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# Impact of Lower Oil Prices on Renewable Energy Technologies

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Falling oil prices are most likely to affect the economic viability of renewable energy technologies that compete directly in the modern sector as large-scale petroleum substitutes. Projects that involve small-scale and rural applications are less likely to suffer.

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The economic sensitivity of renewable energy technologies to changing oil prices is a function of a project's size and location. Renewable energy technologies are those that make use of solar, wind, and biomass resources.

Renewable energy technologies that compete directly in the modern sector as large-scale petroleum substitutes suffer the most from falling oil prices. These include "dendothermal" power plants, fuel alcohol projects, bagasse production schemes, biomass gasifiers for process heat, wind farms, and industrial solar water heating systems.

The economic viability of small-scale or remote (or rural) applications is less likely to be a problem because:

- They are generally smaller, so fuel costs represent a smaller proportion of total costs in the conventional alternative.
- Petroleum fuels are less available and cost more in rural than in urban areas.
- Biomass fuels (such as wood for gasifiers) cost less in rural areas.

Small-scale and rural applications include biogas, biomass gasifiers for engine use, photovoltaic and wind water pumps, solar crop dryers, and domestic solar water heaters. Some of these technologies, such as wind pumps and domestic solar water heaters, are used extensively in many parts of the world.

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## **Abstract**

**The impacts of reduced oil prices on the economic viability of selected technologies which utilize solar, wind and biomass energy sources are examined. The technologies include dendrothermal power plants, bagasse, fuel alcohol, wind electric, biomass gasifiers, solar water heaters, biogas, photovoltaic water pumps and wind pumps. Specific projects in each of these categories which were established or planned when oil prices were above US\$ 28/bbl are reviewed and their economic justifications recalculated at a range of lower oil prices. The findings indicate that the economic sensitivity of renewable energy technologies to changing oil prices is mainly a function of scale and location of the project. Renewable energy technologies that compete directly in the modern sector as large-scale petroleum substitutes, such as dendrothermal power plants and fuel alcohol projects, are the most adversely affected by falling oil prices. Remote and rural applications are less affected because of their generally smaller sizes and, therefore, much lower proportion of fuel costs to total costs in the equivalent sized conventional alternative; the reduced availability and higher cost of petroleum fuels as compared to urban areas; and the lower cost of biomass fuels (eg. wood for gasifiers) in rural areas.**

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## I. INTRODUCTION: LOWER OIL PRICES

1. This paper examines the impacts of reduced oil prices on the economic viability of technologies which utilize solar, wind and biomass energy sources. The objective is to determine which technologies were "hardest hit" by the advent of cheap oil, and what the implications are for renewable energy policies of developing countries as well as those of the Bank. The analysis reviews the economic competitiveness of selected renewable energy technologies (RETs) with petroleum-based alternatives at various price levels. It also examines factors other than oil prices which have equally important bearing on decisions to utilize specific RETs.<sup>1/</sup>

### Overview: Categories Of Renewable Energy Applications

2. Renewable energy applications cover numerous processes and technologies which use solar, wind and biomass resources. These range from small, relatively simple devices such as improved charcoal stoves to megawatt-level, complex solar thermal power plants. RETs also vary in commercial "readiness". A number of technologies can be considered fully developed (e.g. biogas systems, wood-fired power plants) while others are essentially still in the R & D stage (e.g., large solar power plants and ethanol production from woody biomass). For purposes of this report, the analysis will focus on RETs now in use in the field, although not necessarily "commercial" in the conventional sense. This implies that the technologies were, at least, economically competitive with conventional technologies at oil prices prevailing when the installation was originally assessed.

3. It is useful to divide such technologies into two end-use categories:
- a. those that compete directly in the modern sector as relatively large-scale petroleum substitutes; and
  - b. those that serve to meet small-scale, mainly rural energy needs.<sup>2/</sup>

This distinction is important because - as will be shown later - lower oil prices are more likely to affect the economic viability of RETs belonging to the first category. Technologies in the first category, some of which have been the subject of Bank lending or pre-investment activities, include fuel alcohol projects, "dehydrothermal" power plants, bagasse production and utilization schemes, biomass gasifiers for process heat, "wind farms" and industrial solar water heating systems. Small-scale and/or rural applications include biogas, biomass gasifiers for engine use, photovoltaic and wind water pumps, solar crop dryers, and domestic solar water heaters. These technologies are essentially beyond the R&D stage and some, like wind pumps and domestic solar water heaters, are used extensively in many parts of the world.

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<sup>1/</sup> This paper was prepared by Dr. Ernesto Terrado, Matthew Mendis and Kevin Fitzgerald of the Joint UNDP/World Bank Energy Sector Management Assistance Program.

<sup>2/</sup> The scale refers to the size of individual installations, not potential aggregate national contribution.

4. A summary of each renewable energy technology, including an assessment of the sensitivity of its economic viability to lower oil prices, is presented in Chapter 2. Conclusions and policy recommendations that can be drawn from this analysis are presented in Chapter 3. Before proceeding to this discussion, however, it is useful to outline what has actually happened in international and domestic oil markets.

### Actual Oil Price Changes

5. From November 1985 to July 1986 the average FOB price of crude oil on world markets slid from above US\$ 28/bbl to below US\$ 11/bbl. Since mid 1986, crude oil FOB prices remained relatively stable between US\$ 15/bbl and US\$ 18/bbl. As crude oil prices are projected to continue within this range in the medium term, the general economic conclusions reached in this paper are expected to be valid for some time to come.

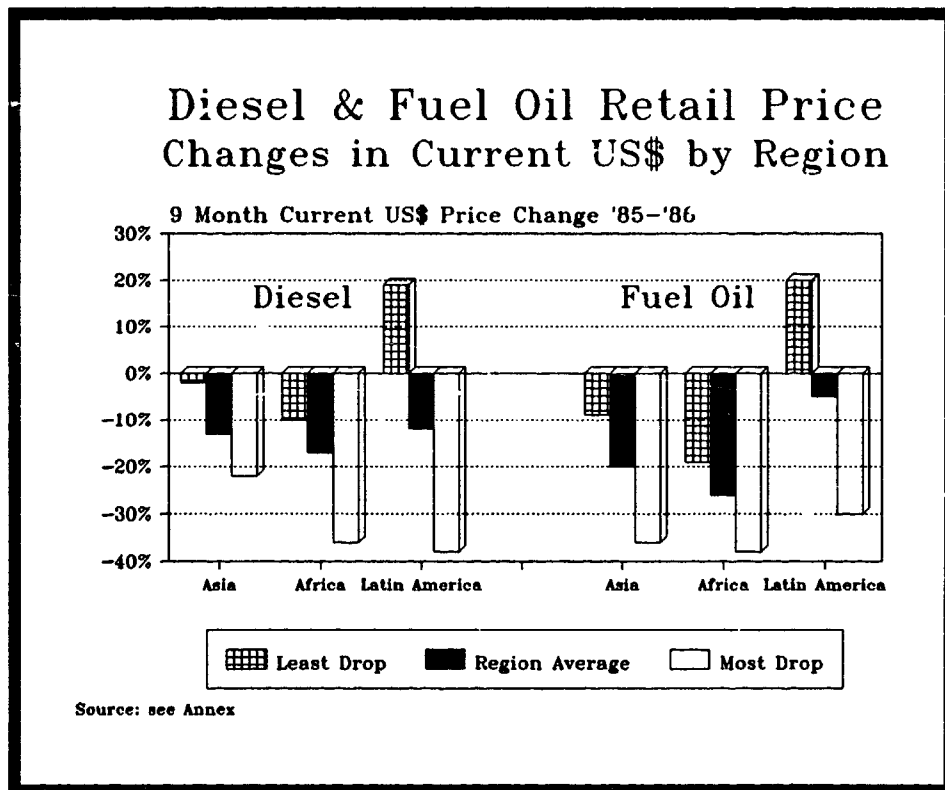


Figure 1 Retail Price Changes in Current US Dollars

6. Data collected from almost 20 developing countries indicate that most countries made only slight retail price adjustments in response to the  $\approx 60\%$  drop in international oil prices between November, 1985 and July, 1986.<sup>3/</sup> In fact, a few countries actually raised nominal retail prices during this period. Figures 1 and 2 illustrate the magnitude of diesel and fuel oil retail price

<sup>3/</sup> Retail petroleum product price changes from late 1985 to mid 1986 in fourteen developing countries are tabulated in the appendix.

changes in three regions between late 1985 and mid-1986.<sup>4/</sup> Measured in current US\$ equivalents, Figure 1 shows that retail prices dropped 15 to 20%, on average, from November 1985 to July, 1986. Real price reductions, shown in Figure 2, averaged 25 to 30% over the same period. There have been two important results from the pattern of only small reductions in local prices of imported fuels:

- a. all petroleum product retail prices in the countries researched were above estimated border prices and;
- b. fuel prices currently faced by investors have changed little in nominal terms.

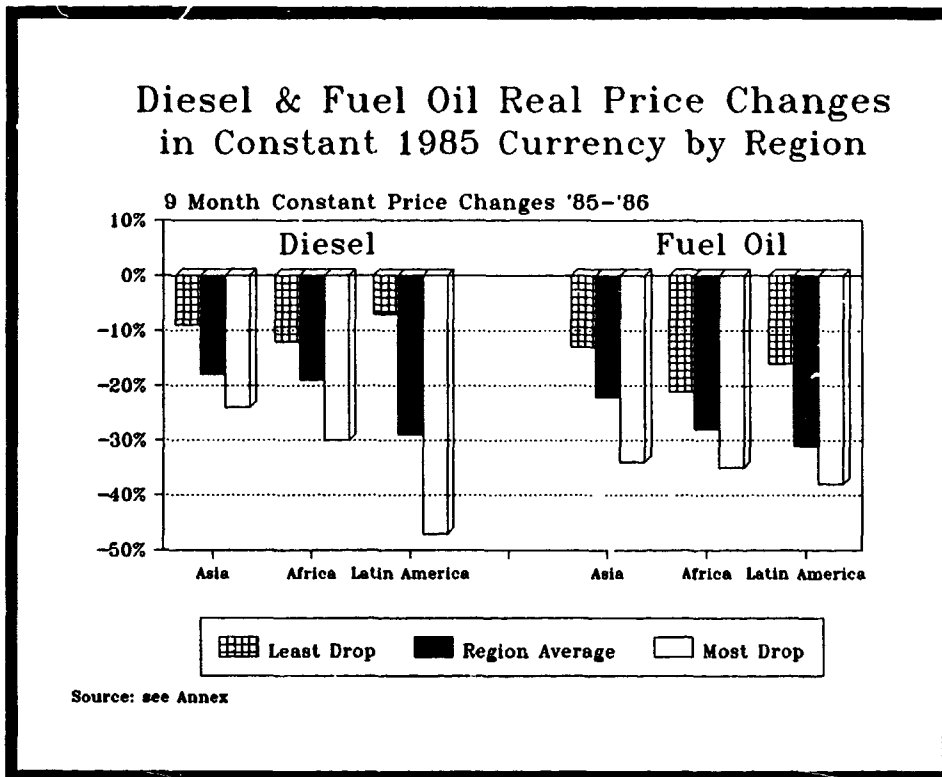


Figure 2 Retail Price Changes in Constant Local Currency

7. Since the drop in international oil product prices have been much more dramatic than retail price cuts, the financial viability of RETs has not been affected nearly as much as the economics have been. For this reason, the analyses of Chapter 2 focus on the economics of renewable energy technologies.



