OLC 75-0801/a

CENTRAL INTELLIGENCE AGENCY
WASHINGTON, D.C. 20505

9 JUL 1975

Mr. Emilio Q. Daddario, Director
Office of Technology Assessment
Washington, D. C. 20510

Dear Mr. Daddario:

As a result of your April 11 request to the Director that Dr. Ronal Larson of OTA meet with CIA employees working in the solar energy field, Dr. Larson did meet on two occasions for discussions with CIA employees. He asked for information o[redacted]and Soviet solar projects, and requested that our personnel informally review a draft OTA report entitled "Solar On-Site Electricity" from a foreign technology viewpoint. I am forwarding with this letter a memorandum on[redacted]d Soviet solar projects and an article entitled "Solar Photovoltaic Power Generation." Also enclosed is the copy of the draft report. Several analysts have read it and have made marginal notations. In addition, we asked fossil fuel and solar energy specialists on the staff of [redacted] the Agency's energy consultants, to comment on some of the comparative engineering economic data presented in the report; their observations have been included at appropriate points in the text. Inasmuch as the Agency's main focus is on the foreign technology aspects of the issues involved, our comments are limited to questions of technical fact and analytical considerations, except for the aforementioned economic data.

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We are happy to be of service to your office in these areas and it is hoped that if you have any further similar requests you will be in touch with my office.

Sincerely,

SIGNED

George L. Cary
Legislative Counsel

Enclosures

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SUBJECT: Foreign Reference Material Relating to Solar On-Site Electricity Generation

A resurgence of interest in solar energy utilization has now taken place within the Soviet government. In January 1974, as part of the May 1972 US-USSR Agreement on Cooperation in the field of Science and Technology, the two nations signed a protocol for Cooperation in the General Problems of Utilizing Solar Energy. Dr. Richard J. Green of ERDA is the US coordinator for joint solar projects. One of the three problem areas deemed appropriate for joint research is solar power stations, designated as Program I under the joint agreement.

The Soviets have reinstituted their own effort with plans for the construction of a solar power station with an output of 1-2.5 MWe. The former design (reflectors mounted on moving flatcars circling the base of a tower supporting a movable receiver-boiler) has been modified to reduce construction costs. The new design involves reflectors located in fixed positions around the base of a tower upon which a stationary tubular boiler is mounted. The heliostat system is made up of 1600 3-by-5m reflectors; the mirrors can be oriented on two axes and track via a photocell-activated servo system. The maximum radius from the tower to the outer circle of reflectors is 200m. The mirrors reflect the sun's radiation onto a boiler mounted on a 40m high tower. The boiler is a vertical cylinder, 7m high and 9m in diameter wrapped in a helical array of tubes. The system is designed to produce 11 tons/hr of super-heated steam at 400-500 deg. C and 35 atm.

The Soviets plan to generate 1.2 MWe with a non-condensing turbine or 2.5 MWe with a condensing system. No storage (either thermal or electric) is involved and the plant is expected to operate for 2000 hrs in the year. They anticipate that the overall conversion efficiency of sunlight to electricity will be about 17% (based on the following stated assumptions: mirror reflectivity, 0.78; interception of radiation by boiler, 0.9; optical absorptivity of boiler tubes, 0.9; thermal efficiency of boiler, 0.85; the efficiency of conversion of solar radiation to steam is about 55% from which, assuming turbine efficiencies of about 30%, the overall plant efficiency comes out to approximately 17%).

SUBJECT: Foreign Reference Material Relating to Solar On-Site Electricity Generation

Design studies are virtually complete and site evaluations for future construction have been performed. In addition, one heliostat assembly has been built and field-tested. Apparently, the Soviets intend to begin construction of a power plant with the above specifications in the near future. Individuals associated with the project have indicated that they believe cost to be the determining factor in the success of the system. Estimates for capital investment of 1000-2000 rubles/kW have been noted, compared with 150-180 rubles/kW for fossil fueled plants. (It should be mentioned here that this solar plant is tiny in comparison with normal Soviet power stations which tend to be of the order of 300-600 MWe and larger in capacity. The very large capital cost factor must therefore be viewed as quite unrepresentative of a large commercial installation to which the fossil fuel cost estimate probably does correspond.)

Congress of the United States

OFFICE OF TECHNOLOGY ASSESSMENT

SOLAR ON-SITE ELECTRICITY

Draft Final Report

April 11, 1975

Solar Photovoltaic Power Generation

Hajime Maeda
Toshiba Research and Development Center,
Tokyo Shibaura Electric Co., Ltd.

1. Introduction

The report by The Club of Rome several years ago and the oil-shock originated by the Middle East quarrel which again flared up the year before last disclosed to the world the magnitude of the energy crisis. Japan is most seriously affected by the crisis because its archipelago covers only a small area (377,000km^2), yet it is densely populated (109 million), while natural resources, including energy resources, are scarce.

Aiming at clean (non-polluting) energy resources and energy independence, Japan's "Sunshine Project" began on July 1st last year under the guidance and sponsorship of the Ministry of International Trade and Industry (MITI).

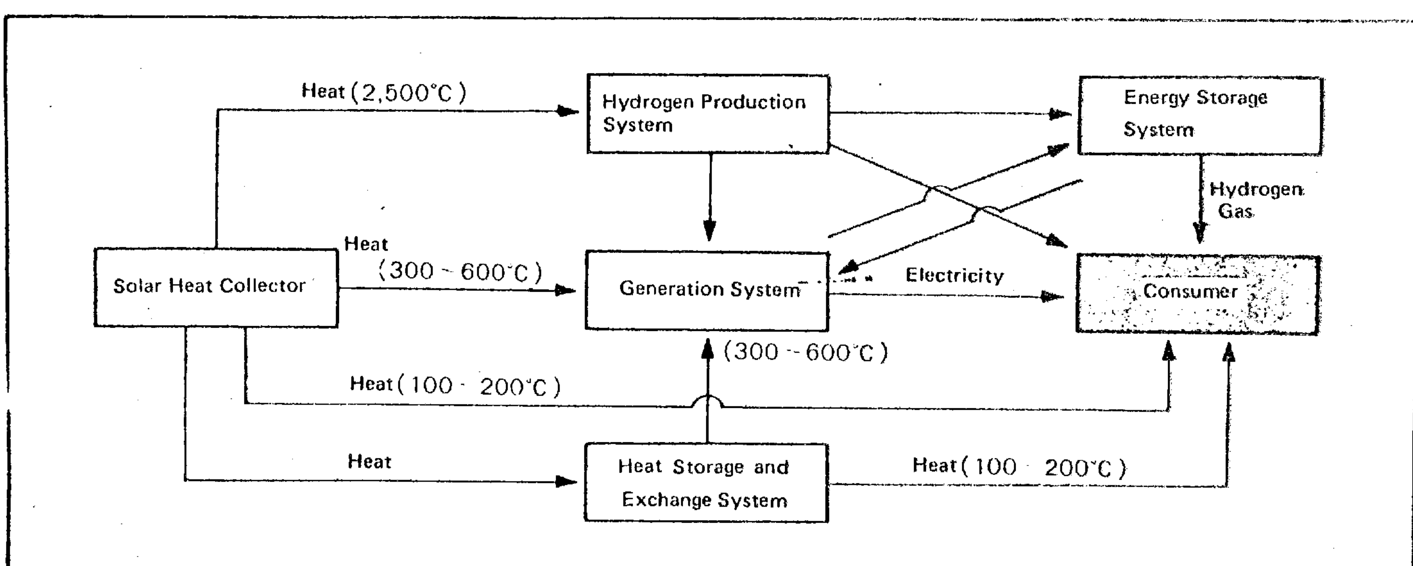
The project intends to develop four types of energy resources: solar energy, geothermal energy, synthetic natural gas derived from coal, and hydrogen energy. The solar energy plan consists of four main items:

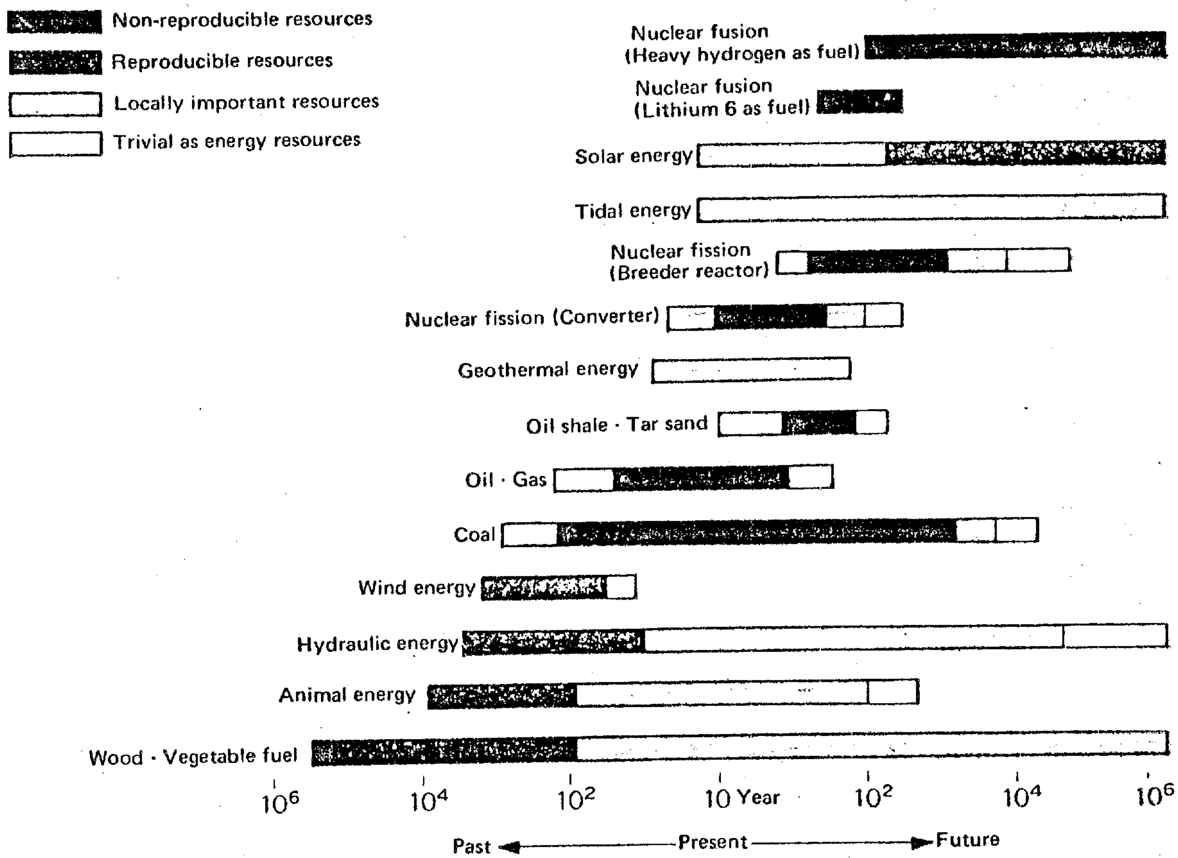
(1) utilization systems,
(2) thermal powr generation,
(3) photovoltaic power generation
(4) heating-and-cooling and hot water supply for dwellings.

As for photovoltaic energy conversion, silicon solar cells have been used in special fields, for example, aboard spacecraft, for communications power sources on remote islands and atop mountains, and for operating navigation lights on buoys and automated lighthouses. As general power sources, however, conventional solar cells are too expensive at their present stage of development and there is thus the need to achieve a technological breakthrough, which will lead to their large scale cost-down. Toshiba R & D Center is meeting the challenge of developing commercially feasible solar cells, since the company, as a comprehensive maker of electric products, is producing electric power generation machinery as well as semiconductor and electronic devices. Further, the company is one of the five major makers of silicon single crystals.

The following is a brief review of the state-of-the-art of the R & D of solar photovoltaic conversion.

Conceptual Diagram of Solar Energy Utilization System





2. General Features of Solar Photovoltaic Power Generation

2-1. Properties of Solar Energy

As prospective energy resources, there are atomic energy nuclear fusion energy, solar energy, geothermal energy, synthetic natural gas, hydrogen and global energies such as ocean energy, wind energy and hydraulic energy. Some of the above are included as a targets of the Sunshine Project. Among these, solar energy has some characteristic features which distinguish it from the others. These characteristic features, which necessitate for its effective utilization a thorough understanding thereof and a development of suitable uitlization techniques, are as follows.

Solar energy incessantly falls on the earth in the form of solar radiation, and is therefore, virtually endless. Its rate of supply is immense (173 x 10^6GW or 13 x 10^{20}Kcal per year) or equivalent to about 140 trillion K*l* of oil per year. However, it also has some "adverse" aspects such as:

(1) It is dispersed in space, resulting in a very low power density (~140mW/cm^2 outside the atmosphere, and, at the maximum, ~100mW/cm^2 on the earth's surface).

(2) On the earth's surface, the radiation power density varies with time, between day and night, and through the year. The variation is especially large in Japan on account of its location around latitude 35°N. Thus, if the seasonal variation as well as the day-period variation of radiation intensity and the incident angle at which it falls are taken into account, together with the effects of bad weather, the average radiation power density must be estimated at one tenth the above mentioned maximum value.

(3) Solar radiation has a wide spectral distribution ranging in wavelength from infrared to ultraviolet (Fig. 1), therefore, a complete utilization of its total energy is impossible. Different methods are effective in utilizing its different regions of wavelength. The heat collector, for instance, plays an important role in the utilization of solar energy in the region of heat radiation including infrared, while the silicon solar cell is effective in utilizing the region of visible light.

Fossil fuel represents an accumulation of this solar radiation over an extremely long period of time, while hydraulic and wind energy represent its condensation in space. One liter of crude oil contains, on the average, 9,400Kcal of energy; this corresponds to an accumulation of solar energy falling on 1m^2 through a 4–5 day period with an efficiency of 100%.

2-2. Characteristics of Photovoltaic Power Generation

For a concentrated utilization of energy, as is general in modern civilization, it is necessary to collect solar energy in some effective way as mentioned above. In order to gain an output power of ten thousand kW on the average on the earth's surface, we need an area of about one km^2 if we assume a

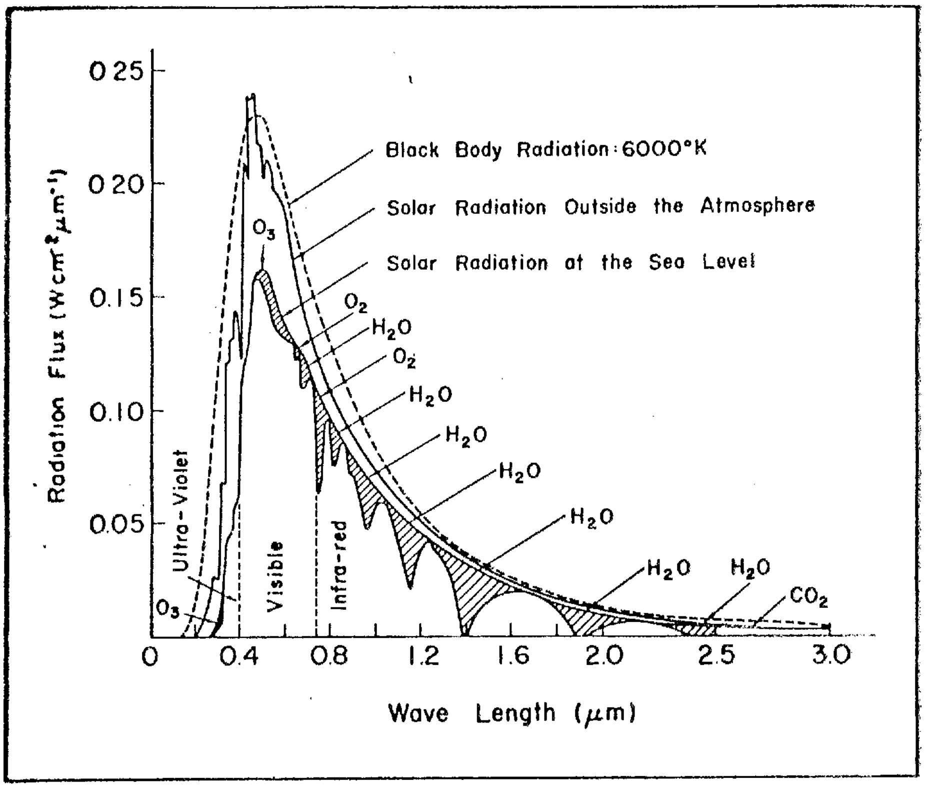


Fig. 1. Energy Spectrum of the Solar Radiation (in Wave Lengths)

conversion efficiency of 10%.

