PN-AAV-347
45920

ECONOMIC VIABILITY OF PHOTOVOLTAIC POWER FOR DEVELOPMENT ASSISTANCE APPLICATIONS

WILLIAM J. BIFANO

NASA Lewis Research Center
Cleveland, Ohio

October, 1982

Prepared for
Sixteenth Photovoltaic Specialists Conference
sponsored by the Institute of Electrical and Electronics Engineers
San Diego, California, September 27-28, 1982

E-1426

ECONOMIC VIABILITY OF PHOTOVOLTAIC POWER FOR DEVELOPMENT ASSISTANCE APPLICATIONS

William J. Bifano

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

This paper briefly discusses the development assistance market and examines a number of specific PV development assistance field tests including water pumping/grain grinding (Tangaye, Upper Volta), vaccine refrigerators slated for deployment in 24 countries, rural medical centers to be installed in Ecuador, Guyana, Kenya and Zimbabwe, and remote earth stations to be deployed in the near future. A comparison of levelized energy cost for diesel generators and PV systems covering a range of annual energy consumptions is also included. The analysis does not consider potential societal, environmental or political benefits associated with PV power.

PV systems are shown to be competitive with diesel generators based on life cycle cost considerations, assuming a system price of $20/W(peak), for applications having an annual energy demand of up to 6000 kilowatt-hours per year.

INTRODUCTION

The Agency for International Development (AID) is sponsoring a program, managed by the NASA Lewis Research Center (LeRC), involving the investigation of photovoltaic (PV) power systems for development assistance applications in rural areas of the Third World. Through a series of competitive, cost-shared contracts with U.S. industry, PV systems are being designed, fabricated and installed at remote sites in developing countries for one to two year field tests. The primary objective of this activity is to determine the economic viability of these systems relative to alternative forms of remote site power. While fulfilling AIDs mandate to investigate small-scale renewable energy systems for selected rural development applications, the project also serves to increase the international awareness of PV technology and promote exports of American-made products.

This paper briefly discusses the development assistance market, identifies potential user agencies and organizations, and examines the present and planned AID-sponsored PV applications in terms of first cost. Also included is a comparison of levelized energy cost for diesel generators and PV systems covering a range of energy consumption. The sensitivity of energy cost to fuel escalation rate and discount rate is also examined.

THE DEVELOPMENT ASSISTANCE MARKET

The development assistance market includes those countries which are beneficiaries of official development assistance from the developed world and concessionary funds from development banks. Reference 1 categorizes the nature of the transfer of funds to developing countries as 1) Official Development Assistance: grants and loans which are at less than fair interest rates, and public sector (government) transfers for foreign assistance; 2) Non-concessional transfers: export credits, private investments, and loans from bilateral or multilateral institutions at fair market rates; 3) International bank lending: non-concessionary loans at fair world market rates (special case), and private sector commercial transfers (bank lending); and 4) Private Sector Grants: primarily grants from religious and philanthropic organizations. Official Development Assistance (ODA) consists of government grants and loans, usually referred to as foreign aid. The U.S. bilateral ODA has three distinct elements: 1) Agency for International Development (AID), 2) Security Assistance Programs (Military Aid) and 3) Food Program (PL-480).

AIDs development assistance expenditures in energy have grown from a level of $18 million in FY 1978 to $49 million in FY 1981. For FY 82, obligations of about $72 million are projected, of which $34 million are earmarked for renewable energy projects (excluding firewood). An additional $30 million in energy projects are covered by the Economic Support Fund. AIDs support of PV technology has been primarily through the centrally-funded PV Development and Support Project for which $3.4 million was authorized over the period 1979 to the present. The PV activities under the Tunisia Renewable Energy Project funded by the Near-East Bureau account for an additional $1 million. Although future central-funding of PV is uncertain, a number of regionally-funded renewable energy projects have the potential for significant levels of funding for PV systems.

