Direction of Solar Photovoltaic Technologies

By Kurokawa Kosuke

1. Introduction

Japan's solar photovoltaic technology development has its origin in the first oil crisis of 1973 and began in earnest in 1994 with the country's "Sunshine Project." It is worth noting that when the project was launched, the government set an exceptionally long-term national goal of 2000. In a bid to reduce the cost of solar cells to one-100th of what it was, the consistent national project has succeeded in accumulating a wide scope of technologies. The creation of a subsidizing scheme for residential photovoltaic (PV) systems in fiscal 1994 acted as an engine for the expansion of the domestic solar PV market. In line with a decline in PV system prices, the percentage of subsidies was reduced in phases until fiscal 2005, when the aid scheme was completely abolished. Nevertheless, Japan is still regarded as the largest solar cell producer in the world today.

In the belief that it is essential to set a long-term goal for energy technology development, as was the case when the "Sunshine Project" was launched, this writer has proposed creating a long-term goal with its target year set at 2030. This proposal, nicknamed "PV2030" Roadmap,[(1),(2)] has served as a bible for the continuation of aggressive technological development. The direction of solar PV technologies presented here is that it should aim at achieving competitive price levels not only for residential use but also for industrial use (14 yen / kWh) and wholesale electricity (7 yen / kWh) so that by 2030 solar energy will supply at least some 10% of total electricity needs in Japan.

2. "PV2030" Roadmap

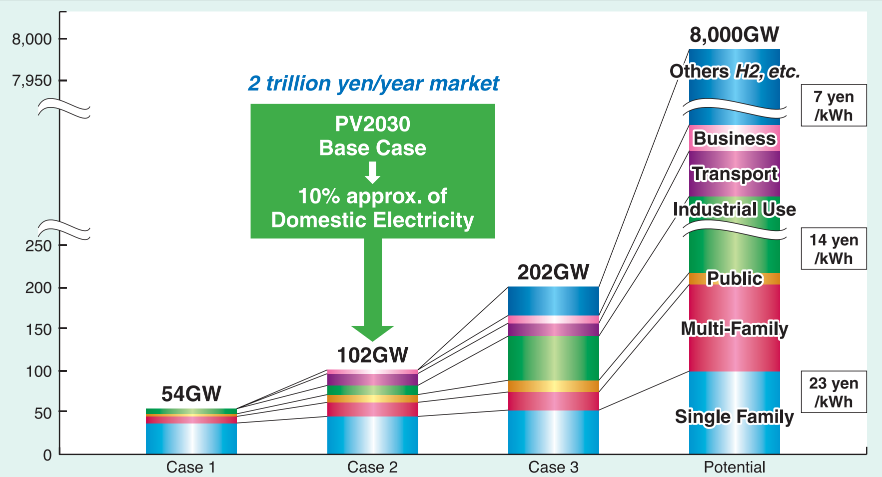
The basic concept of "PV2030," which was established in 2004, is that it has set as its standard case an output level of 100 million kW (100 gigawatts=GW), an amount accounting for approximately 10% of Japan's total electricity supply in 2030. To make this possible, total domestic physical potential (total potential space in Japan where solar PV facilities can be installed) was calculated, and target performance and price levels were set by taking into account competitive electricity prices and technological specifications[(2)] as required by the nature of locations of solar PV equipment.

In *Chart 1*, the bar on the far right indicates the total physical potential (installable space), which is broken down into different types of solar PV use. In this bar, the portions for industrial use and "others" (unused land) are shown in half-broken, discontinuous squares. The total potential adds up to 8,000 GW in terms of solar PV system capacity, an annual electricity production level equivalent to about eight times Japan's gross electricity supply.

Based on the assumption that introduction of solar PV systems will start with residential use (23 yen / kWh), for which competitive electricity prices are the highest, this writer has adopted the scenario that the cost of solar PV electricity will fall to the level of industrial use (14 yen / kWh) by 2020 and to that of wholesale electricity (7 yen / kWh) by 2030.

Case 2 in *Chart 1* indicates a pattern of PV system introduction in the case of 100 GW achieved in 2030, which is the basic scenario under "PV2030." Based on this scenario, it is assumed that by 2030, solar PV systems will have been installed on slightly more than 40% of the rooftops of all single-family houses. Then, it would be natural to assume that there will be many communities in which the penetration ratio of PV systems will be nearly 100%. Moreover, because PV output capacity will fluctuate depending on the amount of sunshine available, the

Chart 1 Installable PV capacity assuming technological development up to 2030 [(2)]



Case 1: Business as usual
Case 2: R&D and market penetration according to PV2030 Base Case
Case 3: Accelerated R&D and market penetration with large–scale industrial use
Potential: Physical limit by residential, public, industrial, unused land, etc.

Source : *6DP2.5, 19th EU-PVSEC, Paris, June 7-11, 2004* need to maintain stability in the power grid system is very likely to pose a constraint to further PV introduction as the penetration ratio rises. This may also act as a constraint to improving the profitability of PV power generation.

