

TECHNOLOGICAL DIFFUSION OF RESIDENTIAL PHOTOVOLTAIC (PV) SYSTEMS IN JAPAN

Yoshinori Inoue and Kumiko Miyazaki

Graduate School of Innovation Management, Tokyo Institute of Technology, 2-12-10
Meguro, Tokyo 152-8550, Japan

ABSTRACT

This paper analyzes the diffusion of residential photovoltaic (PV) systems in Japan focusing on the value chain and the technological trajectory as well as the interaction between technology and markets. This will allow recommendations on proper technology policies and management to solve global warming to be made. By using a techno-economic framework, the business system approach is used in this paper, focusing on efficiency and effectiveness. In our methodology, trend of patent applications and productions, technological trajectories, running costs based on the concept of learning by doing and motivational factors for PV adopters were analyzed. The research findings include: (1) Technological imbalances within the PV system are solved by technological innovation; (2) In a technological evolutionary process, technological diversification progressed without falling into core rigidity problems, led by the development of the national Sun Shine Project; (3) the diffusion of PV systems has reached the take off phase. Based on the research findings, we propose that it is necessary for the actors to receive incentives to create the market. Public relations activity that operates on raising individual environmental awareness and establishing an institutional electricity power buy back program are needed.

Keywords: Diffusion; Photovoltaic; Technological Trajectory

1. INTRODUCTION

In recent years, environmental pollution, global warming and similar phenomena have surfaced as major issues, causing individuals and corporations to change their awareness that results in considerable focus on a more environmentally friendly business. However much of the renewable energy, having low energy densities, was supposedly effective in protecting global warming means that their use poses some problems to be resolved in terms of scale-up technology and economic efficiency. In corporate management terms, these sources of energy do not achieve further penetration due to their lack of effective balance between the initial cost of the facilities and the payoff on the funds invested.

An alarming statistic is that PV in Japan accounts for less than 0.5%¹ of the total generation capacity. Japan is the world's largest advanced country using PV, where the production and the installation capacity are shared by about 48% of the world (NEDO, 2004); PV power generation could become effective in Japan, as it is necessary for the largest petroleum-consuming country of the world to introduce more renewable energies.

The purpose of this paper is to analyze the diffusion process in Japanese PV systems by focusing on the value chain and interaction between technology and markets, and to explore the diffusion factors that contribute to technology, social and energy policy recommendations.

2. PRESENTATION OF THE ISSUES

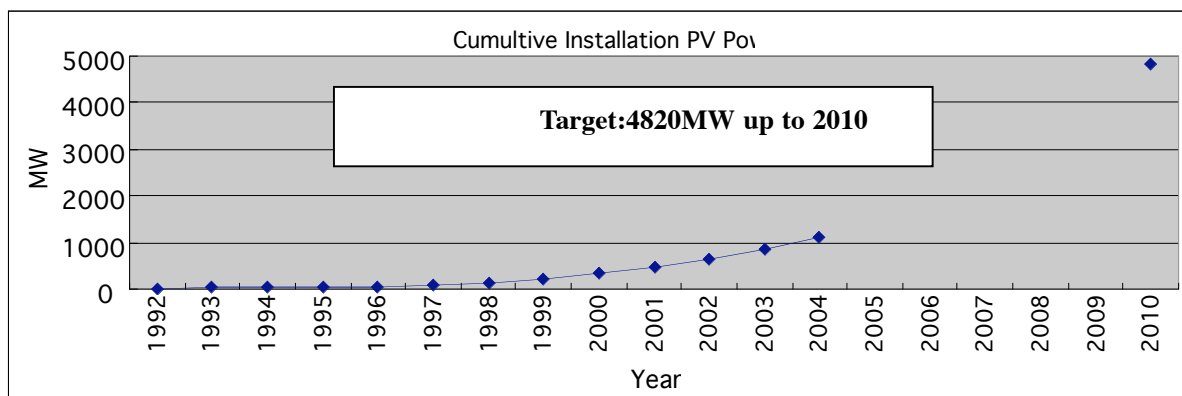
An analysis of Japan's power supply indicated that thermal power generation grew most quickly in during the period of 1990 to 1999, followed by nuclear and hydroelectric power generation. Thermal power generation and Nuclear power generation are assumed further expansion.