## II. IMPACT ON SELECTED RENEWABLE ENERGY TECHNOLOGIES

8. In this chapter, renewable energy technologies that compete directly in the modern sector as relatively large-scale petroleum substitutes are discussed initially. Those that serve to meet small-scale, mainly rural energy needs are discussed later. It will become readily apparent that the economics of RETs in the first group are far more sensitive to lower oil prices than those in the second.

### Dendrothermal Power Plants

9. A dendrothermal power (DTP) system consists of a wood burning power plant and a dedicated plantation of short-rotation tree species. The most recent DTP installations are in the Philippines, where the Government has established dendrothermal power plants in the 3 to 5 MW range as part of its rural electrification plan. Similar installations are contemplated in Thailand, India, Indonesia, Brazil, and other countries. No evaluation reports are available so far on the performance of the Philippine plants. Since wood burning plants use more or less conventional technology, few technical difficulties are expected on the power plant side. Problems have, however, been reported on the plantation side, related mainly to factors which influence biomass yield, such as choice of species and condition of the land. Analysis indicates that overall plant economics is likely to be sensitive to biomass yield, which dictates the size of the dedicated plantation and therefore the magnitude of plantation development and maintenance costs.

10. In assessing the impact of reduced oil prices on DTP systems, there are two basic difficulties. First, plantation development, wood hauling and other costs are very site-specific. For a given plant size, DTP generation costs can vary widely with location. Therefore, any comparison with oil-based alternatives can only be made in a general way. As widely varying site-specific costs are common to most renewable technologies analysed in this paper, the impacts of lower oil prices assessed throughout this paper are limited to general statements. Second, it is not easy to identify the most appropriate alternative system to which the DTP plant should be compared. If deployed as a unit contributing to the base load of a power grid, the criterion for comparison would be related to the minimum LRMC and the alternative to the DTP plant may very well be a non-oil based installation, such as a coal-fired or a hydro plant.

11. Nevertheless, it is possible to obtain some insight from a Bank study of the likely costs at various sizes of a generic DTP plant.<sup>5/</sup> Based largely on Philippine data and at 1983/84 prices, the study calculated generation costs of about 12.1, 8.4 and 6.6¢/kWh; base capital costs of 2,100, 1,700 and 1,300 \$/kW installed; and plantation areas of 2,000, 6,700 and 31,000 hectares for 3, 10 and 50 MW, respectively. The key assumptions include biomass yield at 10 bone-dry

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<sup>5/</sup> World Bank, "Technical and Cost Characteristics of Dendrothermal Power Systems", Energy Dept. Paper No. 31, December 1985.

tonnes/ha/yr and fuel oil price of 20¢/liter (roughly equivalent to a crude oil price of US\$ 37/barrel which is close to 1983/84 Far East border prices).

12. The study compared the above DTP plants with stand-alone diesel systems using fuel oil. Even at a high 20¢/liter, the electricity generation costs of a 3 MW diesel plant (7.7¢/kWh) are substantially below the costs of a 3 MW DTP plant (12.1¢/kWh). The generation costs are roughly comparable (around 8¢/kWh) at the 10 MW level. Thus, under the assumed parameters, including a fuel oil price of 20¢/lt, DTP systems in isolation, such as on a remote island or in an area not serviced by the grid, would be competitive with diesel systems at plant capacities above 10 MW. At lower fuel oil prices, the comparative generation costs are shown in Table 1.

**Table 1 Generation Costs at Various Fuel Oil Prices\***  
¢/kWh

Fuel Oil Price	Diesel	Dendro <sup>6/</sup>
20 ¢/liter	7.9 ¢/kWh	8.40 ¢/kWh
15	6.6	8.34
10	5.4	8.27
5	4.1	8.20

\* Costs for 10 MW plants operating 5500 hrs/yr.

13. The substantial drop in diesel generation cost as fuel oil prices fell below 1983/84 levels has the effect of limiting economic competitiveness to larger scale DTP plants, making this option impractical due to greatly increased land area requirements and low load factors associated with larger systems. In fact, in small island or remote communities not served by the national grid where DTP systems are likely to be most useful, 10 MW is probably beyond existing and foreseeable power demand. Because of this, it can be concluded that for cases approximating the parameters of the above study, current oil prices do not justify new investments in DTP plants.

14. As with most other RETs, however, a full economic analysis based on the characteristics of the particular location is necessary before a definite conclusion could be made about the viability of a DTP project. The analysis would include shadow pricing of labor, which is a highly intense input on the plantation side, determination of the opportunity cost of land, and quantification of long-term employment benefits accruing to people in the area. When assessing the cost of alternatives, the economic or delivered cost of fuel oil at the site should also be determined. This could be considerably more than the international or border prices.

<sup>6/</sup>

The small reduction in DTP generating cost is due to reduced truck fuel cost for wood hauling. Distance from plantation border to power plant is 10.5 km.

## Bagasse

15. In recent years, interest has been renewed in making cane sugar mills energy self-sufficient and, thus, to produce surplus bagasse (the fibrous residue from cane crushing) for generating electricity to be used internally and for sale to the grid. Cane sugar mills exist in some 80 countries and most are not energy efficient: at best, they recover just enough energy from bagasse to meet milling season needs. The investments required in "bagasse projects" are those which considerably improve process steam economy and boiler efficiency, in effect obtaining the same amount of energy with less bagasse fuel. Bagasse dryers, condensing turbo-generators, efficient juice heaters and pre-evaporators can increase thermal efficiency and decrease process steam consumption considerably. Moreover, pelletizers and briquetting equipment can be used to densify surplus bagasse to be stored and transported safely and conveniently. This is especially important for year-round electrical production where the markets for surplus energy are electricity utilities.

16. Davies Hamakua Sugar pioneered in this field with their mills in Hawaii. The F.U.E.L. sugar mill in Mauritius has also installed, at the pilot level, equipment for generating and densifying surplus bagasse, enabling it to sell year-round power to the grid. In 1985, the Bank conducted prefeasibility studies in Guyana and Ethiopia resulting in specific recommendations for bagasse projects in these countries.

17. In a typical bagasse project, economic return is based on revenues from selling surplus power and savings in internal use of petroleum fuels. In other cases, such as the project proposed for Ethiopia, the surplus bagasse product was intended to displace fuelwood in homes and later, to substitute for imported pulp and particle board feedstock. The impact of lower oil prices on project viability is fairly clear in the first case. It is less clear in the second case where the commodity being displaced is not petroleum-based. The Guyana and Ethiopia studies illustrate the differing potential impacts quantitatively.

18. Guyana's public electricity supply is almost totally dependent on imported petroleum. At present it suffers from a lack of generating capacity and system inefficiencies. Enmore, one of the country's 10 sugar mills, was chosen for a bagasse pilot project to demonstrate the feasibility of making the mill independent of diesel which it now uses and, at the same time, generating surplus power from bagasse for feeding to the public grid. The investments total US\$ 10.5 million, most of it by Guysuco for mill equipment and modifications, and partly by GEC for a 14 km transmission line, transformer, and control equipment. The benefits of the project would be savings by Guysuco in diesel fuel (about 830,000 lt/yr during the milling season) and avoided costs by GEC in diesel fuel for 24 GWh/yr of peaking power to be supplied by the Enmore mill. Calculated at the CIF value of diesel fuel at that time, which was US\$ 42/barrel, the economic rate of return for the project was an acceptable 21%. A drop in diesel fuel price by 25% reduces the ERR to 14% and, at half the 1985 price, the rate of return becomes only 5%. Thus, at present international oil prices, this particular project is not justified on the basis of fuel savings alone.

19. The Ethiopia project, proposed by an ESMAP study, consisted of investments in all three Ethiopian sugar mills to enable production of about 100,000 tonnes/yr of surplus bagasse.

The current hydropower surplus and power tariff structure does not make export of bagasse-based energy to the grid a viable option. The highest value end-use for surplus bagasse in the immediate future was determined to be as densified fuel for households and industry. Financial investments of US\$ 12.2 million were required for the project which included densification facilities in each mill.

20. Unlike the Guyana case, the Ethiopian mills are fairly efficient. Only one of the mills would obtain some internal savings in fuel oil. However, the most likely use of the densified bagasse would be as substitute for firewood, acute scarcity of which is being experienced by Ethiopian households. Therefore, the benefits are mainly due to projected sales of densified bagasse which, if priced at 80% of the firewood price (to compensate for its less familiar, harder to ignite form), is thought to have a ready market. Under these conditions, the financial rate of return is about 30%.

21. The economic value of firewood in Ethiopia is difficult to quantify but, considering the serious ecological impacts of massive deforestation which has occurred in the country, is likely to be very high. Assuming that this value is at least as high as imported kerosene, the economic rate of return at 1985 prices would be a high 90%. Even with a 50% drop in kerosene import price, the ERR would still be 43%. Therefore, for this particular project the impact of international oil prices on project viability is insignificant.

### Fuel Alcohol

22. Ethyl alcohol (ethanol) is commonly produced by a fermentation/distillation process using sugar cane juice or molasses (a by product of sugar refining) as feedstock. While other feedstocks, such as cassava, can be used, the technology for producing ethanol from cane or molasses is better developed and more attractive economically because the cane by-product, bagasse, can be used as process fuel. Ethyl alcohol (ethanol) can be used as motor fuel in various ways. As nearly water-free or "anhydrous" ethanol, it can be blended with gasoline up to about 20% without decreasing the mileage yield of the gasohol product and without modifying normal gasoline engines. As hydrous ethanol, it can be used as a straight fuel in specially designed alcohol engines or modified gasoline engines. The mileage yield of straight alcohol is about 75% that of gasoline. Presently, straight alcohol vehicles are used only in Brazil where an ambitious ethanol program has been firmly established.

23. Since 1980, a number of countries have implemented fuel alcohol programs. The largest is that of Brazil where 10 billion liters of ethanol is currently produced for use as a blend and in straight alcohol cars. In Africa, plants in Malawi, Zimbabwe, Kenya, and Mali produce ethanol from molasses to substitute for 3-15% of domestic gasoline demand. The IFC supported the Malawi project and submitted a proposal for a plant in Zambia while the small annexed

distillery in Mali was financed with a World Bank loan. A recent Bank paper<sup>7/</sup> recommended further assessment of proposed ethanol programs for Thailand and the Philippines.

24. In general, the viability of a fuel alcohol program increases when it is possible to use lower economic value molasses rather than cane as feedstock, the sugar mill is far from the coast, thereby reducing the value of molasses as an export commodity, and when the distillery can be annexed to the sugar mill so that surplus bagasse can provide process energy for ethanol production. As the primary economic benefit of ethanol production is the displacement of imported gasoline, the economic rate of return of an ethanol project rises directly with the economic price of gasoline. Exchange rates also affect economic viability, but less robustly because a strengthening local currency will reduce both gasoline import costs and export values of molasses and sugar. Additional benefits that should be accounted for in a full economic analysis include: employment, foreign exchange savings, and security of access to an indigenous transportation fuel.

25. To illustrate the impact of lower oil prices on fuel alcohol projects, it will be sufficient to consider the case of anhydrous alcohol production from molasses (i.e., if project justification is lost for this case, so would it be for ethanol from cane). As with dendrothermal power above, the economics of ethanol projects are very site specific. Hence, two representative projects will be analyzed: a proposal in Swaziland recently reviewed by the Bank and the Brazilian ethanol program.

