, sustained markets. DSI offers an alternative price curve (Figure 2.4) based on conversations with PV manufacturers and assumptions less optimistic in their outlook.

The changes in module (cell) and balance of system (BOS) costs over the past few years have been different in nature. As module designs were first

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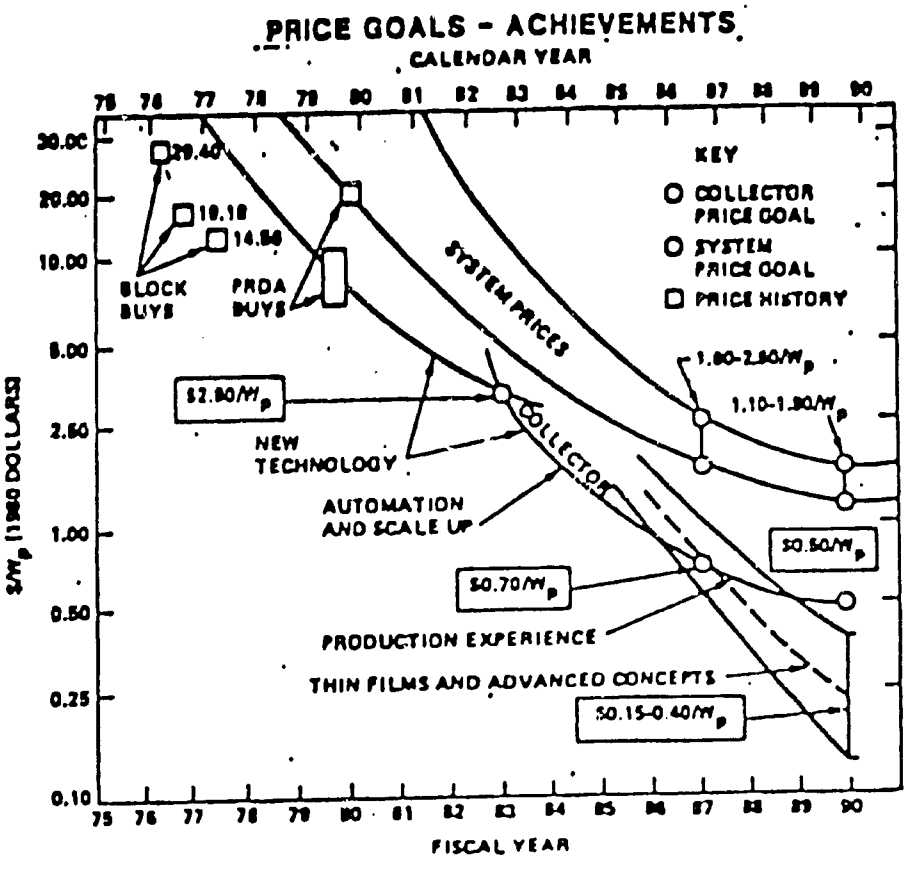
3. Metz and Hammond, Solar Energy in America, AAAS, 1980.

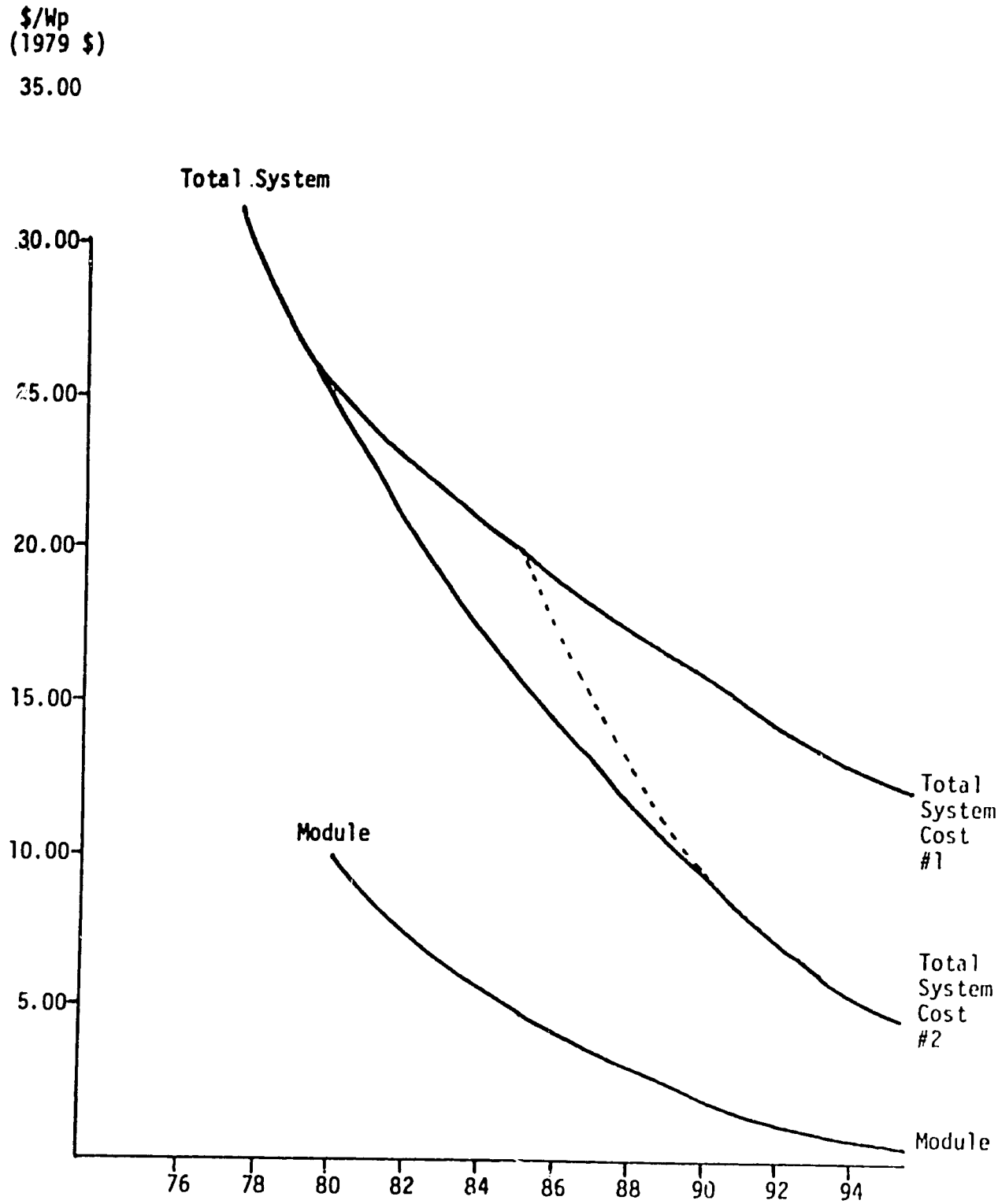
Figure 2.3



Source: U. S. Department of Energy, Electric Power from Solar Cells, 1980.

Figure 2.4

PROJECTED PV MODULE AND SYSTEMS COSTS



developed, costs were high but started to drop rapidly as design repetition and innovation became significant. The BOS costs, on the other hand, have remained high and in 1980 represented 62 percent of the average total system cost as opposed to 39 percent of the system cost in 1975.[4]

The BOS components can be described as follows:[5]

- Array, Structure, and Site Preparation: module mounting frames; frame supports and foundations; security and safety equipment; site clearing, leveling, drainage;
- Electrical: wiring, interconnects; control circuits/instruments; loal management circuits; voltage regulation, power conditioning; enclosure or building;
- Storage: Batteries; racks and venting equipment; enclosure or building;
- Other: system sizing and design; module test and inspection; packaging and freight preparation; maintenance equipment.

The nature of these BOS components indicates that the industries responsible for module production and BOS components are greatly different; the first a new industry using new and creative technologies, the second a more mature industry, less impacted by technological change. Accordingly, one would not expect similar cost variations.

DSI has evaluated several potential price curves for both the module and the BOS. The lower curve in Figure 2.4 shows the module at the average

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4. G. Hein, et. al., "Impact of BOS Costs on PV Power Systems," NASA, 1978. Calculation based on 1975 module cost of $21/Wp and average 1975 BOS cost of $13.35 in 1975 dollars. Total system cost for 1975 is $34.35 in 1975 dollars.

5. NASA Technical Memorandum 79097 (Revised) Photovoltaic Power Systems For Rural Areas of Developing Countries, Louis Rosenblum, William J. Bifano, Gerald F. Hein, and Anthony F. Ratajczak; Lewis Research Center, Cleveland, Ohio. Pg. 13.

$10/Wp for 1980 (in 1979 dollars) which is presently quoted and a $5/Wp projection for 1985. From there it is anticipated that mass production along with lower cost technology will drop the cost to $2/Wp in 1990 and $0.50/Wp in 1995. BOS costs can be assumed to change more slowly. The upper curve in Figure 2.4 shows a total system made up of the module and BOS costs. However, there are other reasonable assumptions for the BOS costs.

The total system cost curve #1 is based upon the module decreasing as previously explained while the BOS slowly decreases by 10 percent (in constant 1979 dollars) every five years. Thus, the BOS cost is plotted under this gradual decrease, reflecting minimum economies through mass production techniques. The BOS reaches $15/Wp in 1985 and $12.50/Wp in 1995. In this scenario the BOS cost represents 75 percent of the total system cost in 1985 and over 90 percent in 1995. It is not reasonable to expect that this ratio will continue to grow as module costs become so low. Rather, it can be assumed that basic changes in the BOS components will occur. We, therefore, project a lower system cost shown as curve #2 which begins in 1985.

During the middle 1980s as the module approaches $5/Wp, it is reasonable to assume the beginning of changes in the BOS components. For example, a recent study has allocated BOS costs as follows:[6]

Category of BOS	Average Fraction of Total BOS Cost
Array, Structure, & Site Preparation	.18
Electrical	.33
Storage	.20
Installation & Checkout	.20
Other	.09
Total	1.00

6. G. Hein, et. al., "Impact of BOS Costs on PV Power Systems," NASA, 1978, Pg. 4.

With these fractions, the various categories can be evaluated to show potential changes as the module costs decline.

Each category serves a different function and will respond differently to a new, probably lighter, smaller and cheaper module. It can be assumed that the structure and electrical components will decrease in weight and complexity and, therefore, cost less. Similarly, in-country manufacturing and local installation will also lower actual costs.

Storage costs can be anticipated in a different manner. At the present time battery costs are rising and the $3.30 allocated to the battery backup for 1980 could increase in the next few years. DSI is assuming that after these first few years of demonstration projects with large storage requirements, there will be less backup storage provided in the total system, thus lowering costs for the storage component.

Accordingly, the lower cost for the module is assumed to drive to a lower cost for the BOS. This can be seen in Figure 2.4 by the dotted line connecting total system cost #1 with total system cost #2 from 1985 to 1990. The resulting total system cost #2 shows the effect of this driving force downwards on the BOS cost with a drop in BOS to $8/Wp or 80 percent of the total system cost in 1990, and a still lower percentage and cost in 1995.

Obviously, this lower amount for a total system represents new technological advances, but more importantly a set of design criteria which would reduce backup. It would be anticipated that medical refrigerators and other limited critical facilities requiring greater temperature protection would be designed with their own protection systems, not with extreme amounts of storage in the total system. Just as brownouts or blackouts

are tolerated today with grid or non-grid systems, so tomorrow's photovoltaic users will tolerate performance standards which are cost effective rather than designed to spend large amounts of money on storage for the limited benefit of overly cautious reliability. It is, therefore, reasonable to assume total system cost #2 provides the most likely scenario.

The detail which explains the impact of the assumptions can be found in Appendix A, Table 2.

C. Economic and Financial Analysis Method

A primary goal of this report is to determine at what point some renewable energy technologies may become cost competitive with conventional technologies. We also want to know under what conditions (e.g., fuel price increases, PV price declines, etc.) this will happen. The method that we will use is to calculate the cost to deliver a particular service (e.g., x gallons of water, y kwh) for each competing technology. Annual costs will be reported for each technology purchased at five-year intervals (between 1980 and 1995) based on new assumptions about the cost of fuel and the cost of the equipment. The change in cost over time for each technology will then be presented in tables or plotted graphically and the various costs and curves will be compared.

A number of issues in the cost calculations must be considered:

1. Future costs are affected by the value of certain variables such as the price of fuel, the cost of the technology which is itself dependent on technological advances, large volume sales and the nature of the design. The level of uncertainty surrounding each variable varies greatly and, therefore, the results of the comparisons can vary greatly depending on the

underlying assumptions made. We do not feel that the level of uncertainty is so great, however, that we can make no useful judgment about future costs. Because of the uncertainty, however, we attempt to "bracket" the most probable outcome by using high and low values which provide reasonable bounds.

Our estimates for the future costs of fuel and PV systems are shown in the previous section.

2. The cost of selecting and operating a system is highly site dependent. For example, it costs more to fuel and repair an IC engine in a remote area than in a city near a refinery and skilled mechanics. The climatic conditions of different sites also make significant differences in the renewable energy systems selected and the cost to deliver a service. We have attempted to incorporate site-specific considerations by calculating costs under various local conditions such as 8 MPH average wind speeds and 15 MPH speeds. Low access sites are also charged high transportation costs for fuel.

3. The calculations have all been done in constant 1979 dollars primarily because most cost projections can be found this way. It is also a complicating factor to attempt to estimate the rate of inflation over the next 20 years.

4. It is unlikely the farmer, the village or even the utility (nation) will pay for the technology on the day that it is delivered with out-of-pocket money. More likely the farmer and the village will borrow the money for the investment from the national government, an agricultural bank or cooperative association. The terms of the loan will vary from country to country and will depend on the ultimate source of the funds. For this analysis, we assume that the terms are as follows: 20 percent down payment on the total purchase price, transportation and installation costs; equal annual payments (at the end of the year) which amortizes the loan in about one-half the useful life of the equipment; a compound interest rate equal to the rate of inflation plus 3 percent.* The utility or the national government will generally also be forced to borrow from such sources as bond issues, banks and/or a development bank. Here again the terms of the loans are very variable. For the sake of simplicity, we will assume capital payment at the start.

5. The cash flow for each competing technology is not uniform. For example, PV has heavy capital cost and low recurrent costs while diesel engines are the opposite. In this analysis, we take into account the time value of money by discounting the annual cash flows of each technology to the present value on

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* Throughout this analysis all discussed rates and rates of interest are in real terms.

the basis of a given rate of interest (discount rate). Generally this method of analysis is called solving for the net present value.* In this report, we use "net present cost" since the value of the benefits (i.e., the services such as gallons of water, kwh) are not known. The value of the discount rate depends on the perspective of the investor.[7] A farmer has a high discount rate since his perspective is relatively short, his future uncertain, and, therefore, the value of a dollar today is great compared to the value of a dollar at the end of the year or next year. The discount rate of a utility or the nation is less than the farmer for a number of reasons. First, the nation generally can take a longer time horizon on its investments; second, it often has sources of finance available at beneficial terms; and, third, lower discount rates favor investments in renewable energy technologies (high front end costs) which may benefit the nation as a whole but not the individual (e.g., they conserve scarce foreign currency resources which would otherwise be spent for oil). On the other hand, the nation must seek to invest its capital in such a way as to maximize the benefit of that investment; that is, at its opportunity cost of other investments. Since we have been working with constant 1979 dollars throughout, we relate interest and discount rates to the rate of inflation(which is one important component of these rates). The rates used here are:

- for the individual in his financial analysis -- at a real rate of 10 percent

- for the nation in its economic analysis -- at a real rate of 5 percent

At these discount rates, the net present cost (NPC) represents the amount of money the individual or the nation would have to be willing to spend today to receive the benefits of the investment. It does not show whether the sum of the benefits outweigh the sum of the costs because the benefits are case- and site-specific. Rather, it can be used to compare one technology against another; the technology with the lower NPC is economically superior to the one with the higher NPC for the individual or the nation respectively.

