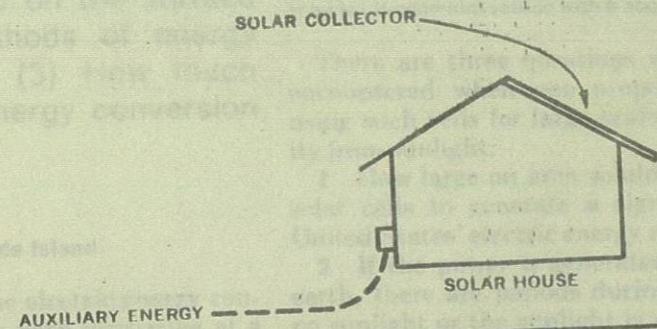
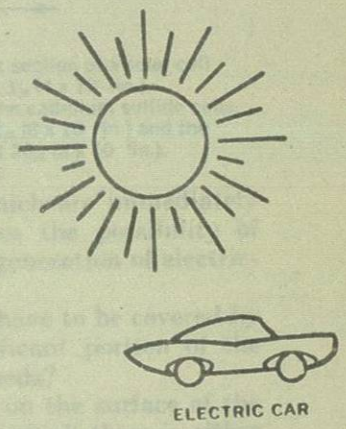
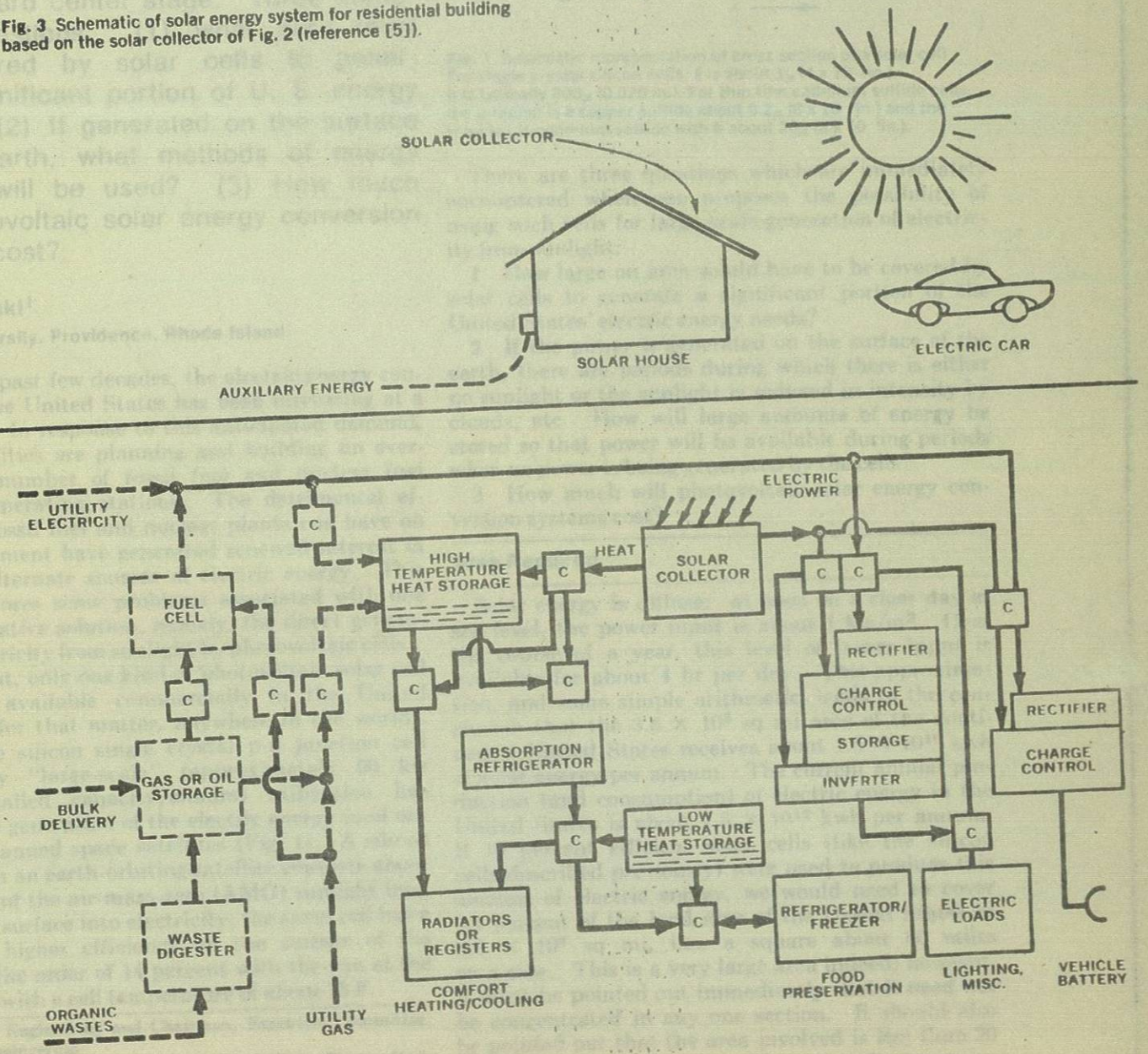