26. Three proposals for ethanol production in Swaziland were analyzed as part of the Swaziland Energy Assessment. The most promising proposal (by CDC/PEA for 65,000 lpd annexed distillery at the Mhlume sugar mill) is designed to produce ethanol at 21¢/liter to meet 20% of a growing national gasoline demand until 1995 (details in Annex). If savings on imported gasoline are the only benefits counted in the economic analysis, the 22% drop in the actual landed price of gasoline<sup>8/</sup>, from 30¢/l in mid-1985 to 24¢/l in July 1986, is enough to cut the project economic rate of return from 28.5% to 18%.

27. The approximate minimum real crude oil prices needed to justify the Brazilian anhydrous ethanol program in economic terms are shown in Table 2 below<sup>9/</sup>. Minimum crude oil break-even prices for hydrous import substitution and export of hydrous ethanol average 25% and 50% higher.

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<sup>7/</sup> Ody, A., "Prospects for Ethanol in Developing Countries", INDD2 Office Memorandum, 21 February 1985, World Bank.

<sup>8/</sup> The FOB price of gasoline in the Middle East market dropped 50% from October 1985 to July 1986, while due to high transportation costs and other levies, the landed cost of gasoline at Matsapha, Swaziland dropped only 22% over the same period.

<sup>9/</sup> Draft Public Sector Investment Review: Brazil, October 1986, LC2BR, World Bank.

**Table 2 Minimum Crude Price for Economic Viability of  
Anhydrous Ethanol Distilleries in Brazil  
in Constant 1984 US\$/barrel**

	<u>São Paulo</u>	<u>Northeast</u>
Build New Distillery	23-28	24-34
Operate Existing Distillery	17-23	20-28

28. The CIF price of crude in November 1985 in Santos, Brazil was US\$ 29.40/bbl. The CIF Santos price had fallen below US\$ 15/bbl by August, 1986 and was nearly US\$ 17/bbl in February, 1988. Hence, since mid 1986, the ethanol program in Brazil could be only marginally justified in a strict economic sense. Because of this the Government of Brazil has announced a suspension of further expansion in fuel alcohol distilling capacity.

29. As anhydrous ethanol substitutes for imported gasoline, the economic viability of ethanol production is robustly sensitive to the cost of imported gasoline. The Swaziland proposal summarized above is for a plant designed to produce ethanol at roughly 21¢/liter, while representative production costs in Brazil range between 18¢ and 26¢/liter.<sup>10/</sup> If the economic cost of gasoline remains above these prices, all else being equal, ethanol production makes good economic sense. Many proposed ethanol installations have been at locations far inland, where the transport component of gasoline costs are high and the export value of molasses is low or nil. Consequently, at such installations (as in Swaziland), the actual landed cost of gasoline will not have dropped as much as the drop in international FOB prices. Hence, the Mhlume proposal still appears viable using actual summer '86 gasoline import prices as delivered to Matsapha, while certain installations in Brazil are on the margin of economic justification.

### Wind Electricity Generation

30. To properly assess the place of wind electricity generation capacity in an electrical grid, planners must consider the uncertainty of wind power supply, daily and seasonal wind profiles and how they match load profiles, fuel savings due to use of wind turbines, as well as possible deferrals of future capital investment in conventional generation capacity. Hence, the economic value of wind power is determined not so much by average cost considerations as by long run marginal cost and wind time distribution characteristics.

<sup>10/</sup> SAR: Brazil Alcohol Rationalization and Efficiency Project, Industry Department, World Bank, 1985. Quoted costs are average 1983 costs of alcohol production in constant 1984 US\$.

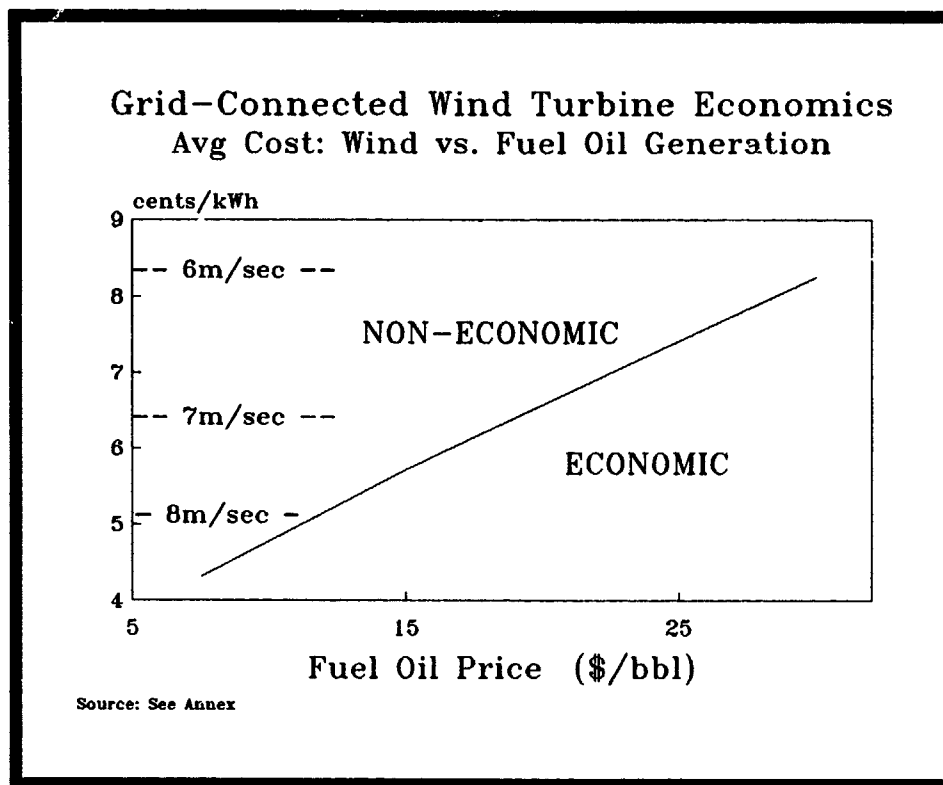


Figure 3 Wind vs. Oil-Based Generation Costs

31. With this *caveat* in mind, a rough "order of magnitude" analysis can be conducted on electricity generation costs of wind vs. thermal. The results of such an analysis are shown in Figure 3 in which representative generation costs over a range of oil prices for a hypothetical grid, supplied exclusively by large base load fuel oil steam plants and smaller diesel oil gas turbine peaking plants, are compared to estimated wind electricity generation costs.<sup>11/</sup> Though actual costs can vary considerably, these generic cost estimates show that lower oil prices can significantly change generation costs. A 50% drop in representative 1985 import prices of diesel oil (from 30¢/l to 15¢/l) and fuel oil (from US\$ 30/bbl to US\$ 15/bbl) could reduce electricity generation costs some 30%, from 8.3¢ to 5.8¢/kWh. Of course, if a significant share of total demand is met by coal, gas, nuclear, or hydro capacity, the actual change in system generation costs due to lower oil prices will be less than that depicted in Figure 3.

32. The wind electricity costs presented in Figure 3 are rough estimates, based on the actual costs of 100kW wind turbines in California wind farms, for a good wind regime (annual average windspeed of 6m/sec) and two excellent regimes (7 and 8m/sec). It is evident that electricity generated with an annual average windspeed of 6m/sec, not unlike the resource in the mountain passes of California, would cost as much as electricity generated by an optimally run oil-

<sup>11/</sup>  
wind farms.

Detailed assumptions are tabulated in the Annex. Wind electricity costs are based on actual costs from California

based system under estimated 1985 economic fuel prices of US\$ 30/bbl fuel oil and 30¢/liter diesel fuel. At lower oil prices, only rare wind resources remain economically competitive with oil-based generation on an average cost basis.

33. Moreover, as amply demonstrated in a recent Bank Energy Department Paper,<sup>12/</sup> unless the wind resource and demand peaks are closely matched, wind turbines displace primarily low cost intermediate and base load capacity. Clearly, in an environment of economic oil prices below US\$ 15/bbl, wind-to-grid electricity generation would not be cost effective unless average annual windspeeds exceed 6m/sec and the wind profile tightly corresponds to demand peaks.

### Biomass Gasifiers

34. In biomass gasifiers, solid combustible biomass materials like wood, charcoal, rice husks, or coconut shells, are thermochemically broken down into a combustible gas. Though the energy content of this "producer gas" (4 to 7 MJ/m<sup>3</sup>) is usually far less than that of natural gas (35 MJ/m<sup>3</sup>), the economics of gasification were attractive enough throughout the early 1980's for industrial and commercial process heat applications to become common in Brazil, Southeast Asia, and the South Pacific. **Heat gasifiers**, primarily large systems replacing fuel oil in industrial applications, are commonly located in urban or peri-urban areas. Conversely, many rural applications are found for **power gasifiers** that burn the gas in internal combustion engines. These applications primarily replace diesel oil in small engines used to generate electricity, pump water, or mill grain. Given these basic differences, the impact of changing oil prices on the economic viability of these systems must be viewed independently.

### Heat Gasifiers

35. Biomass heat gasifiers are presently used to provide process heat in a wide variety of applications including: tea, grain, and lumber drying; glass, tile, and brick manufacturing; cement production, food processing, and greenhouse heating. Heat gasifier systems, consisting essentially of a fuel feed system, reactor chamber, and gas burner, are commercially available in sizes from 100kW to 10MW. The smaller, manually batch fed, systems are commonly used for crop drying, baking or other similar applications. The larger systems are automatically fed and are used to provide heat for industrial kilns, boilers, driers and furnaces. As heat gasifiers can usually be retrofit to existing oil or natural gas burning equipment, the potential number of applications is extremely large. The main constraint to wide scale use of biomass heat gasifiers is posed by their requirement of an economic and reliable source of biomass fuel.

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<sup>12/</sup>  
1987.

Moreno, R., Guidelines for Assessing Wind Energy Potential, Energy Department Paper #34, World Bank, January



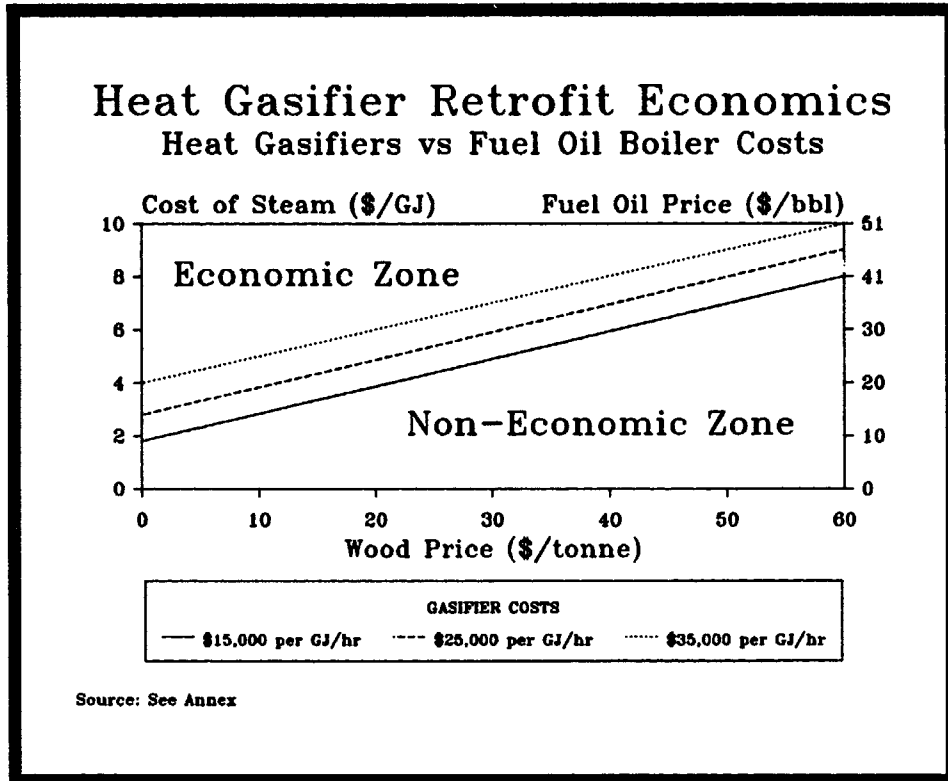


Figure 4 Heat Gasifiers vs. Fuel Oil Boiler Costs

36. As with fuel alcohol programs above, the primary economic benefits of heat gasifiers accrue from savings in imported petroleum fuels. Given the wide range of possible heat gasifier applications, it is difficult to generalize on the economics of these systems. Nonetheless, a brief cost analysis of a generic heat gasifier retrofit to an oil-fired boiler illustrates the sensitivity of this technology to lower oil prices. Figure 4 shows the economic sensitivity of such a system to changes in oil prices, wood fuel prices, and gasifier capital cost estimates.<sup>13/</sup> For a drop in fuel oil price from US\$ 30/bbl<sup>14/</sup> to US\$ 15/bbl the break-even fuelwood price for a moderately priced heat gasifier system (US\$ 25,000/GJ/hr) drops from US\$ 30/tonne to near zero.