Private sector donors, referred to as Private and Voluntary Organizations (PVOs) are

2

nonprofit, tax-exempt institutions engaged in foreign assistance activities such as relief, refugee aid, disaster assistance and development assistance. There are an estimated 400 to 500 U.S. PVOs involved in some form of assistance to developing countries. Typically, PVOs engage in small-scale projects, work directly with aid recipients, and are innovative in approach. Given the current interest in small-scale, renewable energy technologies, PVOs would appear to represent major potential purchasers of PV systems for development assistance applications.

DEVELOPMENT ASSISTANCE APPLICATIONS

Small-scale rural energy applications of primary interest to developing countries include health delivery (medical refrigerators), education (lighting, ETV), communication (VHF and microwave repeaters, 2-way radio, remote earth stations), water pumping (potable, livestock, irrigation) and food processing. To determine the cost-competitiveness of PV systems relative to other remote power systems, a series of U.S. Government-sponsored demonstrations are being conducted by private industry under typical field operational conditions. Data collected from these tests will be used to determine the economic viability and reliability characteristics of photovoltaic systems. Where possible, similar data from small diesel systems will also be obtained for comparative analyses. Contracts provide for the delivery of complete design packages documenting the PV systems fabricated and deployed.

U.S. Government-Sponsored PV Demonstrations

A summary of ongoing and planned development assistance projects sponsored by U.S. AID and/or the Department of Energy (DOE) and managed by NASA LeRC is presented in Table 1. Application categories cover those mentioned above and test sites, covering 3 continents, span the range from 37 degrees N to 17 degrees S latitude. Aside from the Tangaye, Upper Volta system, implemented by NASA LeRC, these field tests are being, or will be developed and deployed by U.S. industry through competitive contracts. These contracts typically involve design, prototype fabrication and testing, manual preparation, shipping and installation, and one to two years of data gathering, monitoring and reporting. In most cases, cost sharing is involved. Excluding experiment-related costs, system costs range from 23 to $31/W (peak). Balance of system (BOS) costs represent 50 to 70% of the total. Lead-acid batteries (PV type) typically account for 1/3 of the BOS cost. These projects are described briefly below:

Tangaye Village Grain Mill and Water Pump - Under U.S. AID sponsorship, a PV system powering a grain mill and water pump was installed in the West African village of Tangaye, Upper Volta and became operational on March 1, 1979. A total of $110,000 of AID funds were allocated for the technical component of the project. This pioneer project has been very successful in that the first-generation PV system has, to date, been on-line about 98% of the time. Although problems were encountered with the PV modules installed initially due to a design defect, the system has proven to be very reliable and easily operated and maintained by local villagers. The system initially consisted of a 1.8 kW (peak), 120 volt PV array, and 540 ampere-hours of battery storage. The system supplies DC electrical power to a commercial hammer mill and a positive displacement water pump. In May of 1981, the system was refurbished and increased in size from 1.8 to 3.6 kW and an improved hammer mill was installed. Surplus PV modules from the DOE Program were used for the expansion. A cooperative was organized to operate the mill. As of July of 1982, the cooperative had a bank account of $1500 and was grinding an average of 1.2 metric tons of finely ground flour per week. Water consumption averaged 74 m^3 per week during the past dry season. Additional information on the operation of this system is given in Reference 2.

Medical Refrigerators - As part of an activity involving both DOE and AID, PV-powered refrigerators for cold-chain preservation of vaccines will be field tested at 28 sites around the world, eight for DOE in conjunction with the Centers for Disease Control (CDC), and 20 for AID. It is estimated that approximately 30,000 rural health centers in developing countries currently use kerosene-fueled, absorption-type refrigerators for vaccine preservation. However, such units do not meet World Health Organization (WHO) requirements and exhibit a number of operational problems as well. In 1979, NASA LeRC, on behalf of DOE, entered into a joint cost-shared project with CDC to develop PV-powered medical refrigerators which meet the WHO requirements. Initially, prototype refrigerator fabrication, test and evaluation contracts were awarded to the Solar Power Corporation (SPC) and Solavolt International as part of a competitive procurement. Upon successful completion of this activity, a contract was awarded to SPC for the deployment of 19 units. The CDC, DOE and AID shares for this effort are $39,685, $78,788 and $131,579, respectively. A similar contract with Solavolt International for deployment of an additional ten units for AID is in negotiation.

