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New Sunshine Project and Recent Progress in Photovoltaic Technology in Japan

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EXCERPT

Developing clean energy technologies alternative to oil have become one of the most important tasks assigned to modern science and technology. The reason for this strong motivation is to stop air pollution from the mass consumption of fossil fuels and to protect the ecological cycles of the bio-systems on the earth. Views of future energy envision that the energy structure in the 21st century will be characterized by the "Best Mix Age" of various energy forms.

The Sunshine Project is a long-term, large-scale project scheduled to run from 1974 to 2000, with the goal of developing sufficient alternative energy sources to supply considerable portion of Japanese total energy demand in 2000's. It includes research and development subprograms for solar energy technologies, geothermal energy technologies, coal technologies, and hydrogen energy technologies. Among them, solar photovoltaics is one of the intensified theme in the renewable energy sub-project in the program.

This paper reviews recent advances in solar energy science and technology in Japan. Firstly, structure and organizations of the New Sunshine Project are introduced as a present feature of national new energy strategy. Secondly, the concept of "The New Sunshine Project" which will start in FY 1993 and aimed goal to 2010 for the purpose of both preserving the global environment and sustaining economic growth. This project consists of the three fundamental ideas of R&D innovation, so called "Eco-Energy City", a new kind of international collaborative R&D of a clean energy network, called "WE-NET" (World Energy Network) which includes the production of hydrogen by water electrolysis from photovoltaic or hydroelectric power generation in natural energy rich countries, the transportation of hydrogen to the requisite countries and the utilization of hydrogen. Thirdly, as an example of sub-project, recent progress of Solar Photovoltaic technology are discussed together with some key issues to achieve utility power application in the near future. Then, the current state of R&D in the improvement of performance are summarized, and expanding wide varieties of photovoltaic application systems are also overviewed. Finally, some possibilities to contribute the world wide environmental issues by the renewable technologies newly developed are postulated and discussed.

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1. Introduction

Developing clean energy technologies alternative to fossil fuels have become one of the most important tasks assigned to modern science and technology. The reason for this strong motivation is to stop air pollution from the massconsumption of fossil fuels and to protect the ecological cycles of the bio-systems on the earth. Views of future energy envision that the energy structure in the 21st century will be characterized by the "Best Mix Age" of various energy forms.

The Sunshine Project is a long-term, large-scale project scheduled to run from 1974 to 2000, with the goal of developing sufficient alternative energy sources to supply considerable portion of Japanese total energy demand in 2000's. It includes research and development subprograms for solar energy technologies, geothermal energy technologies, coal energy technologies, and hydrogen energy technologies. In fiscal year 1993, a re-organization of the national project has been made by combining the Sunshine and Moonlight Projects with the environmental issue new projects. Namely, the "New Sunshine Project" is scheduled up to 2020 with the estimated budget of 1.5 trillion yen.

The paper reviews recent advances in solar energy science and engineering in Japan. Firstly, structure and organizations of the New Sunshine Project are introduced. Secondly, some key issues to achieve utility power application in the near future are postulated from the analysis of the module cost transitions and expected technological innovation with the discovery of new materials. Then, the current states of R&D in the improvement of performance are summarized, and expanding wide varieties of photovoltaic application systems are also viewed. Finally, some possibilities to contribute the world wide environmental issues are postulated and discussed.

2. New Sunshine Program and Its Organizations

Agency of Industrial Science and Technology (AIST) in Ministry of International Trade and Industry (MITI), Japan has started the Sunshine Project in 1974 to develop new energy technology. The Project addresses all new energy technologies except nuclear. The main targets are the development of new technologies for solar energy, geothermal energy, liquefaction and gasification of coal, and the production, transfer, storage, and utilization of hydrogen energy. The project also includes research and development for wind and ocean energy technologies.

Moonlight Project has also started in 1978 to develop energy saving and efficient utilization technology. This project includes improvement of energy conversion efficiency, development of unused energy, and improvement of the efficiency of energy use by stabilizing the energy supply system. The project focuses on large scale energy conservation technology research and development, which deals with fuel cell power generation technology, heat pump technology, and applications of superconducting power technology.

Both projects successfully conducted R&D efforts for new energy generation and efficient utilization areas under the close cooperation of industry, government, and academic organizations including universities. These projects have been steadily providing useful results for basic science and technology, practical applications, and technical informations to peripheral fields.

AIST started the Research and Development Project on Environmental Technology in fiscal 1989 because reducing pollutions in environment has been a critical issue. The Research and Development Project for Environmental

Technology includes studies on carbon dioxide fixation by artificial photosynthesis, separations of carbon dioxide, suppressing of acid rains and biodegradation of chemical compounds.

Since the Sunshine Project has been started in 1974, wide varieties of remarkable progress have been seen in the solar energy utilization technologies. For example, in the Solar Photovoltaic Subproject, Japanese domestic annual production of the solar cells has increased more than one order of magnitude in the recent decade from 1.024 MW/year in 1981 to 20MW/year in 1992, and the factory shipping price of solar cells has been reduced as the New Energy Development Organization (NEDO) procurement prices from ¥4000/Wp in 1981 to ¥600/Wp in 1991.

People are seriously concerned about environmental issues such as global warming, which were caused by expanding socioeconomic activities. As a result, nations recognize that the environment as well as energy and natural resources are critical for sustaining the existence of not only individual countries, but also global scale issues for modern civilization life on the earth. From a long term, global perspective, every effort must be made to achieve technological breakthroughs to solve these problems in addition to socioeconomic issues such as the population increase problem, the North-South problem, the concentrated mass consumption of fossil fuels, and life style changes.

Considering the two sided nature of the energy strategy, that is, continuous growth of mass consumptions of the limited fossil fuels one side, and becoming severe the global environmental issues on the other side, AIST, MITI, Japan has decided to establish "New Sunshine Program" for the development of clean energy technology and environmental technology. Figure 1 shows a comprehensive structure of the new program and its reduction to the Sunshine Project which was formulated in May 1973, prior to the first energy crisis, and started in 1974, the Moonlight Project which was initiated in 1978 for the energy saving technological development, and also environmental technology project progressed from 1989. The past injected budgets are also inserted in the figure. While the new program consists of three parts; a) Renewable Energy Development Technology, b) High Efficiency Utilizations of Fossil Fuels and Energy Storage, and c) International Energy Cooperations, so-called WENET (World Energy Network) using hydrogen conversion and a wide area energy utilization network system nicknamed "Eco-energy City".

3. Program Structure and Objective of New Sunshine Program

Table 1 shows subprojects and their budget distributed in the fiscal year transition from 1992 to 1993. The total estimated budget up to the year 2020 is 1.55 trillion yen. At present, the budget mainly comprises innovative technology development. In future, however, budgets for the International Large Scale collaborative Research and the Collaborative R&D on Appropriate Technology programs will increase up to necessary amount.

The estimate also indicates that the maximum effect (by 2030) will contribute one third of the total energy consumption in Japan and reduce total carbon dioxide emissions by half. Figure 2 shows a log term scenario for the reduction of carbon dioxide emissions by New Sunshine Project with each step of the technological development. Among the many subjects in the clean energy generation and energy conservation technologies that have studied in the Sunshine Project and the Moonlight Project, solar cells and fuel cells show a "positive circulation", or favorable synergistic effect. The development of these technologies led to an increase in demand and a reduction in cost, which was triggered by major recent technological innovations. Nevertheless, full scale introduction of the technology still requires lead time to establish sufficient production capacity and develop adequate marketing. Therefore, the research and development of solar cells and fuel cells must be accelerated to maximize their supply potential and realize the supply of energy alternatives to oil for the Global Warming Prevention Action Plan.

4. Solar Photovoltaic Program and Its Key Issues

Among a wide variety of renewable energy projects in progress, solar photovoltaics is the most promising one as a clean energy resource. It is pollution-free and abundantly available everywhere in the world, and even in space and also can be operated by diffused light. Figure 3 shows the organizations of "Solar Photovoltaic (PV) Subproject" being conducted by the AIST and MITI in Japan. The NEDO was founded in 1980 to accelerate the progress of Sunshine Project after the second oil crisis (1979). Its name was changed to the New Energy and Industrial Technology Development Organization in 1988 with an expanded area of development and a larger budget.

In 1990, a new organization, namely, "PV Power Generation Technology Research Association" (PVTEC) has been organized for the purpose of leading center of R&D in PV Project as an contract leading agent to private sectors. The program assignment in each organization office and their relationship is also illustrated in the figure. While proposals and R&D project result evaluations are made at many stages of committee meetings which consist of experts in the field. Some of committee names are also represented in the figure.

In FY 1993, a total budget of 7.2 billion ¥ (about 60 million US$) for PV-Subproject has been distributed to 12 industrial groups for the technological developments and also 2 government institutes and 6 university groups for the basic research of PV technology. Figure 4 shows plots of solar cell annual productions in Japan since 1981 (3). As can be seen from this figure, the amount of annual production has been increased by one order of magnitude in these ten years, that is, the rate of annual increment is more than 130% in average, and the module cost has been reduced about one order of magnitude from 15,000¥/W_p (about 60US$/$W_p$,1976) to 900¥/$W_p$ (about 6US$/$W_p$,1986). The worldwide annual production data are also shown in Fig. 5.

Table 2 shows the cell and module efficiency records achieved as of May 1990 on three kinds of silicon basis substrate solar cells. While, laboratory phase small area top data are also shown in the parenthesis. On the basis of these module efficiency, the levelized electricity cost has been calculated by the similar method to that listed in DOE the Five Year Research Plan, the US DOE has established the goal of levelized current dollar cost of $0.12/kWh with the module cost of $1/$W_p$ (4). Japanese a-Si solar cell Technical Committee Meeting in Sunshine Project has also estimated separately long-term solar cell module cost target of ¥100-200/W_p (3), which roughly coincides with US DOE goal price, taking into account of the difference in electricity price (5).