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7. David French, The Economics of Renewable Energy Technologies, Al Durriyah Institute and US AID, 1979

* The formula for net present value is:

net present value = initial investment + sum of present values of future cash flows

$$NPV = CF_0 + \frac{CF_1}{(1+i)^1} + \frac{CF_2}{(1+i)^2} + \ldots + \frac{CF_n}{(1+i)^n}$$

6. Shadow Prices -- While the financial analysis is from the perspective of the individual investor who is faced with actual market prices and wages, society as a whole must consider other non-market factors in its calculus of energy projects. Such issues as foreign currency deficit, unemployment, energy independence and environmental quality are not directly considered by the rural farmer but often must be by the country in its economic analysis. For this reason shadow prices are often used in calculating the economic returns of a project from society's perspective. The prices which are often adjusted to incorporate national concerns are the discount rate, cost of labor and cost of imports.

   Discount Rates -- The financial discount rate is approximately equal to the local borrowing rate faced by the investor, the local community (if we talk about village electrification), the entrepreneur or corporation (gasohol) or the rural farmer (water pumps). In the analysis we use a rate of 10 percent above the rate of inflation. For the local farmer or rural community this is probably low, however, government subsidies with preferred loans may bring it to about this level. The economic discount rate reflects the preference of society. It embodies a larger perspective and, therefore, lower rate than for the individual. We have estimated the economic discount rate to be somewhat above the prime lending rate which moves in parallel with the rate of inflation. The economic discount rate used in this study is calculated at five percent above inflation.

   Cost of Labor -- "The shadow wage expresses the cost to the economy of diverting labor from its present occupations to the new project." (David French, The Economics of Renewable Energy Systems for Developing Countries, Jan. 1979.) Typically, agricultural labor is shadow priced below the market cost in countries with high unemployment. Skilled labor, on the other hand, is generally fully utilized and is priced at the market price. In this analysis, labor to construct windmills, maintain electric systems, etc., is priced at a typical market price for such skills.

   Imported Goods -- The shadow price of foreign exchange earnings is typically somewhat higher than the international exchange rate because of most countries desire to stem balance of payments deficits. One way of doing this is to add a "penalty" (e.g. 20 percent) to the cost of all imported goods including fuel and capital equipment, engines, photovoltaic arrays, etc. In this analysis we have not done this because of the complicating issues of finding a proper value which is universally acceptable.

The step-by-step method used to compare the technologies is shown below:

a) Identify a need, service or application which relies on an energy consuming technology, (e.g., water pumping, village electrification),

b) Identify several competing technologies which can satisfy the need or provide the service, (e.g., gasoline IC engine pump, PV pump, wind pump),

c) Select a level of service to be delivered daily (or annually) and match the technologies with that level of demand,

d) Estimate the key variables which determine the cost of the various systems, (e.g., capital cost, useful life, fuel requirements and costs, etc.),

e) Develop the sequence of annual cash flows involved in each investment including the initial cost and the recurrent annual costs. For the financial analysis, the cost is amortized over a reasonable number of years which reflects a normal length of time over which the borrower must repay the loan. In the economic analysis the capital cost is viewed as made at the beginning of the project.

f) Discounting the annual cash flows to the present to find the net present cost.

A simple example of the method is shown below using two imaginary water pumps:

	Pump A	Pump B
Annual water pumped	100,000 gallons	100,000 gallons
Capital cost	$800	$200
Transport cost	$200	$200
Annual maintenance	$ 20	$ 50
Annual fuel Cost	-	$ 50
Salvage value	0	$ 20
Interest rate	Inflation + 3%	Inflation + 3%
Financial discount rate	Inflation + 10%	Inflation + 10%
Economic discount rate	Inflation + 5%	Inflation + 5%
Useful life	10 years	10 years

CASH FLOWS - PUMP A

Financial	$200	175	175	175	175	175					
Capital & Transport*											
Maintenance		20	20	20	20	20	20	20	20	20	20
Economic	$1000										
Capital & Transport											
Maintenance		20	20	20	20	20	20	20	20	20	20

* $1000 with 20% down, $800 amortized over 5 years at 3% interest

Results:

Financial Analysis
Discount Rate = Inflation + 10% : $ 986

Economic Analysis
Discount Rate = Inflation + 5% : 1154

* The economic net present cost is higher than the financial net present cost but this is offset by the belief that society is willing to pay more for the future benefits than the individual. Thus, assuming related social benefits which will also be valued higher, the society is willing to pay for renewable energy sooner than its individual members. In fact, this is the basis for current early interest by governments. The counter intuitive result of higher prices in this report would be overcome if the corresponding benefit stream were available to offset the cost.

CASH FLOWS - PUMP B

Financial	$80	70	70	70	70	70					
Capital & Transport*											
Maintenance		50	50	50	50	50	50	50	50	50	50
Fuel		50	50	50	50	50	50	50	50	50	50
Salvage											-20
Economic	$400										
Capital & Transport											
Maintenance		50	50	50	50	50	50	50	50	50	50
Fuel		50	50	50	50	50	50	50	50	50	50
Salvage											-20

* $400 with 20% down, $320 amortized over 5 years at 3% interest

Results:

Financial
Discount Rate = Inflation + 10% : $ 952

Economic
Discount Rate = Inflation + 5% : 1160

When we compare the Financial NPC of the pumps, Pump B is lower than Pump A and therefore the better investment, all other factors being equal. When we compare the Economic NPC, Pump A is slightly lower, reflecting the favorable impact of the lower social discount rate on the more capital-intensive product. This methodology is used in the first two case studies to compare technologies which carry out the same function. Cash flows are presented in Appendix materials.

D. Reliability and Life Expectancy

The reliability and life expectancy of technologies in remote areas of developing countries are notoriously poor. The lack of spare parts and unavailability of trained mechanics for proper maintenance often leave machines idle for long periods of time and reduce their life very considerably. Even where there is a mature and well-trained agricultural extension program, the problems of low reliability persist.

In this regard, renewable energy technologies are expected to have a distinct advantage over competing gasoline and diesel technologies. Unfortunately the basis for comparison is relatively weak since few renewable systems have been running for a full, expected lifetime. Demonstration projects are generally designed under ideal conditions and staffed with highly trained people to supervise and maintain the systems. Real life conditions are generally very different than demonstration conditions.

The renewable energy literature is full of examples of systems which become inoperative after the trained demonstration team leaves. Experience with family and village size biogas digestors, for example, shows frequent system failure as a consequence of improper input mixture and loss of bacterial digestion. Such systems are often abandoned.

The most frequent life expectancy given for photovoltaics is in the neighborhood of 15 years. This is based less on experience than on the nature of the technology which requires no moving parts to produce electricity. Since the technology is relatively new, there has been no real life experience in a remote setting for anything like this length of time. Furthermore, economic assumptions over the life of the system are based on PV efficiency

when it leaves the factory. It is well known that the efficiency declines over the years as a result of deterioration of the cell's protective surface material. This is not accounted for in most economic comparisons.

One of the few renewable energy technologies which have a long history of reliable service is the windmill in rural America. Yet, this technology has also been supported by a strong agricultural extension service and well-trained mechanics.

Only time will tell about the reliability of renewable energy technologies. The evidence and data is still too scarce to make a sound judgement for remote areas where the user is responsible for maintenance and has paid the bill for the machine. Perhaps the most important lesson is that the low reliability of conventional technologies does not imply that renewable ones will last longer.

In this analysis we have refrained from independently judging relative reliability and life expectancy of renewable technologies. For the most part, we have used, as given, the manufacturer's specifications for these parameters. However, we have also performed analytic sensitivity tests for certain technologies at one-third shorter life. The result is that the economics are relatively sensitive to the expected life.

E. Import Substitutions, Indigenous Manufacture and Employment

As the price of oil has increased, many developing countries have been burdened with an increasing share of their scarce foreign currency reserves outlayed for oil. Increases in the past five years from 5-10% of total imports to 30% or more for oil are not untypical. This has created, in many

countries, severe balance-of-payments deficits which can lead to an absolute decline in economic growth.

Studies postulate that greater reliance on renewable energy resources, which are more equitably distributed than oil can help to relieve the pressure of energy import bills. Furthermore, local manufacture of renewable technologies can further reduce the burden.

This is a very complex issue which can only be answered on a case-by-case, technology-by-technology basis. A recent study[8] suggests that at best renewable energy can substitute for only 8-15% of the LDC's expected demand between now and the year 2000.

The feasibility of local manufacture of the technology depends on the nature of the technology and the capability of the country in similar manufacturing endeavors. At one end of the scale, such technologies as efficient wood-burning stoves, biogas digestors and flat-plate solar collectors are universally within reach. On the other end of the scale, few countries have the capability to produce PV cells. Indeed, without international markets such indigenous manufacture would not benefit from economies of scale expected for the United States and other developed countries.

In between these extremes are many technologies which can be partially fabricated in many countries and locally assembled. Windmills, micro-hydro turbines, charcoal kilns, and the structures for PV systems are examples of some equipment which can be produced in many countries.

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8. P. Palmedo, P. Baldwin, The Contribution of Renewable Resources and Energy Conservation as Alternatives to Imported Oil in Developing Countries, F/DI, February 6, 1980.

In the case study involving water pumping, a locally produced sail windmill is described. While this was fabricated, assembled and installed using local people (and missionary staff) the parts, including tower material, pump, and even the sails, were imported. This example serves to illustrate that in many countries the resources not spent on foreign oil may be spent instead on foreign technology, equipment or structural material. From the perspective of conserving scarce foreign currency it is not clear that there is an advantage in substituting equipment imports for oil imports.

F. Scale

Perhaps the most sensitive parameter in the analysis of renewable energy technologies is scale. Our case studies show that for very small applications renewable energy generally becomes cost competitive with the nearest conventionally fueled competitor. Certain applications in remote areas require power at levels considerably less than the capacity of the smallest conventional systems. Therefore, the required unit level of output is relatively expensive for technologies that are under utilized.

For example, the gasoline pump which has a capability of pumping 30,000 gallons per day or more is costly when the water requirement is only 3,000 gallons per day.

NASA uses this kind of comparison in its classic comparison of PV- and diesel-produced electricity. At the high end of the scale, the diesel is clearly cost competitive; at the low end, PV is superior. The problem with the comparison is that the machines have unequal capacities.

Because the PV is modular, the array can be sized to precisely meet the expected load. The size of the diesel is restricted to standardized, commercially available increments. When it is compared with the PV at the low end, it is substantially oversized.

A fairer comparison would be to pair a smaller diesel or gasoline powered generator with the PV at lower levels. In the village electrification case study we attempt to pair technologies with equivalent levels of capacity.

With the broad range of assumptions discussed in this chapter, it can be seen that there is considerable room for disagreement. In the case studies which follow, care has been taken to document assumptions so that productive discussion can help refine the findings.

3. CASE STUDIES

The three cases selected -- water pumping, electrification of a village and gasohol production -- were chosen for several reasons. First, they are among the most common examples of applications where renewable energy can play a major role. Second, data on the various costs is generally available. Third, real applications are presently being used or tested.

Because the economics of the technologies are site specific, we have attempted to account for site variations by identifying key site-related variables such as wind speed and performed a sensitivity analysis around that variable. For conventional technologies, the key variable is access to the fuel source. We have added a delivery cost to the price of oil for remote areas. For PV it is the price of the array. All of these factors are documented in the presentation of specifications.

A. Small-Scale Water Pumping

1. Background

Water pumping for irrigation is one of the major agricultural energy uses in the Third World according to recent studies.[1] For small-sized farms in the 1 to 5 hectare range, the most common pumping methods today rely on traditional manual or animal-powered or on small internal combustion pumpsets. Where the farm is remote from grid connected power lines, the water table is relatively shallow, and the quantities of water demanded are modest, renewable energy powered pumping methods may be cost competitive with the present practices.

In this section we compare the economics of four alternative systems for pumping water from shallow sources. The four technologies are (1) 3 H.P.

1. Richard Fluck, Agricultural Energetics, AVI Publishing, 1980.

Gasoline Internal Combustion (IC) Engine, (2) 250 Wp Photovoltaic Powered Water Pump, (3) U.S. manufactured wind mill pump, and (4) indigenously built sail wind pump.

These four were selected for a number of reasons. First, under normal operating conditions they can all pump comparable quantities of water from shallow wells, lakes or rivers. Second, the first three are commercially available today and, therefore, real 1980 costs could be easily acquired and used. The sail wind pump has been used in Ethiopia and costs are also available, and finally they serve to illustrate the method employed in this study of comparing net present costs for the financial or economic analyst.

The application that we are examining is a common one; pumping 40 gallons per minute or 12-15,000 gallons per day to a total lift of 15 to 20 feet. This could represent raising water from a shallow well to a field or tank, or raising water from a river or lake to a 15 to 20 foot head. The quantity of water pumped in one day would cover a one hectare plot with one-half centimeter of water. Thus, the pump would be applicable to a relatively small farm in the 1 to 5 hectare range; a size highly representative in many developing countries. Both the PV and the gasoline pumps are mobile so they can be moved from one small land holding to another with relative ease. This flexibility is important where a farmer's land is in checkerboarded small holdings. (See reference at end of case, p. 54).

2. Economic Analysis

a. 3 H.P. Gasoline Internal Combustion Engine Water Pump

We have selected the Briggs and Stratton 3 H.P. model MFE-30. It is one of the smallest readily commercially available gasoline driven pumpsets. While small diesel pumps are available in this size or slightly larger, they

are not so common and have a higher capital cost. The Briggs and Stratton has a capacity of 110 gallons per minute and can pump to a head of 100 feet. Thus, it is slightly over-sized for the application. However, smaller pumps are not readily available. It has a self-priming, centrifugal pump with a 12-volt starter, 2-inch suction and 1-1/2 inch discharge. The capital cost of $490 includes cost of the engine, pump, hoses and mounting frame. At full capacity the pump consumes 1 gallon of fuel in 8 hours. To meet the daily water needs it would require 62.5 gallons of gasoline per year:

$$\frac{15{,}000 \text{ gallons/day}}{6{,}000 \text{ gallons/hour}} \times \frac{1 \text{ gallon}}{8 \text{ hour}} \times \frac{200 \text{ days}}{\text{year}} = \frac{62.5 \text{ gallons}}{\text{year}}$$

We have assumed a 200-day season requiring irrigation. The pump would be used about 2-1/2 hours per day; a 5,000-hour life would give the pump a 10-year useful life. Because of the level of usage, the remoteness from spare parts and professional repair service, we have assumed half this life, 5 years of useful service. Fuel prices are based on the cost schedule shown in Table 1, Appendix A, for remote areas. Transport to the remote area is based on 3,000 miles air freight and 100 miles road for the 86-pound pump. Table 2.1 summarizes the information for the internal combustion engine.