Medical Clinics - Under the AID PV Development and Support Project, PV power systems will be installed at rural health facilities in Ecuador, Guyana, Kenya (two systems), and Zimbabwe in late 1982-early 1983. These sites, representative of similar facilities in other developing countries, stress preventative health care and are staffed by paramedical health officers, interns and/or nurses. The provision of relatively modest amounts of electricity to such facilities is expected to result in a significant improvement in health delivery effectiveness. Characteristic uses of electricity include lighting, refrigeration, sterilizers and 2-way radios. A reimbursable, cost-shared contract was awarded to the Solarex

Corporation to implement this activity. The U.S. Goverment and Solarex shares are $771,310 and $9,684, respectively. In addition, no fee was charged by the contractor.

Remote Villages in Gabon - "Community service" PV packages will be installed in four remote villages in Gabon as part of a cooperative, cost-shared demonstration project between the Government of Gabon and the U.S. DOE. Selected as the test sites are Bougandji, Nyoli, Donguila, and Bolossoville, four remote villages of 1000-1500 population. Energy for four public service applications will be supplied to each village as follows: 1) health - lighting, and ventilation, and medical refrigerator for the dispensary; 2) education - lighting and audio-visual teaching equipment for the school; 3) water supply - water pump, storage and distribution system; and 4) area lighting - outdoor pole light. Standard power packages and loads will be provided to all the villages for each public service application. Contract award is scheduled for February 1983. Systems are scheduled to be operational in November 1983.

Remote Earth Stations - Under the AID Rural Satellite Project managed by the Academy for Educational Development (AED), Washington, D.C., a number of pilot projects will be implemented to demonstrate the economic feasibility of satellite communications for remote areas of developing countries. A key objective of this Project is the development and demonstration of low cost, low power earth stations. In conjunction with this effort, PV power systems will be designed, fabricated and field-tested at one or more remote earth station sites as part of the LeRC-managed PV Development and Support Project. Award of a competitive contract is tentatively planned for April 1983 for development and deployment of the PV power system(s). The procurement of the earth stations is the responsibility of AED.

Utirik Island PV Project - As a result of a request from the President of the Marshall Islands, DOE recently authorized NASA LeRC to implement a cost-shared PV village power project on Utirik Island. The 400 people of Utirik are contributing $100,000 in funds recently appropriated to them by the U.S. Congress under PL 96-126. The U.S. Government share will be a modular PV system being designed and fabricated under an existing NASA LeRC contract with Hughes Aircraft Company. Utirik Island, comprising an area of less than one square mile, and having approximately 46 dwellings and 7 community buildings, will use PV power for lighting of their residences and village roadway, and lighting, fans and refrigerators for some of their community buildings, including a medical dispensary, school, community house and church. System installation is scheduled for September 1983.

Tunisia Renewable Energy Project - Under another cooperative, cost-shared project, in this case between the Government of Tunisia and AID, PV, wind and solar heating units will be installed in the village of Hammam Biadha. The village of Hammam Biadha (population 120) and the surrounding farm area (600 hectares) are situated 130 km southwest of Tunis. The PV portion of the project will consist of the following: 1) a 29 kW, 220 volt, 50 Hz system to serve the domestic, public and commercial sectors of the village, 2) a 1.4 kWp system for a remote farm; and 3) two 1.4 kWp systems to power drip irrigation for a greenhouse and an orchard. A reimbursable, cost-shared contract was awarded to the Solar Power Corporation (SPC) to implement this activity. The U.S. Government and SPC shares are $885,446 and $130,496, respectively. In addition, no fee was charged by the contractor. Operation is scheduled for November 1982.