An energy form which is suitable for utilization as a general use energy source is electricity. Processes for converting solar energy into electricity are thermal power generation and photovoltaic power generation. In the former, the solar energy, caught by a collector system, convert water vapor or other gas vapors, through a heat exchanger system, into a high temperature steam or gas, which is then supplied to a system resembling an ordinary thermal power generating plant. Thus, it is subject to scale merit, being rather inefficient as a small capacity generating unit while suitable as a large capacity centralized power generating system. When it is utilized as a centralized power generating system, the problem of the time variation of solar radiation becomes crucial, and the development of energy storing techniques, such as heat storage, storage batteries, pumped storage power generation, etc., becomes important. In Japan, with its small, narrow land area, construction of this system within the country accompanies locational disadvantages.

In the "photovoltaic" system, on the other hand, powre is actually being generated at every point on the surface of the solar cell fabricated with a certain kind of semiconductor material (as will be described later), and is therefore not subject to the scale merit as is the thermal generation system. Since semiconductor material, as the working material, is spread over a large area, its cost and packaging technique are problematic and require thorough probing. If these problems are solved, its usefulness as a general use power source can be expected at all levels, from small scale use for homes, to medium scale use for buildings, schools, offices and small factories, to large scale use as a centralized power generating system.

2-3. Silicon Solar Cell

A merit of the photovoltaic system is that it has, as its solar cell material, silicon which has the following superior features. First, its characteristic energy, or "band-gap", corresponds to a wavelength of 1.2μ, which happens to be in good coincidence with the useable solar radiation spectrum range. Secondly, it is the element most abundantly found on earth next to oxygen. And thirdly, the technology related to silicon itself has attained remarkable progress during the past quarter century in the transistor industry field.

The silicon solar cell, in spite of a lapse of twenty years since its invention in 1954, has been applied as a power source only to a limited and specialized extent. The few installations per year in Japan generate only several KW. The greatest reason for its limited use as a power source is its prohibitive cost. At the present technological level, the cost for 1KW of maximum output power is approximately ¥15 million (~$45,000), which is several hundred times the cost for conventional power generation such as thermal power generation.

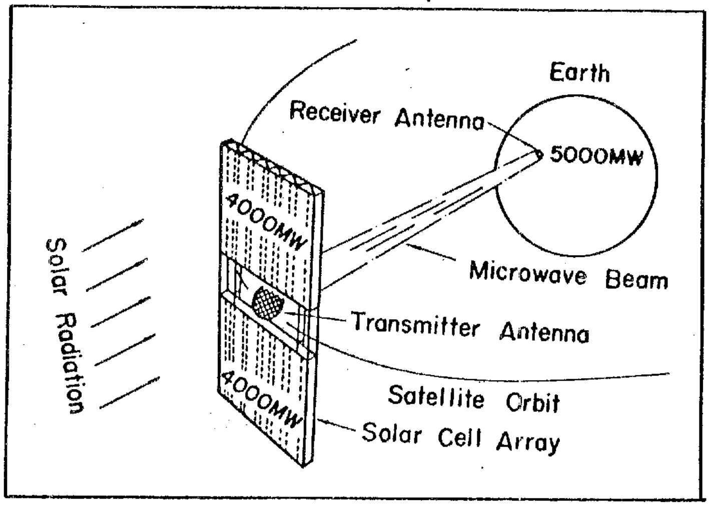
Thus, an essential developmental problem that bars the way to the practical utilization of the photovoltaic system as a new energy source is the development of a technology that leads to a cost reduction of 100 times or more compared to its present level and this cannot be attained through such "improvements" as the development of a mass-production technique, but rather, positive "technical innovations" are require for its attainment.

2-4. Solar Photovoltaic Power Generation Unit

There are proposed, as targets of energy development projects in Japan and the U.S., two forms of photovoltaic power generation systems, the space station and the terrestrial station (Figs.2, 3). In the former concept, which is chiefly proposed by ADL of the U.S. is a station with two 2km square solar cell arrays which will be sent into orbit above the earth and the power generated by it will be transmitted to earth in the form of microwaves. With this system, a constant and maximum radiation can be obtained by controlling the solar cell arrays so as to always to face the sun (the solar radiation source). However, in this case, some new technical problems will have to be solved, (other than reducing the price of the solar cells), such as the launching of such solar satellites, making the station light in weight, effectively controlling the station, transmitting and receiving high power microwaves, etc. The latter concept, advocated by NSF (the National Science Foundation) of the U.S., includes the development of a power station with solar cell arrays spread over a land area of several km² and a hydrogen plant based on the electrolysis of water. The combination with hydrogen gives a means, through the storage of energy, for solving the problem of time variation of solar radiation as well as a means for an efficient transference of energy to the users.

As was described above, photovoltaic generation does not have the scale merit problem and is thus suited for both small and large capacity generation systems. In consideration of the special circumstances of Japan, such as its narrow land area and

Fig. 2. Electric Power Generation in Space



limitations of its satellite technology, together with the prospect of the development of an energy storing technique, medium and small capacity power sources using the photovoltaic system gains importance as target for development. Taking these into account, the author and co-researchers propose the development of a small capacity photovoltaic power source unit and magnification of its capacity through a synthesis of the small capacity power source unit. The target rated performances of the power source unit are as follows:

Maximum output	:	1.2KW
Output voltage	:	100V (D.C.)
Solar cell surface area	:	10m²
Conversion efficiency	:	12%

An example of the application of this unit in the smallest capacity system, the case of utilization as a domestic power source, will now be considered. As shown in Fig.4, the system will be connected to the utility line together with an AC-DC inverter and a controller. When the generation of energy by the solar photovoltaic system is great enough, AC power is supplied to each load from the solar cell array through the AC-DC inverter. But when generation by the photovoltaic cell is insufficient, such as during the night or during periods of bad weather, the deficit power is supplied from the external utility line. When generation by the solar cell array exceeds the load demand, the excess power flows out into the external utility line and is supplied to other users of power in the neighborhood or to a central pumped-storage power station. The inverter is excited by the external power in order to maintain the quality of power, and a controller is provided for optimum operation of the solar cell array. Also, for an evaluation of the quantity of power consumed at the home, the watt-hour meter is provided with reverse rotation when power flows out.

The advantages of the above power generation unit and the generation system are:

(1) Constant supply of power to loads and the maintenance of conditions for optimum operation of the solar cells can be achieved without requiring battery units.