37. As the market for large scale heat gasifiers is generally in populated urban or rural areas, where fuel oil is commonly available and alternate demands for wood fuels exist, the fuelwood price is usually above US\$ 20/tonne. Moreover, as large scale heat gasifiers tend to be fully mechanized, they commonly have capital costs at the high end of the range shown in Figure 4. Conversely, small scale heat gasifier systems, such as those used for tea and copra drying, are usually located in more remote areas where the economic cost of fuel oil is relatively high while the

<sup>13/</sup> Source: Foley, G. and Barnard, G., Biomass Gasification in Developing Countries, Earthscan, 1983. Gasifier cost estimates summarized in Annex.

<sup>14/</sup> Average border prices for fuel oil dropped from \$30-\$35/bbl in November 1985 to \$10-\$15/bbl in July 1986 for countries with or near a port.

economic price of wood and biomass fuels can approach zero. In addition, small scale heat gasifiers are amongst the lowest cost systems shown in Figure 4 because they are often manually fed. For these reasons, the economic feasibility of large scale heat gasifiers will be affected first by decreasing petroleum prices. Small scale installations in remote areas may continue to be competitive because of access to and reliability of low cost biomass fuel supply and high transport costs of petroleum fuels.

### Power Gasifiers

38. Biomass power gasifiers from 5 kW to 1MW are commercially available. A power gasifier system consists of a manual or automatic feed system, a reactor chamber, a gas clean up system and either a diesel or spark ignition engine. If a diesel engine is used, some diesel fuel still must be used to induce ignition. Most commercially available power gasifiers are designed to operate with a specific biomass fuel: wood, charcoal, rice husks or coconut husks. The analysis below focuses on wood and charcoal power gasifiers as these are the most common.

39. The economics of power gasifiers hinges on the savings that can be realized by switching from high cost liquid fuels (i.e., diesel) to low cost biomass fuels. These fuel cost savings must be weighed against the additional capital costs of the gasifier, the increase in operation and maintenance costs, and the reduced reliability of the system. One way to evaluate the tradeoff between capital costs and O&M costs is to compare the levelized costs of electricity generated by each system. This has been done in an ongoing IENHE study which compares generic wood and charcoal gasifiers to diesel stand-alone systems from 5kW to 1MW.<sup>15/</sup>

40. The IENHE study has evaluated commercially available power gasifiers in the following ranges:

- a. Manually fed charcoal gasifiers from 5 kW to 200 kW;
- b. Manually fed wood gasifiers from 5 kW to 200 kW, and;
- c. Automatic feed wood gasifiers from 100 kW to 1 MW.

Figure 5 presents some of the principle findings of this study. The analysis indicates that power gasifier economics is most strongly affected by system size and by the relative cost of petroleum and biomass fuels.

41. Under baseline price assumptions (diesel @ 40¢/l, charcoal @ US\$ 80/mt, and fuelwood @ US\$ 20/mt), the full range of charcoal gasifiers, manually fed wood gasifiers above 30kW, and automatically fed wood gasifiers above 300kW are economically competitive with diesel systems. In this analysis, a 50% fall in diesel prices, to 20¢/l, would make electricity generation by

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<sup>15/</sup>

Assumptions used in the study are presented in the Annex.

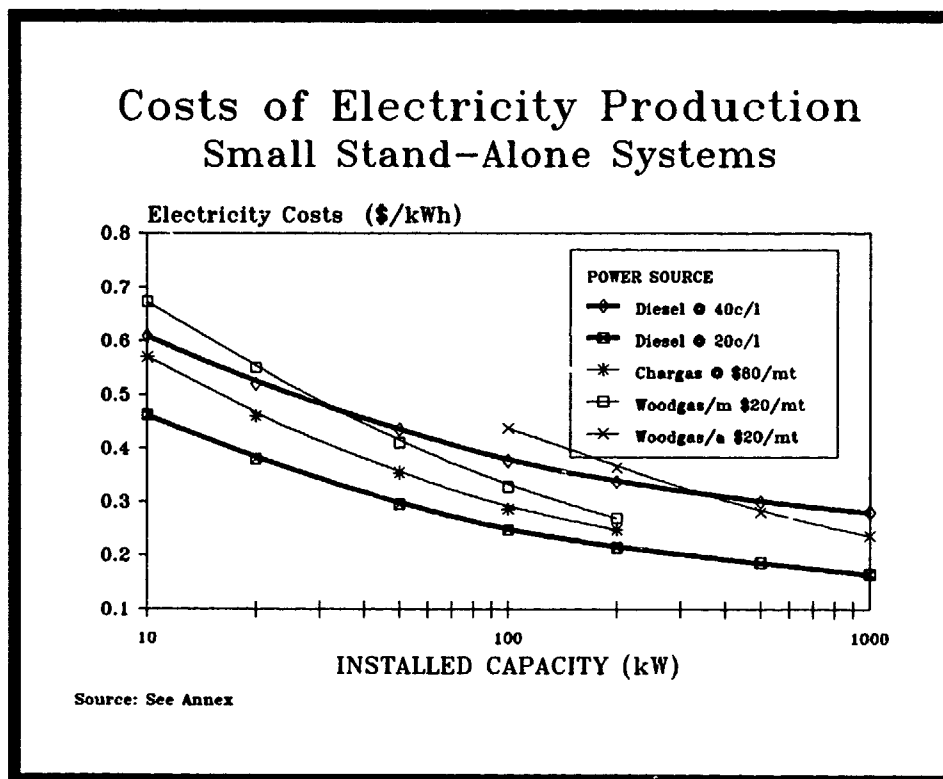


Figure 5 Generation Costs of Gasifiers vs. Diesel

diesel cheaper than either charcoal or wood power gasifiers over the entire range of analysis.

42. With decreasing petroleum prices, it is clear that power gasifiers, like small-scale heat gasifiers, will have a niche only in remote applications where the economic cost of diesel is high due to transport costs, where diesel supply is unreliable, and where there is a surplus of biomass fuels.

### Solar Water Heating

43. The basic principle behind solar water heating (SWH) is simple: by passing a cool fluid through small pipes imbedded in a black collector plate, exposed to the sun and housed in transparent glass, thermal energy is captured in the heated fluid. SWH designs depend on the end use (industrial process heat, restaurant, hotel, or domestic hot water), load and solar resource profiles (daily and seasonal), and water temperature requirements. The solar collector itself is the most expensive system component, commonly constituting over 50% of installed system cost. As most end uses require additional components, such as circulating pumps, temperature controllers, storage tanks, and heat exchangers, the cost of solar water heating can vary significantly with each application.

44. Many developing countries have active solar water heating industries. Solar water heaters for residential and small commercial installations are manufactured locally in Israel and Jordan where as many as 1 in 5 homes use solar water heating. The SWH industries in Morocco, Tunisia, Egypt, Senegal, and Zimbabwe fabricate as well as import some collector components. Both India and Nepal have sound SWH industries supplying residential and commercial systems. Australia, Israel, France, USA, and Japan are major exporters of SWH technology and large domestic markets exist in both Australia and the USA.

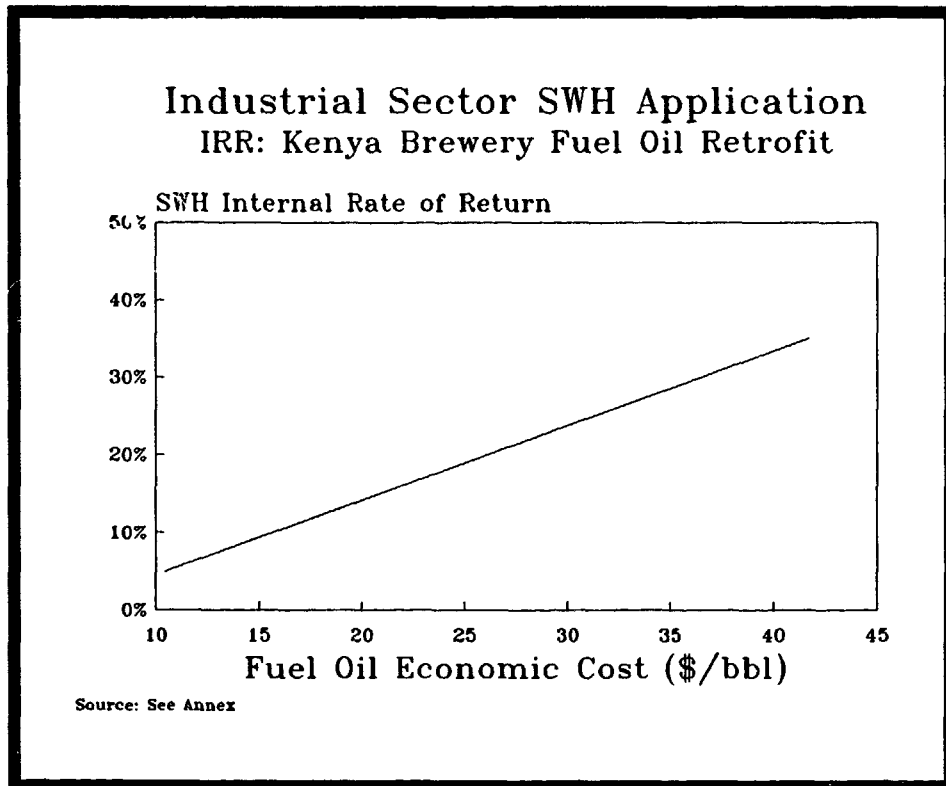


Figure 6 Solar Hot Water Fuel Oil Boiler Retrofit

45. Industrial applications of solar water heating in developing countries are limited to a few large pilot plants in the Middle-East and a few other countries. The brief analysis below, based on an ESMAP study of the potential for solar water heating in Kenya, illustrates that low oil prices can severely curtail the economic advantages of industrial SWH.

46. An ESMAP SWH study for Kenya, originally assessed at 1985 fuel prices, was recently reevaluated at border prices of August, 1986.<sup>16/</sup> The border price of fuel oil fell from US\$ 16.75 to US\$ 11.25/bbl over this period. Because all of the industrial SWH installations originally

<sup>16/</sup>

Joint UNDP/World Bank ESMAP Solar Water Heating Study, Kenya, December 1986. Assumptions and results of this report are summarized in the Annex.

proposed were only marginally viable, this drop caused over 90% to lose economic viability.<sup>17/</sup> Conversely, even though the cost of electricity supply in Kenya fell from 5.5¢/kWh in October 1985 to 4.4¢/kWh in August 1986, all residential installations proposed in the original report (exclusively for the displacement of electric water heating in upper income urban homes) were still found to be economically viable.