ENERGY COST CONSIDERATIONS

Energy costs were calculated for PV systems and a small (4 KVA) diesel generator for annual electrical energy consumptions of up to 20,000 kWh per year (See Figure 1). The 4 KVA diesel unit selected was considered representative of the equipment available in the power range of interest. Typical load profiles were used assuming 24 hour continuous operation. Information on diesel generator capital and operating costs was developed on the basis of discussions with manufacturers' representatives. Using this information, life cycle costs of diesel generators were calculated as a function of discount rate and diesel fuel escalation rate. Discount and escalation rates do not include inflation and all costs are in 1982 dollars. A first year diesel fuel cost of $3 per gallon (delivered) and a labor rate for diesel engine maintenance and repair of $10 per hour were assumed.

Methodology

The present value of the life cycle cost for diesel-generated electricity is the sum of the present values of capital cost (C_D), operations and maintenance costs (O&M), and fuel costs (F).

For this analysis, it is assumed that two diesel units are purchased initially (each having a total lifetime of 100,000 hours) and that one additional unit is purchased at the end of 15 years. The diesel capital cost is taken as the sum of the first year capital cost plus the present value of the capital costs incurred after the first year. Using a unit cost of $4600 plus $1600 for fuel tank, shelter, installation, etc., the present value of diesel capital cost C_D is

$$C_D = \$10,800 + \frac{\$4600}{(1 + k)^{15}}$$

where k = real discount rate. For a real discount rate of 15%, C_D = $11,355.

Diesel O&M costs were determined using the maintenance schedule shown in Table 2 assuming a labor rate of $10 per hour. The life cycle cost of O&M can then be taken as

$$O\&M = 0.555\ HG$$

where

H = annual hours of diesel engine operation

$$G = \frac{1+g}{k-g}\left[1 - \left(\frac{1+g}{1+k}\right)^N\right] = \text{Present Value Function}$$

N = system life (assumed to be 20 years)
k = discount rate
g = annual escalation rate (assumed to be 0 for O&M)

Diesel fuel life cycle cost was taken as the product of the first year fuel cost, the annual fuel consumption and the present value function. The annual fuel consumption was based on the specific fuel consumption characteristics provided by the diesel manufacturers. The first year fuel cost is taken to be $3 per gallon (delivered), typical for a remote village in a developing country assuming no subsidies. The levelized energy generation cost for the diesel was then taken as the product of the total life cycle cost (capital, O&M and fuel) and the capital recovery factor $(k/[1-(1+k)^{-N}])$ divided by the annual electrical output.

For the photovoltaic system, the levelized energy cost, neglecting O&M, is the product of the PV capital cost ($/peak watt) and the capital recovery factor divided by the annual energy output. For this study, it was assumed that one peak watt produces 1.6 kWH per year. For completeness, the calculation includes an average annual replacement and maintenance cost of 10 percent of the annual capital cost.

Cost Comparisons

The results of the calculations are shown in Figure 1 based on a real discount rate of 15 percent, an annual real fuel escalation rate of 3 percent and $3 per gallon first year fuel cost (delivered). The photovoltaic system capital cost was taken as $20 per peak watt ($9/watt for PV module) in 1982 and $12 per peak watt ($3/watt for PV module) in 1990. The balance of system (BOS) costs are expected to drop only slightly (from $11 to $9 per peak watt) by 1990 since these costs represent primarily material and labor. Further decreases in BOS costs may be possible with system design innovations, improved storage technology and use of local (indigenous) labor.

It should be noted that in this analysis, the PV system energy generation cost is not a function of load profile. However, in practice, this cost is likely to vary depending on the amount of storage required. Furthermore, some applications may require only simple control systems and little or no energy storage, hence these figures should be taken as indicating trends only. For actual cost comparisons, site specific information (e.g., load profile, insolation) should be used.

