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PHOTOVOLTAICS - PRESENT STATUS AND COMPARATIVE ANALYSES

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Photovoltaic energy systems have the long-range potential for sup- plying a significant part of the world's need for electricity. Even to- day, such systems offer many benefits compared to other energy systems such as fossil fuel, nuclear and other renewable systems. These include: stability, reliability, require no water, no moving parts, environmentally benign, moderate efficiency, modular, universally usable, easy maintenance, and low power distribution costs. This paper will present information on present costs of the key system components, realistic costs projections and the results of a comparative study of three renew- able approaches for a large system.

PV is extremely rich in options. These range from single crystalline silicon thru multicrystalline silicon, amorphous silicon, thin film polycrystalline materials and a variety of special structural materials and multicomponent materials. In addition, many of these materials can be used in flat array structures or in concentration configurations; and finally, the modules (an encapsulated collection of individual cells) can be stationary or in a tracking system that permits greater electrical out - put. The conversion efficiency for individual cells and modules may range up to 35%; however, many of the higher efficiency numbers are associated with small experimental units that are laboratory samples and are not representative of what is available either commercially or at the preproduction level. The numbers given below indicate maximum values that are available today or will be available in the very near future.

Material	Conversion efficiency
Single Crystalline Silicon	15%
Polycrystalline Silicon	14%
Amorphous Silicon	8%
Copper Indium Diselenide	8%
Cadmium Telluride	8%

In concentrator configurations, the efficiency of silicon and gallium arsenide cells are over 20% although some experimental concentrator subsystems have been made with efficiencies above 25%.

At the present time, the commercially available modules cost about \$5/W_p. All the other components of a PV system are grouped together into what is called the balance-of-system (BOS) and today the BOS costs are in the \$3 to \$4/W_p range. The attached bar graph gives detail information on BOS costs for various systems that have been installed over the past ten years in the U.S. and in Switzerland. This information was published in October 1992 by Shugar, Real and Aschenbrenner. More recent developments indicate that the BOS costs can be reduced to below \$3/W_p. Thus the total systems cost may range from about \$8 to \$12 /W_p today with expected costs dropping to below \$6 in the near future and to below \$5 at the turn of the century.

The encapsulant degradation problem consists of yellowing of the ethylene vinyl acetate film in the encapsulation scheme. This degradation has been noted to occur under operation of the PV system at temperatures above 85 degrees Fahrenheit (85° F) both in the U.S. and in Israel. The U.S. government PV program is studying this problem intensively and the results should either find an improved formulation of the EVA or another material for the encapsulation. This does not appear to be an insolvable problem.

At the present time all the manufacturing lines throughout the world are modest in size since the demand for PV has not yet made the investment in large production facilities a prudent investment. Here again various governments are supporting the development of markets for PV by installing various applications to prove to potential users that such systems are meaningful even at today's costs. In the U.S major programs are under way with utilities, with architects and other building personnel, independent power producers and third-world countries to stimulate market growth which will in turn reduce costs through large production facilities. Various analyses have been carried out by different groups to compare various possible systems for a given application. The results of one analysis is given in the attached table by Stolte, Whisnant and McGowin in May 1993 which compares the costs of a concentrator PV system, a solar thermal central receiver system and a thin-film flat plate PV system. Discussion of the underlying assumptions and base data are in place. It can be seen that the bottom line for this particular system (50 megawatts in central California) indicates that the thin-film copper indium diselenide flat plate module should be used.

Analyses of several utility applications have yielded breakeven costs for substituting PV for standard utility line connection systems in the \$3 to \$6/W_p range. Thus utilities are looking very seriously at the use of PV systems today for many applications. A recent installation in Kerman, California of 500 kilowatts which cost \$12.34/W_p (\$9 for the system plus \$3.34 for site preparation) is being used in place of replacing the power transformer and installing heavier power lines over a long distance. This system is almost cost-effective since the power demand for watering crops coincides with the PV system power product - ion. The U.S. government cost-shared this system with the Pacific Gas and Electric Company which is the largest utility in the country and the largest user of PV. Other significant utility users in the U.S. include Idaho Power and Public Service of Colorado among the more than twenty significant utility users.