# large-scale solar power photovoltaic

Fig. 3 Schematic of solar energy system for residential building based on the solar collector of Fig. 2 (reference [5]).



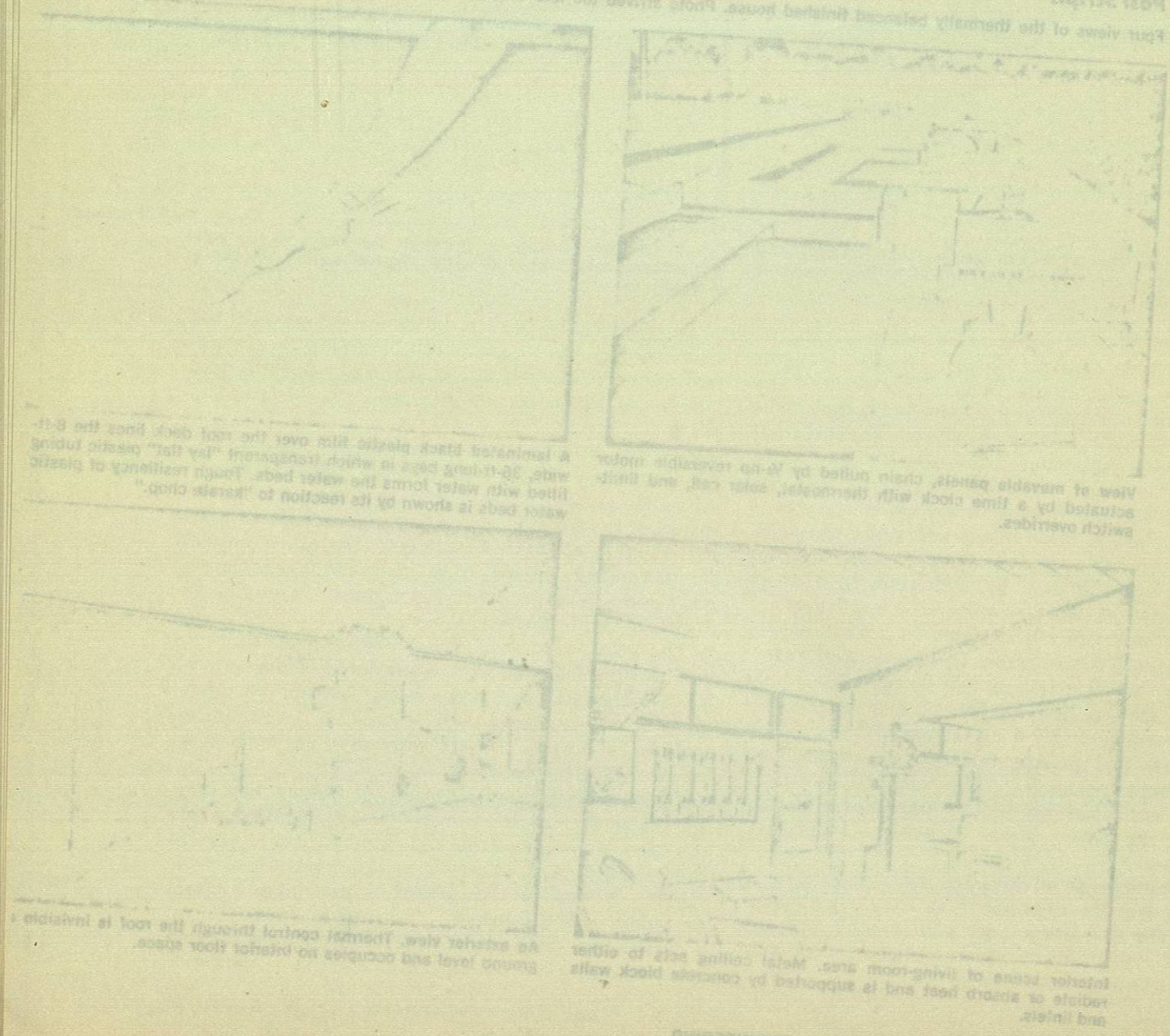
The depth of the evaluation is severely limited by relatively small funding; the house has been separately financed and made available for the period of the test. The evaluation will result in design improvements and will provide a basis for one of the system in other climates. Though it is difficult to anticipate the extent to which this solar-thermal system can anticipate future energy problems, the investigation will considerably extend knowledge of its potential. It will also provide an interdisciplinary standard for appraising technologic innovations in the field of pollution-free energy.