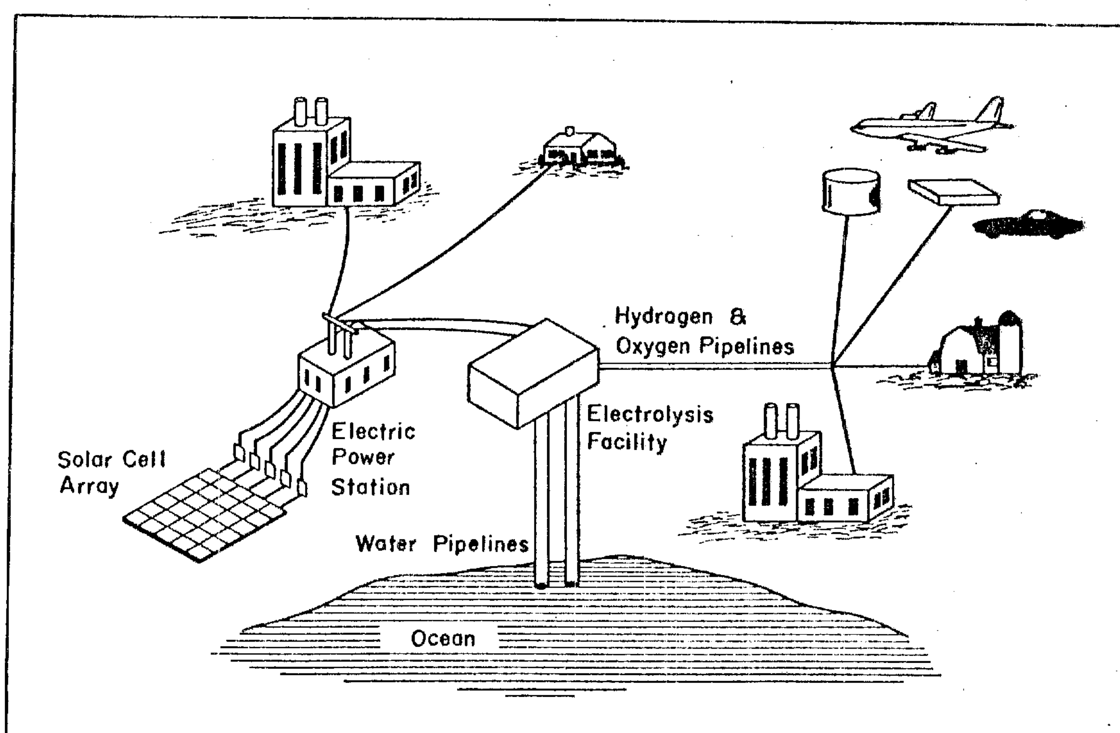


Fig. 3.

Terrestrial Solar Photovoltaic Power Station

(after F. R. Eldridge, the Mitre Corp.)

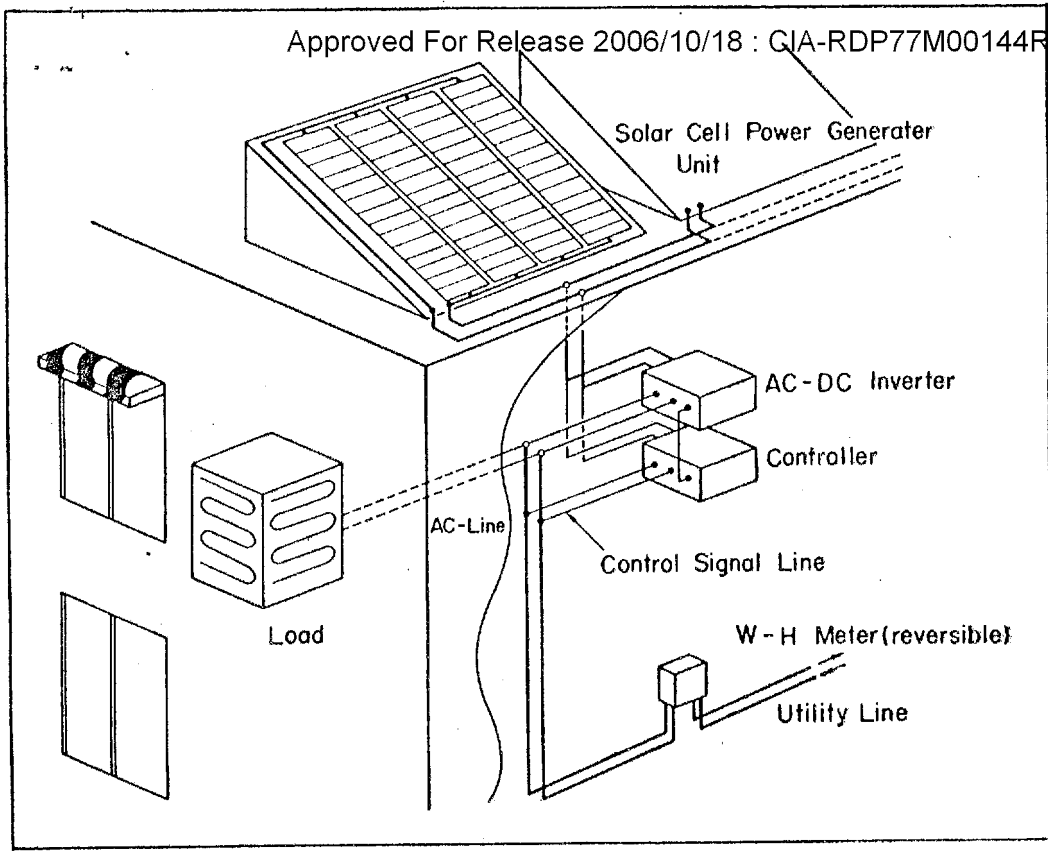


Fig. 4. Roof-top Solar Photovoltaic System for Power Generation

(2) Specific facilities for power transmission and distribution are unnecessary since most of the generated electric power is consumed on the spot. In other words, the system represents a suitable method of utilizating solar energy, which is distributed in low concentrations spatially.
(3) Though essentially an auxiliary power source, its parallel connection with the utility line equivalently increases the generating capacity of the central power stations. It is especially effective therefore, as a measure for power consumption peaks in the summer season in Japan.
(4) The average output per month per unit is about 90KWH, which means that it can furnish a considerable part of the average power consumption of an ordinary household (i.e., ~150KWH). It will play a very important role during the summer peak period as mentioned above.
(5) When larger power is required in buildings, factories, schools, offices, etc., the unit can be effectively utilized by simply connecting many of it in parallel.
(6) It requires no special geographical conditions nor is it a public nuisance, as some other power generation units.

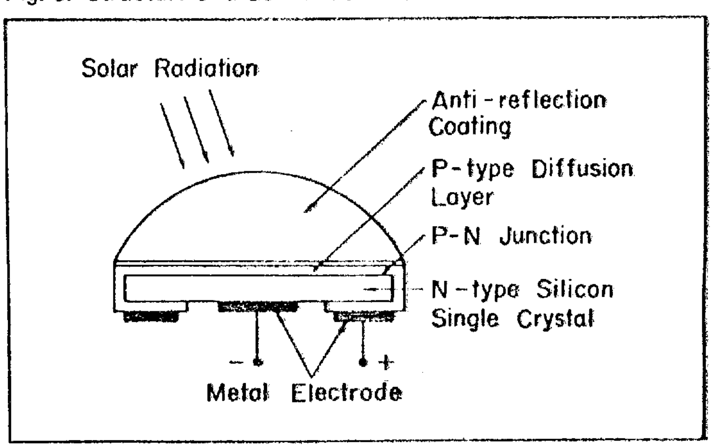
The author and co-researchers plan to obtain, by 1980, a prospect for producing the above unit at a price of around ¥150,000 ($450), that is, one hundred times cheaper than the present cost. This figure was set, by considering the needs of average homes, so as to set a price of ¥240,000 ($720) per unit together with the inverter and the controller, a price similar to the price of home cooler's. If a maintenance cost of ¥9,000 ($27) per year and a lifetime of 20 years are assumed, the power generation cost will be ¥20 (₵ 7)per KWH, and if this is reduced to about one third this level by means of allight collecting technique and others, it can favorably compete with the power generation cost of newly constructed thermal power plants, i.e. ¥8.90 per KWH. Of course, the author does not assume the cost competition as the final, or end result of solar energy use rather the problem of environmental pollution and the imminent exhaustion of present conventional energy resources gave rise to the desire to develop new energy technologies, and the cost itself can be considered fluid if considered in a social context.