Chart 2 shows a roadmap for technological development that will enable generational shifts in solar PV technologies, which will be necessary to realize the scenario based on the above-mentioned pattern of PV introduction.[1] Cost reduction for solar PV power depends primarily on the technology of manufacturing solar cells and the PV market size. There will be a significant difference in the ultimate production cost between technological optimization during the period of a relatively small market and mass production technology intended for a large market. If the intrinsic speed of production converted into solar cell capacity increases while at the same time the market size becomes large, the amount of initial investment will not be a major problem. The problem then will be how to control running costs, such as those of materials and operation. For cost reduction on solar cells, it is essential to improve the quality of technology and boost the market size in a balanced manner.

Long-term plans under "PV2030" require solar cells to attain the above-mentioned costs of electricity generation as a major goal of the project. Therefore, individual targets are set for each factor. For example, targets for solar PV modules are 100 yen / W by 2010, 75 yen / W by 2020 and 50 yen / W or lower by 2030. At the same time, the plans envision the possibility of the emergence of diverse solar cells, ranging from bulk crystalline silicon (bulk c-Si) to thin-film silicon (TF-Si) and CIS (copper-indium selenium) or similar advanced TF cells, and set module conversion efficiency and cost goals for each type. Envisioning a breakthrough in technology, these plans have not ruled out more light-sensitive solar cells. For TF bulk crystalline silicon cells, for example, they require a module conversion efficiency rate of 22% (25% for cells) and the cost of 50 yen / W, and call for solar cells as thin as 50 microns to avoid excessive dependence on the silicon feedstock industry. The envisioned solar-cell conversion efficiency is equivalent to the efficiency that will enable the installation of approximately 8 kW of solar PV power on the rooftop of a single-family house, a PV level enough to meet whole electricity needs of an all-electric home.

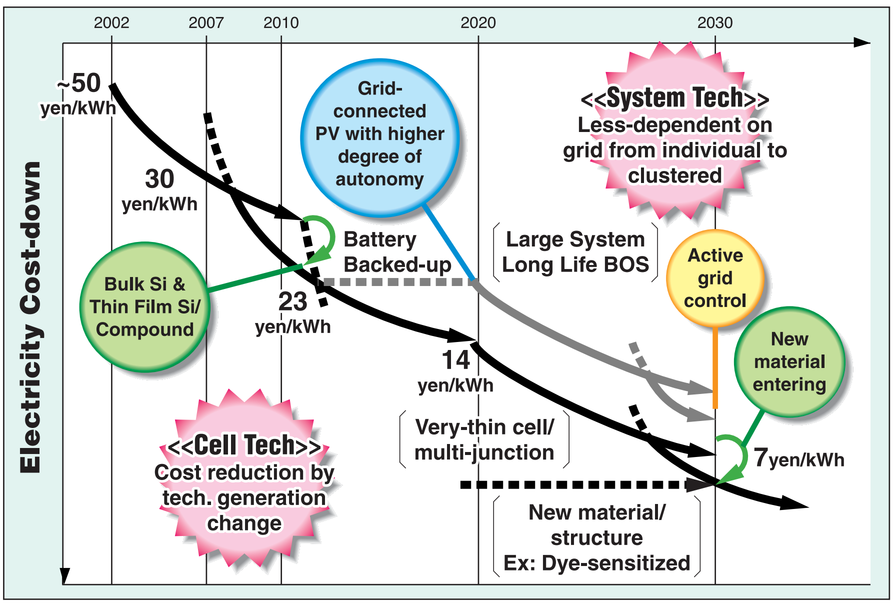
3. Regional- & Global-scale Deployment[3]

In a "regional-scale deployment approach," the so-called "autonomy-enhanced PV cluster (AE-PVC)" will be adopted to build community networks[4-7].

- In or around 2030 when conversion efficiency in a residential area comprising mostly single-family dwellings approaches the level envisioned in the "PV2030" Roadmap, all-electric homes will meet their power needs with solar PV power alone.
- In order to attain a 100% solar PV penetration ratio in a residential area, it is necessary to build a regional power grid network in which all domestic load and PV power are linked into a coherent whole.
- This means that the network must have active power electronic functions to allow free mutual power flows in all directions.
- Any difference between electricity demand and solar PV output in the network as a whole is to be autonomously equalized by a battery storage system installed in the area.
- As an advanced concept, the development of power routers is desirable so that such routers will allow free and mutual sharing of electricity with neighboring regional networks. These will act like hubs on the Internet.
- From the viewpoint of an external network, a regional network can be operated at the point of connection as a single, well-controlled power source or a load. This therefore should greatly increase the value added of a regional network in entering into a connection agreement. This also means that a network meets technological requirements for equalizing seasonally fluctuating supply and demand by using a power pool.
- A community like the one shown in *Chart 3* (on the next page) will be able to fully utilize its solar PV potential for itself. This is exactly what we call a "solar PV town or city."