References

1. The Federal Power Commission, The 1970 National Power Program, Guidelines for the Growth of the Electric Power Industry, Part I, Government Printing Office, Washington, D. C.
2. Ray, H. E., "New House for Hot Dry Region," *Electric Vol. 91, No. 10, Feb. 1911*, "Home Solar Radiation Adaptation and Implications," Paper 71-WA-563, presented at the ASME Winter Annual Meeting, Washington, D. C., 1971.
3. Ray, H. E. and Yehou, J. L., "A Naturally Air-Conditioned Building," *Mechanical Engineering*, Vol. 82, No. 1, Jan. 1970, pp. 12-16.

Post Script

Four views of the thermally balanced finished house. Photo shown too late to be incorporated in article.



Interior view of living room and metal ceiling sets to either provide or absorb heat and is supported by concrete block walls and interior.

An exterior view. Thermal control through the roof is provided by ground level and occupies no weather floor space.

View of movable panels, chain pulled by 1/2-in. reversible motor, which overrides.

View of movable panels, chain pulled by 1/2-in. reversible motor, which overrides. Water beds in shown by reaction to "kettle drop".

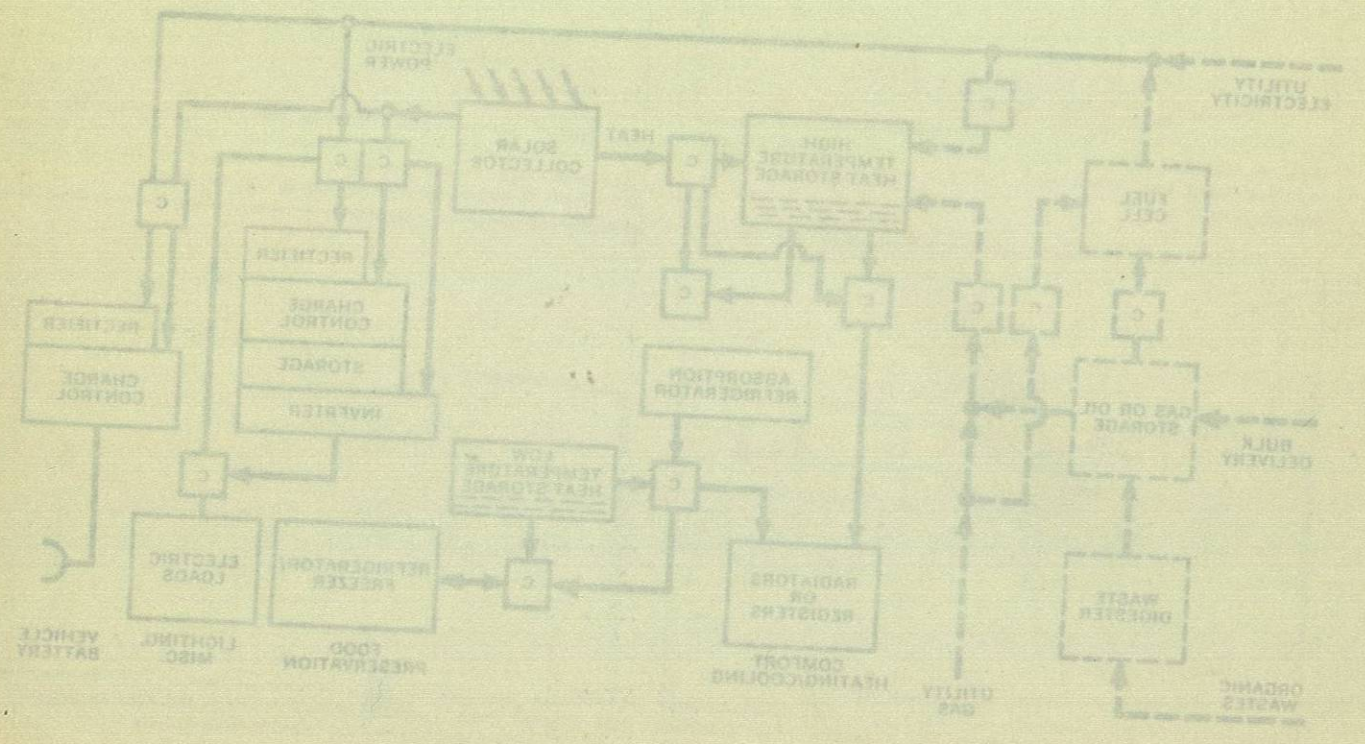
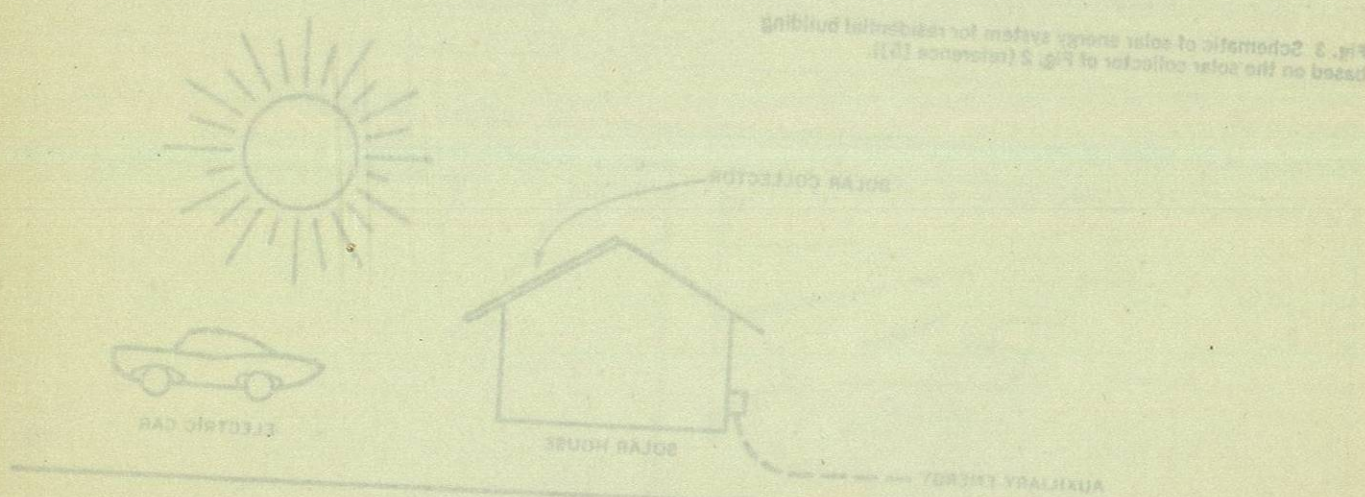
Water beds in shown by reaction to "kettle drop". Flood with water forms the water beds. Tough resiliency of plastic water beds in shown by reaction to "kettle drop".