The diffusion of PV began in the first half of the 1990s and showed an exponential rate of increase. Rapid progress reached installation capacity of 1134MW in 2004, however it is projected that it will only achieve 23% of the target capacity of 4820MW by 2010. In such a situation, an important issue at the moment is to extend the installation capacity of residential PV since residential PV accounts for about 80% of the total PV market leading to a larger potential market

¹ Estimated value: Cumulative installed PV power was 1.13GW (source: IEA); generation Capacity of electric power companies was 235GW(source: METI) as of 2004.

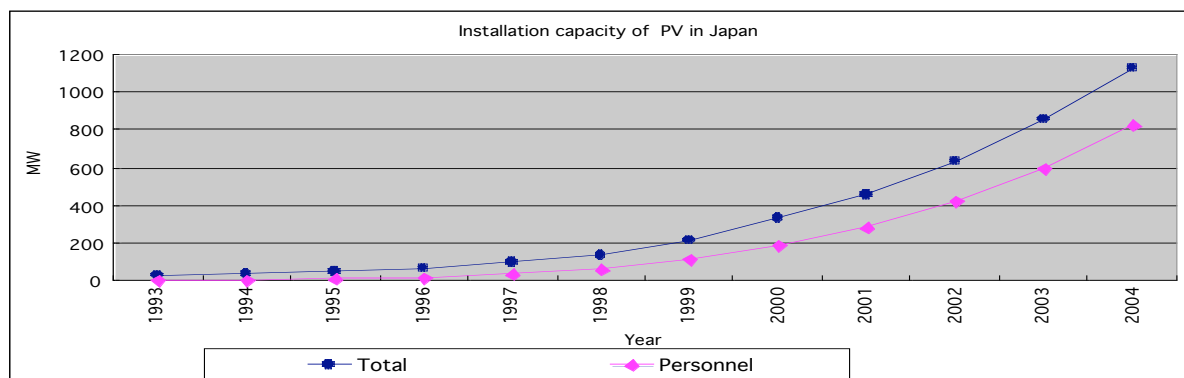
Residential Photovoltaic (PV) Systems in Japan

of PV use. Figure 1 shows the trend of cumulative installed capacity of PV systems in Japan. Figure 2 shows the share of residential PV in Japan. This paper analyzes the diffusion process in terms of residential PV.



Source: NEDO 2005

Figure 1. Cumulative Installed PV Power



Source: NEDO 2005

Figure 2. Cumulative Installed Residential PV Power

3. TECHNOLOGICAL SYSTEM OF PV POWER GENERATION

Figure 3 shows a typical structure of a residential PV system. Solar arrays: the aggregate of solar modules which in turn are aggregate of solar cells, are built on the roof of a house along with a power conditioner and other electric equipment. The power generated by the PV system is used internally to consume or channeled along the electric power grid via the system interface to delivery its customers.