To examine how realistic this cost target, an attempt has been made on the real module cost transition with mass production scale for three kinds of commercially available solar cells as shown in Fig. 6. The plots show about 30% scale merit for the CZ-c-Si solar cell, and the 25% scale merit of a-Si solar cell. An interesting result from the observation of these plots is that the $1/$W_p$ module cost goal reaches at 100MW_p/year for crystalline Si basis solar cell, while ¥100/W_p for a-Si solar cell also coincides with the result of feasibility calculation study by Sunshine Project Committee (3).

In a realistic cost forecast, further cost reduction is expected in the coming ten years as shown in Fig. 7 with blooming of the two steps of technological innovations. The first innovation in progress is based on low-cost polycrystalline technologies applicable to well developed single crystalline silicon solar cell fabrication processes. Another remarkable innovation we have seen in these ten years, is the a-Si thin film technology. Concerning these cost transition, a full use of the large scale merit might be the most important strategy to achieve the long-term goal by the year of 2000.

5. R&D Efforts to Improve PV Performance

As it has shown in Table 2, the production cost target of solar cell modules in the Sunshine Project is ¥500/W_p by 1995, and ¥100-200/W_p at the beginning of the year 2000 from the estimation at 1990. In order to achieve this target, tremendous R&D efforts have been in progress from raw materials, cell fabrication technologies to the photovoltaic system engineering. NEDO is a leading center of the Sunshine Project contract work for this purpose. Some subproject theme and their near term target aimed to 1992 are listed in Table 3 (5). While, results of recent R&D efforts are summarized as following;

(a) Low cost SOG-Si technology

i) Low cost solar cell grade silicon (SIG)

In a process for producing low cost solar grade silicon (SOG-Si) from tricloroshilane, a new type of fluidized bed reactor made of SiC-Si has been developed and is being scaled up from present 10tons/year pilot plant to 100tons/year aiming the cost reduction down to ¥6.8/gr. from ¥27/gr. With the 10 tons per year pilot plant material, a cell conversion efficiency of 18% or more is achieved on 10x10cm^2 substrate, while the laboratory phase 2x2cm^2 cell yield 20.5% top data.

ii) Poly-silicon substrate material manufacturing technology

The casting process has been improved by the production of high quality and large scale square ingots. Slicing technology has also been investigated. Continuous production technology for 30cmx30cm ingots and slicing technology have recently been studied. Regarding the spinning method, which requires no slicing, a high speed manufacturing process for producing 10cmx10cm sheet wafers has been investigated. With this casting sheet, 12.3% efficiency has been achieved so far. The cast cube poly-crystalline silicon solar cell by Kyocera has a 15.7% efficiency (5).

iii) High efficiency crystalline silicon solar cell technology

As has been shown in Table 2, more than 18% cell efficiency has been achieved in a recent few years. In the small area research phase cell for world top data, 21.9% (6) on the passivated emitter type cell by UNSW (7) and 19.8 by Hitachi on ordinary CZ wafer cell (8) have been achieved. Figure 8 shows the progress of the commercial basis c-Si solar cell efficiency in production. There are two ways for the cost reduction of the crystalline silicon solar cells. The first is to attain mass production and second is to develop methods required to improve cell efficiency. An intermediate determination made in 1985 documents that a solar cell with a 9% efficiency rate will be at the level of ¥700/W, assuming 10MW per year production level through the development of mass production technology. However, further cost reductions will not be possible through increases in production capacity. On the other hand, if a cell efficiency improvement of 1% is reached, more than 10% cost reduction should be obtained. The possibility of ¥500 per watts cost thus emerges, assuming 16% efficiency and the same level of present production costs for single cells or modules is therefore equivalent to the reduction of solar cell costs per output.

In the technological development of high efficiency solar cells, if an efficiency of 16% is obtained, the outlook for a cost level of ¥500 per watts will be possible. At present, 15.3% efficiency has been achieved from a solar cell using a casting substrate in which only the front surface is passivated by SiO_2 film of about 100Å thickness after textured etching.

(b) Progress of a-Si solar cell efficiency

In the amorphous silicon solar cells, there has been a noticeable progress in a recent decade with the invention of amorphous silicon carbide (a-SiC) and its heterojunction solar cell. Because this alloy a-SiC has not only valency controllability with impurity doping (p-n control), and also energy gap controllability with variation of carbon content in the system. A step-like improvement has been seen with a-SiC/a-Si heterojunction solar cell. This event opens up an amorphous silicon alloy age with a series of new materials such as amorphous silicon germanium (a-SiGe), microcrystalline silicon (μc-Si), amorphous silicon nitride (a-SiN), etc. (10). With these new materials, amorphous silicon solar cell efficiency is improving day by day as shown in Fig. 9. Table 4 shows mile stones of a-Si solar cell technology to be accomplished by FY 1993 for the utility power applications. According to a recent histogram of several thousands modules massproduction data (11), the in-line efficiency is being reached to 9%, and several institutes reported more than 10% efficiency for the $100cm^2$ or more area as the top data in a recent few years (12). While, the laboratory phase efficiencies are more than 13.2% with a-SiC/a-Si heterojunction (13), 13.7% for a-Si/a/SiGe stacked junction (14), and 15.04% and 21% for a-Si/poly c-Si two and four terminal stacked junction solar cells, respectively (15). The recent data are summarized in Table 5. Figures 10 and 11 show some examples of V-I characteristics of single junction cell and its stacked cell.

6. Expanding PV Application Systems

As it has been discussed in the previous section, the cost reduction by the massproduction scale merit would be the most important strategy. With reducing the solar cell price, a wide variety of new applications such as solar powered consumer electronics, water pumping and semi-power applications like air ventilations in house and car are recently in progress very quickly. Figure 12 shows electricity cost for the load-continuous 24hrs operation, equivalent on the present conventional power source and 1984 photovoltaic source reported by the Strategies Unlimited (16). In this figure, the forecasted electricity price at 1995 is also inserted by the author from the extrapolations of market size expansion prospect shown in Fig. 6. While, in the bottom area, the power size of some photovoltaic applications is also notified. A large scale photovoltaic power generation hooked up to utility grids would be one of the most promised system in future. For the purpose of system operation experiments and demonstrations, NEDO and the ANRE (Agency of Natural Resources and Energy) in MITI have organized to aid new investment for PV system development. These projects have proved the feasibility of intermediate and more large photovoltaic systems. In Japanese domestic area, more than thirty power plants are now operating from the power level of 3kWp to 200kWp. 2kW x 100 sets of the private house PV system operations are in progress at Rokko island by NEDO/Kansai electric power Co. 1MWp NEDO plant is operating well since 1986 at Shikoku-island. New challenges with full use of light-weight electricity generator have also made on sky, sea and land as shown in Fig. 13. The door to a new frontier is being opened now as we take a major step toward the realization of the limitless clean energy for future generation.

The results of these consideration indicate that the economically feasible age of photovoltaics will come unexpectedly early in the near future, if the continuous efforts are paid to promote R&D work and market pulls stimulations by means of government support with international cooperations. Anyhow, the most important emphasis should be placed on to stop the fossil fuel contaminations with a world wide scale energy policy and to grow up this newly born clean energy technology for our future civilization of mankind.

7. A New Role for Contribution to the Environmental Issue

As discussed in section 2, solar photovoltaic power generation is the most promised clean energy resource to maintain 21st century's civilization life in the earth. Therefore, the penetration of PV technology into the utility power generation might be the prime importance with the market size expansions by use of big scale merit of solar cells and PV system development. In fact, about two order of magnitude increase in solar cells domestic production in recent ten years as seen in comparing Figs. 5 and 6 has accomplished more than on order of magnitude reduction of the solar cell module price. These cost reductions have led to a great expansion of market size from consumer electronics to semi-power applications such as water pumping, remote power generator substituted to diesel electricity. With yield of feasibility in these semi-power application and full use of the maintenance free and fuelless significances of solar photovoltaics, many kinds of anti-pollution apparatus can be operated by solar photovoltaic power. For example, there are ashing of pollutant gas in air by the glow discharge decomposition and cleaning of water by electrochemical processing as shown in Table 6. Massproduction of the hydrogen energy is planned by utilization of solar photovoltaics in the Sahara desert (17). There exists a possibility to stop desertification by the photovoltaic water pumping with some plants of implantation. "Gobi project" has being organized for this purpose. The preliminary study team has started in 1990 to survey the natural conditions with a NEDO Gel Electrification project (18).