Table 2.1

RELEVANT GASOLINE IC[1] SPECIFICATIONS AND COSTS

Capital Cost	$490
Transport	$300
Annual Maintenance	$ 75
Fuel[2]	1 pint/hour
Daily Usage	2-1/2 hours
Useful Life	5 years
Fuel Cost	see Appendix A, Table 1

1) Briggs and Stratton 3 H.P. pump. Capacity 110 gallons/minute; 2-inch suction hose; 1-1/2-inch discharge hose; 5000-hour life.

2) Usage 2-1/2 hours per day.

b. Photovoltaic Powered Water Pump

We will examine the Tri-Solar Corporation Model SEI-15M Portable Sun Pump with 250 Wp photovoltaic array. This pump is commercially available through the Tri-Solar Corporation, 6 Alfred Circle, Bedford, Massachusetts 01730. It pumps 40 gallons per minute, 12-15,000 gallons per day to a height of 8 to 15 feet. It utilizes a submersible, centrifugal pump. No battery is included. The present quoted price of $5,250 includes frame, the PV array with tempered glass surface. Estimates of performance are based on a 5 to 6 hour daily peak sunlight, 200 days per year. The expected lifetime is 15 years. Transport costs are based on 3,000 mile air freight.

Projected costs for the system are based on DOE and DSI projections for the decline in the cost of PV arrays (see Section 2). The balance of system costs decline slightly between 1980 and 1995. Details are in Table 3.2.

c. Mechanical Wind Powered Water Pump -- U.S. Manufactured

We will compare the U.S. manufactured Aeromotor wind machine. Since the sizing of the windmill is highly site specific, i.e., dependent on the average local wind speed, two wind regimes (15 mph and 8 mph) and therefore two different sized machines are compared. For the 15 mph average wind regime the Aeromotor 8-foot windmill is required. It is mounted on a 27-foot tower and has a 6-inch cyclinder. In 15 to 20 mph winds, it pumps 1,875 gallons per hour and, therefore, 8 hours of pumping are expected daily. The cost of the windmill is $2,670 FOB Dallas, Texas. The system weighs 900 pounds.

The second windmill for 8-mph winds is the Aeromotor 10-foot windmill, mounted on a 21-foot tower. It has an 8-inch cyclinder and pumps 3,300 gallons per hour in 15 to 20 mph winds. The total system costs $3,803 FOB Dallas and weighs 1,400 pounds.

Table 3.2

RELEVANT SPECIFICATIONS AND COSTS FOR
250Wp PHOTOVOLTAIC SYSTEM[1]

	1980	1985	1990	1995
Capital Cost	5250	3500[2]	1813[3]	750[4]
Transport	800	800[5]	500[6]	500
Maintenance	75	75	75	75
Useful life pump	10	10	10	10
array	15	15	15	15
Salvage value 10 years	50	50	50	50

1) "Tri-Solar" pumping system.

2) Decline in array to $5.00/Wp and BOS to $9.00/Wp.

3) Total cost of $7.25/Wp with $2.00/Wp cost of array includes indigenous manufacture of BOS and system redesign to allow for less efficient, less expensive pump.

4) Total cost of $5.00/Wp reflecting $.50/Wp array cost and regional manufacture of entire system.

5) Air transport @$2-2 1/2/lb +

6) Reduction in cost reflects local manufacture.

Both U.S. windmills are further described in a comparative table, Table 3.4, along with those of indigenous manufacture. It is not expected that the costs will decline significantly between now and 1995.

d. Locally Built Mechanical Wind Pumping Machine

The model for this is the Cretan sail wind machine built along the banks of the Omo River in Ethiopia as described by Peter Frankel in Food from Windmills, Intermediate Technology, November, 1975. "The systems were developed by the American Presbyterian Mission for use by the local people in order to permit all the year-round cultivation which is not otherwise possible ... Some 19 windmills of various types were operational and under the control of local villagers and a further five were in operational condition on mission land for cultivation, experimentation or demonstration." The region is accessible by four-wheel drive truck requiring seven days from Addis Ababa. The Omo River flows all year and provides 80 to 90 percent of the input to Lake Rudolf. Local people cultivate millet, maize and beans plus several types of gourd and tobacco on areas which are seasonally inundated either by flood-water or by seepage. This has generally allowed them one harvest (in December) from a rather limited area. The availability of food has always been a problem in the area.

Cost and technical data have been extracted directly from the report cited above. Adjustments have been made to make them comparable with the preceding pumps.

- The cost of labor and "free" parts has been estimated in our cost figures. The shadow wage is equal to an estimated wage for a skilled artisan in metal working, welding, carpentry, supervision, etc.
- Since the windmills total output is well below the 12-15,000 gallons per day, we have employed costs for 3 and 5 windmills.
- We have decreased output to reflect an increase in the head from 9 feet to 15 feet.

Table 3.3

INDIGENOUS WIND PUMPING MACHINE[1]
OMO RIVER, ETHIOPIA

	8 MPH Average Wind Speed (5 wind machines)	15 MPH Average Wind Speed (3 wind machines)
Capital Cost	4900[2]	2940
Transport	Included	Included
Installation	Included	Included
Annual Maintenance	100	100

1) Omo River wind project as described in Peter Frankel, in Food from Windmills, Intermediate Technology, November, 1975.

2) Each wind machine cost $980 including parts and labor.

Table 3.4

ASSUMPTIONS FOR MECHANICAL WIND PUMP - MASS PRODUCED

	1980 U.S. Manufacture		1990 Indigenous Manufacture	
	8MPH Wind Speed 10 Foot Windmill	15MPH Wind Speed 8 Foot Windmill	8MPH Wind Speed 10 Foot Windmill	15MPH Wind Speed 8 Foot Windmill
Capital Cost				
Windmill	1999	1136	2537[3]	1781[3]
Tower	1037	980		
Cylinder	650	437		
Misc. Equip.	117	117		
Transport	800[1]	800	400[2]	400
Installation	450	450	450	450
Salvage Value	1000	700	700	400
Maintenance	100	100	100	100
Calculated Useful Life	10 Years			
Terms of Purchase	20% down, 3% above inflation interest rate amortized over 1st 5 years			

1) 50c per lb. sea freight.

2) Local manufacture of structural elements requires less freight.

3) Two thirds cost of U.S. manufacture.

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Accounting for a shadow wage and overhead rate for labor to build, transport and install the windmills (20 days @ $15 per man day of city labor) and the costs for material, the total cost of one 14-foot windmill is $980. In 8 mph average wind speed, 5 machines are needed; in 15 mph winds, 3 windmills are necessary. The estimated life expectancy is shown for 10 and 15 years. Table 3.3 reports the basic information for the Omo windmill and Table 3.4 compares it with the U.S. manufactured windmill.

3. Comparison

In Tables 3.5 and 3.6 the four different sources of energy are juxtaposed to facilitate comparison. The summary tables are supported by detailed cash flow analysis in Appendix B. Table 3.5 shows the comparison of NPC using financial discount rates of 10 percent and Table 3.6 provides the comparison for an economic discount rate of 5 percent. The tables lead to conclusions regarding pumping by the different means.

4. Conclusions

(1) Because of its rapidly declining capital costs and low recurrent costs, the PV system becomes very attractive in the late 1980s (Table 3.2). However, the precipitous decline in PV costs is based on several risky assumptions. The first is that the price of the array would decline to $.50 per Wp by 1995. This is the DOE goal although 5 to 10 years late. Second, the decline in costs would allow manufacturers to use less efficient (and therefore, cheaper pumps and other components) since they could match them with somewhat more PV cells. Third, the cost of manufacture and shipping would decline significantly because of regional manufacture of components. In 1990 indigenous manufacture of pumps, frames, cost, etc., could make parts locally available. By 1995, regional manufacture of the cells in more

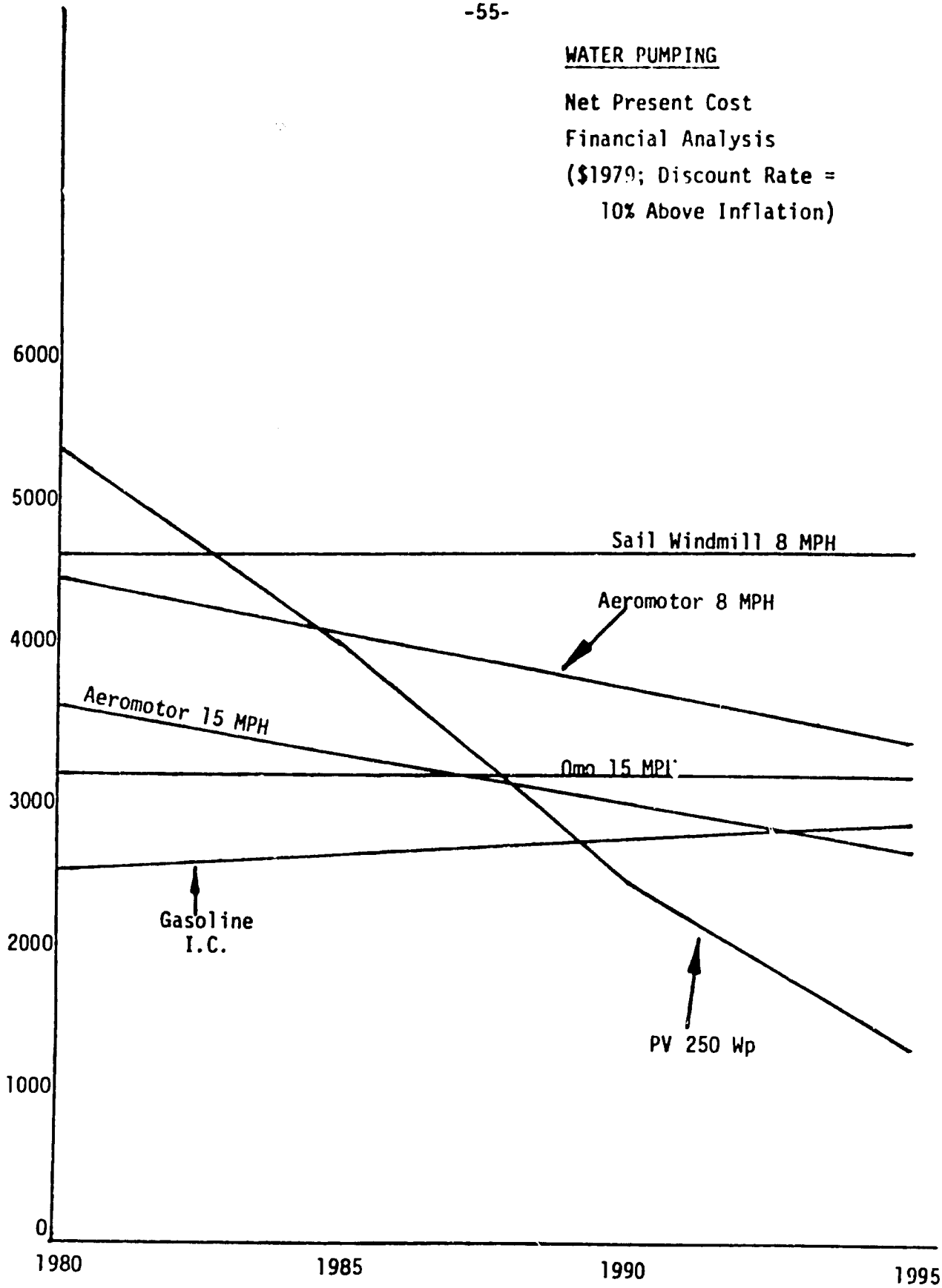
* Including overhead expenses.

Table 3.5 (Summary)

NET PRESENT COST -- WATER PUMPING 12-15,000 GALLONS/DAY
(1980 - 2000 FINANCIAL ANALYSIS)

		1980	1985	1990	1995
Gasoline IC S_2		2581	2687	2802	2928
S_3		2608	2753	2921	3102
PV 250 Wp		5502	4150	2437	1347
Windmill	8MPH	4622	→ *	3280	3280
	15MPH	3750	→ *	2744	2744
Sail Windmill	8MPH	4796	4796	4796	4796
	15MPH	3248	3248	3248	3248

*→ Indicates no substantial change in price


WATER PUMPING
Net Present Cost
Financial Analysis
($1979; Discount Rate =
10% Above Inflation)
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
Sail Windmill 8 MPH
Aeromotor 8 MPH
Aeromotor 15 MPH
Gasoline
I.C.
PV 250 Wp

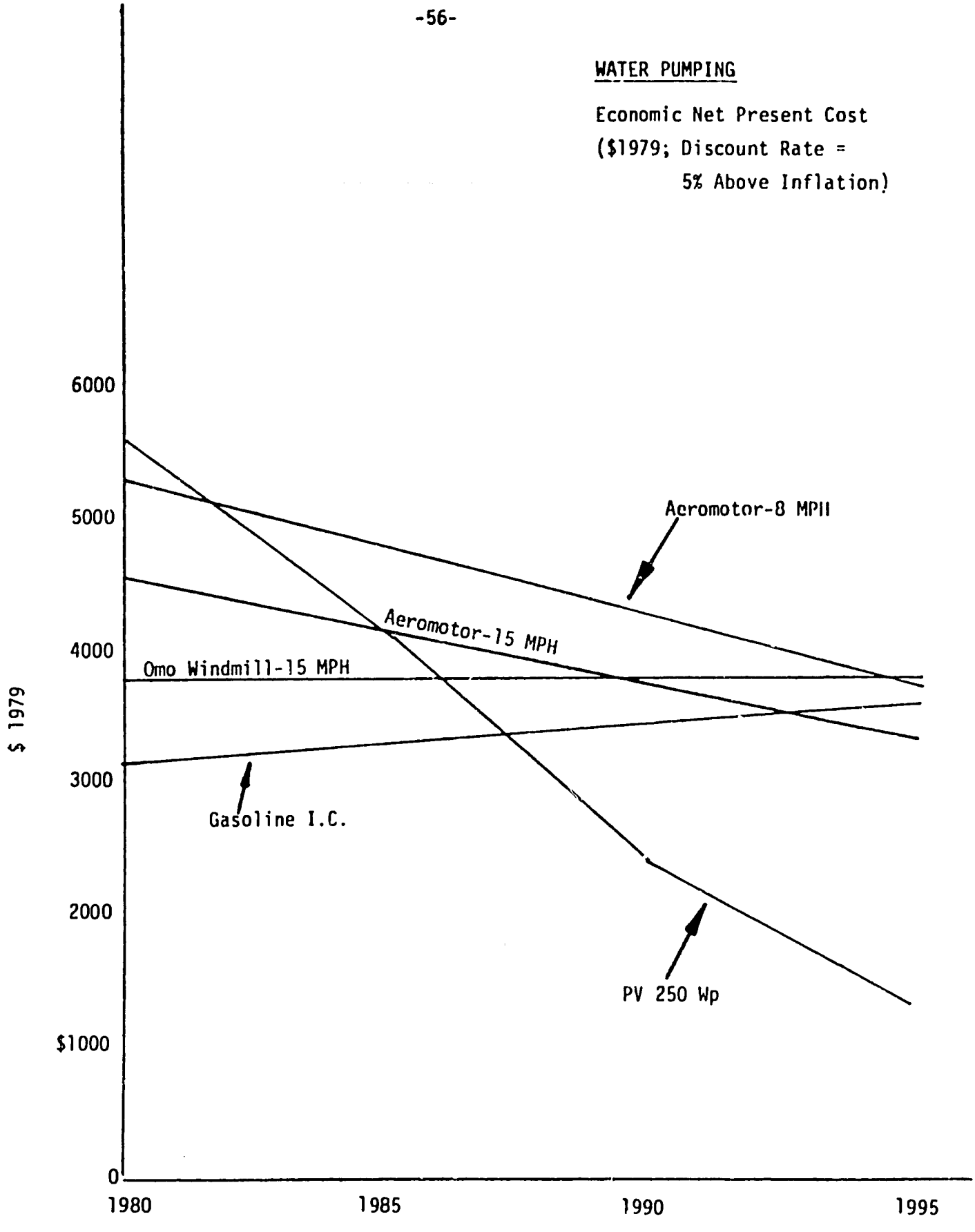

WATER PUMPING
Economic Net Present Cost
($1979; Discount Rate =
5% Above Inflation)
6000
5000
4000
3000
2000
$1000
0
$ 1979
1980
1985
1990
1995
Aeromotor-8 MPH
Aeromotor-15 MPH
Omo Windmill-15 MPH
Gasoline I.C.
PV 250 Wp