Residential Photovoltaic (PV) Systems in Japan

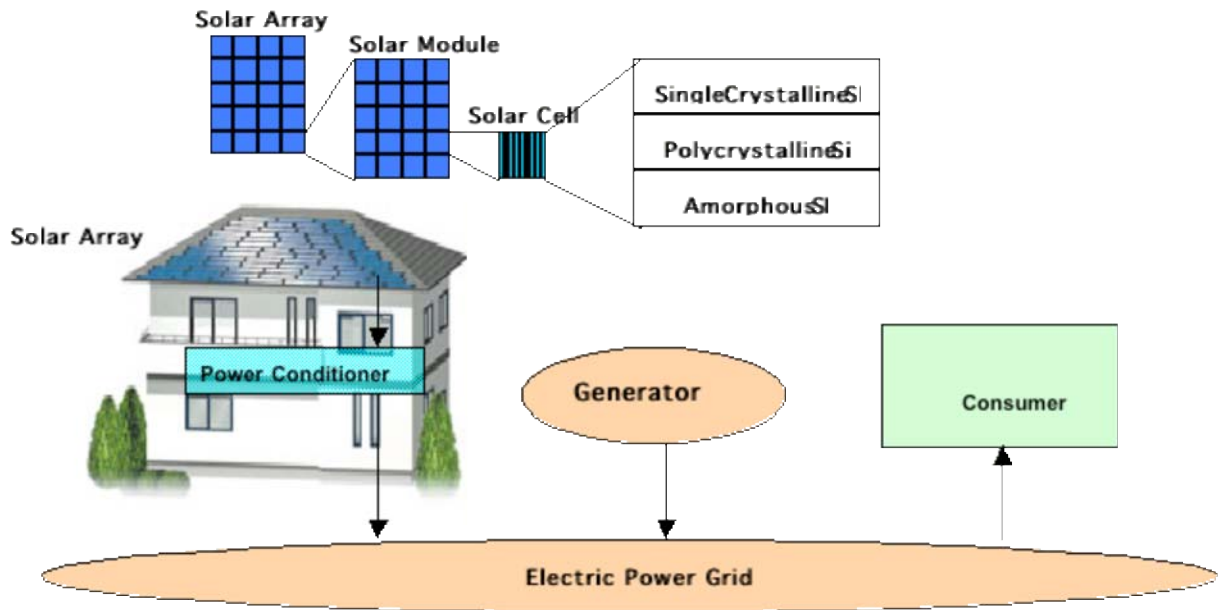


Figure 3. Technological System of Power

In this system, solar energy is converted directly to electric power using solar modules. The main material used in the construction for residential usage is still silicon, but other materials have also been developed under many R&D organizations in industries, government and academic society. Other materials are being developed either for their potential for cost reduction or their potential for high efficacy. Cost for the materials has decreased significantly in recent decades; nevertheless, PV electricity generating costs are still higher than the costs of using conventional power plants. Initiatives to encourage the wide diffusion of PV through the use of market instruments such as green pricing and rate based incentives are necessary. These may be implemented by the government, finance industries or utility companies (Ikki, 2003).

The power obtained from a residential PV system cannot completely be consumed in each residence on some occasions. In Japan, electric companies use a buy back program to purchase surplus electric power on a voluntary basis. Each residential PV system user is usually connected to a commercial power grid to feed power to the electric company, which then supplies the electricity to other consumers. A limitation of PV power is that it does not have enough stability performance as a commercial power grid.

The PV system has a feature of a complex product system (CoPS : Hobday,1998), which has been defined as a 'high cost and engineering-intensive product, sub-system or constructs by a unit of production'. The PV system consists of solar modules and other devices for power grid connection involving a specialized contractor or home builder who utilizes a customization process when designing and constructing each PV system home. Also, it has the feature of a technological system (1983, Hughes), which includes physical artifacts, organization, and legislative artifacts such as market deployment initiative or RPS (Renewable Portfolio Standard) law². Actors mainly involved include one owner, home builder/dealer, PV maker, electric company and government (

Figure 4)

This paper discusses the issues of emergence and diffusion of technological innovations of PV. Moreover we analyze the technological trajectory of the focusing device (Mowery & Rosenberg, 1979). This device pertains to the efficiency and stability performance that is essential in the pursuit for better economy based on an increasingly larger PV system as well as future evolutions in the mode of system connectivity to a power grid.

² A law, which obliges electric power companies to use more than a fixed quantity of electricity by renewable energy.