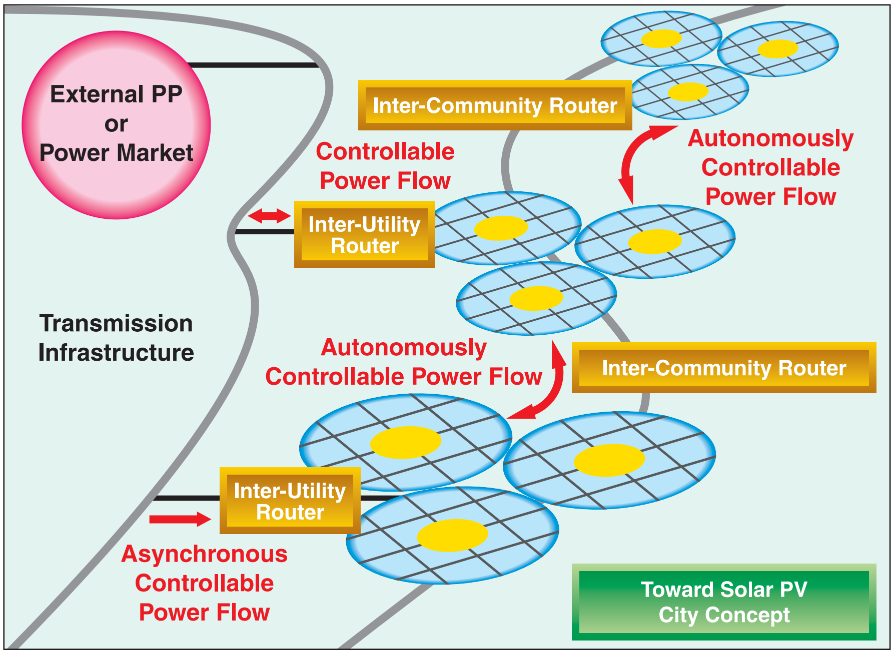
With respect to a "global-scale deployment approach" to solar PV power, especially for 2050 and beyond, this writer has suggested the possibility of global-scale deployment through the use of

Chart 2 Cost-cutting scenario through technology shift toward 2030 [1,2]



Source : "Overview of 'PV Roadmap Toward 2030'" (NEDO); 6DP2.5, 19th EU-PVSEC, Paris, June 7-11, 2004

Chart 3 "Solar PV City" – Extension to wide-area autonomous network (5)–(7)



Source : *International Solar City Conference, Oxford, UK, April 3-6, 2006; WCPEC-4, Hawaii, April 8-12, 2006; Microgrid Symposium, Nagoya, 2007*

large-scale energy networks based on an autonomous and distributed logic, rather than a centralized logic. For this purpose, the author has conducted in-depth and many-faceted research mainly within the framework of joint research through the International Energy Agency (IEA). [(8),(9)]

- For solar PV power to become a core of principal renewable energy sources in the second half of the 21st century, a scenario has been created in which a very large-scale PV system (VLS-PV) will be introduced to deserts and other unused land in phases and in a sustainable manner.[(8)]
- In realizing this plan, it has been proposed that in building solar PV systems with output of 1 million-1.5 million kW, a gradual scenario be written: rather than building the total system at once, it should be expanded from year to year. This means that capacity to be installed each year will be obtained by dividing the total output by the number of years of the average usable life of each solar PV module (20-30 years).[(8)]
- Under the scenario, a module plant capable of producing the volume of modules required each year will be built in the neighborhood of a PV system region and, thereby ensuring sustainable regional development and stable employment, it will be possible to realize ultimately a large-scale solar PV region. Since such a region will be able to sell electricity to neighboring regions by maintaining an equilibrium between scrapping and renewal of modules, the region will be able to operate, maintain and renew the system on its own on a sustainable basis.[(8)]
- Methods have also been examined for effectively using electricity generated in deserts and other regions in combination with technologies for pumping water and desalination to realize advanced irrigation systems for agricultural development. Efforts are being made to optimize development scenarios by devising a socioeconomic evaluation tool that organically links diverse factors.[(9)]

4. Conclusion

Neighboring regional power grid systems may be autonomously controllable with localized sensing through the use of the power router technology mentioned earlier. By the end of the 21st century, such systems will develop into a global network.[(9)]

For the world's six largest deserts, including the Sahara and Gobi, remote sensing by satellite has been used to select regions which can be used for solar PV power (namely, flat areas without sand hills). It has been found that total annual PV power output in such regions could reach 420 trillion kWh a year. This figure is greater than the 400 trillion kWh in global annual consumption of primary energy expected in 2100.[(9)]

The realization of solar PV supply systems with such attractive potential will require the development of new elemental technologies and a new concept of networking infrastructure. When these requirements are met, solar PV systems, centering on VLS-PV, will autonomously develop into a global network after 2050, contributing to sustained development and peace of the world.[(7)] Of renewable energy sources that are the only alternatives for the survival of the ecosystem of this irreplaceable Earth, solar PV power is bound to play the important and powerful role of the fourth hitter in a baseball game. JS

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