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Table 1. Program Structure & Budget of New Sunshine Project

	Sub-Project	Main Items	FY '92	FY '93
		Annual Budget (Billion Yen)	50.3	53.9
Renewable Energy Development	Solar Energy		7.0	7.7
		*Solar Cells & PV System	6.5	7.1
		*Solar Thermal Applications	0.4	0.5
		*Others	0.1	0.1
	Geothermal Energy		4.9	4.6
		*Binary Cycle & Dry Rock	2.2	2.2
		*Exploration & Extraction	2.7	2.4
		*Others	0.1	0
	Wind Energy		1.0	1.1
	Biomass,Ocean etc.		0.1	0.1
High Efficiency Utilization & Storage	Fossil Fuel Basis		17.6	17.7
		*Bituminous Coal Liquefaction	11.3	11.6
		*Integrated Coal Gasification	4.5	3.8
		*Coal Based Hydrogen	1.6	2.1
		*Others	0.2	0.2
	Fuel Cells		6.9	6.6
		*Solid Oxide and Polymer Electrolyte	4.3	5.0
		*Phosphoric Acid Fuel Cells	2.5	1.6
	Superconducting Power Storage		3.7	3.9
	Ceramic Gas Turbine		2.1	2.3
	Lithium Battery		0.3	0.8
WENET (World Energy Network)	Hydrogen-Fueled Turbine		0	0.2
	Hydrogen Generation by Water Electrolisis		0.1	0.2
	CO_2 Fixation		5.3	7.3
	NO_x Control System for Lean-Burn Engine		0.1	0.4
	Wide Area Energy Utilization System (Eco-Energy City)		0.1	1.0

Table 2. Tageted efficiency and mile stone of PV electricity cost in sunshine project

Efficiency & PV Electricity Cost \ Target Year		Present 1990	Near Term (1995年)	Long Term (2000年)
Solar Cell / Module Efficiency (%) $100cm^2$ Area Level (Top Data in R&D)	Xstal-Si	19 /17.1 (23.2)	22 / 18*	24 / 21
	Poly-Si	15.7 / 13.5	20 / 16	21 / 18
	a-Si	10 / 8.7 (12.0)	12 / 10*	14 / 12*
	Stacked a-Si [4T // 2T]	10.6 / 9.2 [16.8 // 15]	14 / 11* [20//18]	18 / 15* [22//18]
Production Scale(MW_p / year)		16.8	40	250
Module Cost (¥/ W_p)		650 ** ($5.0)	500* ($3.8)	100-200* ($1.5)
BOS Cost (¥/ W_p)		500 ($3.8)	350 ($2.7)	200 ($1.5)
System Life (Year)		20	22	25
Levelized Electricity Cost (¥/ kWh)		52.3 [115] (¢40/kWh)	35.1 [72] (¢27/kWh)	14.5 [26] (¢11.1/kWh)

* Sunshine Project Milestone ** NEDO Procurement Price

*** Annual sunshine period 1100hrs / year are assumed

[ ]: Included 6% interest for 20 years system life.

Table 3. Target for the next term of advanced solar cell fabrication technology development

Item		Target for 1993
Thin substrate	1. High-purity substrate fabrication technology	Impurity concentration: Oxygen: 2×10^{17} atom/cm^3 or less Carbon: 5×10^{6} atom/cm^3 or less Minority carrier diffusion length: 150μm or over Ingot size: 20 cm x 20 cm Substrate thickness: 200μm or less (Cell conversion efficiency (of 10cm square): 18% or over)
	2. High-speed substrate fabrication technology	Substrate size: 20cmx20cmx0.1mm Production speed: 1 wafer/min or over Cell conversion efficiency (of 10cm square): 14% or over
	3. New cell design and fabrication technologies	Polycrystal cells Cell conversion efficiency (of 10cm square): 18% or over Cell conversion efficiency (of 15cm square): 17% or over Monocrystalline cells: Cell conversion efficiency (of 2cm square): 23% or over
Tandem solar cells	1. Amorphous/polycrystal silicon tandem cell technology	Cell conversion efficiency (of 10cm square): 14% or over
	2. Amorphous/compound semiconductor tandem cell technology	Cell conversion efficiency (of 30cmx 40cm) 13% or over

Table 4. Target for the next term of amorphous solar cell manufacturing technology development.

Item	Near term technical milestone targeted by 1993
1. Higher quality	Degradation rate (after one year): 10% or less (Conversion efficiency of a 1-cm^3 cell: 13% or over
2. Larger area	30cm by 40cm submoduls conversion efficiency: 10% or over Degradation rate (after one year): 15% or less
3. High reliability	Degradation rate (after one year) 5% or less initial conversion efficiency (of 10cm square): 11% or over (Initial conversion efficiency (of 1cm^2): 12% or over)
4. Fundamental technology (1) Complex transparent conducting film	Transmittanee: 85% or over Pesistance: 5Ω/□ or less Plasma resistance: ±10% or less (of change in transmittance and resistance) Haze factor distribution: ±10% or less Substrate size: 30cm by 40cm Cost: ¥50/10cm square or less (at a yearly demand of 120 thousand square meters per factory, corresponding to 10MW)
(2) Narrow bandgap materials	Conversion efficiency (of 1cm^2): 4% or over (when a 5,000-A amorphous silicon filter is used)

Table 5. Summary of the Recent Achievement of a-Si basis Solar Cell performance in Japan (As of April,1993)

(a) a-Si Single Junction Solar Cells, R & D Phase

Voc (V)	Jsc (mA/cm²)	F.F.	η (%)	A (cm²)	Institute	Remarks	
0.967	17.7	0.703	12.0	0.033	Osaka U	p-μc-SiC (ECR)	['87]
0.857	18.7	0.749	12.0	1.0	Mitsui-T	multi-p layer	['90]
0.895	18.4	0.728	12.0	1.0	Hitachi	multi-p layer	['91]
0.89	18.3	0.74	12.0	1.0	Sumitomo		['90]
0.891	19.13	0.70	12.0	1.0	Solarex		['89]
0.927	18.4	0.705	12.0	1.0	Fuji-Elect	BF_3 Pulse CVD	['91]
0.90	18.9	0.72	12.3	0.09	TIT	δ-doped p layer	['90]
0.923	18.4	0.725	12.3	1.0	Fuji-Elect	Pulse CVD;p-a-SiC:H	
0.899	18.8	0.74	12.5	1.0	Fuji-Elect	p-a-SiO:H	['91]
0.885	19.13	0.747	12.65	1.0	SEL	Reverse Bias;Annealing	['91]
0.887	19.4	0.741	12.7	1.0	Sanyo	Superchamber	['92]
0.909	19.8	0.733	13.2	1.0	Mitsui-T	$(p\text{-}a\text{-}Si:H / p\text{-}a\text{-}C:H)_n$	['92]

(b) a-Si Solar Cells, Single Junction Submodule

Voc (V)	Jsc (mA/cm²)	F.F.	η (%)	A (cm²)	Institute	Remarks
12.53	130.1	0.735	12.0	10 x 10	Sanyo	TCO improvement
12.55	116.3	0.699	10.2	10 x 10	Sanyo	Superchmaber TMB
2.409	611.6	0.686	10.1	10 x 10	Mitsubishi	a-Si / a-Si / a-SiGe
53.9	328	0.714	10.05	30 x 40	Fuji-Elect	a-Si / a-Si, a-SiO p layer
39.41	426	0.67	9.3	30 x 40	Fuji-Elect	IVE
			10.0	10 x 10	Sanyo	Through Hole Contact Cell
			11.1	10 x 10	Sanyo	n / i interface H Treatment

(c) a-Si basis Stacked Junction Solar Cells

	Jumction Structure	Voc (V)	Jsc (mA/cm²)	F.F. (%)	η (%)	Institute
2 Terminal	a-SiC / a-Si	1.75	8.16	71.2	10.2	Solarex
	a-Si / a-Si	1.80	9.03	74.1	12.0	Fuji
	a-SiC / a-SiGe / a-SiGe	2.20	7.90	68.0	11.8	Sharp
	a-Si / a-Si / a-SiGe	2.32	7.30	73.0	12.4	Sumitomo
	a-Si / a-Si / a-SiGe	2.55	7.66	70.1	13.7	ECD
	a-Si / poly-Si	1.33	15.6	64.0	13.3	Osaka Univ.
	a-Si / c-Si	1.48	16.2	63.0	15.0	Osaka Univ.
4 Terminal		0.871	16.4	72.0	10.3	
	a-Si // $CuInSe_2$	0.432	17.4	68.0	+ 5.3	ARCO
					15.6	
		0.917	10.4	76.0	7.25	
	a-Si // poly-Si	0.575	30.2	79.2	+ 13.75	Osaka Univ.
					21.0	

Table 6. Contributions to the global environmental issues by PV

Local	(1) Solar PV power generation	Clean sustainable Energy resource
↑	(2) Cleaning of air pollution	Ashing of pollutant gases by the glow discharge decomposition by PV
Environment	(3) Cleaning of water	Electrochemical processing by PV
↓	(4) Generation of hydrogen energy	Electrolyze of water by PV
Global	(5) Stop of the desertification Greenery of the desert	PV Water pumping with implantation