Residential Photovoltaic (PV) Systems in Japan

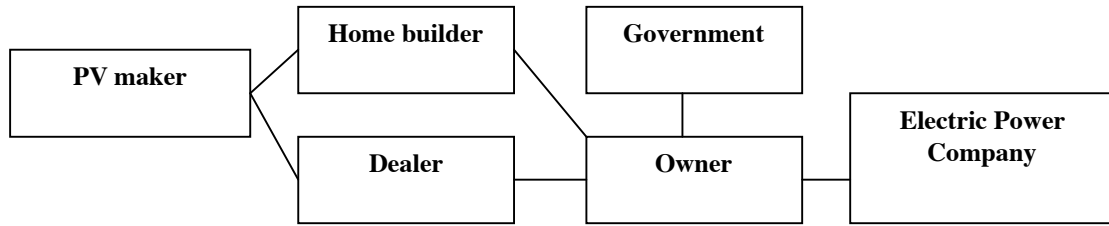


Figure 4. Actors Concerning Residential PV Systems

4. ANALYTICAL FRAMEWORK FOR PV SYSTEM

In terms of the theory of diffusion of innovations, Rogers (1990) proposed product adopters which are divided into five categories: innovators, early adopters, early majority, late majority and laggards. Later, Moore (1991) pointed out the difficult step involved in actually making the transition from visionaries (early adopters) to pragmatists (early majority).

4.1 Diffusion and Economic Value

In a business that aims to create value, the diffusion of a technology may be the key to its success (OECD, 1974). To that end, one should increase the availability through technological innovation to ensure consumer appeal and use; this will create economic value for the PV owners, who are the principal actors.

The economic value produced through PV is the amount subtracted by the opportunity cost for the power generation from WTP (Willingness to pay: Brandenberger, 1996) by the electric company. Initial analysis of the business process of PV systems might be worthwhile, as a first step.

4.2 Analytical Approach Based on Business System

We analyze the diffusion process of PV by using the framework of a business system that integrates a process with structural theory. A business system has a work division structure based on the mechanism of accumulating business resources of constituents. The advantage or disadvantage of a business system is objectively evaluated in terms of profit gained and value added. However, since profit and value added are the composite results of various factors, Kagono (2004) proposed that a business system is evaluated in terms of efficiency, effectiveness, and difficulty of imitation, adaptability and sustainability.

This paper analyzes efficiency and effectiveness, which are the most important criteria in the short term.

4.2.1 Efficiency

Efficiency is generally defined as the factor for converting an input into an output. The criterion of efficiency requires the selection of the option that produces the greatest effect from the use of a certain resource (Simon, 1945). The viewpoint is whether the option selected can generate maximum efficiency from input to output of technological innovation. Solar modules change the solar energy into electric output using semiconductors, which have restrictions on some of their materials and given performance. Scientific and technological activities are implemented in order to raise efficiency and performance by considering the above restrictions.

Studies to date, Mowery and Rosenberg (1998) argue that the endogenous logic prescribes the technological innovation of the system which consists of mutually depending subsystems. In other words, the enhanced performance of the product system is a prerequisite to enhance not only one part but also the mutually-dependent parts. Therefore, since the actor's attention is focused on the activities of developing the subsystems, this may cause a bottleneck response in terms of increasing overall system performance. This bottleneck response becomes the next development target for the actors to meet the market needs of the product and where technological disequilibrium would be solved.

On one hand, natural trajectories (Nelson & Winter, 1977) which carries out a rise in performance through stages such as a fall in profit and path dependency were discussed in their

Residential Photovoltaic (PV) Systems in Japan

evolutionary theory. Later technological paradigms and technological trajectories, trying to account for both continuous change and discontinuities in technological innovation were put forwarded by Dosi (1982).

We analyzed the technological trajectories of the PV systems empirically. We also analyzed the technological changes of the PV system as a focusing device by using the concept of technological trajectories, where then validated the efficiency as a result of technological selection with the target economic value. We analyzed volumes of published papers, patent applications and production that are an indicator of the technological innovation that raises the efficiency of solar cells and the performance of solar modules.

4.2.2 Effectiveness

Of all the evaluation criteria for a business system, the most important one is value for its customers (Kagano 2004). According to organization theory, a member of an organization contributes to the organization in return for inducements offered to him/her (Simon, 1997). An organization cannot continue to survive unless it gives all its customers more incentives than contributions (Kuwata 1998). Therefore we investigated whether the business system could find value for residential PV owners as well as from the perspective of equilibrium with stakeholders.