Table 3.6 (Summary)

NET PRESENT COST -- WATER PUMPING
(1980 - 2000 ECONOMIC ANALYSIS)

		1980	1985	1990	1995
Gasoline IC S_2		3167	3268	3379	3498
	S_3	3209	3358	3533	3727
PV 250 Wp		5537	4050	2362	1300
Windmill	8MPH	5240	→ *	3750	3750
	15MPH	4283	→ *	3269	3269
Sail Windmill	8MPH	5474	547[illegible]	5474	5474
	15MPH	3747	3747	3747	3747

*——► Indicates no substantial change in price

industrialized LDCs (e.g., India, Brazil) would be possible and further lower costs.

(2) The increasing price of fuel even under the S_3 scenario makes very little difference to the total net present cost of the system. The slope of the Gasoline IC engine indicates that the cost of gasoline plays only a minor role in total cost. Furthermore the S_2 and S_3 curves are very similar, indicating that the difference between 2 percent and 5 percent annual price increase is not great.

(3) The value of wind pumping is, as would be expected, highly site-dependent. For areas with 8 mph winds neither the Aeromotor nor the OMO-type pumps are cost competitive. However, at 15 mph average annual wind speed both wind machines become cost competitive around 1990.

(4) The Omo wind pump is more expensive than the competing Aeromotor wind pump because of its relative inefficiency. At higher wind speeds, the Omo pump is less expensive because of the lower initial cost.

(5) An increase in the desired level of pumping would be to the advantage of the gasoline pump since it could easily expand its output by pumping more than 2-1/2 hours per day. If the quantity of water required doubled, the gasoline IC would decline relative to the others since its capital outlay would remain constant. Consumption of gasoline would double, but since the out years are discounted, the most this would represent is a smaller present cost than similar capital investments which must be amortized at the beginning.

(6) The Economic NPC with a social discount rate results in an economic advantage for PV over the gasoline IC a few years earlier than with a Financial NPC using the discount rate of a farmer.

B. Electrification of a Village.

1. Background

This case study develops three alternatives for providing electricity to rural areas based upon renewable and non-renewable resources. Traditionally, rural economies have chosen between national grid extension or small scale diesel generators as the basic means of electrifying villages. Today, as it becomes apparent that costs for expanding grids to reach these isolated and remote communities may be prohibitive, decentralized solutions are considered. However, when they require diesel fuel in an area of short supply, an evaluation of renewable resources is worth making. This study accordingly, compares rural electrification procedures based upon diesel generation, photovoltaic cells, and wind power. Systems suitable for remote use are described and discussed. In addition, a set of assumptions is provided to identify the key variables and major constraints.

Village electrical loads can include lights for the domestic, commercial and public sectors, radios and television sets, refrigerators for domestic and commercial purposes as well as for health needs such as drug preservation. In this study, minimal attention will be paid to selection of these specific services to be provided and their distribution requirements. Rather the focus will be on the use of the generating technology itself.

A base load has been chosen in order to compare the systems and define their costs. The base load is small in scale, providing approximately 5,600 kilowatt hours a year or about 15 kilowatt hours a day. As an example, at 60 watts a unit, this could provide lighting in several rooms in each of 20 homes. Alternatively, it would provide refrigerators at

115 watts per unit for over 10 locations. Village loads vary with the functions and activities as well as the number of inhabitants. The choice of services for a village is beyond the scope of this study.

2. Economic Analysis

a. Diesel Generation

In many areas of the world, diesel generated power is common for rural isolated communities. Data are available on equipment costs, maintenance requirements and fuel use, but it is difficult to establish real costs for the fuel itself and thus the generated electricity. Estimates of these variables have been made previously in an earlier section and are noted as applicable.

The costs for diesel generated power can be established with the following information:

- Base data on system specifications and performance
- Fixed costs of equipment and installation
- Annual Costs of financing and maintenance less fuel, and
- Fuel costs based upon varying scenarios.

These data will provide a basis for later comparison of alternative electric generating systems presented in Tables 3.10 and 3.11. Details for diesel and other costs are presented in Appendix 3, "Cash Flow Analysis for Electrification of a Village."

Winco Division of Dyna Technology, Inc. (Minneapolis, MN) produces a variety of diesel generating systems ranging in size from small units suitable for auxiliary domestic use to larger units designed for construction projects. These air-cooled systems are available both for domestic and

overseas use in either 50 or 60 Hz with appropriate outlets. A small unit is rated at 4 Kw and has a shipping weight of 624 pounds.

In the small scale system, it has been estimated that the generator will be run for five hours per day at 80 percent efficiency for 350 days or 1,400 hours per year to produce 5,600 kilowatt hours per year. Table 3.7, "Diesel Generator Specifications and Costs" presents the basis for cost estimates. These costs assume a life time of 10 years with oil changes at 60-hour intervals, tuneups at 1,000 hours, overhauls at five years, and replacement at 10 years.

Table 3.7

DIESEL GENERATOR SPECIFICATIONS AND COSTS

	4 Kw
1979 Capital Cost	$3465
Fuel Use	142 gallons/hour
Daily Usage	5 hours @ 80% efficiency
Oil Capacity	3.5 pints
Shipping Charge	1,000
Installation	1,000
Useful Life	10 years
Annual Output	5,600 kwh
Oil Change Interval	60 hours
Engine Tuneup Interval	1,000 hours
Engine Overhaul Interval	5 years
Annual Usage	350 days

b. Photovoltaic Cells

As previously discussed in Chapter 2, much of the cost associated with the use of photovoltaic cells to produce electricity comes from the balance of system (BOS) components including the batteries. A 3.5 Kw system capable of producing 5,600 Kwh at certain specified locations was chosen, and specifications and costs as presented in Table 3.8 were developed using the changing costs and design philosophy discussed previously.

Table 3.8

3.5 KW PHOTOVOLTAIC ELECTRIFICATION SPECIFICATIONS & COSTS

	1980	1985	1990	1995
Module Cost ($/wp)	10.00	5.00	2.00	.50
Balance of System ($/wp)[1]	16.50	12.50	8.00	4.50
Battery ($/wp)	3.30	3.50	2.75	2.00
Invertor [2]	5,500	5,500		
3.5 Kw System Cost	$98,250	$61,250	$35,000	$17,500
Transport	4,500	4,500	2,500[5]	2,500
Annual Output	5,600 Kwh	5,600 Kwh	5,600 Kwh	5,600 Kwh
Annual Operation & Maintenance (10% Capital Cost)	1,000	670	350	175
Useful Life Array	15 yrs	15 yrs	15 yrs	15 yrs
Useful Life Battery	5	5	5	5
Salvage Value Array ($/wp)[3]	1.00	.25	.25	.25
Salvage Value Battery ($/wp)[4]	1.75	1.37	1.00	1.00

1) BOS includes Battery Costs and Installation.
2) Invertor from DC to AC not included in BOS; use DC power beginning 1990.
3) Salvage value at end of 10 years -- 50% of that year's module cost.
4) Salvage value at end of 5 years -- 50% of that year's cost.
5) Reflects local manufacture and less transport.

c. Wind Power

A third alternative for remote village electrification is the use of a wind driven generator. Systems are available for those locations where the average yearly wind speed is appropriate to the machine design and village requirements. Traditionally, windmills have served agricultural and industrial purposes and been used to supplement or backup conventional electrical needs. Their availability now as a complete system makes them a convenient electrical alternative for appropriate wind locations.

Wind machines are available from several different manufacturers in varying sizes. The Pinson Cycloturbine (Marstons Mills, Massachusetts) has

been selected as an example of a present "state-of-the-art" system. This machine has a vertical axis with straight blades of 10-foot length which are cyclically pitched and follow a schedule of angle change preset for the specific site. The starting wind speed is 8 mph with a shut down at 55 mph. Governing wind speed is at 30 mph and it is generally assumed that 12-13 mph average yearly wind speed is necessary for economic usage.

The Pinson machine is presently available without batteries at $8,000. An invertor such as the Best No. B48-5000 is appropriate and available at $2,500. Batteries can be sized as needed and the Surrette No. 8D will supply 221 Ah with 20 units of 12 volts each for a 220-240 volt system. Table 3.9, "Relevant Wind Machine Specifications and Costs," presents the basic data.

Table 3.9

RELEVANT WIND MACHINE SPECIFICATIONS AND COSTS -- 4 KW MACHINE

	1980	1985	1990	1995
Capital Cost[1]	$7,200	$6,500	$5,800	$5,800
Invertor[2]	$2,500	$2,500	--	--
Batteries[3]	$4,000	$4,000	$4,000	$4,000
Installation	$1,000	$1,000	$1,000	$1,000
Transport[4]	$3,500	$3,500	$1,500[5]	$1,500
System Weight (lb)	4,600	4,600	4,600	4,600
Annual Output Kwh[6]	5,412	5,412	5,412	5,412
Useful Life (years)	15	15	15	15
Useful Life Battery (years)	5	5	5	5
Salvage Value at 10 years	$1,500	$1,000	$1,000	$1,000
Operation & Maintenance				

1) Declines by 10% each 5 years through 1990 to reflect local construction.
2) DC to AC requires invertor; use DC 1990 onwards.
3) 221 AMP hours storage; 2-3 days storage
4) $.50 - $.60 per lb sea freight; $.25/lb local freight & handling.
5) Reduced shipping due to local manufacture.
6) At 12 mph average annual wind speed.

A recent study[2] has suggested that cost savings over 10 percent are possible with design modifications and high quantity production in a more traditional wind turbine generator. Accordingly, 1985 and 1990 costs have been developed to reflect a decrease based upon design refinements and quantity production.

3. Comparison

The following Tables 3.10 and 3.11 provide a net present cost comparison of three alternatives using both financial and economic analyses. These data include the rising cost of diesel fuel as previously described and cost savings in PV and wind systems based upon some design changes and larger production rates. Figure 3.1 gives a further graphic comparison over time.

Table 3.10 (Summary)

NET PRESENT COST -- VILLAGE ELECTRICITY SYSTEMS (1980-1995 FINANCIAL ANALYSIS)

	1980	1985	1990	1995
Diesel S_2	20,217	21,317	22,490	24,328
Diesel S_3	21,177	23,813	27,798	33,089
PV	103,713	70,565	37,665	19,762
Wind	20,169	20,169	14,690	14,690

Table 3.11 (Summary)

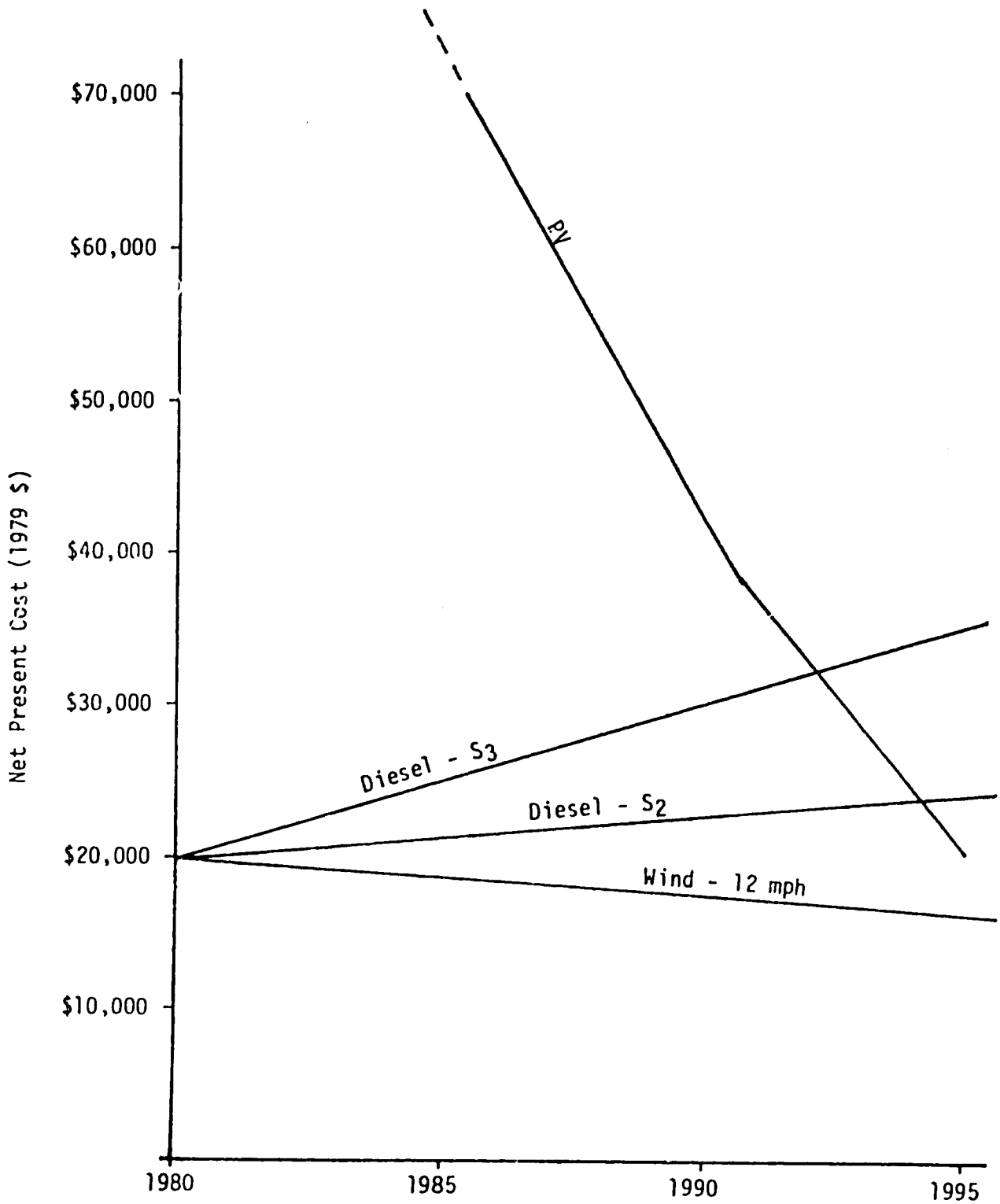
NET PRESENT COST -- VILLAGE ELECTRICITY SYSTEMS (1980-1995 ECONOMIC ANALYSIS)

	1980	1985	1990	1995
Diesel S_2	25,106	26,495	27,948	29,622
Diesel S_3	26,460	30,215	34,969	41,013
PV	110,192	74,642	40,256	21,405
Wind	22,028	22,028	15,587	15,587

2. "Development of an 8 kw Wind Turbine Generator for Residential Type Applications," M. C. Cheney, et. al., United Technologies Research Center, East Hartford, Connecticut; prepared as part of the United States Department of Energy, Division of Distributed Solar Technology Federal Wind Energy Program; June 25, 1979.