3. Problems in the Way to Industrialization as a General Use Power Source

3-1. Structure of Silicon Solar Cells and Its Fabrication Process

For the discussion of technical problems, a brief explanation of an example of a conventional solar cell will be given. As shown in Fig.5, we start with N-type silicon wafer, which is doped with a group-V chemical element and in which electrons (negative electric charge) carry electricity. Then we dope boron,

Fig. 5. Structure of a Conventional Solar Cell



a group-III element, to make a thin P-type region, where electricity is carried by positively charged quasi-particles called "holes".

At the boundary of the P- and N-regions, called the P-N junction, an electric field is built-in, and when a radiation of a wavelength less than 1.2μ, which corresponds to the band gap of silicon, reaches the P-N junction, electrons and holes are created and separated by the built-in electric field toward the N-type and P-type regions, respectively, and thus electric power is generated. Of course, metallic electrodes are necessary to take out the built up power.

Created electrons and holes vanish with certain probabilities before they reach the electrodes. Therefore, the conversion efficiency is chiefly determined by the average time lapse before the charge carriers "vanish". This is called the "life time" and is determined by the degree of purity and perfection of the crystal, and by the necessary distance traversed by the carriers (therefore by the cell construction design). The output voltage originating from the built-in electric field is nearly 0.6V, if the voltage drop in the cell is neglected. In order to reduce this voltage drop it is desirable that the series resistance within the cell is small. In this point, certain kinds of III-V group compounds, for example gallium arsenide, are superior to silicon.

Also, the coating which is to prevent loss by reflection of the solar radiation on the cell surface is very important and obviously cannot be dispensed with. As seen above, the fabrication process of a solar cell consists of single crystal wafer fabrication, P-N junction formation, electrode metallization and anti-reflection coating.

3-2. Discussious of the Production Cost and the Energy Consumption in the Production

The toughest problem for the industrialization of the solar photovoltaic power generation unit is the reduction of cost. In Fig.6, a cost estimation is carried out for a unit which is capable of generating 1KW during optimum conditions.

The estimation, on the basis of the present day technology, gives a prohibitively high value of \$66,700. Let's look into the reason for this.

In the first stage of cell production, silica, the raw material is processed, through reduction and purification, into pure polycrystal silicon. Then, a single crystal seed is immersed in the melt of the above polycrystal silicon and is pulled upwards at a few mm per minute, rotating slowly, generating a single crystal ingot of cylindrical shape with a diameter of several centimeters. The fabrication process for polished silicon wafers, which constitutes the starting point for the fabrication of all sorts of silicon devices today, begins with the slicing of the above cylindrical ingot, and follows with cutting, lapping and polishing. The slicing process causes a substantial silicon loss of more than 70%. There is at present, no way to reduce this loss. In addition, the succeeding processes result in substantial labor costs and reduced yields.

Fabrication of solar cells, mentioned in the preceeding section, is carried out by the batch process, which requires many processing steps and each wafer or each chip results again in substantial labor costs and very low yields.

It is clear that the price reduction envisaged for making the solar cells commercially practical cannot be achieved by merely increasing the manufacturing scale. We present here, as a future technology, a new ribbon crystal growth technology combined with a fully automated continuous production system for processing the ribbon crystals so developed into solar cells (Fig.8). An estimation is carried out on the basis of the ribbon crystal

Fig. 6. Solar Cell Cost Analysis

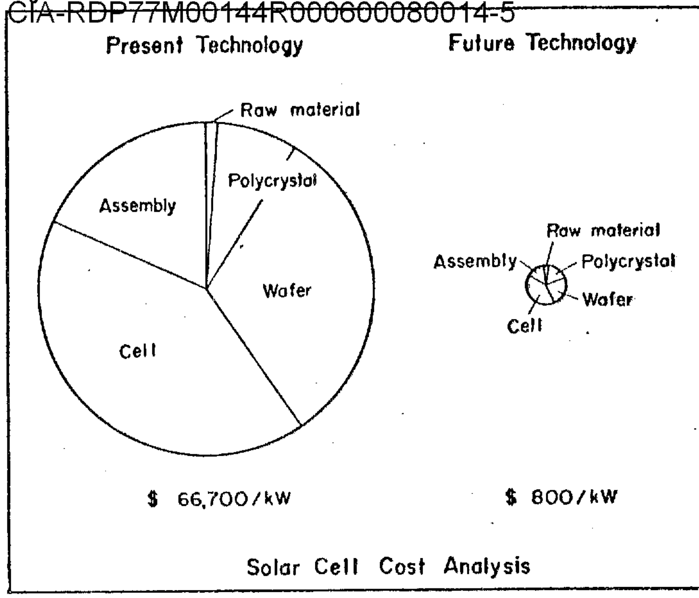


Fig. 7. Energy Balance of Solar Cells

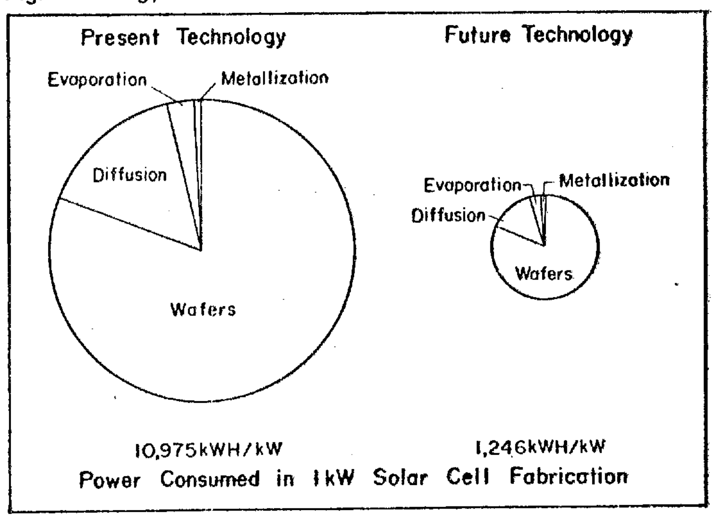
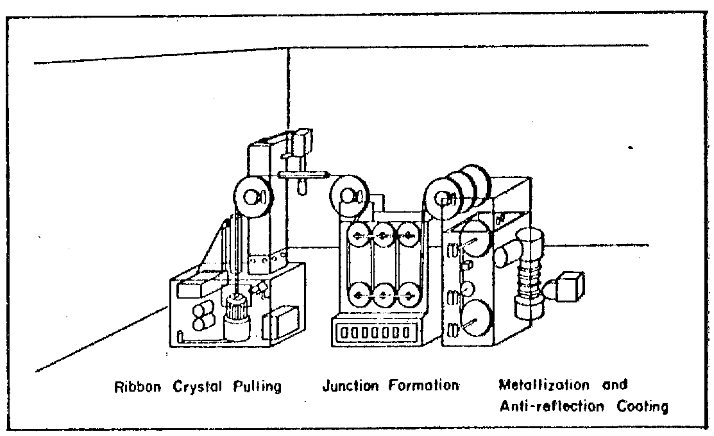