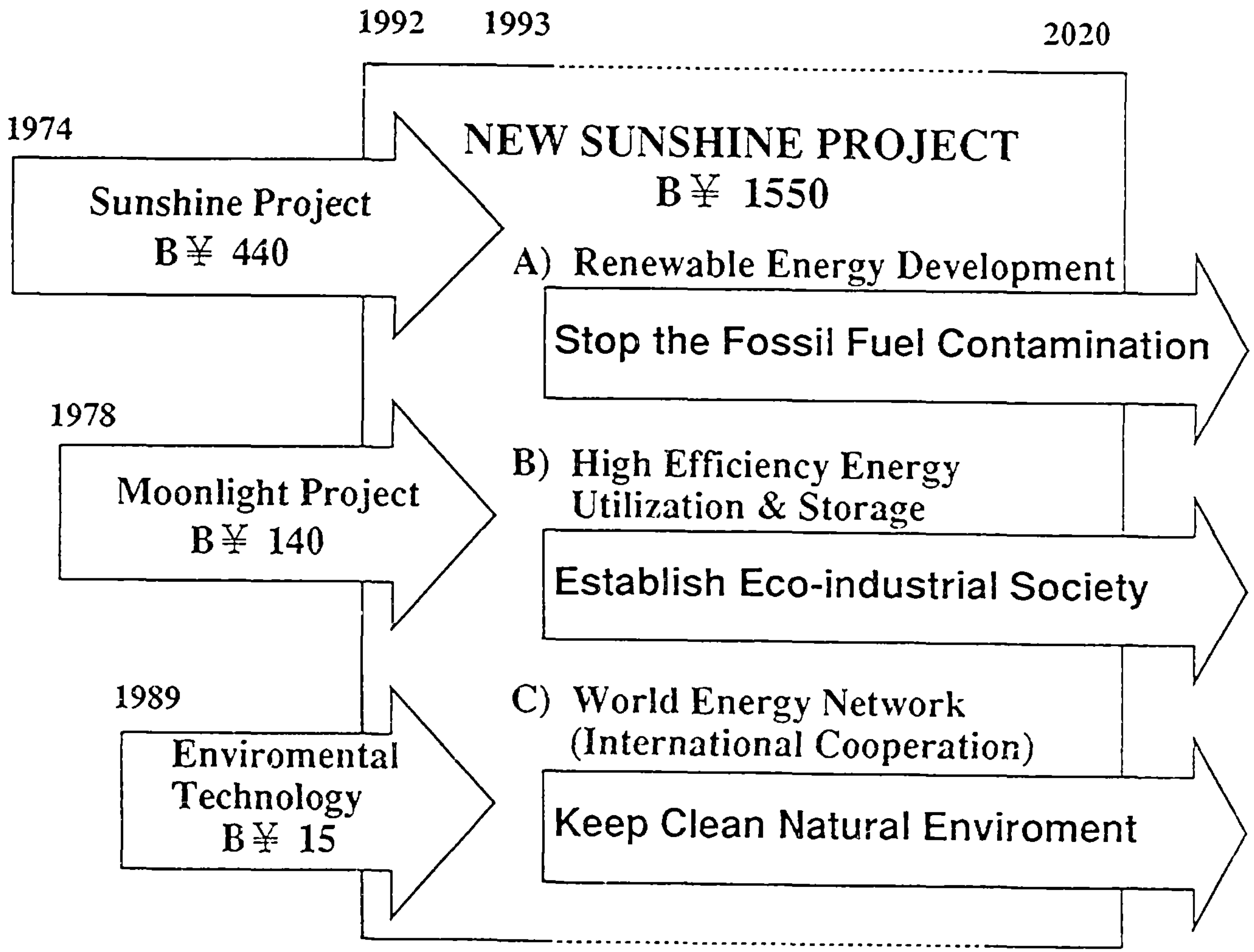


Fig. 1. Organizations and Objectives of New Sunshine Project

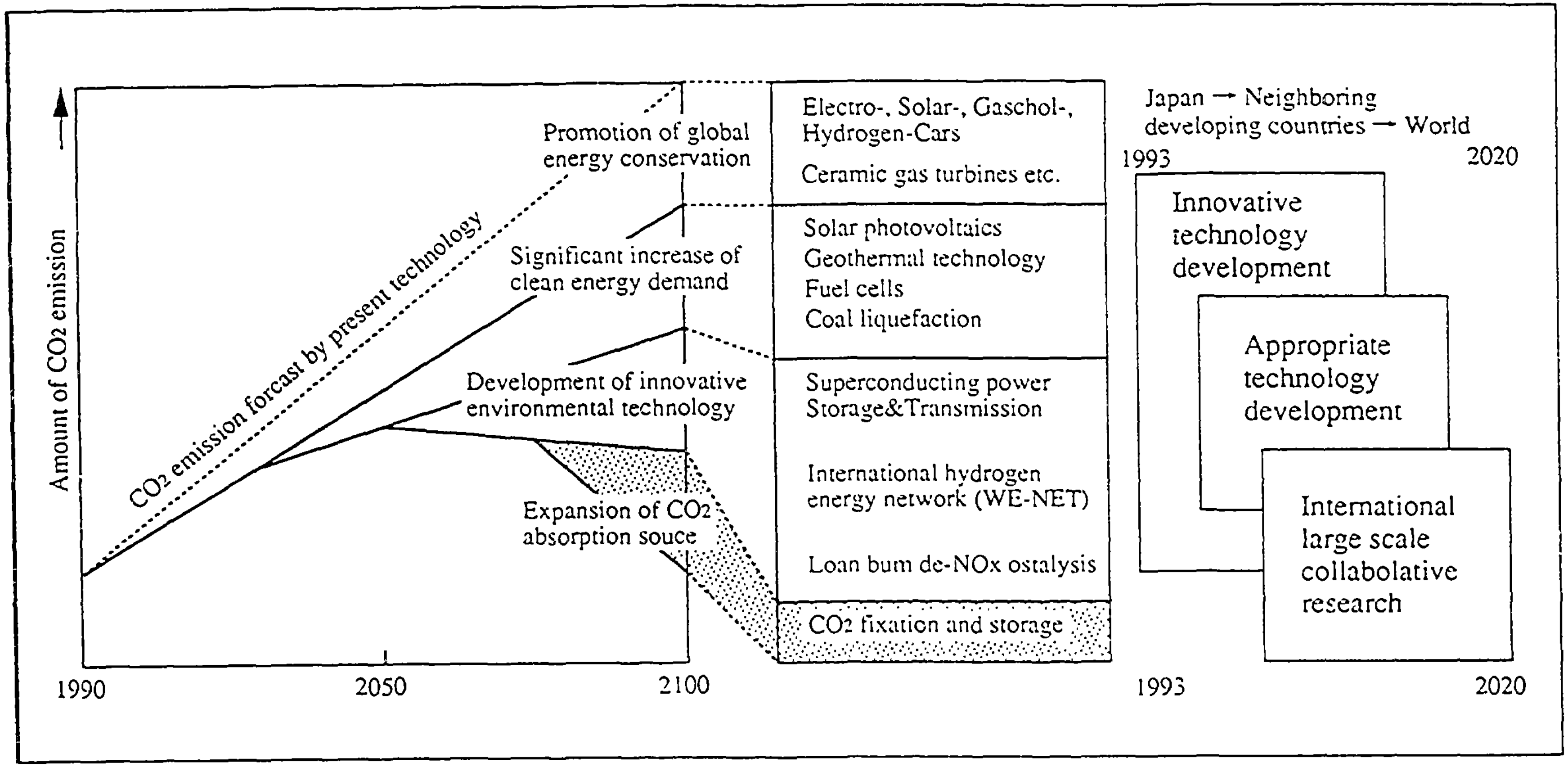


Fig.2 Contribution to the reduction of CO_2 emission by New Sunshine Project

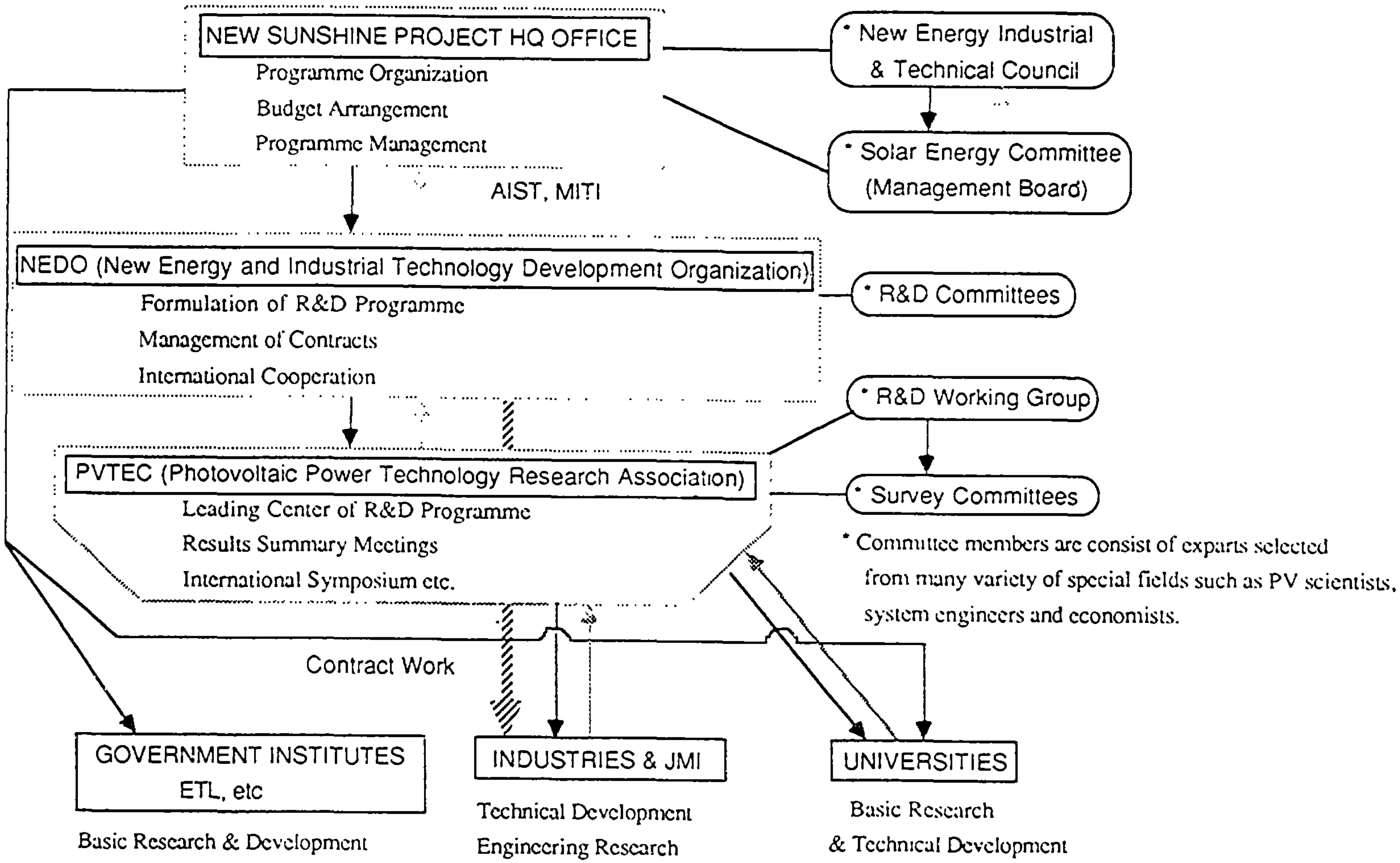


Fig. 2. PV subproject organizations and relationship between program lead centers and contractors.