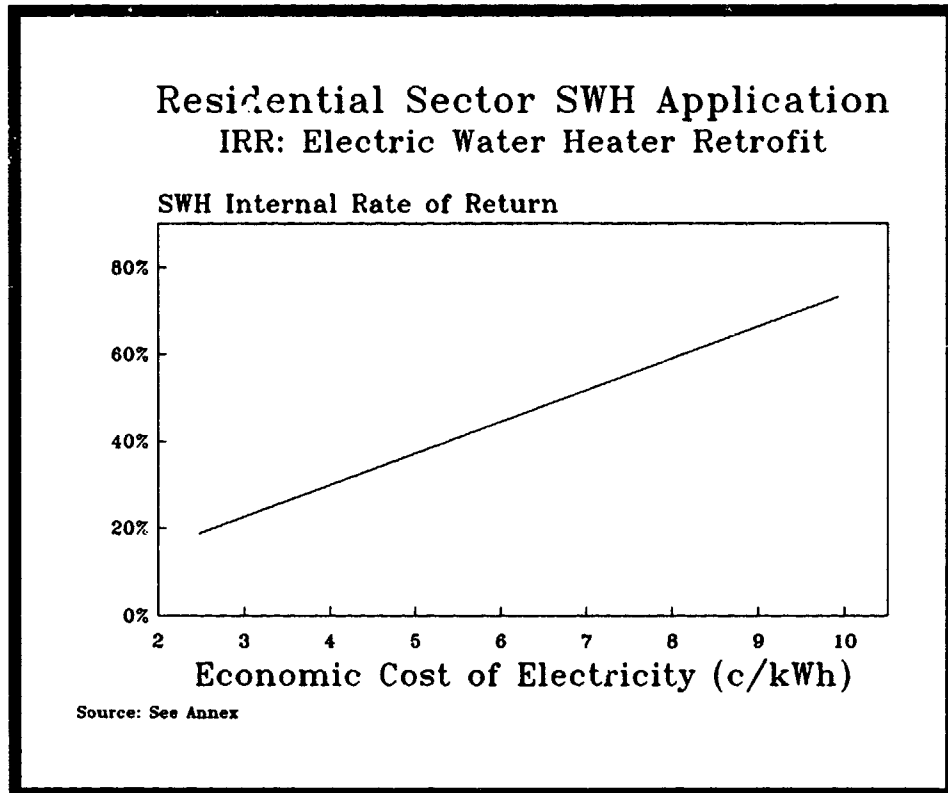


Figure 7 Solar Hot Water Electric Water Heater Retrofit

47. The economic sensitivity to fuel prices of two representative SWH installations in the Kenya study are displayed in Figures 6 and 7. Under the assumptions used in the Kenya report,<sup>18/</sup> it can be generally stated that if the economic price of displaced fuels remains above US\$ 150/TOE (US\$ 25/bbl fuel oil, 4¢/kWh, or US\$ 50/mt wood), state-of-the-art SWH installations in locations with good solar resources may be cost effective. As the landed cost of fuel oil dropped to around US\$ 10/bbl in July 1986 and are below US\$ 15/bbl as of February, 1988 for most countries with a port and the price of fuelwood rarely exceeds US\$ 50/mt, SWH installations that

<sup>17/</sup> For purposes of this paper, installations with an economic rate of return above 15% are considered economically viable.

<sup>18/</sup> Economic rates of return were calculated by comparing the economic value of displaced fuels to SWH system costs (including imported collectors and locally made balance of system components) calculated @ \$103/m<sup>2</sup> of collector area for industrial applications and \$126/m<sup>2</sup> for all others over a 15 year lifetime at 10% discount rate.

displace these fuels may not be cost effective unless cheaper, domestically produced SWH systems are available.

48. While the actual drop in fuel oil prices in Kenya has severely curtailed the economic viability of SWH systems that displace fuel oil, systems that displace electricity were barely affected because generation costs did not change markedly and the economics of SWH retrofits for electric water heaters are robust. State-of-the-art solar water heating systems sized for Kenyan conditions cost about 4¢ per kWh displaced. As electricity system costs commonly range from 3¢-10¢/kWh for hydro-power to 5¢-20¢/kWh for thermal generation, SWH systems can deliver hot water for domestic uses at lower cost than electrical water heating in most places with a good solar resource. Nonetheless, this does not imply that SWH is the lowest cost water heating technology. Comparing SWH system costs to those of electric water heaters does not assure SWH a market niche if fuel oil boiler retrofitting is cheaper.

### Biogas

49. Biogas is the gaseous product (mainly methane) obtained in the anaerobic (oxygen-free) digestion of dung and other biomass wastes. About 6-7 million biogas digesters have been built in China,<sup>19/</sup> about half a million in India, and a few thousands in other developing countries. A majority of the digesters use cattle or pig manure as feedstock. Most of the digesters now in operation are "family size", each unit yielding about 2 m<sup>3</sup> of biogas daily and requiring dung from at least 3 cattle or 6 pigs. The larger digesters are often built for institutions (schools, prisons, etc.), industries (slaughterhouses, breweries) and communities, where gas from a big digester is piped to the kitchens of several families.

50. The costs of establishing and operating a biogas digester include capital investment for the digester, gasholder, pipes, and accessories; labor for construction, dung collection, and system operation; and the costs of water, land (for the installation), and the dung itself. Some of these items require cash outlays, others do not. The family-sized KVIC system in India, for example, has a capital cost of about Rs 4250.

51. The first principal benefit is the fuel value of the gas. If used for cooking, it may displace kerosene, fuelwood, or dried dung. For lighting with a mantle lamp, it usually substitutes for kerosene. As fuel for an internal combustion engine to obtain direct shaft power for flour milling, water pumping, or electricity generation, it displaces diesel fuel, gasoline, or grid electricity. The slurry or dried sludge represents the second principal benefit in terms of its value as fertilizer or "soil conditioner". The value of the sludge is often assessed as equal to or even greater than the fuel value of the gas, depending on the particular installation.

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<sup>19/</sup> Taylor, R.P., Decentralized Renewable Energy Development in China: The State of the Art, World Bank Staff Working Paper #535, 1982.

52. In the financial analysis, the flow of costs and benefits is evaluated over the digester lifetime of 15-20 years. The value of gas in terms of substituted fuels is fairly easy to determine. However, valuation of sludge or slurry as fertilizer substitute has always been an item of disagreement. Although the viability of a biogas installation can only be assessed on a case by case basis, it is possible to make some general statements. Without subsidies, it is virtually impossible to make a system financially viable on the basis of the fuel value of the gas alone. Counting the fertilizer value of the sludge, there may be some instances where acceptable financial rates of returns may be achieved. It may also be generally said that due to the scale factor, family-size systems are generally less viable than community-sized biogas systems. These statements are drawn from recent analyses done by many authors when petroleum product prices were high. Clearly, at current (1986) oil prices, the financial viability of biogas systems in general has either remained the same or worsened.

53. It must be kept in mind, however, that national policies for disseminating biogas systems are adopted not only on the basis of fuel substitution goals. There are indeed other economic benefits, including: destruction of pathogens in the raw dung, health benefits to households from using a smokeless fuel, reduction of pressure on the forests from fuelwood collection, employment generation, reduction of uncertainty in fuel supply, and reliance on indigenous rather than imported energy.<sup>20/</sup> For obvious reasons, there have been no general agreements on how these externalities should be quantified and incorporated into the economic analysis of biogas projects.

54. It is beyond the scope of the present analysis to make a judgement on the economic desirability of biogas technology. The only task is to assess the potential impacts of lower prices of competing petroleum fuels. As the preceding discussion clearly indicates, it has been difficult to justify biogas systems on the fuel value of the gas alone even when oil product prices were high. Therefore, lower oil prices would cause very little change in the financial viability of biogas systems.

### **Photovoltaic and Wind Powered Water Pumping for Village Water Supply and Irrigation**

55. Wind power has been used for grinding grain for centuries. Water pumping by windmills played a major role in the agricultural development of the American West and land reclamation in Holland. Relative to the history of wind power, photovoltaic technology or PV has just been born. Today's photovoltaics (solar cells) convert about 10% to 14% of the energy in incident sunlight into electricity. Falling production costs have recently made direct solar electric conversion competitive with diesel as a power source for remote power supply applications. While PV pumping systems require power conditioning equipment to convert direct current electric power into rotating mechanical power for the pump, most windpumps transfer the rotary motion of the blades directly to the pump via a mechanical shaft. Well designed wind machines can convert 25-

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<sup>20/</sup> Conversely, equity and distributional concerns are raised by biogas technology: affluent households have more opportunities to build biogas digesters than poorer people who would be deprived of dung otherwise available to them for conversion to dried fuel.

40% of the power in the wind into rotary power. In remote locations with mean monthly windspeed in excess of 3 m/sec, wind can be the most economic power source for water pumping.

56. Since 1979, significant operating experience with PV pumping has been gained through UNDP and USAID funded projects. Major projects include the Mali Aqua Viva Program, Desert Development in Egypt, Solar Pumping in Botswana, Remote Village Water Supply in India, and the UNDP Pump Test Project. Small PV pumping systems are in place throughout the Carribean, Africa, South and Southeast Asia.

57. In the developing world, wind pumps are produced in Kenya, Ethiopia, Mali, South Africa, India, Pakistan, China, Thailand, Philippines, Peru, Argentina and Brazil. Data on installed windpump capacity has not been gathered on a global scale. Nonetheless, as over 50 known windpump manufacturers were operating globally in 1983 (20 for more than 20 years),<sup>21/</sup> it is evident that the industry serves a significant global market.

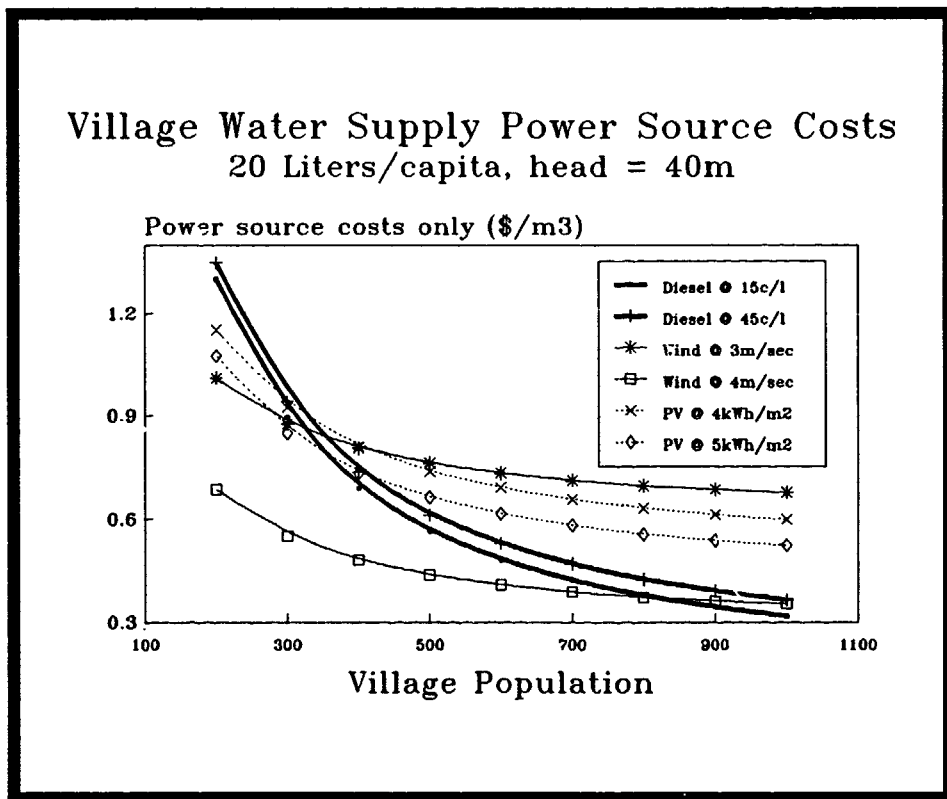


Figure 8 Village Water Supply Costs: PV, Wind & Diesel



58. Both wind and solar electric pumps convert low density power flows into pumped water. Conversely, a diesel pumpset is designed to convert a dense form of potential energy into a relatively large mechanical torque on demand. The smallest diesel engines deliver about 2.5 kW of power at rated load, while many small-scale pumping applications could be satisfied with less than 500 Watts of power, four hours daily. Consequently, in many small village water supply and irrigation applications, diesel pumpsets supply only a fraction of the water they are rated to deliver over their lifetimes. Because of the technical lower limit to diesel pumpset size, photovoltaic and windpumping technologies carve out an economically competitive niche in small scale mechanized water supply.