Figure 3.1

NET PRESENT COST -- VILLAGE ELECTRICITY SYSTEM
1980-1995 (FINANCIAL)



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4. Conclusions -- Village Electricity

a. Despite great drops in the price of PV cells, indigenous manufacture and fabrication of equipment and system redesign to lower costs (e.g. DC use in 1990, less storage), the PV system is cost competitive only after 1990 and this is under the worst oil price scenario.

b. In areas with strong winds -- average annual wind speed of 12 mph or better -- wind machines are cost competitive today and will continue to increase in attractiveness. Since electricity output increases or decreases as a function of the cube of the wind speed, the attractiveness of wind machines at areas with lower wind speeds must be examined closely.

c. Once again, an Economic NPC favors the PV system a few years sooner than the Financial NPC, reflecting the social propensity to accept the costs of the more capital-intensive systems.

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5. Solar Energy for Village Development; Norman L. Brown and James W. Howe; Science, Vol. 199, February 10, 1978.

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7. Photovoltaic Power Systems For Rural Areas of Developing Countries; Louis Rosenblum, William J. Bifano, Gerald F. Hein, and Anthony F. Ratajczak, Lewis Research Center, Cleveland Ohio; NASA Technical Memorandum #79097 (Revised).

8. Photovoltaic Power Systems for Rural Areas of the Third World, An Overview; NASA-Lewis Research Center, Cleveland, Ohio; October, 1980.

9. Development of An 8 KW Wind Turbine Generator For Residential Type Applications Prepared by M.C. Cheney, et al., United Technologies Research Center, East Hartford, Connecticut; As part of the United States Department of Energy Division of Distributed Solar Technology Federal Wind Energy Program; June 25, 1979.

10. Impact of Balance of System (BOS) Costs on Photovoltaic Power Systems; Gerald F. Hein, James P. Cusick, and William A. Poley, National Aeronautics and Space Administration Lewis Research Center, Cleveland, Ohio; DOE/NASA/1022-78/40 NASA TM-78939.

C. Ethanol Production

1. Production and Applications

Ethanol (grain alcohol) can be produced from a variety of biomass materials for use as a substitute for a number of petroleum products, particularly gasoline. The basic technologies of fermentation and distillation used in ethyl alcohol production are well developed and widely used.

Ethanol can be used as a liquid fuel either as straight alcohol or as a mixture with gasoline (gasohol). A gasohol mixture containing up to 20 percent alcohol can be used by a conventional gasoline engine without modification. Although ethanol has less than two-thirds the heat content of gasoline, gasohol provides fuel economy and performance comparable to straight gasoline. This is due to the significantly improved combustion efficiency and octane rating that the ethanol addition provides. In contrast, pure ethanol must be used in engines designed specifically to accommodate the fuel's unique combustion and corrosion properties. Thus, the use of ethanol in gasohol offers the following advantages:

- ethanol can be substituted on a one-to-one basis for gasoline
- gasohol makes full use of ethanol's octane boosting characteristics
- gasohol can be used by conventional gasoline engines without modification

For these reasons, ethanol use as a blend with gasoline to form gasohol is considered here as the most important advantageous method of use as a petroleum substitute.

Ethanol is produced by the fermentation of sugar by yeast. The three major sources of this sugar are:

- sugar rich materials such as sugar cane juice, molasses or sweet sorgum

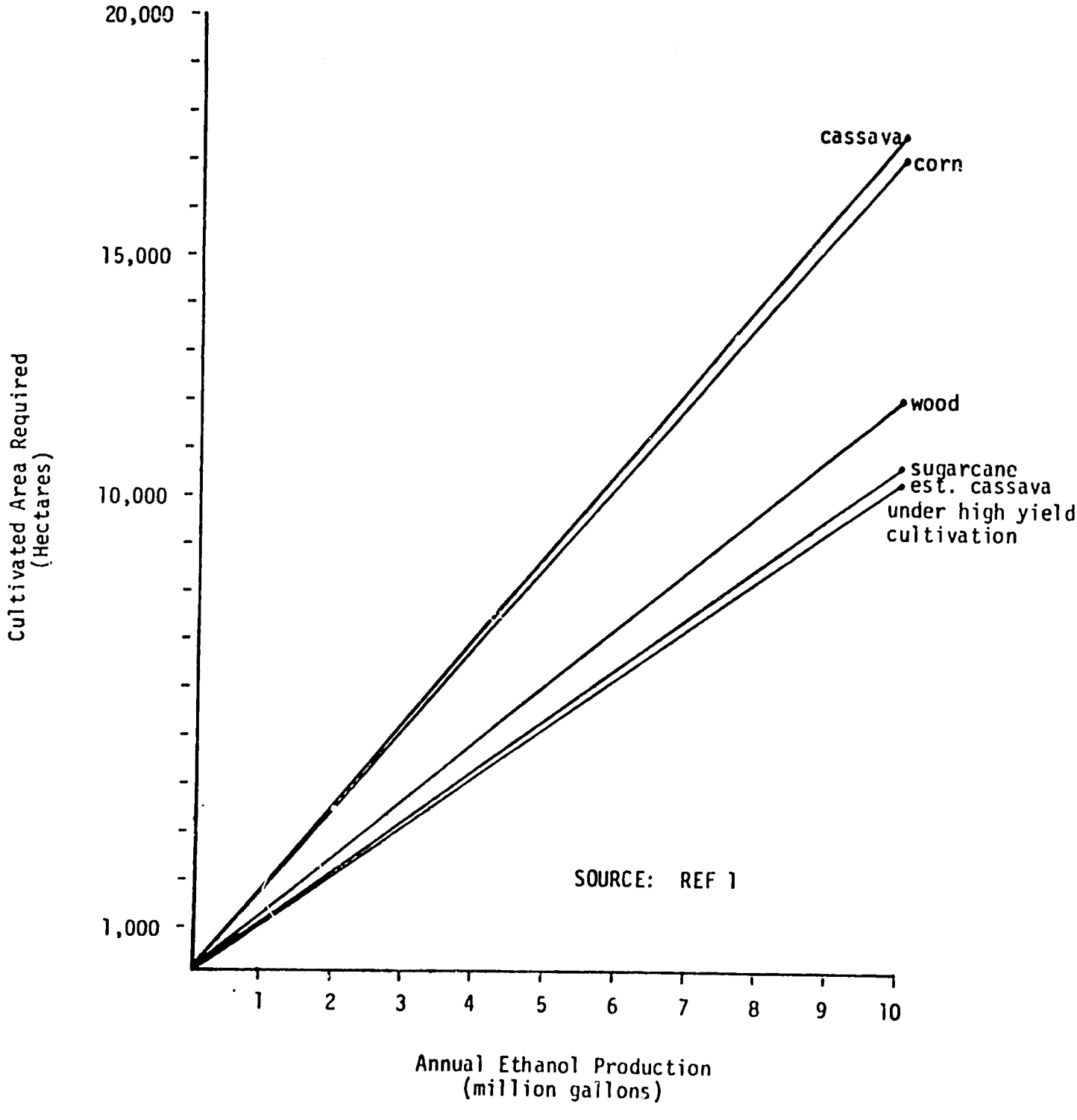
- starch materials such as corn, rice or cassava which can be converted to sugar by addition of enzymes
- cellulose material such as wood or crop residues which can be converted to fermentable sugars by acid hydrolysis

It should be noted that the economics of ethanol production depend greatly on the raw material used. For example, if starch or cellulose materials are used, provision must be made for their conversion to sugar, a step that is not necessary when natural sugar materials are used as the feed stock. Some raw materials such as sugar cane provide bagasse which can be used to fuel the distillation process while operations based on other raw materials will require outside sources of heating fuel. Certain raw materials will be available only on a seasonal basis. Thus production equipment may be idle for as much as 6 months each year. Certain raw materials may produce by-products from the fermentation process that are of value locally as animal feed or soil conditioner. These factors all influence the feasibility of a particular ethanol production project.

The major components of the cost of ethanol production are: capital cost recovery, raw material costs, operating expenses and credits for the sale of by-products. Of these, the cost of raw materials is the most significant, typically accounting for 50-75 percent of the final product cost. Raw material costs will generally depend on local market conditions and the cost of transportation to the ethanol plant. The availability of a sufficient quantity of raw materials at an acceptable price should be considered as the key to a viable ethanol production facility. As Figure 3.2 illustrates, the crop land areas needed to supply significant volumes of ethanol are quite large.

Figure 3.2

CROP LAND REQUIREMENTS
FOR ETHANOL PRODUCTION



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2. Ethanol Production from Sugar Based Raw Materials

The most extensive experience world-wide in ethanol production is with facilities using sugar based raw materials, particularly sugar cane. In Brazil, over 300 such distilleries have been built in conjunction with that nation's alcohol fuel program. This experience provides the bulk of available data on the commercial production of ethanol fuel.

Sugar containing raw materials offer several advantages which make them the most desirable feed stock for ethanol production. Because fermentable sugars are directly available, no conversion of starch or cellulose is needed. Thus the capital and operating costs of sugar based plants are lower than for plants using other raw materials. In addition, bagasse may be available to provide "free" fuel for the process. In areas where competing uses for bagasse exist, production costs will be higher than those shown here.

Capital cost data from Brazil have been used to estimate the cost of various size sugar based ethanol plants. Table 3-12 below illustrates the effects of economy of scale on final product cost.

Table 3-12

Raw Material	Plant Capacity (Liters/Day)	Capital Cost ($Million)	Days/ Year Operated	Annual Production (Gallons)	Capital Cost Per Gallon (@10%/20 Yr)
Sugar Cane:	20,000	2.5	180	.95M	$0.30
	120,000	9.5	180	5.7M	$0.19
	240,000	15.6	180	11.4M	$0.16
Molasses:	20,000	2.2	180	.95M	$0.27
	120,000	7.6	180	5.7M	$0.15
	240,000	12.5	180	11.5M	$0.13

(Source: REF. 1)