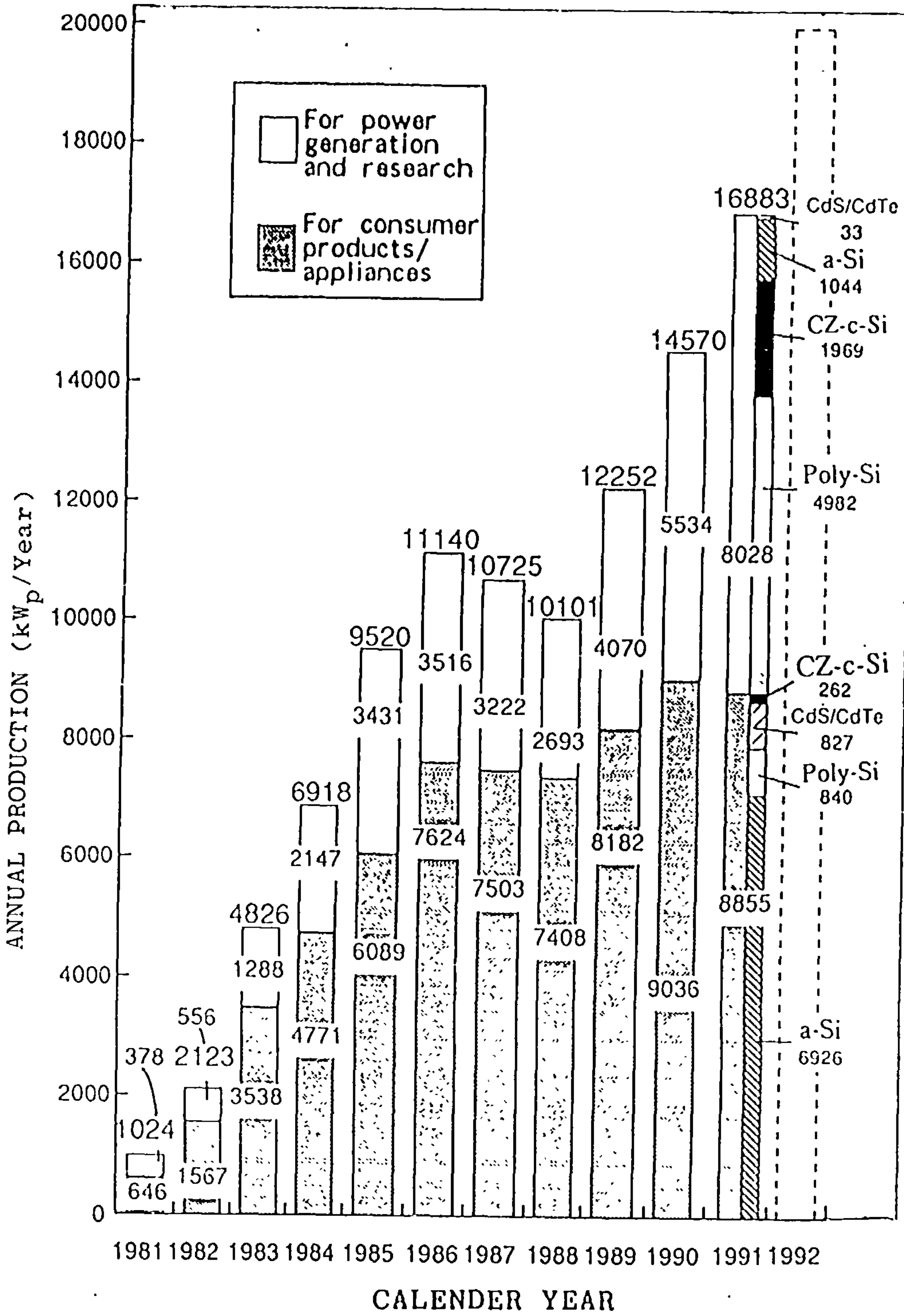


Fig.4. Transitions of solar cell annual production in Japan.

注）生産量の表示出力は各種太陽電池のAM1.5入射1kW／m²条件下で出力換算した値であり、各社のアンケート調査を集計したものである。

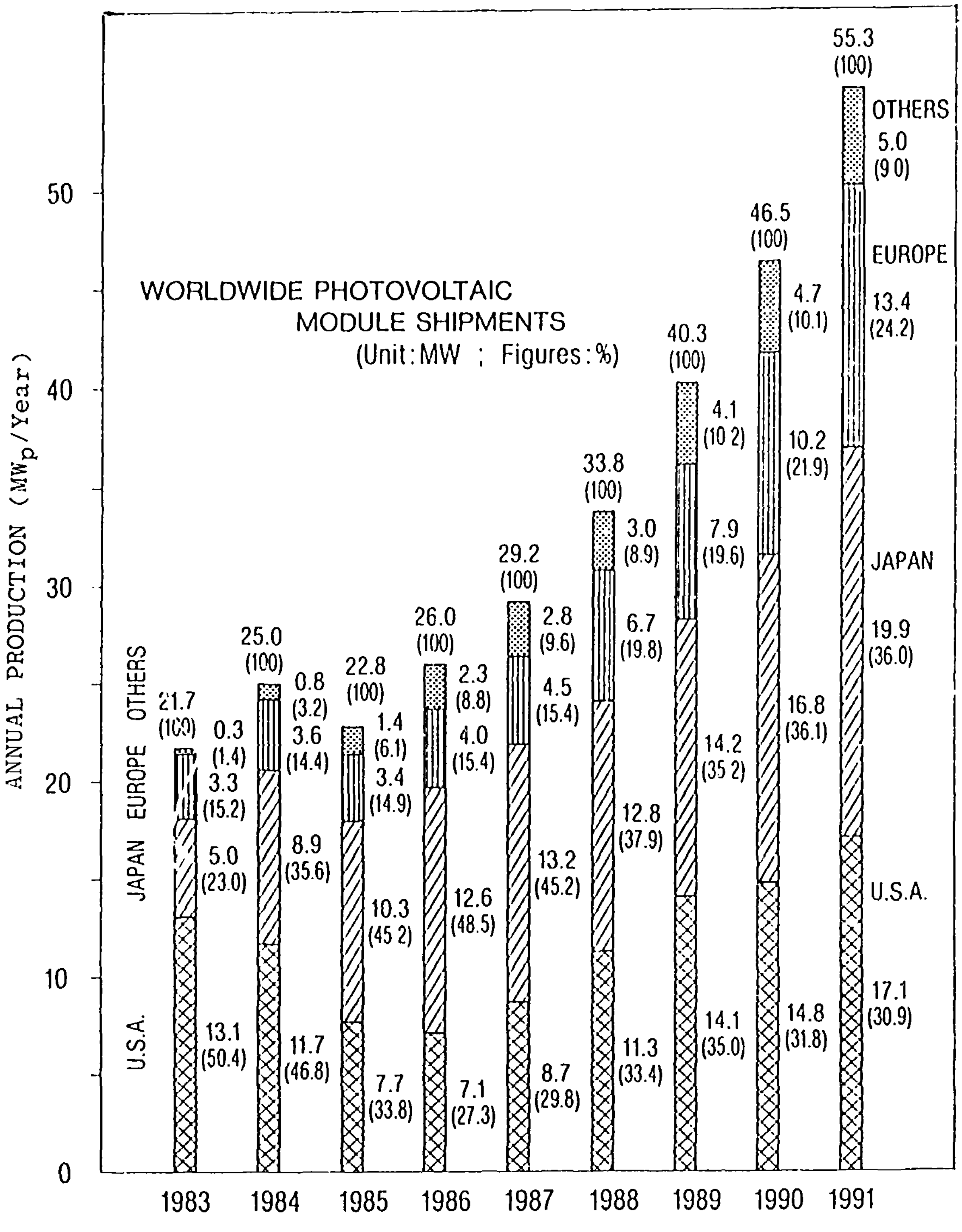


Fig.5. WORLDWIDE PHOTOVOLTAIC MODULE PRODUCTION

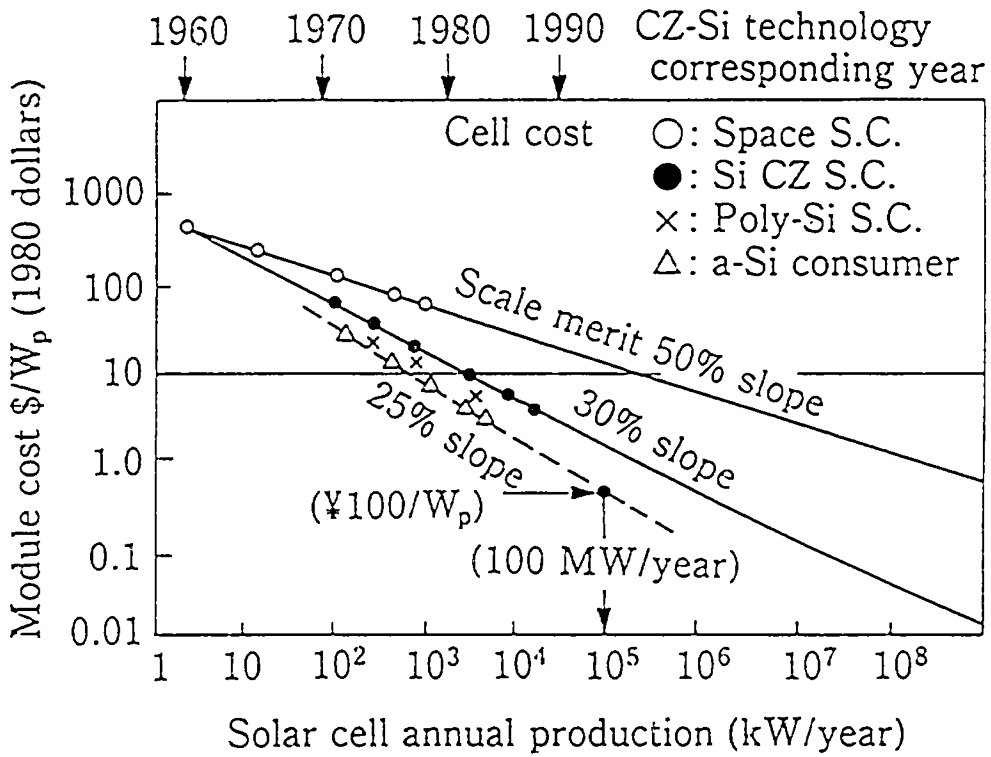


Fig.6. Reduction of solar cell module cost with increasing production scale. The "scale merit" in the figure means the percentage of cost reduction with an increase of one order of magnitude mass-production scale in the factory.