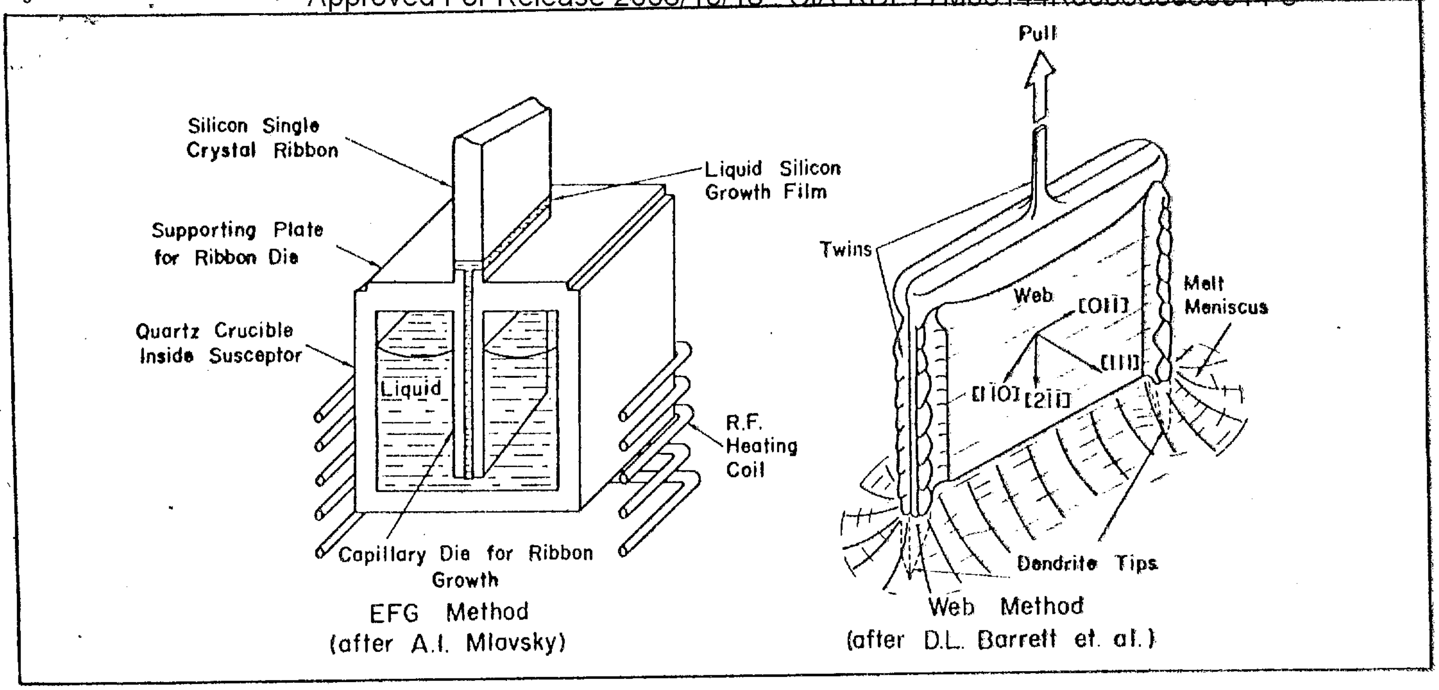
Fig. 8. Automated Continuous Fabrication System of Solar Cells



growth rate of $80cm^2$/min. which is the author's first milestone to be reached in next 3 years. The cell production system is designed to be matched to this ribbon growth rate. The solar cell cost then becomes \$800/unit, which is about an 80-fold reduction of the present cost.

The amount of electric energy which is required to produce the solar cells is another very important factor for the examination of their feasibility, since it would be rather ridiculous if

Fig. 9. Silicon Ribbon Crystal Pulling



this energy exceeds that which the solar cells can generate during their lifetime. Shown in Fig.7 is a comparison between the energies needed in producing a solar photovoltaic generation unit with an output power of 1KW at the peak output by present day technology and a unit developed by the future technology, envisioned above which utilizes the ribbon crystal. In the former case, an electric energy of about 11,000KWH is required and it takes more than 10 years to generate this amount of energy with this unit. With the application of future technology it will take only one or two years to recover the energy consumed during fabrication.

3-3. Silicon Ribbon Crystal Growth

The foremost object of the development of this technology is to present the crystal in a form which is convenient for the automation of the fabrication process of the cell elements, which, as clarified in the previous section, accounts for the majority of the high cost in the production of the present-day solar cell fabrication process. Another is the contraction of the production cost of the polished wafer itself. Further, the presentation of wafers with larger face areas may be added as third object.

The ribbon crystal growth methods may be broadly classified into two groups: the dendrite method(s) in which the crystal itself is given a property to grow in a ribbon shape, and the capillary method(s) in which melt is drawn out from a ribbon shaped die and is solidified.

If silicon melt is rapidly cooled to below the melting point under certain conditions, a crystal in the form of a leaf of a coniferous tree is seen to grow. That crystal is called a dendrite and includes twin-boundaries within itself. Its direction of growth is the<211>crystallographic direction and its surface is the {111} plane. Its width never exceeds several mm. By controlling the conditions of the dendrite growth such as the velocity of growth and the temperature, two dendrites and, between them, a film shaped crystal, thinner than the dendrites, and having parallel mirror planes may be made to grow. This is called a web crystal. So far, web crystals with a 3cm width have been obtained, and a growth rate of the order of 20cm/min is considered possible.

Research on dendrite growth was initiated in 1960 at the Westinghouse Electric Co. and a web crystal was developed in 1967. However, on account of limited needs from the field of semiconductor devices at that time, its further development was subsequently slowed down. In Japan, research on dendrites was made by Toshiba also around 1960. Advantage of the web method is that ribbon crystals with a comparatively large width and a good degree of crystal perfection together with good crystal surfaces can be obtained at a high growth velocity, while its disadvantage is that it requires a high level of production technique for controlling the temperature distribution, pulling rate and mechanical vibration. Consequently, multiple pulling from a single crucible is very difficult.

The capillary method is theoretically based on the same idea as that of the manufacturing of sheet glass or polyethylene sheet. Since Stepanov and others in Russia applied the method to germanium, many improvements have been made, and the one attracting greatest attention at present is the method developed for alumina by LaBelle Jr. and others in Tyco Laboratories and named EFG (Edge-defined Film-fed Growth) method. In this method, if a die material which is wetted with silicon melt is chosen, the melt is supplied stably to the upper-edge of the die through capillary action (as shown in the left in Fig.9), and at the same time, the outer contour of the upper-edge of the die (not the inner contour) determines the shape of the ribbon crystal. These circumstances are exactly the same as those in a case reported by Stepanov and others except that the relative configuration of the die and the ribbon crystal is different between the vertical and horizontal configurations. As for the application of the EFG method to silicon, Tyco Laboratories have carried out intensive development with funds from the NSF and have succeeded in growing a ribbon crystal with a width of 2.5cm and a thickness of 200μ and in the trial manufacture of a solar cell with an efficiency of 10%. Various other methods of forming the crystal such as drawing downward or laterally, drawing by supporting the melt with a film, etc., have been proposed and tested.

At present, the EFG method is more popular, but there still remain many problems which must be solved prior to its successful development. One of them is that a decisively good die material has not yet been found: since the silicon melt has such a strong reactivity that it reacts with almost any material, the die therefore, can be easily corroded and the silicon contaminated. Another problem is that sufficiently flat crystal surfaces have not yet been obtained. In the future, a method based on improvements in these points, a "modified" capillary method, so to speak, might come into the spotlight as an important candidate for industrial solar energy technology.

3-4. Silicon Thin Film and Compound Semiconductors

Solar radiation absorption by silicon crystals is 80% and 90% when the thickness of the crystal is 10μ and 100μ respectively. Therefore, if the price of the silicon material goes up in the future and thus occupies a substantial portion of the cell cost, thin films with a thickness of the order of 10μ will be economically more advantageous than thicker materials, although the conversion efficiency might be smaller by 10% or so. From the above viewpoint, an attempt is being made to fabricate solar cells by generating a polycrystalline thin film on a low-cost basis with the crystal grain size controlled so as to be equal to, or larger than, the order of the film thickness and forming a P-N junction or Shottky barrier on its surface. As a method for thin film generation, such processes as vacuum deposition, sputtering, iron-plating and chemical vapor deposition are now being considered.

For attainment of the fabrication of polycrystal devices at an output efficiency that can be of practical interest and with a good reproducibility, studies of physical and electrical properties of the polycrystal itself, and especially those of the crystal grain boundaries, will be very important. The major practical problem needed to be solved will be the discovery of a cheap yet high-quality base material.