Figure 3.3

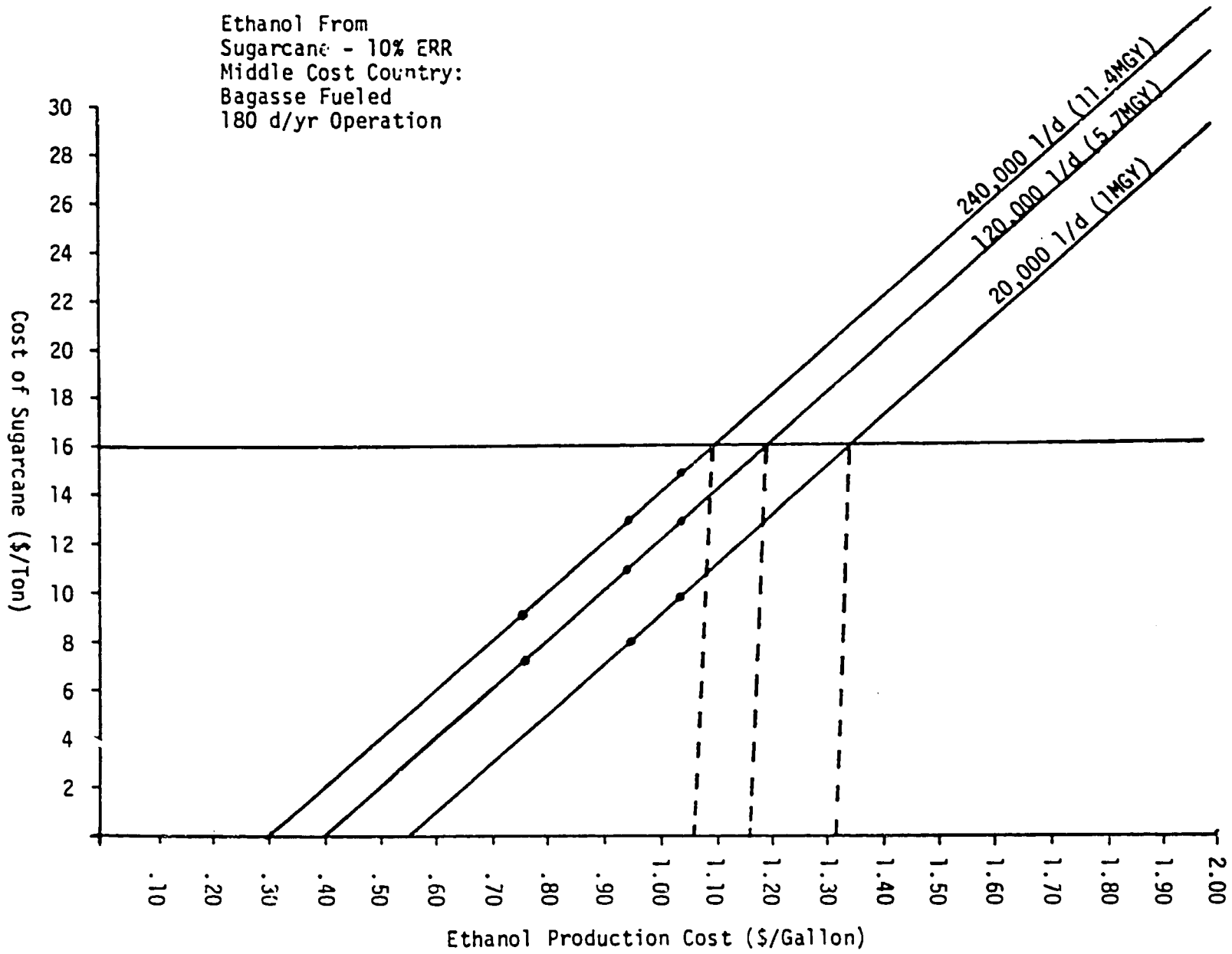

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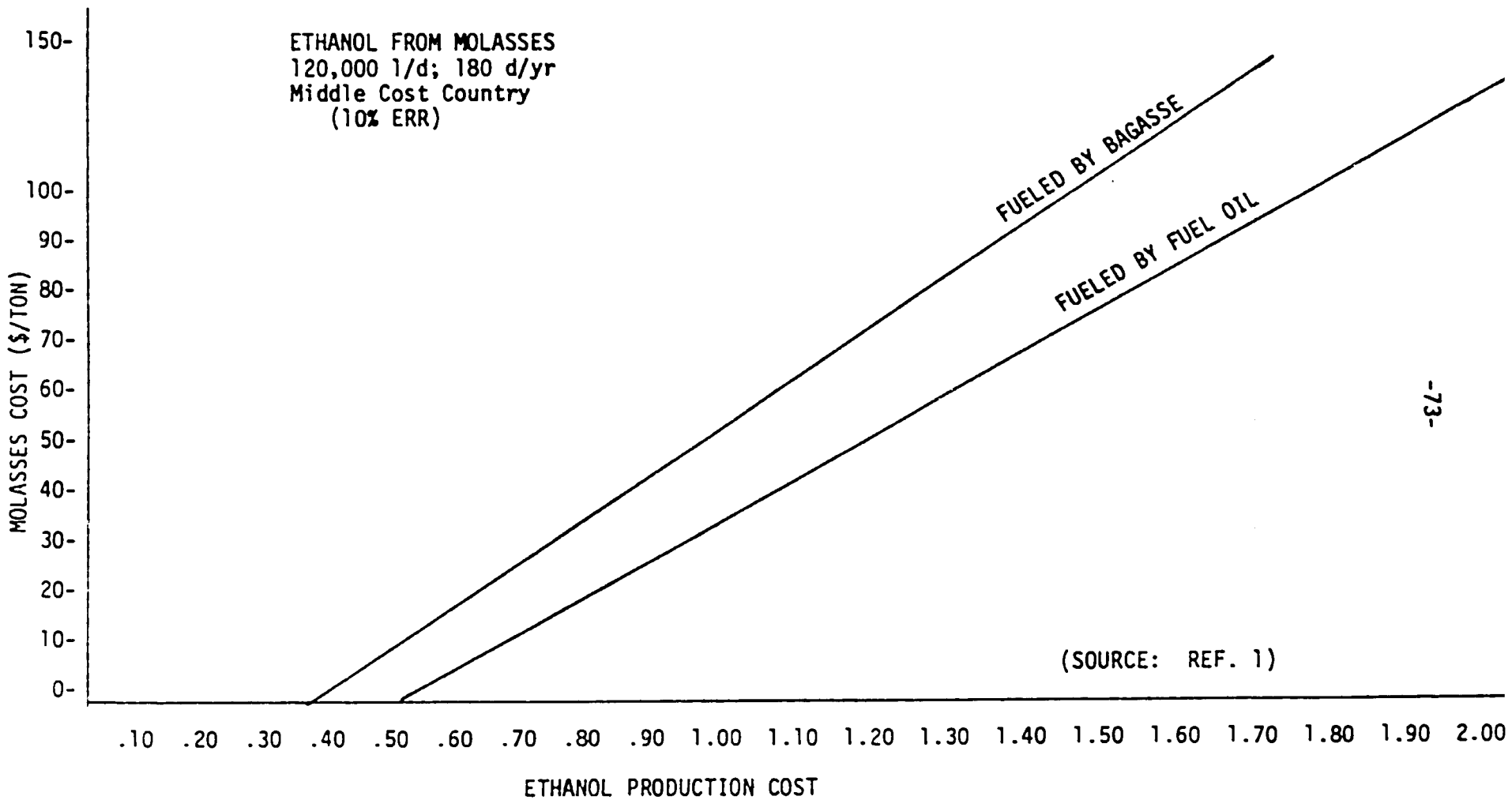
Figure 3.4



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A much more significant contributor to the cost of the final product is the cost of the raw material. This is illustrated by the data in Table 3-13 below.

Table 3-13

Raw Material	Cost/Ton	Ethanol Yield/Ton	Raw Material Cost/Gallon
Sugar Cane	$10	18.5 Gallons	$0.54
	$15	18.5 Gallons	$0.81
	$20	18.5 Gallons	$1.08
Molasses	$40	74 Gallons	$0.54
	$60	74 Gallons	$0.81
	$80	74 Gallons	$1.08

Figures 3.3 and 3.4 show the expected production costs for various ethanol plants using sugar cane or molasses as raw materials. These figures are based on experience in Brazil, with capital costs escalated by 25 percent to reflect expected costs in medium cost developing countries and assuming a 10 percent economic rate of return.* As these figures show, with 1980 gasoline prices of $1.09 per gallon, ethanol production from sugar cane (120,000 liter per day plant) may be attractive if the raw material can be obtained at $14 per ton or less. Similarly, ethanol from molasses (bagasse fueled) may be attractive if the feed stock can be obtained for $65 per ton.

3. Ethanol Production from Starch Based Raw Materials

Starch containing materials such as corn, cassava and rice can be used for ethanol production by converting the starch to fermentable sugar through

* This section does not use the net present cost as in previous methodology used to compare technologies. In this section the key variable is feedstock, not technological process.

the action of enzymes. Although this process has been used for years by the beverage alcohol industry, its use for alcohol fuel production is quite limited. The capital costs shown in Table 3-14 assume the use of energy saving designs not commonly found at beverage alcohol distilleries.

Table 3-14

Raw Material	Plant Capacity (Liters/Day)	Capital Cost ($Million)	Days Operated Per Year	Annual Production (Million Gallons)	Capital Cost Per Gallon @10%/20 Yr
Cassava or Corn	20,000	3.1	275	1.4	$0.26
	120,000	11.4	275	8.5	$0.16
	240,000	19.0	275	17.0	$0.13

Although capital costs for starch based ethanol plants may be somewhat higher than for sugar based plants, the availability of raw materials over a longer portion of the year may increase plant utilization, thus lowering product cost. As with sugar based plants, however, raw material costs are the major determinant of final product cost.

For certain starch feed stocks, by-products of considerable local value may be produced. Experience in the U.S. has shown that the value of the spent grain (as animal food) and carbon dioxide (for industrial use) produced by fermentation may be $0.30 to $0.60 per gallon of ethanol produced (2,3). The value of these by-products in developing countries is likely to be much lower depending on local demand. Table 3-15 shows the impact of raw material costs on ethanol production cost assuming no credit for sale of by-products.

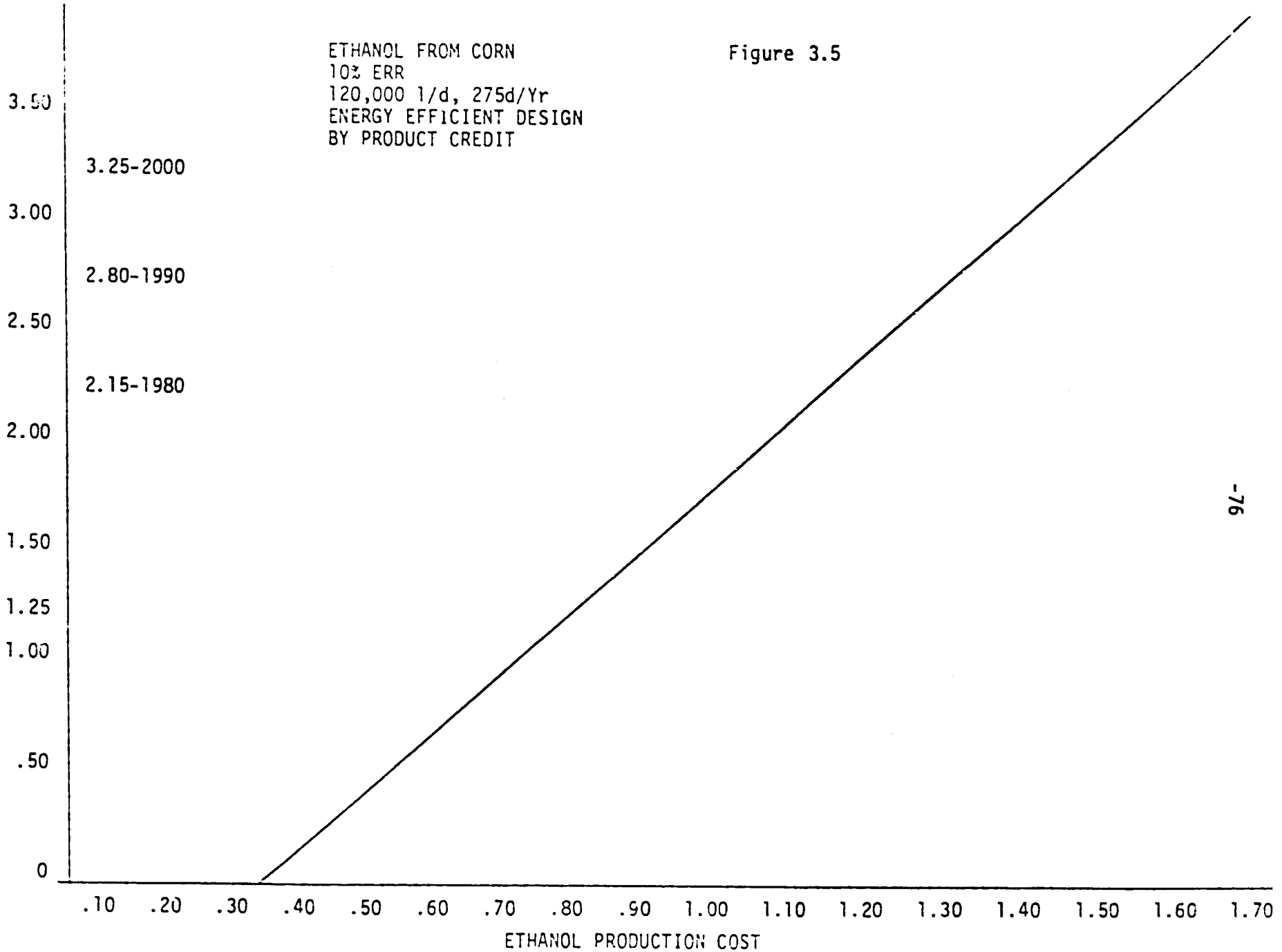

Figure 3.5

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Figure 3.6

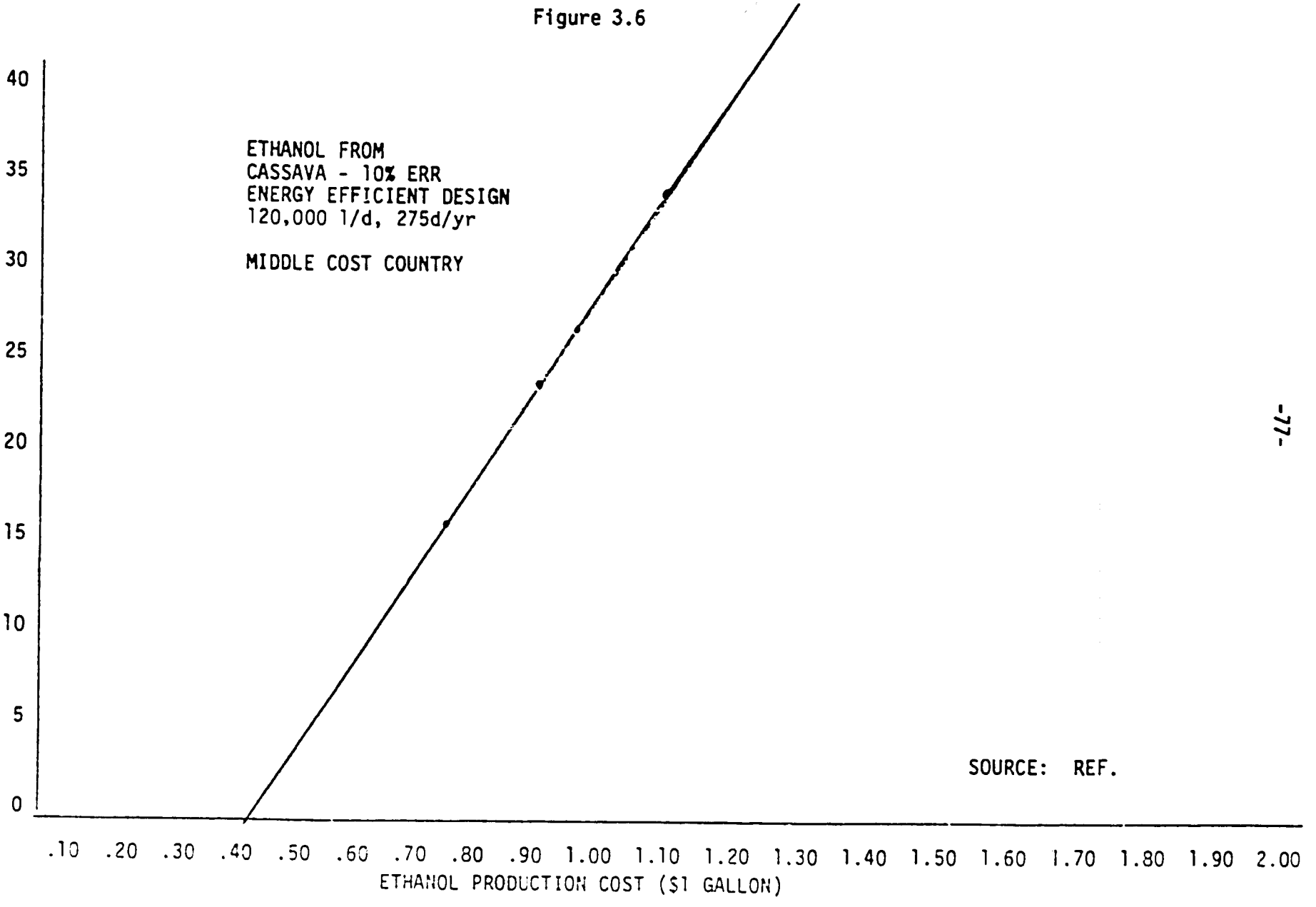

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Table 3-15

Raw Material	Cost/Ton	Ethanol Yield/Ton	Raw Material Cost/Gallon
Corn	$ 84.70 (2.15/bu.)	95.5 Gallons	$0.89
	$110.30 (2.80/bu.)	95.5 Gallons	$1.15
	$128.10 (3.25/bu.)	95.5 Gallons	$1.34
Cassava	$20	46.5 Gallons	$0.43
	$40	46.5 Gallons	$0.86
	$80	46.5 Gallons	$1.72

Figures 3.5 and 3.6 provide estimates of ethanol production costs as a function of raw material costs. Because the data for corn based plants comes largely from experience in the U.S., it is believed that a by-product credit of about $0.30/gallon may be included in the data compiled by the World Bank. Data on cassava based plants is available only from research and demonstration facilities. Thus, production cost figures presented are estimates only.

4. Ethanol Production from Cellulose Based Raw Materials

Cellulose materials are comparatively difficult to convert into fermentable sugars. The process, which involves subjecting the feed stock to heat and acid, is the subject of ongoing research. Although no commercially viable cellulose-based processes are available at present, some authorities believe they may be developed in the next 10-20 years (2,3). Once the technical problems are resolved, cellulose raw materials offer the advantages of being potentially available in many areas (any type of vegetation such as wood or crop residue may be used), and of supplying the fuel needed for distillation as well as the sugar needed for fermentation.