A laminated black plastic film over the roof deck faces the 8-ft. wide, 36-ft-long beds in which transparent "lay flat" heating tubing is installed.



1970-2010 Solar Power  
Photovoltaic

Fig. 3 Schematic of solar energy system for residential building based on the solar collector of Fig. 2 (reference 10).



# via the effect

Power via solar energy is moving inexorably toward center stage. Three immediate questions: (1) what area must be covered by solar cells to generate a significant portion of U. S. energy needs. (2) If generated on the surface of the earth, what methods of energy storage will be used? (3) How much will photovoltaic solar energy conversion systems cost?

J. J. Loferski<sup>1</sup>  
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Over the past few decades, the electric energy consumed in the United States has been increasing at a rapid rate. In response to this anticipated demand, electric utilities are planning and building an ever-increasing number of fossil fuel and nuclear fuel powered generating stations. The detrimental effects that fossil fuel and nuclear plants can have on the environment have generated renewed interest in potential alternate sources of electric energy. This article explores some problems associated with one such alternative solution, namely, the direct generation of electricity from sunlight by photovoltaic cells.

At present, only one kind of photovoltaic solar cell is readily available commercially in the United States (or for that matter, anywhere in the world). This is the silicon single crystal p-n junction cell whose only "large-scale" (approximately 50 kw newly installed capacity/annum) utilization has been in the generation of the electric energy used on-board unmanned space satellites (Fig. 1). A silicon solar cell on an earth-orbiting satellite converts about 11 percent of the air-mass-zero (AMO) sunlight incident on its surface into electricity; the same cell has a somewhat higher efficiency on the surface of the earth: of the order of 14 percent with the sun at the zenith and with a cell temperature of about 75 F.

<sup>1</sup> Professor of Engineering and Chairman, Executive Committee, Division of Engineering. Based on a paper contributed by the ASME Solar Energy Division.