Besides silicon, there are, for the solar cell material, various compound semiconductors with various different features. It is possible, for instance, to select a material with a band gap better fitted to solar radiation than silicon. Further, it is fascinating to think of superposing two or more materials. Cadmium sulphide is low in both material and fabrication cost. Gallium arsenic (GaAs) permits the decreasing of series resistance to a small value so its conversion efficiency would not drop marked by even under a high concentration of light. It also has a large output per unit weight. For each of these uses and possibilities, matched with the best features of each, may well be imagined, but none of these can compare with silicon in an all-around evaluation as a general use power source at the present time.

4. Present Status of R&D Schedule

The main problem for the industrialization of the solar photovoltaic generator is the crystal growth technique, but besides this there also exist various other important problems which need to be solved. They are: such technical problems as the preparation of raw material, solar cell fabrication and the assembling of solar cell arrays; such system problems as energy storage, collection and pursuit of solar radiation, and combinations with solar heat air-conditioning; and such social problems as the environment, architecture engineering, legislation concerning electric power supply, and its popularization policy.

As for preparation of the raw material, for instance, if 2% of the estimated total quantity of Japanese domestic power generation in the year 2000 ($1.5x10^{12}$ KWH), is to be furnished by silicon solar cells with a thickness of 100μ, 10^5 tons of polycrystal silicon is required, and this in turn requires, assuming a durable period of 20 years for the cells, a production capacity of 5,000 tons per year or 20 times the present capacity. On a global scale, it can give rise to a new resource problem. This constitutes a further motive for the development of the thin film technique. Further, an integration is being considered between the process of reduction and purification of the raw material and the process of ribbon crystal fabrication.

4-1. Japan's Sunshine Project

Concerning solar photovoltaic power generation, the penultimate goal is the development of a high-performance, low-cost system by around 1990. The target and content of the enforcement plan from 1974 to 1980 states that "Studies will be made on the technical feasibility of producing photovoltaic generator systems with a substantial price reduction equal to, or less than, 1/100 the present price if the system is fabricated by the present technology. For this purpose, research and development will be made on a new fabricating process for semiconductor crystals, on solar cell devices as well as on peripheral technology." The program was started with the following division of work:

(a) Basic research of solar cell;
----- Electrotechnical Laboratory,

– Silicon solar cell –

(b) Silicon ribbon crystal by vertical pulling;
----- Tokyo Shibaura Electric Co., Ltd.

(c) Silicon ribbon crystal by horizontal pulling;
----- Toyo Silicon Co., Ltd.

(d) Silicon thin film crystal of particle acceleration growth type;
----- Nippon Electric Co., Ltd.

(e) Silicon thin film crystal of particle non-acceleration growth type;
----- Hitachi Ltd.

(f) Compound semiconductor solar cell;
----- Matsushita Electric Industrial Co., Ltd.

(g) New type solar cell;
----- Sharp Corporation.

Besides these, research on solar cells composed of various kinds of compound semiconductors is to be undertaken at each of the above organizations. Further, under the management of Japan Electric Machine Industry Association, a research committee undertaking studies on utilization systems is to be created for the purpose of conducting surveys and research on other important technical problems, problems concerning utilization technology as well as social problems.

The total appropriation allotted to the Sunshine Project in the fiscal 1974 budget amounted to ¥2.4 billion ($7.2 million), from which expenses for the consignment of research and development to private sectors in the field of solar photovoltaic systems amounts to some ¥200 million ($0.6 million).

Also at universities and other research institutions, independently of the Sunshine Project, basic research such as on the development of solar cells utilizing new materials, solar cells with new structures, such as hetero-junction, etc., are beginning to be undertaken actively.

4-2. Present Status of R & D in the U.S.

Research and development of solar cells in the U.S. have been carried out by NASA and under its strong sponsorship, with the aim of power supply for space satellites, the accumulation of technology has been immense. In 1974, $1.5 million was spent for solar cell development, with about forty specialists engaged in research activities in this field at the Jet Propulsion Laboratory, Pasadena, Calif.; the Lewis Research Center, Cleveland, Ohio; and the Goddard Spacecraft Center, Greenbelt, Md. The direction of development in the above activities (for space stations) is somewhat different from that for terrestrial application, and lays more stress on such things as the weight factor, or output power density per kg, and protection against radioactivity, though, of course, some considerations are given to the lowering of cost.

As for terrestrial application, many research activities at universities and other institutions have joind the research and development program under the supervision of the National Science Foundation these past two or three years. NSF's expenditure for 1974 in the field of photovoltaic generation is $8 million. According to NSF's plan, by 1977, a level of solar-cell technology that could produce electric power at a cost of $5 per watt at the peak power output could be attained on the basis of refining present techniques. The goal by 1979 is to demonstrate the feasibility of dropping the cost by a factor of 10, to 50 cents per watt at peak power output. This would involve such new techniques as fabricating cells in continuous silicon ribbons. In 1981, a pilot line for manufacturing arrays with a cost of 50 cents per watt, and in 1986, a pilot line for arrays with a cost of 30 cents per watt would be started respectively, establishing a mass-production system in 1990.

Moreover, many private companies are conducting research and development in this field: Centralab., Heliotek Division of Textron Inc., Sylmar, Calif.; Solarex, Solar Power Corp., Braintree, Mass.; and Solar Energy Systems Inc., Newark, Del. Some oil companies have invested in the research activities at these organizations.

Achievements in price reduction have been announced by some organizations, but so far they are limited to refinements of the present techniques. Concerning silicon ribbons and silicon thin films, many organizations are now carrying out research. The most prominent among them is the research on silicon ribbon growth by the aforementioned EFG method conducted at Tyco Laboratories, Wattham, Mass. Further, the Westinghouse Research Laboratory is seeking funds to reactivate its research program for web growth methods, which was dropped about seven years ago.

4-3. Recent Events

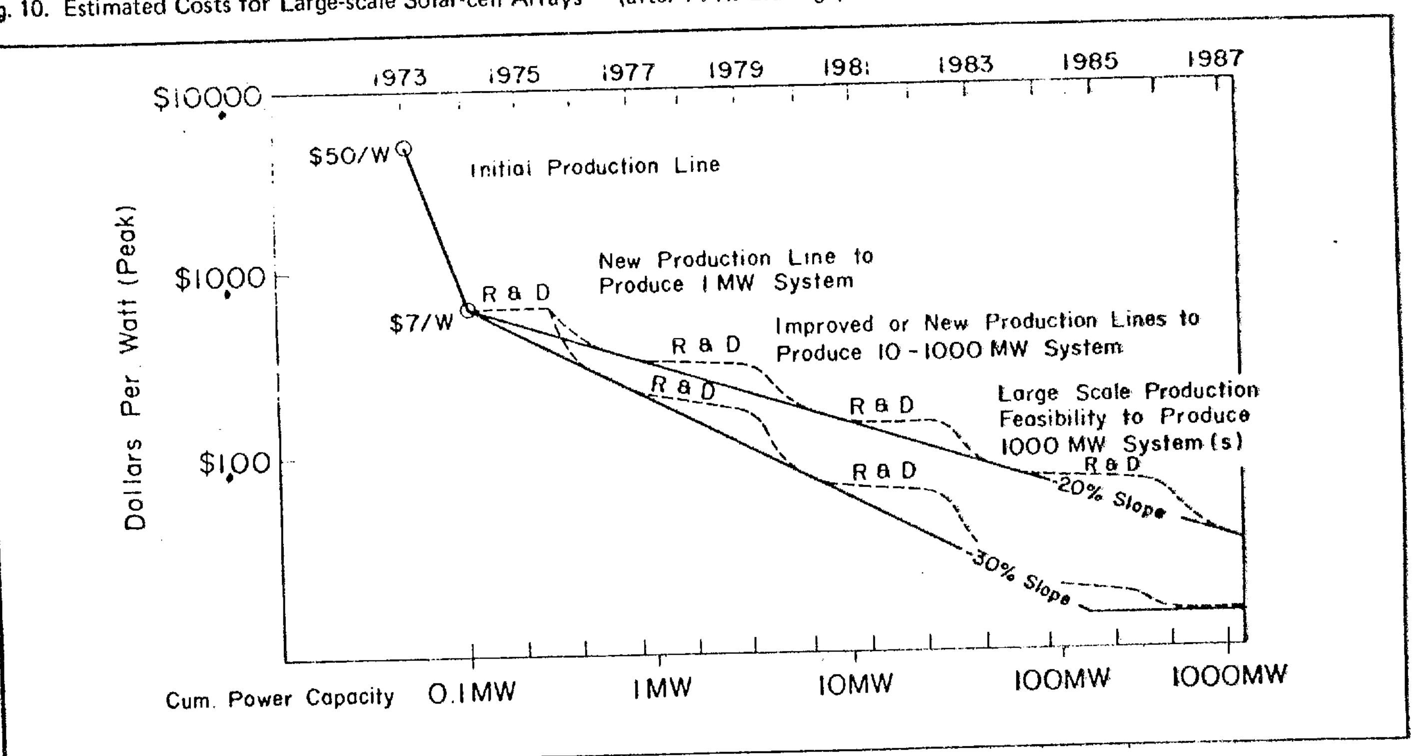
On October 26, last year, the "Solar Energy Research, Development and Demonstration Act of 1974" was proposed in the U.S. This includes an additional appropriation of $1 billion over 5 years, in which $54 million a year is to be spent for photovoltaic systems. Moreover, the negotiations for a joint venture by Mobil Oil Corp. and Tyco Laboratories, Inc., which was made public last summer, reached agreement and Mobil Tyco Solar Energy Corp. was established this Janaury. Owned 80% by Mobil and 20% by Tyco, the new company will develop and commercialize solar cells made of silicon ribbon fabricated by Tyco's EFG method. Mobil, it is said, intends to invest some $30 million over the next 5 years.