Table 1.

Direct Balance-of-System Costs: Comparison of Roof- and Ground-Mounted Systems in Switzerland and the USA

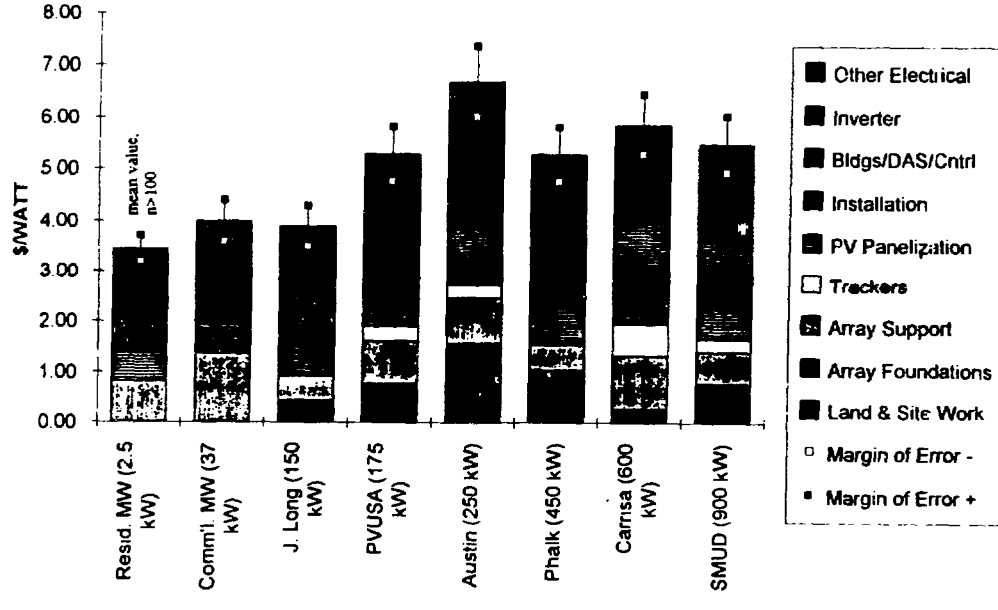

Table 2. Total Capital Requirements
Third Quarter 1990 Dollars (1000s), Carrisa Plains Site

	Fresnel Lens		Central Receiver		CIS Flat Plate	
	$	**$/Watt**	**$**	**$/Watt**	**$**	**$/Watt**
Buildings & Site Improvement	1,200	0.02	1,900	0.04	1,230	0.02
Array Structure	37,920	0.76			13,380	0.27
Photovoltaic Modules	80,800	1.62			66,910	1.35
Heliostat System			53,300	1.07		
Receiver System			18,800	0.38		
Receiver Tower			6,300	0.13		
Power Conditioning Unit	5,920	0.12	4,300	0.09	5,850	0.12
Balance Of Plant	3,090	0.06	16,400	0.33	7,060	0.14
Master Control System	120	0.00	800	0.02	80	0.00
Total Field Cost	129,100	2.58	101,800	2.04	94,500	1.91
Engg. & Const. Mgmt	5,200	0.10	6,100	0.12	2,800	0.06
Owner's Costs	5,400	0.11	5,400	0.11	2,900	0.06
Contingencies	14,200	0.29	19,700	0.39	9,800	0.20
Total Plant Cost	153,900	3.08	133,000	2.66	110,000	2.22
Escalation (Mixed Year $)	(2,900)	(0.06)	(2,500)	(0.05)	(2,100)	(0.04)
Total Cash Expended (mixed year $)	151,000	3.02	130,500	2.61	107,900	2.18
AFDC (Mixed Year Dollars)	6,800	0.14	5,800	0.12	4,800	0.10
Total Plant Investment	157,800	3.16	136,300	2.73	112,700	2.27
Preproduction Costs	3,200	0.06	2,900	0.06	2,300	0.05
Inventory Capital	800	0.02	700	0.01	600	0.01
Land	200	0.00	300	0.01	200	0.00
Total Capital Required	162,000	3.24	140,000	2.80	116,000	2.34