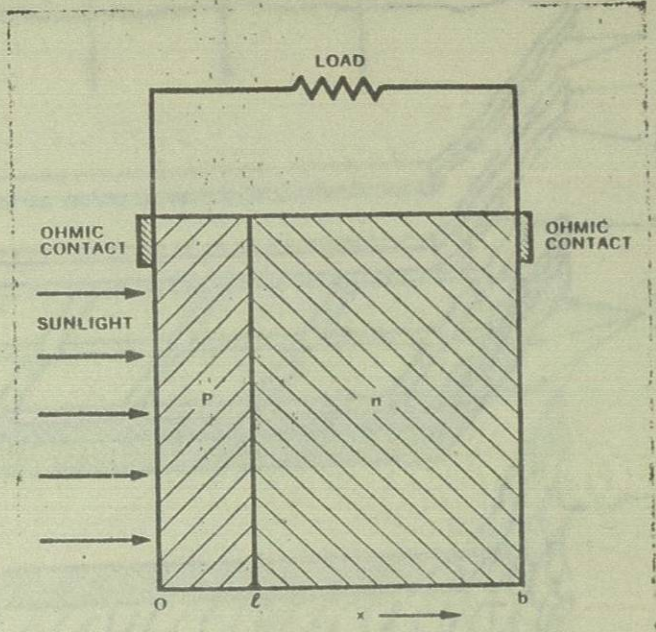


Fig. 1 Schematic representation of cross section of a solar cell. For single crystal silicon cells,  $l$  is about  $1\mu$  ( $4 \times 10^{-6}$  in.),  $b$  is typically  $800\mu$  ( $0.020$  in.). For thin film cadmium sulfide cells, the p-region is a copper sulfide about  $0.2\mu$  ( $8 \times 10^{-6}$  in.) and the n-region is cadmium sulfide with  $b$  about  $20\mu$  ( $8 \times 10^{-4}$  in.).

There are three questions which are immediately encountered when one proposes the possibility of using such cells for large-scale generation of electricity from sunlight:

- 1 How large an area would have to be covered by solar cells to generate a significant portion of the United States' electric energy needs?
- 2 If the power is generated on the surface of the earth, there are periods during which there is either no sunlight or the sunlight is reduced in intensity by clouds, etc. How will large amounts of energy be stored so that power will be available during periods when no power is being generated by the cells?
- 3 How much will photovoltaic solar energy conversion systems cost?

### Area Required

Solar energy is diffuse: at noon on a clear day at sea level, the power input is about  $1 \text{ kw/m}^2$ . Over the course of a year, this level of power input is available for about 4 hr per day. This approximation, and some simple arithmetic, leads to the conclusion that the  $3.6 \times 10^8$  sq mi area of the continental United States receives about  $1.5 \times 10^{16}$  kwh of solar energy per annum. The current annual production (and consumption) of electric energy in the United States is about  $1.5 \times 10^{12}$  kwh per annum. If 10 percent efficient solar cells (like the silicon cells described previously) were used to produce this amount of electric energy, we would need to cover 0.1 percent of the land area of the United States or  $3.6 \times 10^4$  sq mi, i.e., a square about 60 miles on a side. This is a very large area indeed; however, it must be pointed out immediately that it need not be concentrated in any one section. It should also be pointed out that the area involved is less than 20 percent of the roof area of all man-made structures



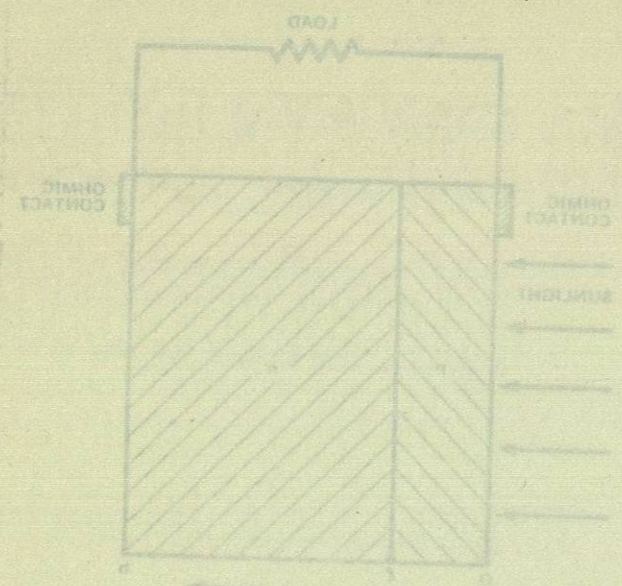


Fig. 1 Schematic representation of a solar cell. For single crystal silicon cells,  $\epsilon$  is about  $1.1 \times 10^{-14}$  W/m<sup>2</sup>. It is typically 600 W/m<sup>2</sup> for thin film silicon solar cells. The p-region is a carbon sulfide about  $0.5 \mu\text{m}$  thick and the n-region is carbon sulfide with a depth  $50 \mu\text{m}$  to  $100 \mu\text{m}$ .