Due to equipment needed for conversion of the cellulose, capital cost can be expected to be somewhat higher than for starch based plants. As with other ethanol production systems, however, raw material costs are likely to be the major factor in final product cost. With an ethanol yield of 41.3 gallons per ton, the impact of wood purchase price on ethanol cost is illustrated below:

Wood Cost $/Ton	Raw Material Cost/Gallon
$ 25	$0.61
$ 50	$1.21
$100	$2.42

Fuel wood in the Northeastern United States is presently selling for $50 to $100 per ton.

5. Summary

The feasibility of ethanol production from biomass is highly site specific. The economics of alcohol manufacture depends most directly on the cost of raw materials and the value of the gasoline which the ethanol product would replace.

Figure 3.7 provides a graphic comparison of ethanol production costs with expected world gasoline costs. Since ethanol used in gasohol can be substituted one for one for gasoline, ethanol production can be considered financially viable when production costs equal the prevailing cost of gasoline. As the figure indicates, as the world price of gasoline increases,* the number of raw materials attractive for ethanol production also increases. In countries where sufficient quantities of sugar cane or molasses are presently available, ethanol production may be competitive today with gasoline

* Recall that these costs do not reflect national or local taxes or profits and are therefore lower than actual prices paid at the pump.

prices of $1.10 per gallon. As gasoline prices continue to rise, ethanol production will become attractive to increasing numbers of countries capable of supplying the needed volume of raw materials at reasonable prices. In general, ethanol production from sugar containing feed stocks is expected to be economically attractive today or in the near future depending on local raw material costs. Starch based ethanol plants are somewhat less attractive, but may be feasible very shortly in countries capable of providing raw materials at a reasonable price.

In addition to the financial factors, a number of other concerns associated with large scale ethanol production must be considered including the following:

- Significant land areas are required to supply the needed raw materials (eg. 100 sq. km. of sugar cane land would be required to supply a 10 million gallon/year plant)
- Unless raw materials are produced on presently unused land, ethanol production will compete with local food and/or fuel demands.
- Religious concerns and taxation of alcohol regarding alcohol use where fears of controlling access are felt, may influence local acceptability of ethanol production.
- Central government participation may be required to ensure raw material availability, distribution facilities and to balance food and fuel requirements.
- Commercial experience with large scale ethanol facilities using raw materials other than sugar cane, molasses and corn is largely lacking. As a result, high design and start up costs can be expected.
- Experience in Brazil suggests the creation of one job for each $10,000 invested in ethanol production.

6. References for Ethanol Analysis:

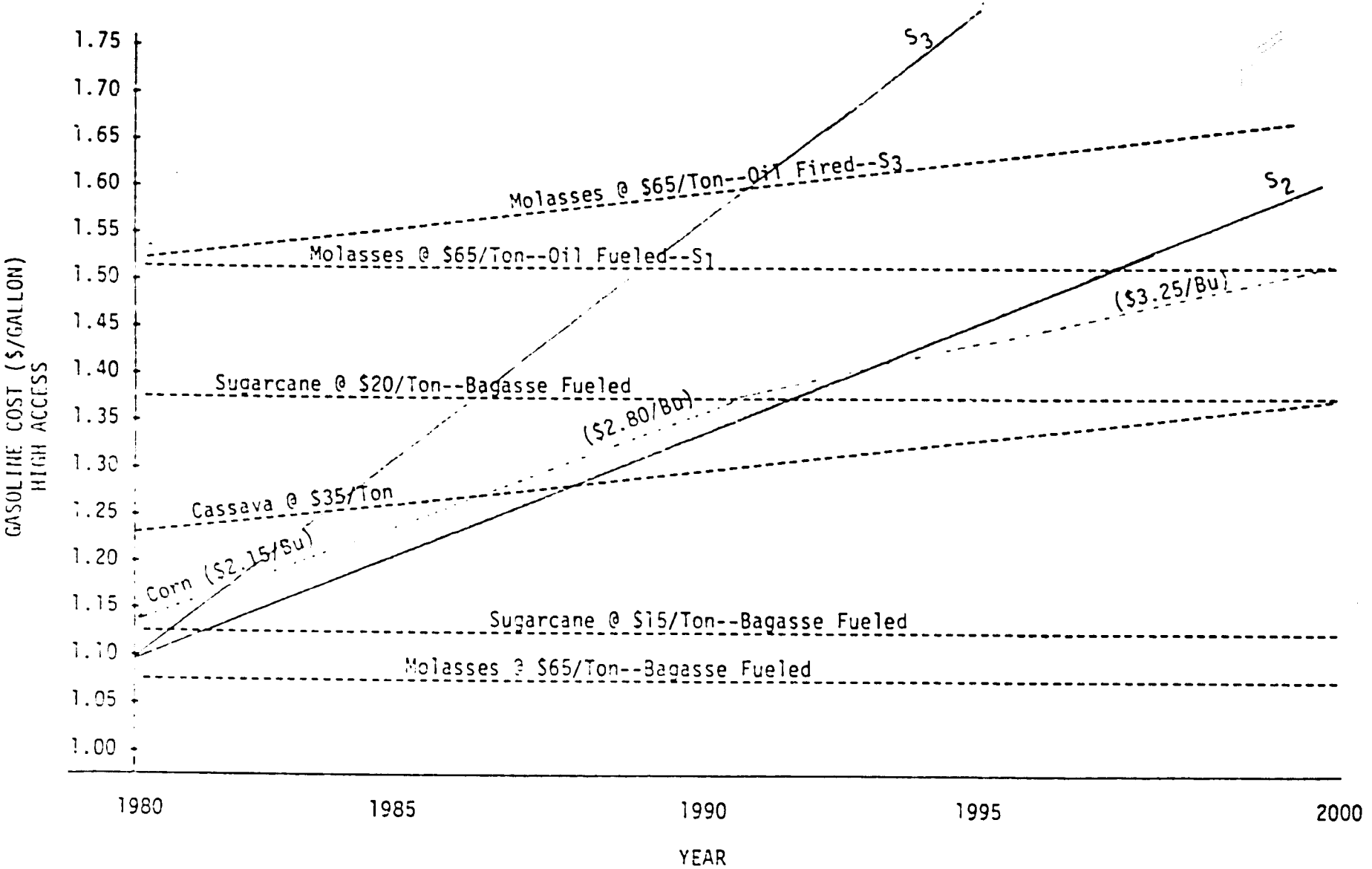
1. Alcohol Production from Biomass in the Developing Countries, World Bank, September, 1980.

2. The Report of the Alcohol Fuels Policy Review, DOE, June, 1979

3. Ethanol Motor Fuels and "Gasohol", Thomas A. Sladek, Colorado School of Mines, May, 1978.

Figure 3.7

ETHANOL PRODUCTION BASED ON 120,000 l/d FACILITIES



Source: Ref. 1

APPENDIX A

SELECTED SUPPORTING COST DATA

Table 1

PRICE OF FUEL 1980-2000 REMOTE AREAS
(1979 $ PER GALLON)
No Taxes or Profits Included

	S_2	S_3
1980	2.34	2.34
1981	2.38	2.40
1982	2.42	2.45
1983	2.46	2.51
1984	2.50	2.57
1985	2.54	2.63
1986	2.58	2.69
1987	2.62	2.75
1988	2.66	2.82
1989	2.71	2.89
1990	2.75	2.95
1991	2.79	3.02
1992	2.84	3.10
1993	2.90	3.17
1994	2.93	3.24
1995	2.98	3.32
1996	3.03	3.40
1997	3.08	3.48
1998	3.13	3.56
1999	3.18	3.64
2000	3.23	3.73

Table 2

DECLINING BOS COSTS

	1980 BOS $16.50		1985 BOS 15.00		1990 BOS 8.00		1995 BOS 4.50	
Array, Structure and Site Preparation	18%	$2.97	17%	$2.50	16%	$1.25	17%	$ .75
Electrical Components	33%	5.45	33%	5.00	25%	2.00	22%	1.00
Storage	20%	3.30	23%	3.50	34%	2.75	44%	2.00
Installation and Checkout	20%	3.30	20%	3.00	19%	1.50	11%	.50
Other	9%	1.49	7%	1.00	6%	.50	6%	.25
Module	$10.00		5.00		2.00		50	

ASSUMPTIONS

1) Lighter/different design of module

2) Designs with prioritized service, also less storage than current designs

3) In-country installation/manufacturing

4) Demonstration period phenomenon ends after FY '85

5) Changes in protection/insulation on critical user components rather than on total system

APPENDIX B

CASH FLOW ANALYSES FOR PUMPING TECHNOLOGIES

1980 - 1990 CASH FLOWS PV PUMP

Financial Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital & Transport	1210	1057	1057	1057	1057							
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage Value												-500
Total Annual Cash Flow	1210	1132	1132	1132	1132	1132	75	75	75	75	75	-500

Net Present Cost
Discount Rate
Inflation +10% =5502

Economic Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital & Transport	5250											
Maintenance	75	75	75	75	75	75	75	75	75	75	75	
Salvage Value												-500
Total Annual Cash Flow	5250	75	75	75	75	75	75	75	75	75	75	-500

Net Present Cost
Discount Rate
Inflation +5% = 5537

ASSUMPTIONS

Capital Cost:	$5,250 in 1980
Transport Cost:	$ 800, $2-2 1/2 per lb. air freight
Terms of Purchase:	20% down payment, 5 year amortized loan at 3% above inflation
Useful Life:	Ten years pump, 15 years PV array
Salvage Value:	At end of ten years salvage value $2.00 Wp for array

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1985 - 1995 CASH FLOWS PV PUMP

Financial Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	
Capital & Transport	860	751	751	751	751	751						
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage												-50
Total Annual Cash Flow	860	826	826	826	826	826	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +10% = 4150

Economic Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	
Capital & Transport												
Maintenance	3500	75	75	75	75	75	75	75	75	75	75	
Salvage												-50
Total Annual Cash Flow	3500	75	75	75	75	75	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +5% = 4050

ASSUMPTIONS

Capital Cost: BOS @$12.50 - Battery @$3.50+array @$5.00 = $14.00/Wp x 250 Wp = $3,500
Transport: Air Freight $800 $2 - 2 1/2 per lb.
Terms of Finance: 20% down payment, 5 year amortized loan at 3% above inflation
Useful Life: Ten years pump, 15 years PV array
Salvage Value: At end of ten years $.20/Wp = $50

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1990 - 2000 CASH FLOWS PV PUMP

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport	463	404	404	404	404	404						
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage												-50
Total Annual Cash Flow	463	479	479	479	479	479	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +1[illegible]

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport	1813											
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage												-50
Total Annual Cash Flow	1813	75	75	75	75	75	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +5% = 2362

ASSUMPTIONS

Capital Costs:	7.25/Wp x 250Wp = 1813
Transport:	$500 reflecting some parts locally manufactured
Terms of Finance:	20% down payment, 5 year amortized loan at 3% above inflation
Useful Life:	Ten years pump, 15 years PV array
Salvage Value:	At end of ten years $.20/Wp - $50

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1995 - 2005 CASH FLOWS PV PUMP

Financial Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
Capital & Transport	210	183	183	183	183	183						
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage Value												-50
Total Annual Cash Flow	210	258	258	258	258	258	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +10% = 1347

Economic Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
Capital & Transport	750											
Maintenance		75	75	75	75	75	75	75	75	75	75	
Salvage Value												-50
Total Annual Cash Flow	750	75	75	75	75	75	75	75	75	75	75	-50

Net Present Cost
Discount Rate
Inflation +5% = 1300

ASSUMPTIONS

Capital:	$3.00Wp x 250Wp = $750 based on local manufacture and lost cost
Transport:	$300 materials
Terms of Purchase:	20% down payment, 5 year locan amortized at 3% above inflation
Useful Life:	Ten years pump, 15 years PV array
Salvage Value:	At end of ten years salvage value $.20Wp for array

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1980 CASH FLOWS MECHANICAL WIND PUMP - U.S. MANUFACTURE

Financial Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital & Transport +installation												
8MPH	1011	883	883	883	883	883						
15MPH	784	685	685	685	685	685						
Maintenance		100	100	100	100	100	100	100	100	100	100	
Salvage Value												
8MPH												-1000
15MPH												- 700
Total Annual Cash Flow 8MPH	1011	983	983	983	983	983	100	100	100	100	100	-1000
15MPH	784	785	785	785	785	785	100	100	100	100	100	- 700

Net Present Cost Discount Rate Inflation +10% =	8MPH	15MPH
	4622	3750

Economic Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital & Transport +installation												
8MPH	5053											
15MPH	3920											
Maintenance		100	100	100	100	100	100	100	100	100	100	
Salvage Value 8MPH												-1000
15MPH												- 700
Total Annual Cash Flow 8MPH	5053	100	100	100	100	100	100	100	100	100	100	-1000
15MPH	3920	100	100	100	100	100	100	100	100	100	100	- 700

Net Present Cost Discount Rate Inflation +5% =	8MPH	15MPH
	4622	3750

1990 CASH FLOWS MECHANICAL WIND PUMP - AEROMOTOR DESIGN INDIGENOUS MANUFACTURE

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport +installation												
8MPH	667	592	592	592	592	592						
15MPH	526	450	460	460	460	460						
Maintenance		100	100	100	100	100	100	100	100	100	100	
Salvage Value												
8MPH												-700
15MPH												-400
Total Annual Cash Flow 8MPH	667	692	692	692	692	692	100	100	100	100	100	-700
15MPH	526	560	560	560	560	560	100	100	100	100	100	-400

Net Present Cost
Discount Rate 8MPH 15MPH
Inflation +10% = 3280 2744

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport +installation												
8MPH	3387											
15MPH	2731											
Maintenance		100	100	100	100	100	100	100	100	100	100	
Salvage Value 8MPH												-700
15MPH												-400
Total Annual Cash Flow 8MPH	3387	100	100	100	100	100	100	100	100	100	100	-700
15MPH	2731	100	100	100	100	100	100	100	100	100	100	-400

Net Present Cost
Discount Rate 8MPH 15MPH
Inflation +5% = 3280 2744

VILLAGE CONSTRUCTED WIND PUMPING MACHINE OMO, ETHIOPIA

Financial Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital Cost 8MPH	980	856	856	856	856	856						
15MPH	588	514	514	514	514	514						
Annual Maintenance		150	150	150	150	150	150	150	150	150	150	
Salvage Value 8MPH												-1000
15MPH												- 600
Total Annual Cash Flow 8MPH	980	1006	1006	1006	1006	1006	150	150	150	150	150	-1000
15MPH	588	664	664	664	664	664	150	150	150	150	150	- 600

Net Present Cost Discount Rate	8MPH	15MPH
Inflation +10% =	4796	3248

Economic Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital Cost 8MPH	4900											
15MPH	2940											
Maintenance		150	150	150	150	150	150	150	150	150	150	
Salvage Value 8MPH	4900	150	150	150	150	150	150	150	150	150	150	-1000
15MPH	2940	150	150	150	150	150	150	150	150	150	150	- 600