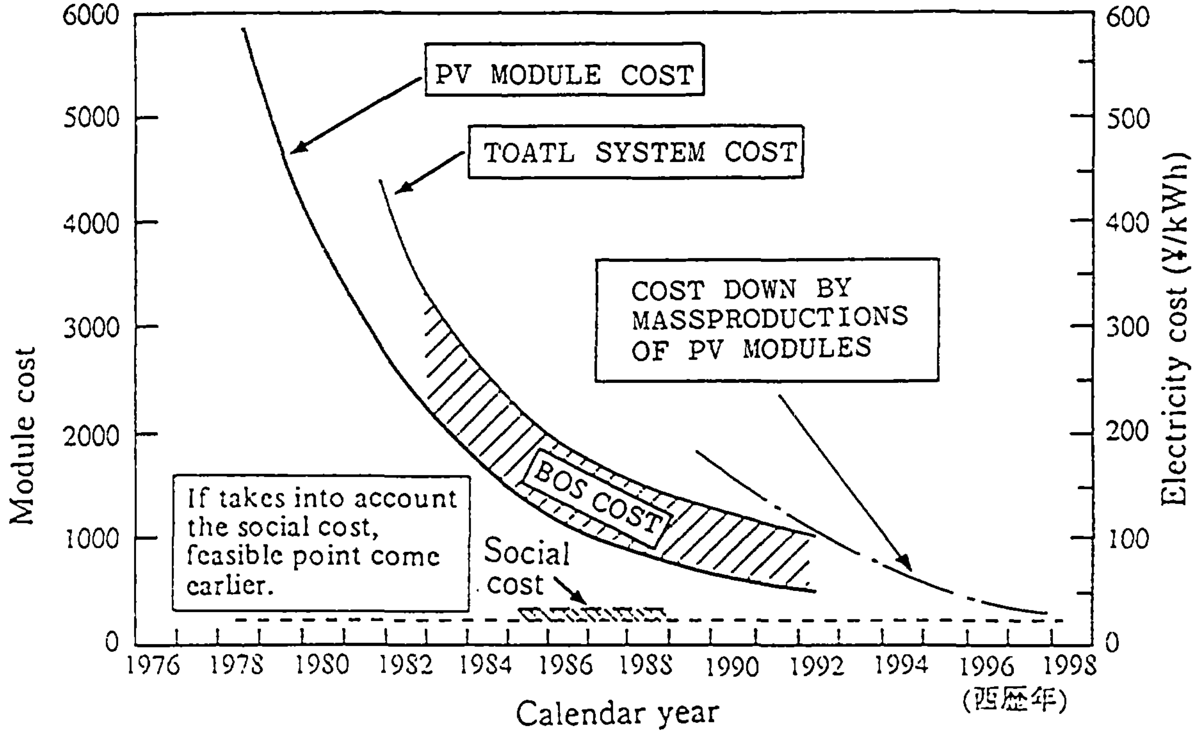


Fig.7. Transitions in solar cell module cost and electricity cost and their projections with technological evolution and forecast market size expansion.

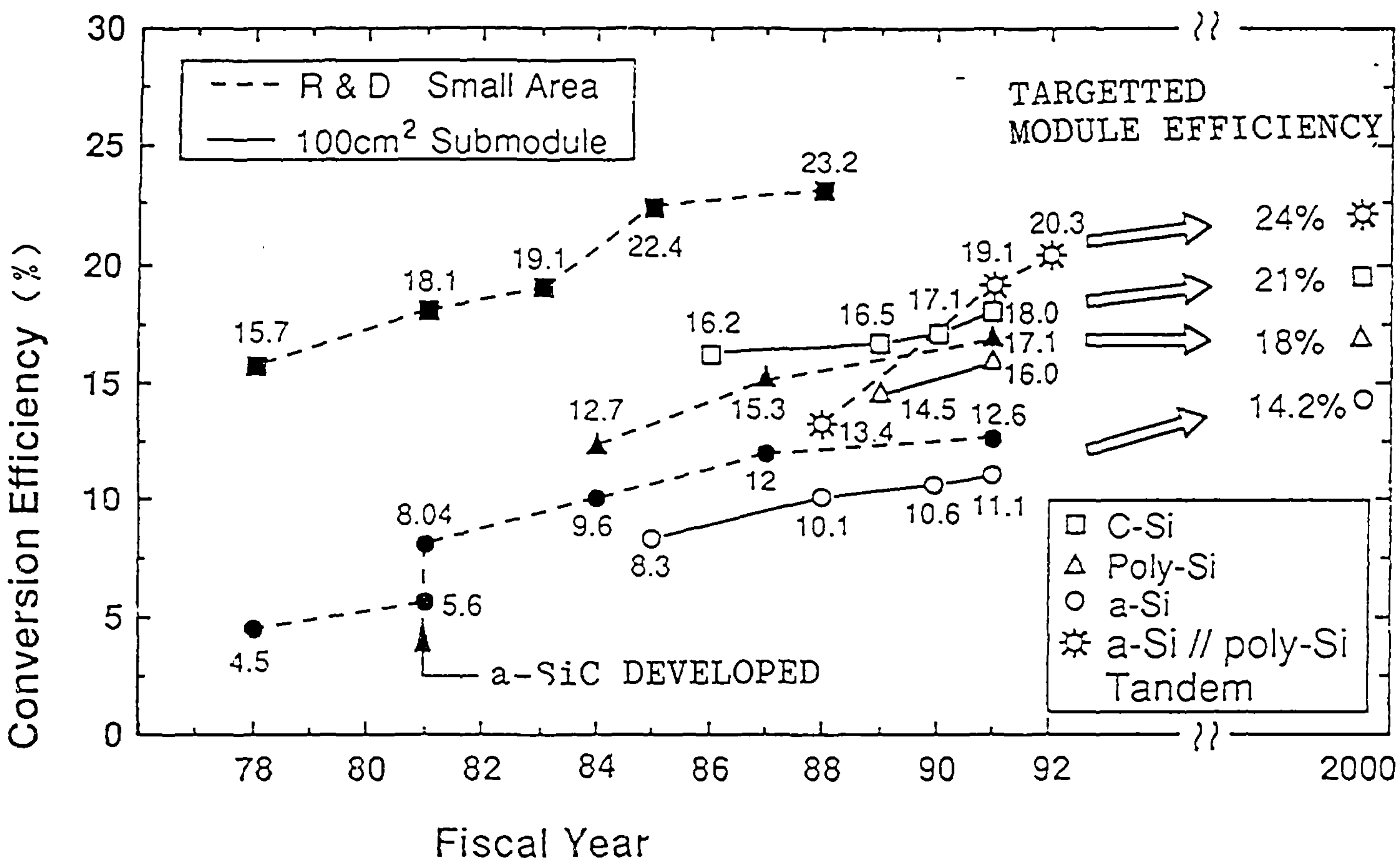


Fig.8. Transitions of solar cell efficiencies in R & D phase of small area cell (solid) and large area cell(open)