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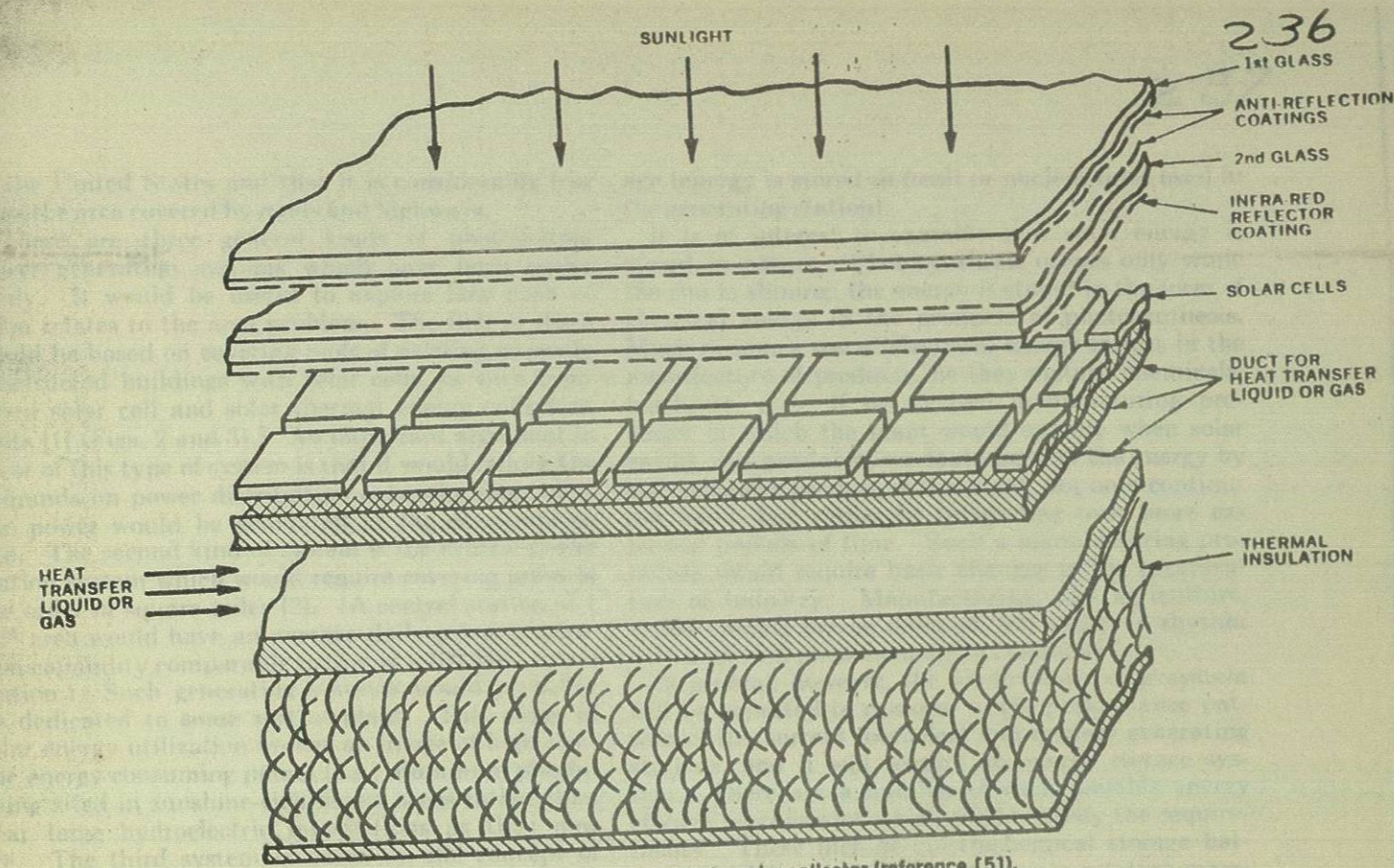


Fig. 2 Proposed structure of combination thermal photovoltaic solar collector (reference [5]).