As shown in Figure 1, the cost break-even point for photovoltaic systems occurs at 6000 kWH and 12,000 kWH annual energy consumption in 1982 and 1990, respectively.

Figure 2 shows 1982 energy cost as a function of discount rate for PV systems and diesel generators producing 5000 and 10,000 kWH per year. Assuming a 3 percent fuel escalation rate, PV energy cost is less than diesel energy cost for discount rates of 19 percent or less at 5000 kWH per year, while for 10,000 kWH per year, discount rates of about 7 percent or less are required to make PV competitive.

Figure 3 shows energy cost as a function of fuel escalation rate again for diesels at 5000 and 10,000 kWH per year. For the conditions shown, PV is competitive with diesel for 5000 kWH per year even assuming a zero fuel escalation. However, for 10,000 kWH per year, fuel escalation rates well exceeding 10 percent would be required for cost competitiveness, again under the given assumptions.

CONCLUDING REMARKS

Development assistance applications under investigation as part of U.S. Government-sponsored projects range in system size from 0.1 to over 30 kW (peak). Based on life-cycle cost considerations, PV systems of about 4 kW (peak) or less generally appear to be cost-competitive relative to diesel generators today assuming a system price (installed) of $20/watt (peak). However, actual system prices incurred for initial U.S.G. field tests range from $23 to $31/watt (peak). Further reductions in BOS price appear necessary to assure near-term market growth.

REFERENCES

1. J. F. Day III and R. Sacks, "Impact of International Financial Institutions on Markets for Solar Energy Systems," SERI/RR-8228-1, Strategies Unlimited, Mountain View, California, October 1979.

2. J. E. Martz, A. F. Ratajczak and R. DeLombard, "Operational Performance of the Photovoltaic-Powered Grain Mill and Water Pump at Tangaye, Upper Volta," NASA TM-82767, February 1982.

TABLE 1 - U.S. GOVERNMENT-SPONSORED DEVELOPMENT ASSISTANCE APPLICATION FIELD TESTS

APPLICATION	LOCATION	NOMINAL SYSTEM SIZE, kW(PEAK)	OPERATIONAL DATE	ESTIMATED COST, $/W(PEAK) PV MODULE	BOS	TOTAL	SUPPLIER/ IMPLEMENTER
Grain grinding/ water pumping	Tangaye, Upper Volta	3.6[1]	March 1, 1979	18.00[2]	22.00[2]	40.00[2]	NASA-LeRC
Medical refrigerators	16 countries	0.2-0.4	October 1981-October 1982	12.00	13.00	25.00	Solar Power Corporation
Medical refrigerators	10 countries	0.2-0.4	January-March 1983	IN NEGOTIATION			Solavolt International
Medical clinics	5 systems in 4 countries	1.5	December 1982-March 1983	10.00	21.00	31.00	Solarex Corp.
Community service	4 villages in Gabon		November 1983	11.00[3]	25.00[3]	36.00[3]	TBD
- health		0.9					
- education		0.5					
- potable water		2.0					
- area lighting		0.1					
Remote Earth Station	TBD	1.5-3.0	March 1984	TBD	TBD	TBD	TBD
Village Power	Utirik Island, Marshall Islands	8.0	September 1983	10.00[3]	13.00[3]	23.00[3]	Hughes Aircraft Co.
Village Power/ water pumping	Hammam Biahda, Tunisia	33.0	November 1983	11.00	15.00	26.00	Solar Power Corporation

[1] Initially 1.8 kW; refurbished and expanded to 3.6 kW in May 1981.
[2] In 1978 $ with modules rated @ 60° C; all other costs in 1982 $ @ 25°C.
[3] LeRC estimates.