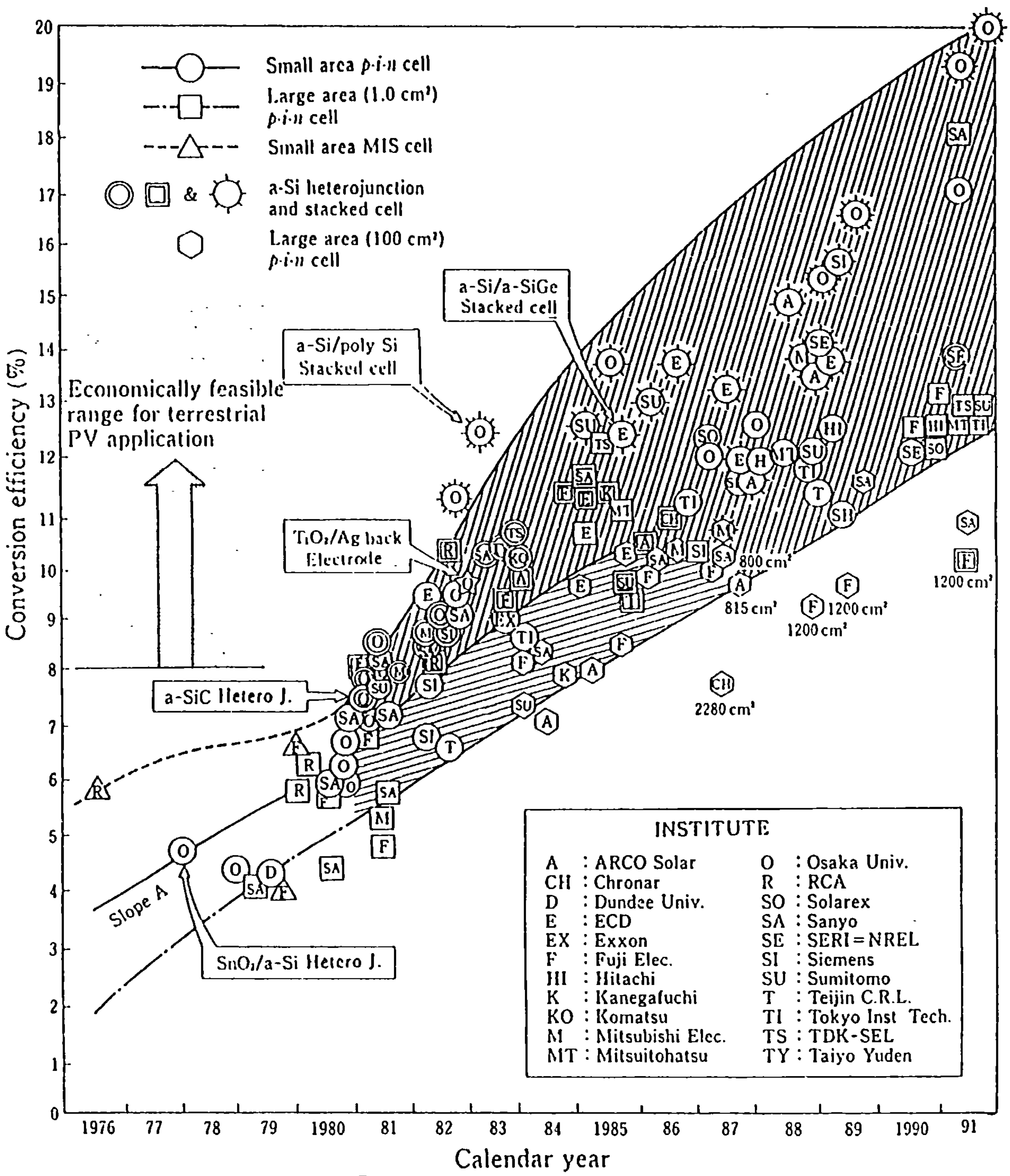


Fig.9. Progress of a-Si solar cell efficiencies for various types of junction structures as of August 1992. A steep slope change is seen with the appearance of a-Si alloys such as a-SiC, μc-Si, or a-SiGe

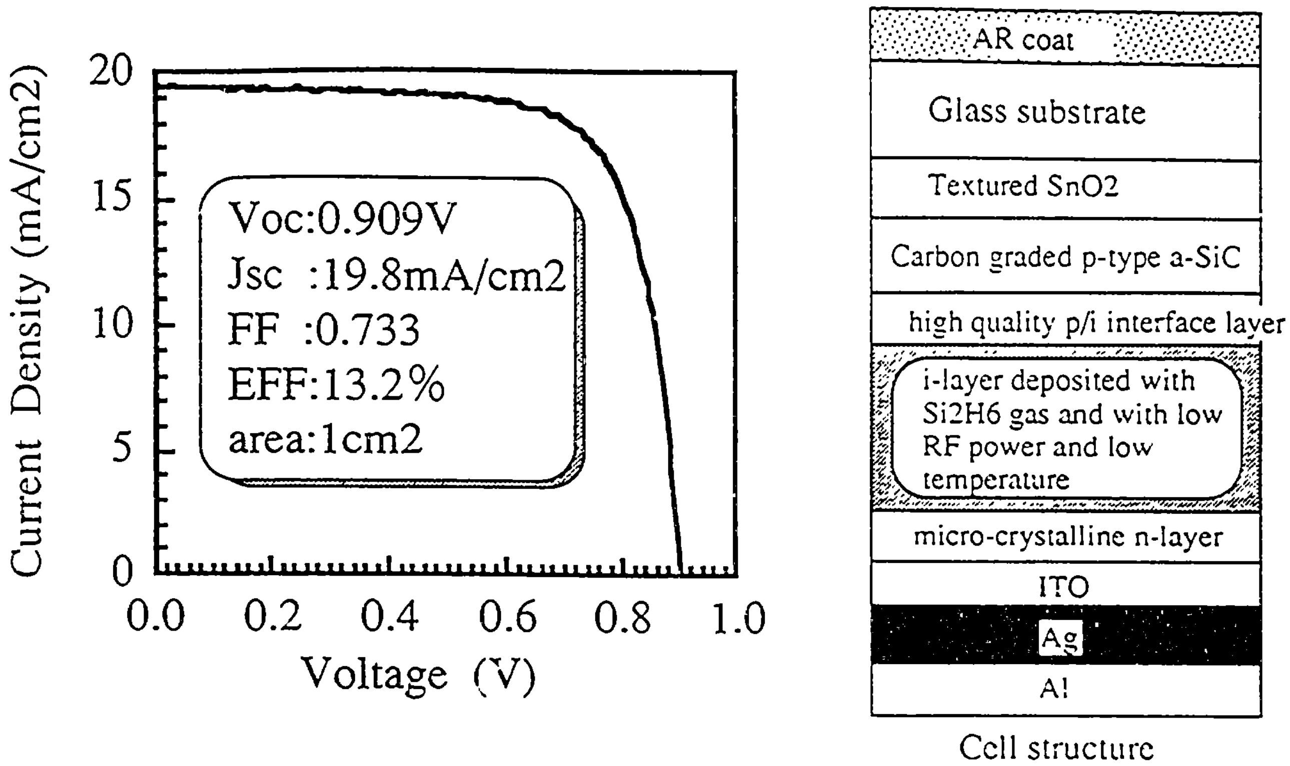
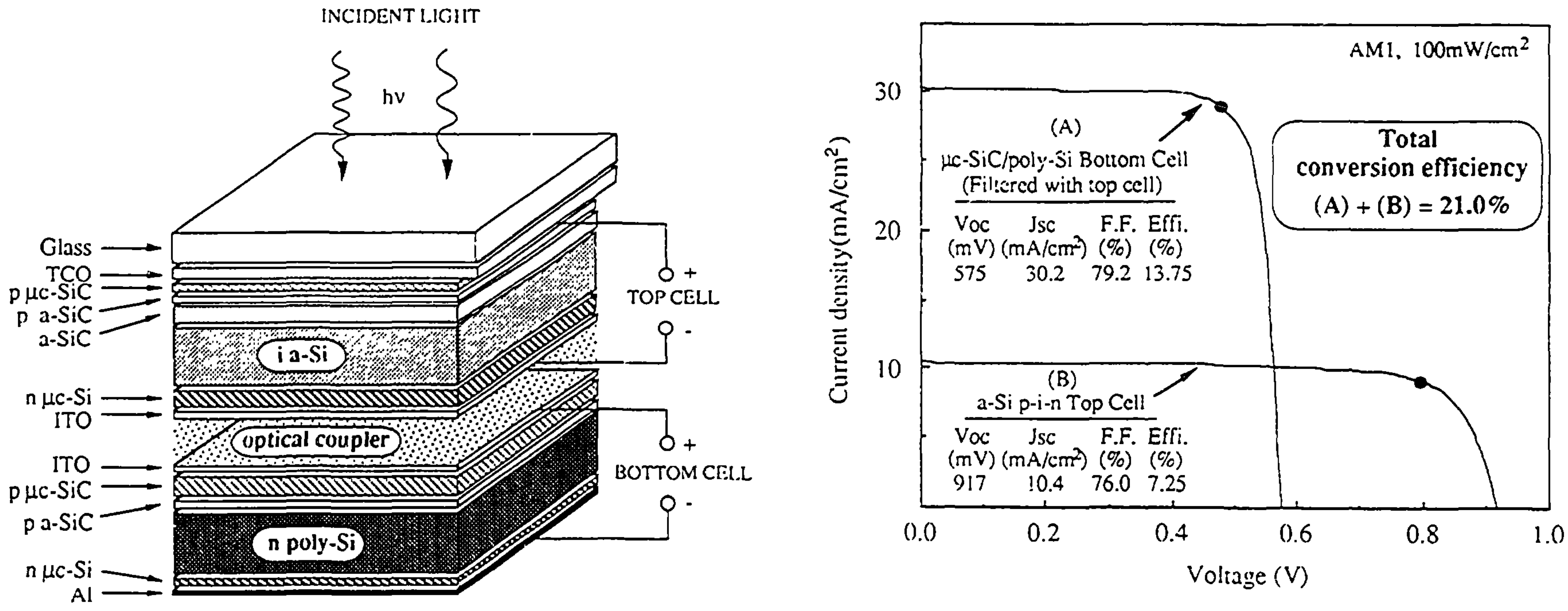


Fig.10. I-V characteristics of single junction pin type a-Si solar cell with highest conversion efficiency

(Mitsui Toatsu Chemicals, Inc.)



(a) (b)

Fig.11 . Junction structure (a) and the output characteristics (b) of the a-Si // poly-Si four terminal tandem solar cell. (Osaka University)

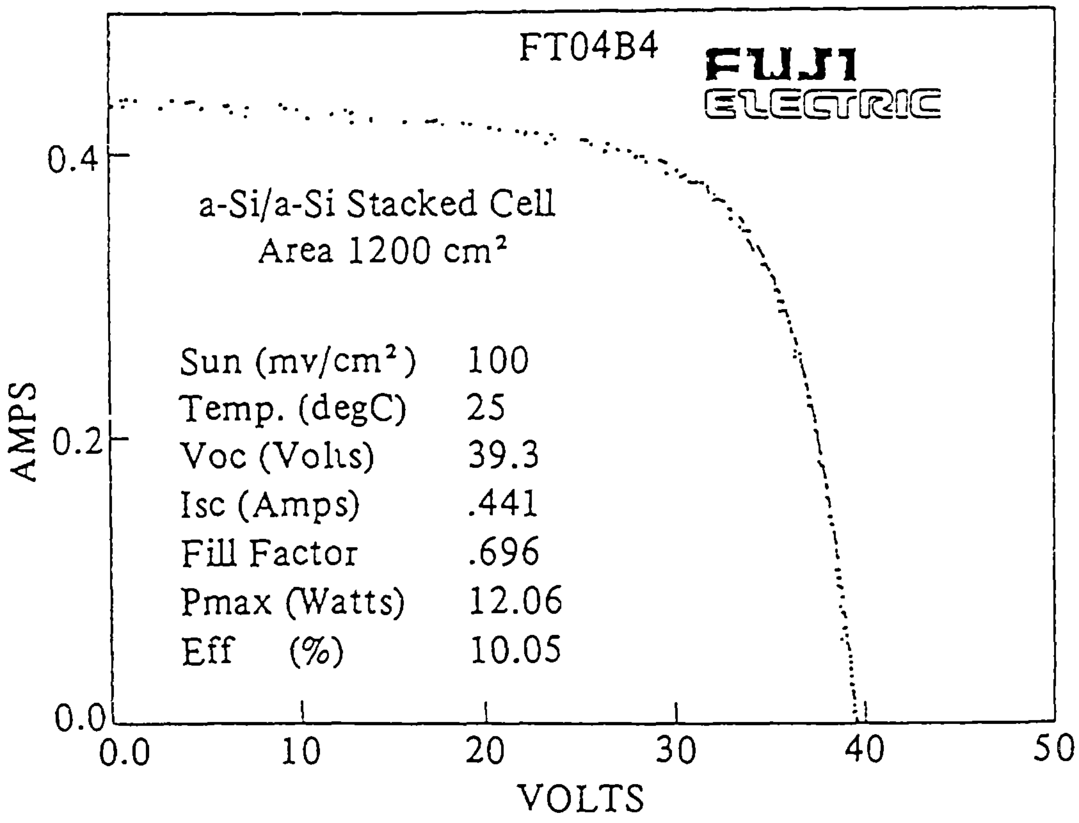


Fig.11(c). V-I characteristics of large area a-Si/a-Si stacked Solar Cell having more than 10% efficiency. (Fuji Electric Co.Ltd.)