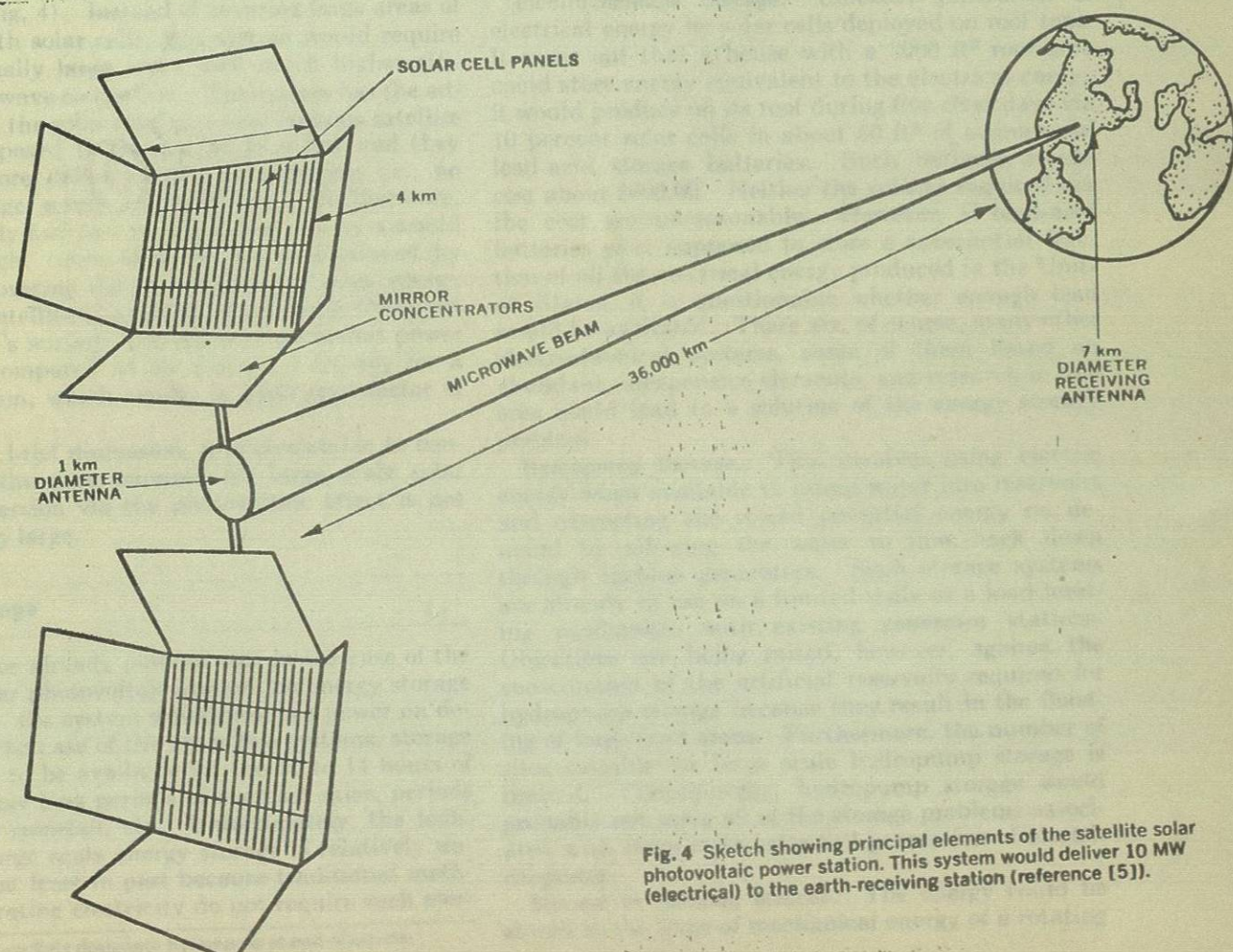


Fig. 4 Sketch showing principal elements of the satellite solar photovoltaic power station. This system would deliver 10 MW (electrical) to the earth-receiving station (reference [5]).