59. Figure 8 shows representative village water supply costs at 40m head provided by diesel, photovoltaic, and wind energy sources.<sup>22/</sup> Because fuel accounts for only 5-20% of total water costs, the diesel cost curves are largely insensitive to fuel price changes. In comparison to PV pumpsets and windpumps, the hypothetical 67% drop in diesel fuel price from 45¢ to 15¢/liter makes diesel pumping economically competitive with PV and wind at 12% and 21% smaller village populations.

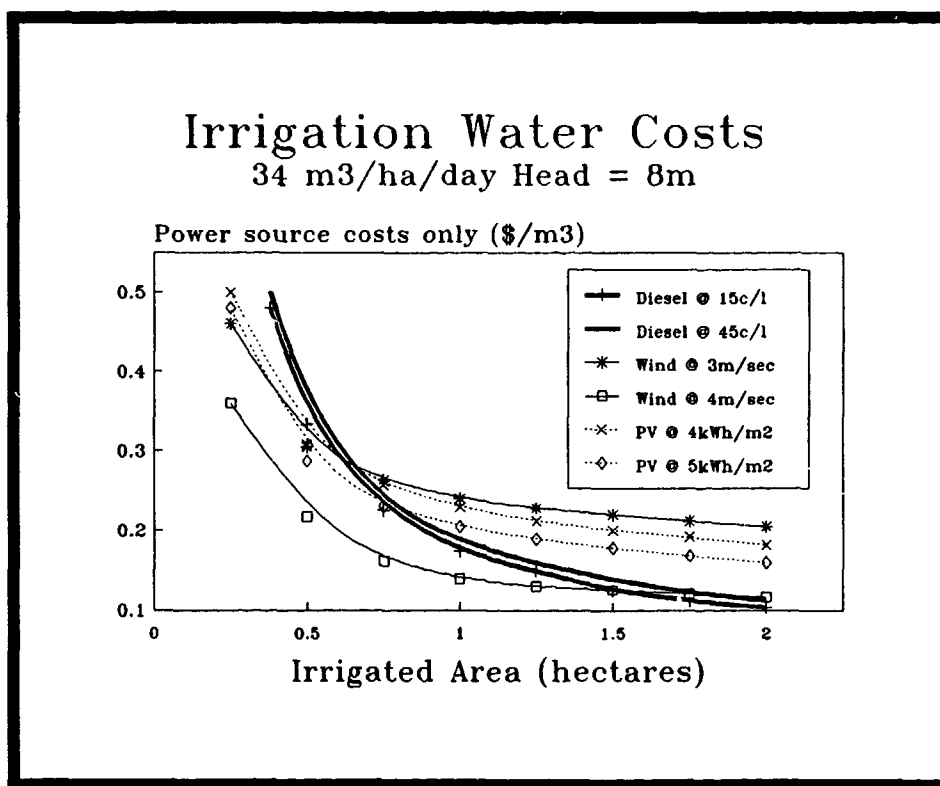


Figure 9 Irrigation Water Supply Cost: PV, Wind & Diesel

<sup>22/</sup>

Water cost curves generated by the World Bank Handpump Model, Urban Water Supply Department. Water costs include annualized costs of each pumpset, the well, and storage. Assumptions for village water supply and irrigation models are presented in the Annex.

60. Irrigation water costs at 8m head are shown in Figure 9. As above, a 67% drop in diesel fuel cost would make diesel economically competitive with PV and wind at 6% and 16% smaller irrigated plots. Clearly, the economic tradeoff between power sources for either water pumping application is not significantly changed by a large drop in oil prices.

61. In actuality, the landed cost of diesel fuel in remote regions where these technologies are cost effective has not changed nearly as much as international prices because of significant overland transport costs.<sup>23/</sup> In addition, the operators of village water supply systems or small pumps for irrigation often face retail fuel prices well above economic prices due to lack of regulation in outlying areas.<sup>24/</sup> For these reasons, the actual impact of lower international oil prices on village water supply has been far less than the extreme case assumed above of a 67% price drop for diesel fuel.

62. Moreover, the final choice of pumping system is commonly based on more than just annual water costs. Other factors such as reliability, fuel availability, and ease of maintenance can rank as important as water costs. In areas where the supply of diesel fuel may be erratic or spare parts and skilled mechanics are scarce, photovoltaic and wind power systems may be the most reliable power sources. However, the need for financing can be significantly greater for PV and wind pumps. Hence, access to credit can become a major issue in the tradeoff between diesel and renewable technologies for water pumping.

63. In sum, the impact of lower diesel fuel prices on the viability of PV and wind power for water pumping is relatively small because:

- a. fuel costs constitute only a fraction of annualized water costs for small diesel pumpsets, and so, a large fuel price decrease results in only a small drop in annual water cost for diesel pumped water;
- b. large price decreases have not occurred in remote areas because falling import costs constitute a small part of the final diesel fuel price when long overland transport is required, and;
- c. other factors such as reliability, maintenance requirements, and access to credit can become as important as annualized water cost in the final decision between diesel, wind, and solar powered water pumping.

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<sup>23/</sup> Recent Bank reports cite a transportation margin on diesel fuel of up to 18¢/liter for a 1500 km overland haul in Zaire and transport costs of 10¢/liter for 1120 km overland transport in Uganda. This indicates an average overland transportation cost of roughly 10¢/tonne-km.

<sup>24/</sup> Retail prices of small quantity purchases is often uncontrolled in remote regions. For example, the official retail price of kerosene was 50¢/liter below the actual market price in Kano City, Nigeria in 1980 [Fishwick, 1981].

### III. CONCLUSIONS

#### Factors Influencing the Effect of Lower Oil Prices on RETs

64. The analyses presented in Chapter 2 indicate that, in general and with the discount rate used in Bank studies, the economic sensitivity of renewable energy technologies to lower international oil prices can be a function of scale and location. Though lower oil prices reduce the economic viability of renewable energy technologies, high transport costs and diseconomies of small scale conventional alternatives make renewable technologies the most economic choice in some locations.

65. **Scale:** Fuel costs generally comprise a larger percentage of total annualized system costs for large-scale petroleum-based conventional energy technologies than for small-scale applications. Hence, a marked decrease in fuel oil and diesel fuel prices reduces large-scale conventional energy costs significantly, while barely changing the total costs of smaller conventional energy technologies. Because of this, renewable energy technologies that compete directly in the modern sector as large-scale petroleum substitutes are most adversely affected by falling oil prices.

66. A concrete illustration of this general result can be seen in Table 1 and Figure 8. In Table 1, a 50% drop in fuel oil price (from 20 ¢/l to 10 ¢/l) would reduce the cost of electricity generated by a 10 MW diesel by over 30%. In Figure 8, a 67% drop in diesel fuel price (from 45 ¢/l to 15 ¢/l) would reduce the cost of water, pumped by a 2.5 kW diesel for a village of 500, by less than 10%.

67. **Location:** RETs that are large-scale petroleum substitutes tend to be located close to urban areas, while the smaller, stand-alone technologies are often used in rural and remote applications. The economic prices of petroleum fuels generally increase with distance from major urban areas because of transportation and distribution costs. Likewise, the economic prices of biomass fuels generally decrease with distance from major urban areas due to increasing availability in rural areas. For these reasons, the economic viability of rural and remote RET applications is affected less by falling international oil prices than large-scale, petroleum substitution RETs located near urban areas.

68. Two additional attributes of location serve to insulate the economics of small-scale, rural RET applications from the fall in oil prices. First, as shown in Figures 1 and 2, the regulated financial prices of diesel fuel and fuel oil have not been reduced nearly as much as the drop in international FOB oil product prices. It has been noted that retail prices of small quantity conventional fuel purchases is often uncontrolled in remote regions. Hence, operators of small-scale rural energy applications can face financial fuel prices well above regulated prices and far above economic fuel costs. Second, a reliable supply of conventional fuels is much more common in and near cities than in remote regions. Even though the economic analysis may show a particular RET to be slightly more expensive than a conventional power source, an intermittent conventional fuel supply could well be enough to make the renewable application the appropriate choice.

**TECHNICAL ANNEX**

<b>Fuel Alcohol Base Case Assumptions</b> .....	<b>27</b>
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SELECTED PETROLEUM PRODUCT PRICE CHANGES: 1985 - 1986

ASIA

FUELS e/	UNIT	BANGLADESH b/				PAKISTAN c/				INDIA d/				INDONESIA e/				PHILIPPINES f/			
		(July 86)		(1985)		(July 86)		(July 85)		(1986)		(1985)		(July 86)		(Nov 85)		(June 86)		(Jan 86)	
		Tk	US c	Tk	US c	PRs	US c	PRs	US c	Rs	US c	Rs	US c	Rp	US c	Rp	US c	P	US c	P	US c
Gasoline Premium	liter	12.88	42.51	14.67	53.35	6.95	41.00	7.15	44.69	7.43	57.20	7.00	56.70	440	38.90	440	39.18	6.90	33.67	7.40	38.74
Gasoline Regular	liter													385	34.04	385	34.28	6.53	31.85	7.03	36.81
Kerosene	liter	6.71	22.15	7.22	26.25	3.00	17.80	3.30	20.63	2.25	17.30	2.11	17.10	165	14.59	165	14.69	4.86	23.71	5.76	30.16
LPG	kg	9.08	29.97	8.40	30.55					4.06	31.20	3.62	29.30					7.44	36.29	9.74	50.99
Motor diesel	liter	6.71	22.15	7.22	26.25	3.85	22.90	4.25	26.56	3.50	26.90	3.39	27.40	200	17.68	242	21.55	4.76	23.22	5.72	29.95
Industrial diesel	liter													200	17.68	220	19.59				
Fuel Oil	liter	4.70	15.51	5.46	19.85	1.55	9.20	1.62	10.09					200	17.68	220	19.59	2.82	13.76	4.12	21.57
NATURAL GAS																					
Domestic mcf		44.88	148.12	40.80	148.36	18.09	107.55	18.00	112.50												