TABLE 2. ESTIMATED MAINTENANCE COSTS FOR 4 KVA DIESEL GENERATOR

Maintenance schedule	Description	Estimated Cost	Cost per Hour of Operation
200 hours	Oil Change, Air Cleaner, Fuel Filter	$22 parts + 1 hour labor	$0.16
500 hours	Valve Adjustment, Injector check	2 days labor (16 hours)	.32
10,000 hours	General Overhaul	$750 for parts and labor	.075
		TOTAL O&M	$0.555

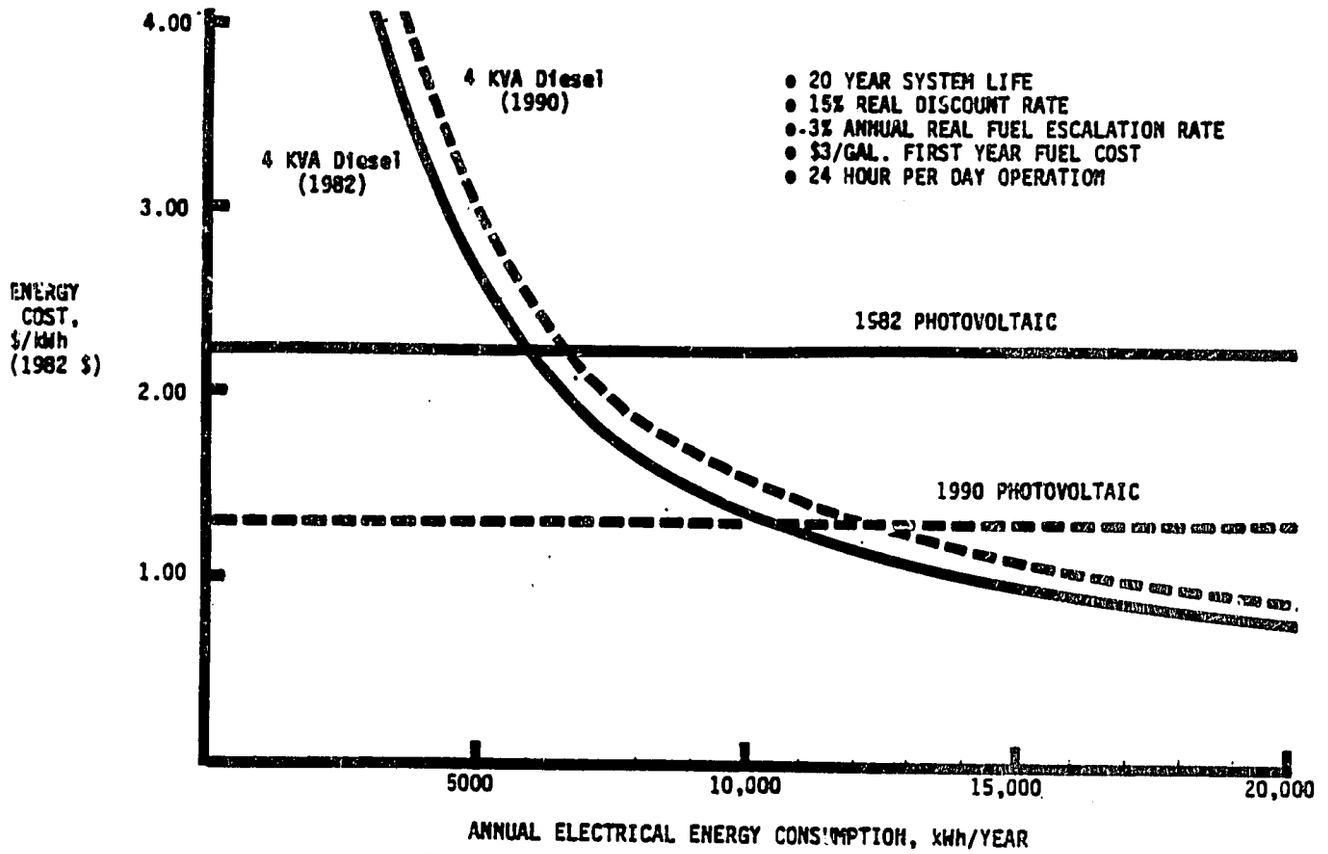