Net Present Cost Discount Rate	8MPH	15MPH
Inflation +5% =	5474	3747

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1985 - 1995 CASH FLOWS GASOLINE IC PUMP

Financial Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Capital & Transport	181	228	228	228		165	233	233	233		
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		159	161	164	166	169	172	174	178	181	183
S_3		164	168	172	176	181	184	189	194	198	203
Total Annual Cash Flow S_2	161	462	464	467	241	409	480	482	486	256	258
S_3	161	465	471	475	251	421	492	497	502	273	278

Net Present Cost	S_2	S_3
Discount Rate Inflation +10% =	2687	2753

Economic Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Capital & Transport	790						790				
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		159	161	164	166	169	172	174	178	181	183
S_3		164	168	172	176	181	184	189	194	198	203
Total Annual Cash Flow S_2	790	234	236	239	241	244	1037	249	253	256	258
S_3	790	239	243	247	251	256	1049	264	269	273	278

Net Present Cost	S_2	S_3
Discount Rate Inflation +5% =	3268	3358

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1990 - 2000 CASH FLOWS GASOLINE IC PUMP

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Capital & Transport	165	233	233	233		169	239	239	239		
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		172	174	178	181	183	186	189	193	196	199
S_3		184	189	194	198	203	208	213	218	223	228
Total Annual Cash Flow S_2	165	480	48[illegible]	486	256	427	500	503	507	271	274
S_3	165	492	497	502	273	447	522	527	532	298	303

Net Present Cost	S_2	S_3
Discount Rate Inflation +10% =	2803	2921

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Capital & Transport	790						790				
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		172	174	178	181	183	186	189	193	196	199
S_3		184	189	194	198	203	208	213	218	223	228
Total Annual Cash Flow S_2	790	247	249	253	256	258	1051	264	268	271	274
S_3	790	259	264	269	273	278	1073	288	293	298	303

Net Present Cost	S_2	S_3
Discount Rate Inflation +5% =	3379	3533

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1995 - 2005 CASH FLOWS GASOLINE IC PUMP

Financial Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport	169	239	239	239		174	245	245	245		
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		186	189	193	196	199	202	205	209	212	216
S_3		208	213	218	223	228	233	238	244	250	256
Total Annual Cash Flow S_2	169	500	503	507	271	447	522	525	529	287	291
S_3	169	522	525	530	298	476	553	558	564	325	331
Net Present Cost	S_2	S_3									
Discount Rate Inflation +10% =	2928	3192									

Economic Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport	790						790				
Maintenance		75	75	75	75	75	75	75	75	75	75
Fuel S_2		186	189	193	196	199	202	205	209	212	216
S_3		208	213	218	223	228	233	238	244	250	256
Total Annual Cash Flow S_2	790	261	264	268	271	274	1067	280	284	287	291
S_3	790	283	288	293	298	303	1098	313	319	325	331
Net Present Cost	S_2	S_3									
Discount Rate Inflation +5% =	3498	3727									

DEVELOPMENT SCIENCES INC.

APPENDIX C

CASH FLOW ANALYSES
FOR ELECTRIFICATION OF A VILLAGE

1980 - 1990 DIESEL GENERATOR CASH FLOWS - 4 Kw

Financial Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Capital & Transport + Installation	1093	955	955	955	955	955					
Maintenance (Tuneup)		700	700	700	700	700	700	700	700	700	700
Oil Change		163	166	169	173	176	180	183	187	191	195
Fuel S_2		1376	1432	1461	1490	1520	1550	1581	1613	1645	1678
S_3		1376	1445	1517	1593	1672	1756	1844	1936	2033	2135
Overhaul							1500				
Annual Cash Flow											
S_2	1093	3194	3253	3285	3318	3351	3930	2464	2500	2536	2573
S_3	1093	3194	3266	3341	3421	3503	4136	2727	2823	2924	3030
Net Present Cost Inflation + 10%	S_2 20,217		S_3 21,177								

Economic Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Capital & Transport + Installation	5465										
Maintenance		700	700	700	700	700	700	700	700	700	700
Oil Change		163	166	169	173	176	180	183	187	191	195
Fuel S_2		1376	1432	1461	1490	1520	1550	1581	1613	1645	1678
S_3		1376	1445	1517	1593	1672	1756	1844	1936	2033	2135
Overhaul							1500				
Annual Cash Flow											
S_2	5465	2239	2298	2330	2363	2396	3930	2464	2500	2536	2573
S_3	5465	2239	2311	2386	2466	2548	4136	2727	2823	2924	3030
Net Present Cost Inflation + 5%	S_2 25,106		S_3 26,460								

1990 - 2000 CASH FLOWS 4 Kw WIND MACHINE

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport + Install + Batteries[1]	2460	2150	2150	2150	2150	2150						
Maintenance		615	615	615	615	615	615	615	615	615	615	
Battery Replacement							800	700	700	700	700	
Salvage Value - Battery							-1000					-1000
Windmill												-1500
Annual Cash Flow	2460	2775	2775	2775	2775	2775	415	1315	1315	1315	1315	-2500
Net Present Cost Inflation + 10%	14,690											

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport + Install + Batteries	12300											
Maintenance		615	615	615	615	615	615	615	615	615	615	
Battery Replacement							4000					
Salvage Value - Battery							-1000					-1000
Windmill												-1500
Annual Cash Flow	12300	615	615	615	615	615	3615	615	615	615	615	-2500
Net Present Cost Inflation + 5%	15,587											

[1] $12,300 total cost installed, 20% down, 5n, i=3% above inflation

1980 - 1990 CASH FLOWS 4Kw WIND MACHINE

Financial Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital + Transport + Install[1] + Batteries + Invertor	3640	3179	3179	3179	3179	3179						
Maintenance[2]		685	685	685	685	685	685	685	685	685	685	
Battery Replacement[3]							800	700	700	700	700	
Salvage Value - Battery[4]							-1000					-1000
Windmill												-1500
Annual Cash Flow	3640	3864	3864	3864	3864	3864	495	1385	1385	1385	1385	-2500
Net Present Cost Inflation +10%	20169											

Economic Analysis

	Down Payment	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	
Capital + Transport + Install + Batteries + Invertor	18200											
Maintenance		685	685	685	685	685	685	685	685	685	685	
Battery Replacement							-4000					
Salvage Value - Battery							-1000					-1000
Windmill												-1500
Annual Cash Flow	18200	685	685	685	685	685	685	685	685	685	685	-2500
Net Present Cost Inflation +5%	22028											

1) Total $18,200, 20% down, n=5, i=3% above inflation
2) 5% of cost
3) $4,000 cost
4) $1,000 value

DEVELOPMENT SCIENCES INC.

1990 - 2000 DIESEL GENERATOR CASH FLOWS - 4 Kw

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Capital & Transport & Installation	1093	955	955	955	955	955					
Maintenance & Tuneup	700	700	700	700	700	700	700	700	700	700	700
Oil Change		198	201	205	208	211	215	218	222	225	229
Fuel S_2		1711	1745	1780	1816	1852	1889	1927	1965	2004	2045
Fuel S_3		2241	2353	2471	2594	2723	2860	3003	3153	3311	3476
Overhaul							1500				
Annual Cash Flow S_2	1093	3564	3601	3640	3679	3718	4304	2845	2887	2929	2974
S_3	1093	4094	4209	4331	4457	4589	5225	3921	4075	4236	4405

Net Present Cost	S_2	S_3
Inflation +10%	22490	27798

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Capital & Transport & Installation	5465										
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		198	201	205	208	211	215	218	222	225	229
Fuel S_2		1711	1745	1780	1816	1852	1889	1927	1965	2004	2045
S_3		2241	2353	2471	2594	2723	2860	3003	3153	3311	3476
Overhaul							1500				
Annual Cash Flow S_2	5465	2609	2646	2685	2724	2727	4304	2845	2887	2929	2974
S_3	5465	3139	3254	3376	3502	3634	5275	3921	4078	4236	4405

Net Present Cost	S_2	S_3
Inflation +5%	27948	34969

DEVELOPMENT SCIENCES INC

1995 - 2005 DIESEL GENERATOR CASH FLOWS - 4 Kw

Financial Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport & Installation	1093	955	955	955	955	955	955				
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		215	218	222	229	232	236	239	242	246	250
Fuel S_2		1889	1927	1965	2004	2045	2086	2128	2170	2214	2258
Fuel S_3		2860	3003	3153	3311	3476	3650	3832	4024	4225	4437
Overhaul							1500				
Annual Cash Flow S_2	1093	3759	3800	3842	3888	3932	5477	3067	3112	3160	3208
S_3	1093	4730	4876	5030	5194	5363	7041	4771	4966	5171	5387

Net Present Cost	S_2	S_3
Inflation +10%	24328	33089

Economic Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport & Installation	5465										
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		215	218	222	229	232	236	239	242	246	250
Fuel S_2		1889	1927	1965	2004	2045	2086	2128	2170	2214	2258
S_3		2860	3003	3153	3311	3476	3650	3832	4024	4225	4437
Overhaul							1500				
Annual Cash Flow S_2	5465	2804	2845	2887	2933	2977	4522	3067	3112	3160	3208
S_3	5465	3775	3921	4075	4240	4408	6086	4771	4966	5171	5387

Net Present Cost	S_2	S_3
Inflation +5%	29622	41013

1985 - 1995 DIESEL GENERATOR CASH FLOWS - 4 Kw

Financial Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Capital & Transport & Installation	1093	955	955	955	955	955					
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		180	183	187	191	195	198	201	205	208	211
Fuel S_2		1550	1581	1613	1645	1678	1711	1745	1780	1816	1852
Fuel S_3		1756	1844	1936	2033	2135	2241	2353	2471	2594	2723
Overhaul							1500				
Annual Cash Flow - S_2	1093	3385	3419	3455	3491	3528	4109	2646	2685	2724	2763
S_3	1093	3591	3682	3778	3879	3985	4109	3254	3376	3502	3634

Net Present Cost

	S_2	S_3
Inflation + 10%	21317	23813

Economic Analysis

Capital & Transport & Installation	5465										
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		180	183	187	191	195	198	201	205	208	211
Fuel S_2		1550	1581	1613	1645	1678	1711	1745	1780	1816	1852
Fuel S_3		1756	1844	1936	2033	2135	2241	2353	2471	2594	2723
Overhaul							1500				
Annual Cash Flow - S_2	5465	2430	2464	2500	2536	2573	4109	2646	2685	2724	2763
- S_3	5465	2636	2727	2823	2924	3030	4639	3254	3376	3502	3634

Net Present Cost

	S_2	S_3
Inflation + 5%	26492	30215

DEVELOPMENT SCIENCES INC.

1995 - 2005 DIESEL GENERATOR CASH FLOWS - 4 Kw

Financial Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport & Installation	1093	955	955	955	955	955	955				
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		215	218	222	229	232	236	239	242	246	250
Fuel S_2		1889	1927	1965	2004	2045	2086	2128	2170	2214	2258
Fuel S_3		2860	3003	3153	3311	3476	3650	3832	4024	4225	4437
Overhaul							1500				
Annual Cash Flow											
S_2	1093	3759	3800	3842	3888	3932	5477	3067	3112	3160	3208
S_3	1093	4730	4876	5030	5195	5363	7041	4771	4966	5171	5387

Net Present Cost

	S_2	S_3
Inflation + 10%	24328	33089

Economic Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Capital & Transport & Installation	5465										
Maintenance & Tuneup		700	700	700	700	700	700	700	700	700	700
Oil Change		215	218	222	229	232	236	239	242	246	250
Fuel S_2		1889	1927	1965	2004	2045	2086	2128	2170	2214	2258
S_3		2860	3003	3153	3311	3476	3650	3832	4024	4225	4437
Overhaul							1500				
Annual Cash Flow S_2	5465	2804	2845	2887	2933	2977	4522	3067	3112	3160	3208
S_3	5465	3775	3721	4075	4240	4408	6086	4771	4966	5171	5387

Net Present Cost

	S_2	S_3
Inflation + 5%	29622	41013

DEVELOPMENT SCIENCES INC.

1995 - 2005 CASH FLOWS PV VILLAGE SYSTEM - 3.5 Kw

Financial Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
Capital & Transport[1]	4000	3494	3494	3494	3494	3494	3494					
Annual O & M[2]		175	175	175	175	175	175	175	175	175	175	
Battery Replacement[3]							1400	1223	1223	1223	1223	
Salvage Value - Battery[4]							-3500					-3500
- Array[5]												- 875
Annual Cash Flow	4000	3669	3669	3669	3669	3669	1569	1398	1398	1398	1398	-4375
Net Present Cost Inflation + 10%	19762											

Economic Analysis

	Down Payment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
Capital & Transport	20000											
O & M		175	175	175	175	175	175	175	175	175	175	
Battery Replacement							7000					
Salvage Value - Battery							-3500					-3500
- Array												- 875
Annual Cash Flow	20000	175	175	175	175	175	3675	175	175	175	175	-4375
Net Present Cost Inflation + 5%	21405											

1) $20,000, 20% down, i=3, n=5
2) 10% capital cost
3) 5-year life $2.00/wp
4) $1.00/wp
5) $.25/wp

DEVELOPMENT SCIENCES INC

1990 - 2000 CASH FLOWS PV VILLAGE SYSTEM - 3.5 Kw

Financial Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport[1]	7500	6550	6550	6550	6550	6550	6550					
Annual O & M[2]		350	350	350	350	350	350	350	350	350	350	
Battery Replacement							1400	1223	1223	1223	1223	
Salvage Value - Battery							-3500					-3500
- Array												- 875
Annual Cash Flow	7500	6900	6900	6900	6900	6900	4800	1573	1573	1573	1573	-4375
Net Present Cost Inflation + 10%	37665											

Economic Analysis

	Down Payment	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
Capital & Transport	37500											
O & M		350	350	350	350	350	350	350	350	350	350	
Battery Replacement							7000					
Salvage Value - Battery							-3500					-3500
- Array												- 875
Annual Cash Flow	37500	350	350	350	350	350	3850	350	350	350	350	-4375
Net Present Cost Inflation + 5%	40256											

1) $37,500 capital & transport, 20% down, n=S, i=inflation + 3%
2) 10% capital cost

1985 - 1995 CASH FLOW PV VILLAGE SYSTEM - 3.5 Kw

Financial Analysis

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	
Capital & Transport[1]	14250	12446	12446	12446	12446	12446	12446					
Annual O & M		700	700	700	700	700	700	700	700	700	700	
Battery Replacement[2]							963	841	841	841	841	
Salvage Value - Battery							-4795					-3500
- Array												- 875
Annual Cash Flow	14250	13146	13146	13146	13146	13146	9314	1541	1541	1541	1541	-4375
Net Present Cost Inflation + 10%	70565											

ECONOMIC ANALYSIS

	Down Payment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	
Capital & Transport	71250												
Annual O & M		700	700	700	700	700	700	700	700	700	700	700	
Battery Replacement							4813						
Salvage Value - Battery							-4795						-3500
- Array													- 875
Annual Cash Flow	71250	700	700	700	700	700	718	700	700	700	700	700	-4375
Net Present Cost Inflation + 5%	74642												

1) $71,250 capital cost, 20% down, n=S, i=3%
2) $4,813 battery cost, 20% down, n=S, i=3%

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