AFRICA

FUELS	UNITS	ZAIRE g/				KENYA h/				TANZANIA i/				SWAZILAND j/			
		(Aug 86)		(Jan 86)		(July 86)		(Nov 85)		(July 86)		(Oct 85)		(July 86)		(Nov 85)	
		Z	US c	Z	US c	K Sh	US c	K Sh	US c	T Sh	US c	T Sh	US c	Sw c	US c	Sw c	US c
Gasoline Premium	liter	32.0	54.47	33.0	59.89					30.65	72.98	19.65	115.59	73.0	33.18	99.0	37.67
Gasoline Regular	liter									25.40	60.48	16.55	97.35	65.0	29.55	95.0	35.19
Kerosene	liter	23.0	39.15	25.4	46.10	3.47	21.68	4.72	28.61	11.45	27.26	7.50	44.12	59.0	26.82	81.0	30.00
LPG	kg	69.0	117.45	71.0	128.86	5.89	36.81	7.38	44.73	15.11	35.98	10.15	59.71			155.3	57.52
Motor diesel	liter	26.0	44.26	28.0	50.82	5.00	31.25	5.78	35.03	14.10	33.57	8.55	50.29	61.0	27.73	83.0	30.74
Industrial diesel	liter					1.88	11.75	2.27	13.76	11.82	28.14	7.45	43.82	58.0	26.36	86.0	31.85
Fuel Oil	liter	15.0	25.53	18.0	32.67	1.51	9.44	1.95	11.82	8.60	20.48	5.49	32.29				

LATIN AMERICA

FUELS	UNITS	HAITI k/				COSTA RICA l/				BRAZIL m/				BELIZE n/				ECUADOR o/			
		(Aug 86)		(Sept 85)		(Aug 86)		(Nov 85)		(May 86)		(Oct 85)		(Apr 86)		(1985)		(July 86)		(July 85)	
		G	US c	G	US c	C	US c	C	US c	Cr\$	US c	Cr\$	US c	BZ\$	US c	BZ\$	US c	S/.	US c	S/.	US c
Gasoline Premium	liter	2.52	50.4	2.97	59.4	24.00	42.63	24.00	45.45	4.65	33.60	2.26	26.40	0.89	44.30	0.98	49.20	17.28	15.85	17.00	25.30
Gasoline Regular	liter													0.86	43.10	0.96	47.80	13.25	12.15	13.20	19.70
Kerosene	liter	1.80	36.0	2.35	47.0	17.00	30.20	17.00	32.20					0.51	25.70	0.61	30.70	3.74	3.43	3.55	5.30
LPG	kg																	10.67	9.78	10.33	15.40
Motor diesel	liter	2.05	41.0	2.97	59.4	19.00	33.75	19.00	35.98	3.02	21.82	1.58	18.46	0.70	34.80	0.76	37.80	10.65	9.77	10.40	15.50
Industrial diesel	liter																				
Fuel Oil	liter					6.00	10.66	6.00	11.36	1.52	10.97	0.78	9.12					7.49	6.87	6.60	9.80

NOTES TO TABLE

- 1/ **SOURCE:** Petroleum product prices are quoted in local currency and are converted to US\$ at prevailing market exchange rates as noted. In countries where no distinction is made between grades of gasoline or grades of diesel oil, prices for these products are listed as premium gasoline and motor diesel. For further product specification, such as gasoil in Africa, see notes for each country.
- 2/ **SOURCE:** All prices from de Lucia and Associates, converted at Tk30.3 = \$1 (July '86) and Tk27.5 = \$1 (1985). Fuel oil price is ex-depot.
- 3/ **SOURCE:** All petroleum prices from de Lucia and Associates. Fuel oil price = Rs 1650/mt, assumed 6.7 bbl/mt. Prices converted to \$US at Rs 16.82 = \$1 (July '86) and Rs 16 = \$1 (July '85). Natural gas prices, from EGYD1, World Bank, are for the first 7 mcf/month consumed at domestic rates.
- 4/ **SOURCE:** All prices from de Lucia and Associates, converted to \$US at Rs 13 = \$1 (1986) and Rs 12.35 = \$1 (1985).
- 5/ **SOURCE:** World Bank Staff Appraisal Report #5942-IND, 11 April 1986 and World Bank Economic Memorandum #6201-IND, 20 May 1986. Petroleum product prices remained unchanged between 1 April 1985 and March 1986. These prices are reported as November 1985 prices and are converted to \$US at 1123 Rp = \$1. July 1986 prices announced by the Department of Mine and Energy, Indonesia on 9 July 1986, were converted at 1131 Rp = \$1.
- 6/ **SOURCE:** All prices from official Government price change announcements obtained from East Asia and Pacific Country Programs Department, Philippines Division, World Bank and EGYD1, World Bank. Fuel oil price is wholesale. January 1986 prices are pre-election price reductions. Average product prices before the price change of 25 January were 60 Centavos/liter higher. January 1986 prices converted to \$US at 19.1P = \$1; June 1986 prices at 2.05 P = \$1.
- 7/ **SOURCE:** Eastern and Southern Africa, Country Programs Department, South Central Division, World Bank. All prices are Reference Prices (without distribution margin) in Kinshasa and are, therefore, retail prices in Kinshasa. Diesel prices are for "gasoil" in Zaire. January 1986 prices converted to \$US at 55.1 = \$1; August 1986 prices at 58.75 Z = \$1.
- 8/ **SOURCE:** 1985 prices from Kenya Solar Water Heating Project Green Cover, March 1986, World Bank. July 1986 prices were announced in the June 1986 Budget, Government of Kenya. Diesel fuel prices for "gasoil" in Kenya. Industrial diesel prices are for 2500 sec fuel oil and fuel oil prices are for 1000 sec fuel oil. November 1985 prices converted to \$US at 16.5 Ksh = \$1; July 1986 prices at 16 Ksh = \$1.

9/ **SOURCE:** Official announcement October 3, 1984 and Budget statement June 1986, Government of Tanzania. Official prices announced on October 3, 1984 were unchanged as of April 1986 for gasoline, kerosene and diesel. Hence, it is assumed that no significant retail price changes occurred between October 1984 and April 1986. 1985 prices converted to \$US at \$17 TSH = \$1 (Oct. '85 Avg); July 1986 prices at 42 Tsh = \$1. Prices quoted for diesel are for "diesel gas oil" in Tanzania. 1985 LPG and heavy fuel oil prices are wholesale.

10/ **SOURCE:** 1985 prices from Swaziland Energy Assessment, Yellow Cover, World Bank. July 1986 prices from personal communication with USAID regional economist for Southern Africa. Prices quoted for diesel are for "bus rate" diesel fuel as almost all diesel pumps in the country are set at the bus rate. Industrial diesel 1985 price is for "mid-duty" diesel fuel. November 1985 prices converted to \$US at 2.7E = \$1; July 1986 prices at 2.2 E = \$1.

11/ **SOURCE:** September 1985 prices from Latin America and the Caribbean, Country Programs Department, World Bank. August 1986 prices from Shell Oil, Haiti (new prices effective May 1986). Diesel prices are for "gasoil" in Haiti. All prices converted at G5 = \$1.

12/ **SOURCE:** August 1986 prices have not changed (in nominal colones/liter) since 1983, as per SDE Costa Rica. August 1986 prices converted to \$US at 56.3 CRC = \$1; November 1985 prices at CRC 52.8 = \$1.

13 **SOURCE:** Central Bank of Brazil, July 1986 Bulletin. Prices in Cr\$/liter for gasoline and diesel oil, and Cr\$/kg for fuel oil, assumed to be residual with density of .94 kg/l. October 1985 prices converted to \$US at 8.56 Cr\$ = \$1; May 1986 at 13.84 Cr\$ = \$1. A price freeze on petroleum products has been in effect since early 1986, but a new 28% tax has been imposed on gasoline on 25 July 1986. This tax is not reflected in the table.

14/ **SOURCE:** All prices from de Lucia and Associates, converted to \$US at 2B\$ = \$1 for each period.

15/ **SOURCE:** July 1985 local prices from Table 2.2, Ecuador Energy Assessment, December 1985, World Bank. 22 July 1986 local prices quoted in Office memorandum of 31 July 1986 of EGYD2, World Bank. Local prices converted to \$US at official rates for July 1985: 67.175 SUCRES = \$1; and July 1986 = 109 SUCRES = \$1 (before devaluation).

### Fuel Alcohol Base Case Assumptions

69. Assumptions and results of the base case analysis for the Mhlume project include:

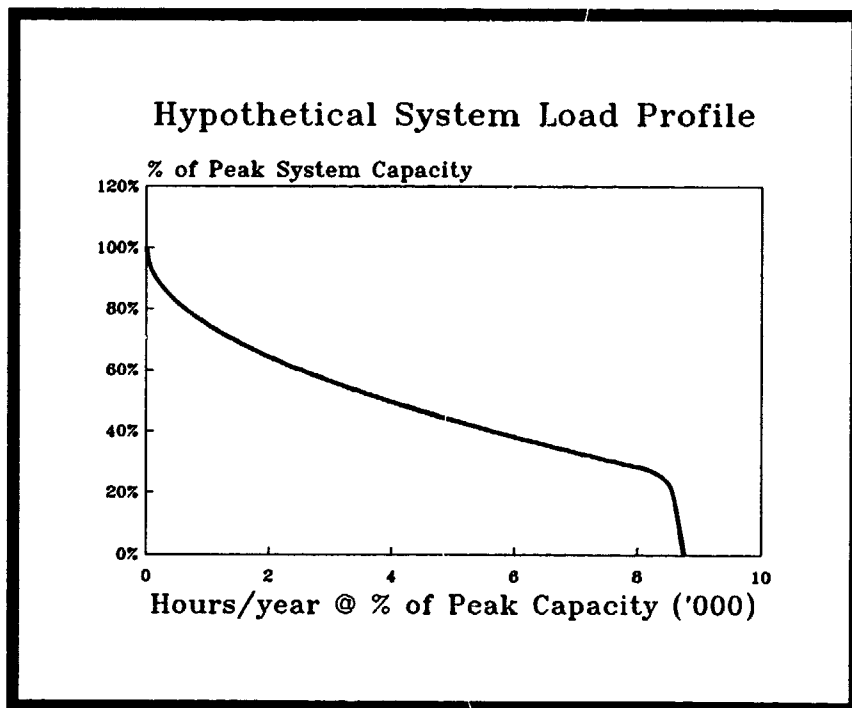
	Original (May 1985)	Revised (July 1986)
Discount Rate	10%	
Interest Rate	12%	
Exchange Rate	E2.1 = US\$ 1	
Plant Size (liters/day)	65,000	
Average Production ('000 liters/yr)	11,938	
Operation (days/year)	250	
Plant Life (years)	20	
Salvage Value	10%	
Recovery (liters alcohol/mt molasses)	250	
Molasses Ex-mill price (US\$ /mt)	24	
Capital Cost (US\$ million)	6.38	
Amortized Capital Cost (¢/liter/year)	7.16	
Variable and Fixed Costs (excluding debt service) (¢/liter)	12.68	
Economic Cost, Mhlume (¢/liter)	19.84	
Transport to Matsapha (¢/liter)	0.85	
Ethanol Cost Matsapha (¢/liter)	20.69	20.69
Gasoline Import Parity 93 RON Matsapha (¢/l)	28.09	21.81
Difference Between Gasoline Import Parity and Economic Production Costs (¢/liter)	7.40	1.12
Savings on Fuel Oil and SFF Levies (¢/liter)	1.69	1.69
Total Economic Cost Differential (¢/liter)	9.09	2.81
Economic Rate of Return	28.5%	18.0%



### Wind Electricity Generation

70. The wind generation costs quoted in Figure 3 are representative annualized costs derived from actual 1986 installed costs of 100 kW turbines in California wind farms, estimated O&M costs, and annual energy production at  $\approx 25\%$  capacity factor.<sup>25/</sup>

71. The oil-based electricity generation costs shown in Figure 3 were derived by finding the least cost generation mix, of large fuel oil steam base load plants and diesel oil gas turbine peaking plants, to meet a hypothetical load duration curve at representative 1985 fuel oil and diesel import prices (shown below) and at fractions of those prices. As fuel prices can change much more quickly than actual generation capacity, **this least cost generation mix will represent a lower bound to actual oil-based generation costs for any given utility.**



#### Thermal Plant Cost Assumptions

	400 MW Fuel Oil Steam	50 MW Diesel Oil Gas Turbine
<b>Capital Cost</b>		
including Reserve (\$/kW)	1,100	450
Annual O&M (% of Cap)	2.5%	3%
Lifetime (yrs)	25	15
Annual cost @ 10% (\$/kW)	148.50	72.50
<b>Fuel Price</b>	US\$ 30/bbl (20 ¢/l)	30 ¢/l
Thermal Efficiency	36%	28%
Fuel Cost (¢/kWh)	4.7 ¢/kWh	10.9¢/kWh

<sup>25/</sup> "Study of the Potential for Wind Turbines in Developing Countries", Phase I Draft Report, for USDOE and the World Bank by Strategies Unlimited, December 1986.