Also in Japan, a plan of Kyoto Ceramic Co., Ltd. for introducing Tyco's technology and establishing, together with two or three other companies, a joint enterprize for manufacturing silicon ribbons for solar cells was announced in past January.

In Japan, the national budget for fiscal 1975 is now under deliberation in the Diet. The unofficially announced total appropriation to the Sunshine Project is said to be only ¥3.7 billion. The amount originally demanded was ¥16.8 billion. In this field too, like other fields, the scale of developmental investment seems to be two figures smaller in comparison with the U.S.

In consideration of the fact that Japan has world's second largest semiconductor industry, and that the solar photovoltaic technology might provide a way out for Japan with its scarcity of natural resources and its ever mounting oil import bill, it is desired that development should be strongly advanced with a long range vision, undertaking sufficient examinations of its feasibility at each stage of development, and also obtaining a nationwide concensus on this plan.

Fig. 10. Estimated Costs for Large-scale Solar-cell Arrays (after F. R. Eldridge, the Mitre Corp.)



TO MR. CARY

FROM: Don

DATE 3 July 1975

SUBJECT:

SUSPENSE DATE

Letter to Daddario, OTA, encouraging OLC-channeled communication and transmitting requested materials.

NOTE:

Lyle raised the issue of our burgeoning contacts with OTA with Mr. Duckett personally and at a 9:00 meeting last week. Consensus was that we should keep these contacts within OLC channels. Mr. Duckett agreed to so inform
STAT [redacted] The attached letter to Emilio Daddario transmits information to OTA which was requested by one of their employees and also enunciates the new policy of dealing strictly through OLC. You may want to send a copy of the letter and revised memorandum to Mr. Duckett and to [redacted] STAT

Lyle approved the letter.

COORDINATED WITH (list names as well as offices):

Name	Office
Name	Office
Name	Office

ACTION REQUIRED BY GLC: Signature on letter

CENTRAL INTELLIGENCE AGENCY
WASHINGTON, D.C. 20505

OLC 75-1414
23 JUN 1975

MEMORANDUM FOR: Dr. Ronal Larson
Office of Technology Assessment
Congress of the United States
119 D Street N.E.
Washington, D.C. 20515

SUBJECT: Foreign Reference Material Relating to Solar On-Site Electricity Generation

1. Reference is made to the letter from the Director of the Office of Technology Assessment to the Director, Central Intelligence Agency, dated 11 April 75, relative to Congressional interest in the problem of utilization of solar energy for on-site generation of electricity and auxiliary heat. We are returning to OTA herewith a copy of the draft report on Solar On-Site Electricity which you left with us. Several analysts have read it and have made marginal notations. In addition, we asked fossil fuel and solar energy specialists on the staff of our energy consultants,
STAT [redacted] to comment on some of the comparative engineering economic data presented in the report; their observations have been included at appropriate points in the text. Inasmuch as our main focus is on the foreign technology aspects of the issues involved, we have limited our comments mainly to questions of technical fact and analytical considerations, except for the aforementioned remarks on costs.

2. We are also forwarding per your request the information on Japanese and Soviet solar projects which were described by [redacted] STAT
at the time of your visit on 15 May.

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SUBJECT: Foreign Reference Material Relating to Solar On-Site Electricity Generation

A resurgence of interest in solar energy utilization has now taken place within the Soviet government. In January 1974, as part of the May 1972 US-USSR Agreement on Cooperation in the field of Science and Technology, the two nations signed a protocol for Cooperation in the General Problems of Utilizing Solar Energy. Dr. Richard J. Green of ERDA is the US coordinator for joint solar projects. One of the three problem areas deemed appropriate for joint research is solar power stations, designated as Program I under the joint agreement.

The Soviets have reinstituted their own effort with plans for the construction of a solar power station with an output of 1-2.5 MWe. The former design (reflectors mounted on moving flatcars circling the base of a tower supporting a movable receiver-boiler) has been modified to reduce construction costs. The new design involves reflectors located in fixed positions around the base of a tower upon which a stationary tubular boiler is mounted. The heliostat system is made up of 1600 3-by-5m reflectors; the mirrors can be oriented on two axes and track via a photocell-activated servo system. The maximum radius from the tower to the outer circle of reflectors is 200m. The mirrors reflect the sun's radiation onto a boiler mounted on a 40m high tower. The boiler is a vertical cylinder, 7m high and 9m in diameter wrapped in a helical array of tubes. The system is designed to produce 11 tons/hr of super-heated steam at 400-500 deg. C and 35 atm.

The Soviets plan to generate 1.2 MWe with a non-condensing turbine or 2.5 MWe with a condensing system. No storage (either thermal or electric) is involved and the plant is expected to operate for 2000 hrs in the year. They anticipate that the overall conversion efficiency of sunlight to electricity will be about 17% (based on the following stated assumptions: mirror reflectivity, 0.78; interception of radiation by boiler, 0.9; optical absorptivity of boiler tubes, 0.9; thermal efficiency of boiler, 0.85; the efficiency of conversion of solar radiation to steam is about 55% from which, assuming turbine efficiencies of about 30%, the overall plant efficiency comes out to approximately 17%).

SUBJECT: Foreign Reference Material Relating to Solar On-Site Electricity Generation

Design studies are virtually complete and site evaluations for future construction have been performed. In addition, one heliostat assembly has been built and field-tested. Apparently, the Soviets intend to begin construction of a power plant with the above specifications in the near future. Individuals associated with the project have indicated that they believe cost to be the determining factor in the success of the system. Estimates for capital investment of 1000-2000 rubles/kW have been noted, compared with 150-180 rubles/kW for fossil fueled plants. (It should be mentioned here that this solar plant is tiny in comparison with normal Soviet power stations which tend to be of the order of 300-600 MWe and larger in capacity. The very large capital cost factor must therefore be viewed as quite unrepresentative of a large commercial installation to which the fossil fuel cost estimate probably does correspond.)

3. If there are questions concerning any of the enclosed references or comments, please feel free to contact us again.

STAT

Chief
Physical Sciences and
Technology Division/SI

Attachment: a/s