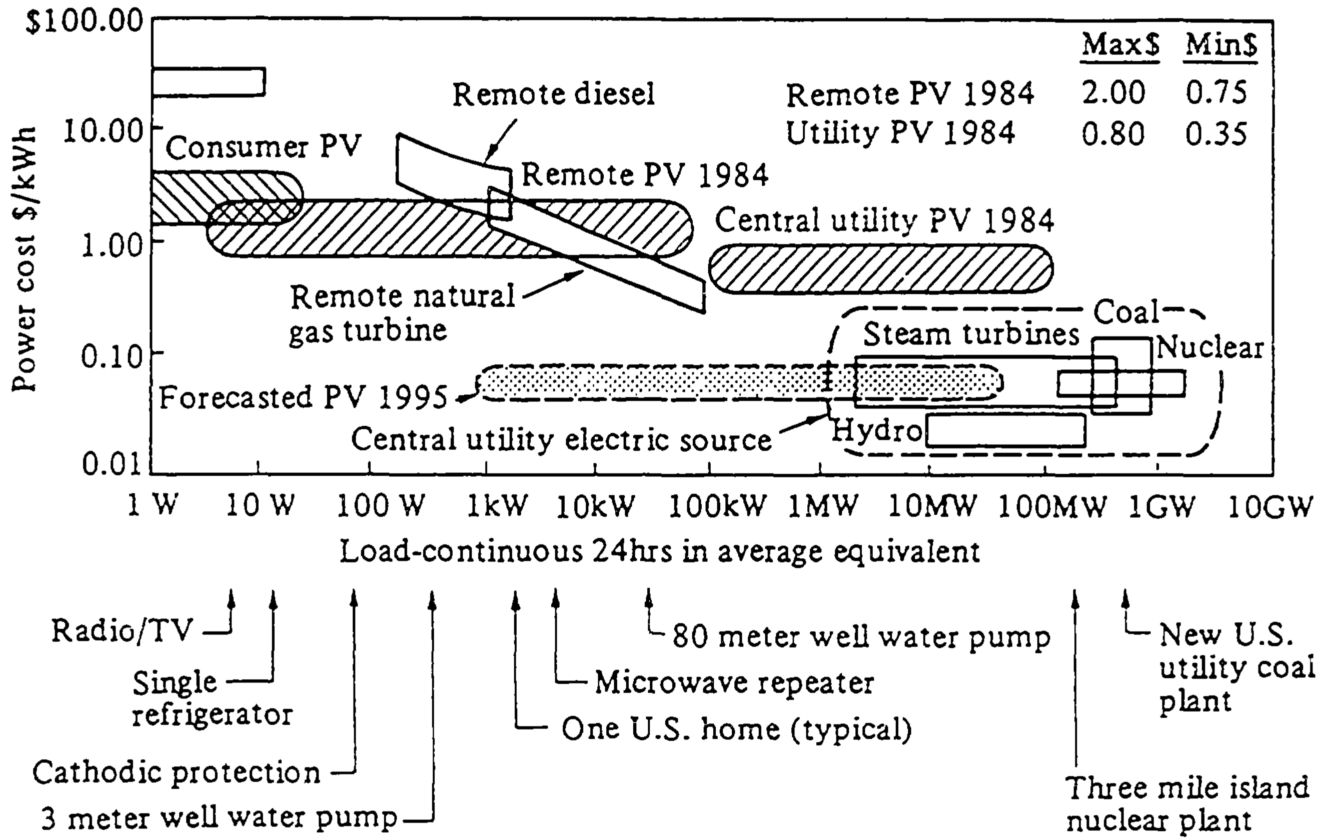


Fig.12. Economic domains for selected photovoltaic-powered applications and their typical power levels.

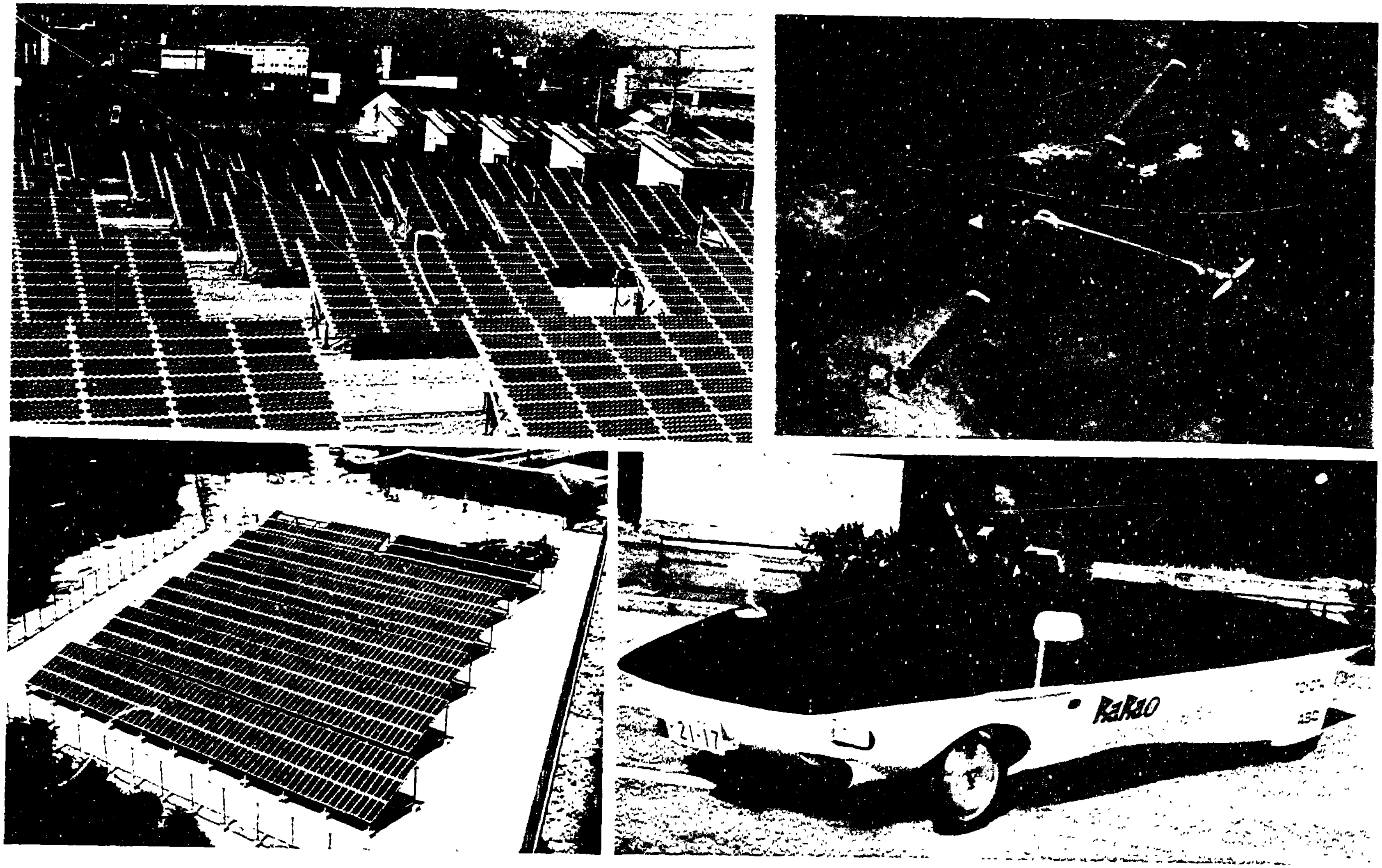


Fig.13. Some topics in the PV system technology development: (a) 200 kW (2 $kW_p \times 100$ houses) demonstration and test facility for dispersed small scale PV systems (Rokko island, Hyogo Prefecture). (b) 200 kWp island bulk power supply in Tokashiki island, Okinawa Prefecture. (c) "Tanpopo-go" a-Si solar cell powered engine plane flying over the USA in September 1990. (d) The first town drive solar car "RaRaⅡ-go" Gold Prize awarded at Asahi Solar Car Rally held on October 10th, 1990.

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Summary

A review is given on current state of the art of solar energy utilization technology in Japan. Program structure and organization of the "New Sunshine Project" are introduced. Technical mile stones and some key issues to achieve this objective are also demonstrated. Then, recent results of R&D efforts in the solar photovoltaic subprojects are summarized and discussed. Finally, present state of the arts in the photovoltaic system development and its industrializations are also overviewed together with possible new approaches to contribute the global environmental issues by the photovoltaic technology.