**Biomass Gasifiers****Heat Gasifiers**

72. A recent Earthscan study<sup>26/</sup> estimated the capital costs of heat gasifiers to vary from US\$ 15,000 to US\$ 35,000 per GJ/hr of rated boiler output. The higher end of the range represents highly mechanized systems while the lower end represents manually operated systems. The principle economic assumptions and results of this study are tabulated below.

Capital Cost (\$/GJ/hr)	15,000	25,000	35,000
Lifetime (years)	12	12	12
Discount Rate 10% (CRF=.147)	10%	10%	10%
Annualized Cap Cost (\$/GJ/hr)	2,205	3,675	5,145
O&M (\$/yr)	1,500	2,500	3,500
Fixed Costs (\$/GJ)	1.85	2.85	3.95
Woodfuel Cost (\$/mt)	20	20	20
Energy Content (GJ/mt)	15	15	15
Conversion Efficiency	65%	65%	65%
Woodfuel Cost (\$/GJ)	2.05	2.05	2.05
<hr/>			
<b>Total Costs (\$/GJ)</b>	<b>3.9</b>	<b>4.9</b>	<b>6.0</b>

73. By way of comparison, the conversion efficiency in a conventional fuel oil boiler is approximately 85% and the energy content of fuel oil is 37.6 MJ/l. At 20¢/liter (US\$ 31.75/bbl) the energy cost of fuel oil steam is roughly US\$ 6.26/GJ. As the case presented in Figure 4 is for a heat gasifier retrofit to an existing fuel oil boiler, the total costs of the retrofit gasifier are compared to the energy costs of the fuel oil boiler over a range of fuel oil prices.

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<sup>26/</sup>

**Power Gasifiers**

74. In the IENHE analysis, estimates of installed cost, plant life, annual power output, efficiency, and O&M cost vary by technology and plant size. Some representative installed cost and plant life assumptions in the baseline comparison are tabulated below. The discount rate, fuel costs, and load characteristic under which these technologies are compared is also specified.

	Installed Cost (\$/kW)		Lifetime (years)	
	50kW	500kW	50kW	500kW
High speed diesel	585	553	6	8
Charcoal gasifier	910	-	5	-
Wood gasifier (manual)	1300	-	5	-
Wood gasifier (automatic)	-	2135	-	6
Discount rate	10%			
High speed diesel fuel costs (¢/l)	40			
Charcoal costs (\$/mt)	80			
Wood fuel costs (\$/mt)	20			
Hi speed diesel energy content (MJ/l)	36			
Charcoal energy content (MJ/kg)	29			
Wood energy content (MJ/kg)	14			
Moisture content (w.b.) wood	30%			
Load characteristic:	30 % of time: 80 % of rated load			
	70 % of time: 30 % of rated load			

### Solar Water Heating

75. A recent ESMAP study of the Potential for Solar Water Heating in Kenya provides a unique case study on the impact of lower oil prices on the economic and financial viability of solar water heating (SWH) applications. The study originally assessed SWH systems using October, 1985 fuel prices and was revised using August 1986 prices. Between October 1985 and August 1986, petroleum product border prices in Kenya declined on average 32% and nominal retail prices were reduced on average 20%.<sup>27/</sup> Economic and retail fuel prices as of October 1985 (used in original study) and August 1986 (used in revision) are presented in Table A1.

TABLE A1

FUEL	ECONOMIC	ECONOMIC	RETAIL	RETAIL
	PRICE 85	PRICE 86	PRICE 85	PRICE 86
	\$US/TOE	\$US/TOE	\$US/TOE	\$US/TOE
Gas Oil	260	140	405	363
Fuel Oil 1000 sec	120	81	144	108
2500 sec	143	107	167	134
LPG	321	276	410	347
Kerosene	321	193	320	240
Charcoal	151*	161*	151	161
Wood	46*	48*	46	48
Electricity	222	178		
Residential A			251	267
Residential D			145	154
Commercial			166	176
Industrial			142	151

\* Retail prices assumed as economic prices.  
1985 prices @ 17 KSH - \$US1; 1986 prices @ 16 KSH - \$US1.

76. The technical performance of optimal solar water heating systems was simulated in forty five sites. The average installed system cost was determined to be US\$ 126/m<sup>2</sup> while the simpler systems used in industrial applications averaged US\$ 103/m<sup>2</sup> of collector area. A sample of the original and revised economic evaluations are summarized in Table A2. The financial net present worth of each installation in the revised analysis is presented as an indication of the impact of lower retail oil prices on the viability of SWH systems from the consumer's perspective. In the original report (1985), all applications had a positive net present worth.

<sup>27/</sup> Real petroleum product retail price reductions averaged 21%. These prices are peculiar to Kenya and the following summary is not intended as a general model of the impact of lower oil prices on the economic viability of solar water heating.

Table A2

APPLICATION	DISPLACED FUEL	ERR 1985	ERR 1986	NPW @	
				r=.25	i=.13
Mt. Kenya Safari Club	Fuel Oil	18	9	-3763	
Nyali Beach Hotel	Fuel Oil	21	11	-5240	
Diplomat Cafe	Electricity	>60	44	3255	
Kenya Brewery	Fuel Oil	15	<5	-15471	
Elliot's Bakery	Gas Oil	>60	23	80216	
Dandora Creamery	Fuel Oil	23	10	-4404	
Health Center	Electricity	>60	30	6567	
Health Center	Kerosene	>60	>60	46172	
University Dormitory	Gasoil	45	14	311184	
Rural Dormitory	Wood	<15	<5	-2331	
Residential	Electricity	>60	30		
Tariff A					854
Tariff D					290

77. In general, the applications which displace kerosene, electricity, and (marginally) gasoil still appear favorable using revised 1986 fuel prices. Due to the extremely low prices of both fuel oil and wood, SWH applications that displace these fuels do not appear to be cost effective. Table A2 shows that the economic rate of return for most applications displacing petroleum products has dropped to less than 50% of the rate of return calculated at 1985 oil border prices. This significant reduction in economic viability is due solely to the 32% (on average) drop in petroleum products border prices.

78. From the consumer's perspective, the financial viability of the sample applications is indicated by the NPW column in Table A2.<sup>28/</sup> Installations with a negative net present worth are not financially viable under the assumptions used. The NPW for the proposed Mt. Kenya Safari Club installation under 1985 retail prices of fuel oil (fuel saved) and electricity (pumping costs) was US\$ 420. This compares with a NPW of -US\$ 3763 using 1986 retail prices. The difference between these two indices of financial viability is due solely to the 25% drop in the retail price of fuel oil.

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28/

The NPW was calculated at discount rate of 25%, for systems financed @ 13% interest over 10 years, assuming no increase in fuel prices, 25% duty on imported parts and no sales tax on solar equipment. A 20% premium on foreign exchange was used throughout the analysis.

## Water Pumping Model Assumptions

### Village Water Supply

79. Each system is sized to provide 20 liters of water/capita/day. This represents a minimal health standard daily water requirement.

### Irrigation

80. Systems are sized to pump peak daily water demand  $Q_{max} = 1.76 \times Q$  and  $Q = 34 \text{ m}^3$  daily average per hectare. This peak ratio is derived from Kenyan irrigation practices as described in Small-Scale Solar-Powered Pumping Systems: The Technology, Its Economics and Advancement, UNDP/World Bank, June, 1983. Irrigation water costs include only the costs of the pumpset and well.

### All Systems

81. In water lifting applications, the daily hydraulic demand is measured by the volume-head product:  $m^4 = \text{daily water demand}(m^3) \times \text{lift}(m)$ . Since the size and cost of a pumping system is directly related to the hydraulic demand it is designed to serve, water costs are commonly compared over a range of hydraulic demands to determine where economic tradeoffs occur. The computed water costs include annualized power source capital cost, fuel, O&M, and the costs of storage and wells.

82. Pumping systems are sized for a solar resource of  $5\text{kWh}/m^2/\text{day}$  and winds of  $4\text{m}/\text{sec}$  during the critical demand month. These assumptions represent a normal solar regime for equatorial countries and a good wind resource.

Discount rate	10%
Period of analysis	20 years
Fuel inflation	0%
Useful life	
mechanical equipment	10 years
non-mechanical equipment	20 years
Maintenance costs	
mechanical equipment	10% of capital costs
non-mechanical equipment	1% of capital costs
Diesel efficiency	7.5% fuel to hydraulic energy

Total Dynamic Head TDH = Lift + 10m friction and pumping to storage  
 Pumped volume  $Q$  ( $\text{m}^3/\text{day}$ ) = Population  $\times$  20 liters/capita/day/1000

Diesel system costs

Installed engine cost \$3000 for 2.5 kW engine  
 Pump cost (\$) =  $275 + 25(\text{TDH}) + 75Q/4$ , but at least \$750

Solar system costs

Installed array cost \$12/Wp  
 Pump cost (\$) =  $275 + 25(\text{TDH}) + 75Q/4$ , but at least \$750

Wind system costs

Installed system cost \$500/ $\text{m}^2$  swept area of rotor

Well cost  $2000(Q)^{1/4}$ , or \$2000 for  $Q < 16$ .

Storage cost  $1000(Q \cdot 0.3)^{1/4}$

**Renewable technology system sizing**

Array size in peak watts:  $W_p = Z \times Q \times \text{TDH} \times \text{PEAK}$

Swept area of windmill rotor in  $\text{m}^2 = 1.13Q \times \text{TDH} \times \text{PEAK} / v^3$

$v$  = design month mean windspeed (m/sec)

PEAK =  $Q_{\text{max}}/Q$

$Q_{\text{max}}$  = peak daily demand during design month

$Z$  = sizing factor from table below.

**SIZING FACTOR (Z)**

PUMP EFF	Design Month Daily Insolation		
	4kWh/ $\text{m}^2$	5kWh/ $\text{m}^2$	6kWh/ $\text{m}^2$
40%	1.97	1.61	1.33
50%	1.60	1.30	1.08
60%	1.28	1.04	0.87

Source: IT Power, Solar Powered Pumping Systems: Their Performance, Cost and Economics, July 1986.

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