FIG. 1. PHOTOVOLTAIC AND DIESEL ENERGY COST COMPARISONS

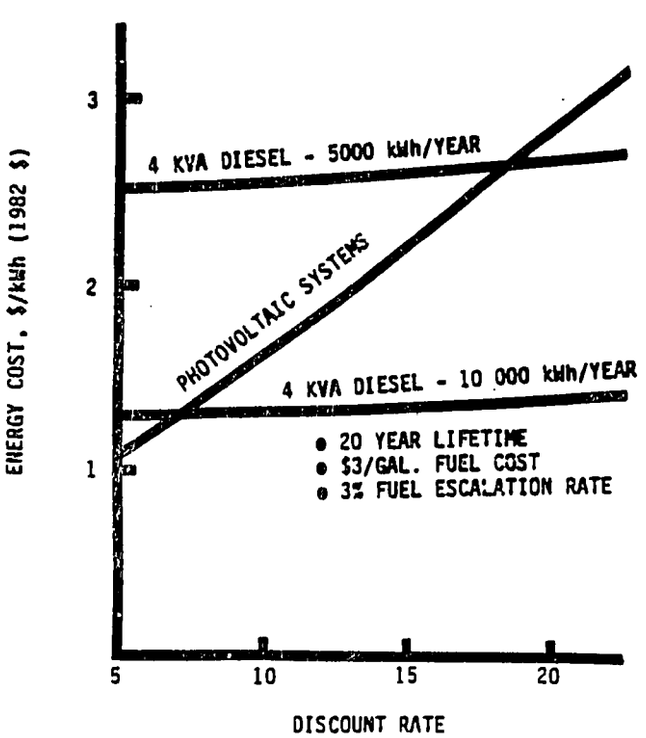

FIG. 2. ENERGY COST AS A FUNCTION OF DISCOUNT RATE FOR 1982 PV SYSTEMS AND DIESEL GENERATORS AT 5000 AND 10,000 kWh/YEAR OUTPUT

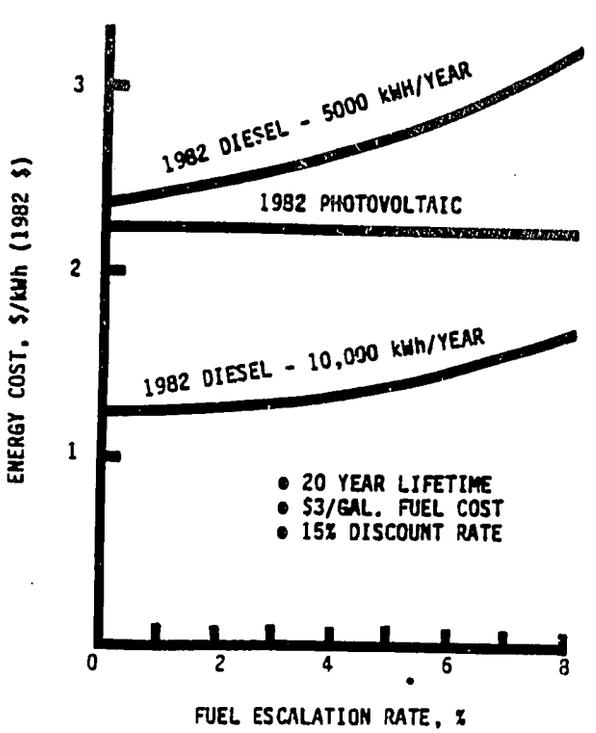

FIG. 3. ENERGY COST AS A FUNCTION OF FUEL ESCALATION RATE FOR 1982 DIESEL GENERATORS AT 5000 AND 10,000 kWh/YEAR OUTPUT