According to the two-factor theory (Herzberg, 2003), motivational factors such as the sense of responsibility and/or achievement lead to a contribution factor by giving him/her a feeling of satisfaction, although hygiene factors such as monetary incentives do not necessarily bring him/her satisfaction. Therefore, it is necessary to prevent hygiene factors from turning into dissatisfaction. Thus, the motivational and hygiene factors resulting from the use of PV systems as a personal business are verified by market research³ using questionnaires where we assume promotional factors for PV systems.

5. ANALYSIS OF PV SYSTEMS

5.1 Business Process

The business process of PV system is illustrated in Figure 5 and can be broken down into the development phase, involving:

- Investigation of the installation point, regulation procedure and subsidiary's program.
- Financing for installation.
- System design and procurement of solar modules, power conditioners for electric power grid connection.
- Manufacturing of PV modules and power conditioners.
- Scheduling, transportation, installation and testing.
- Operation and maintenance.

owner Home Builder/dealer		Home Builder /Dealer	PV Maker	Home Builder /Dealer	Owner	Electric Company	
Related Law Regulation Procedure	Installation Cost Subsidy	Design Procurement	PV Module Power Conditioner	Scheduling Transportation Installation Testing	Power Generation Power Sale	Buy Back Acquisition Adjusting	Distribution
INV,Plan	Financing	Engineering	MFT,INS	Construction	O&M	O&M	O&M

MFT:Manufacturing
INS:Inspection

INV:Investigation

Figure 5. Business processes of PV systems

³ Research data was provided by NEF (New Energy Foundation in Japan)

Residential Photovoltaic (PV) Systems in Japan

The business process of PV systems is designed to allow economic value to be obtained by the competitive strategies of the electric companies, PV owners, home builders/dealers and PV makers. This business process seems free of any potential obstacle to the successful acquisition of economic value for four reasons:

- First, electric power companies would gain the difference between the prices paid by the power company (to purchase power from the PV owners) and the power charges paid by electricity consumers.
- Second, PV owners would benefit from saving on their costs of power generation with PV Systems.
- Third, home builders/dealers benefit from savings labor/man-hours, derived from a reduced procurement cost and more efficient construction schedule.
- Fourth, home builders/dealers would benefit from saving on its costs from the experience effect.

5.2 Efficiency

Figure 6 shows the trend of scientific and technological papers⁴ and patent applications⁵ issued with production volume in the type of solar cells used for residential PV in Japan. The following describes the relation between these scientific or technological papers and patent applications appears.

(1) Regarding the single crystalline silicon cell, publications began with only a few papers appearing in 1975. Patent applications for single crystalline silicon cells began to be issued in 1974 and increased gradually in 1989.

(2) Regarding polycrystalline silicon solar cells, scientific and technological papers slowly began to appear in 1975,. Patent applications for polycrystalline silicon solar cells began to be issued almost simultaneously with scientific and technological papers until the 1980s.

(3) Regarding amorphous silicon solar cells, scientific and technological papers slowly began to appear from 1980. Patent applications for amorphous silicon solar cells began to be issued in 1976, with only about 120 applications per year were issued until the 1980s.

The analysis reveals the following relations between patent applications and quantity of production:

- Regarding the single crystalline silicon cell, production began after 15 years from the issue of early patent applications. Even if patent applications had been reduced, the quantity of production slowly increased from the second half of the 1990s.
- Regarding polycrystalline silicon solar cell, production started 15 years after the issue of early patent applications along with single crystalline silicon cells. Continuing the application, the quantity of production increased quickly from during the second half of 1990.
- Regarding the amorphous silicon solar cells, continuous production commenced 15 years after the issue of early patent applications, similarly just as single crystalline silicon cells and polycrystalline silicon solar cell did.

5.2.1 Relation Between Patent and Production

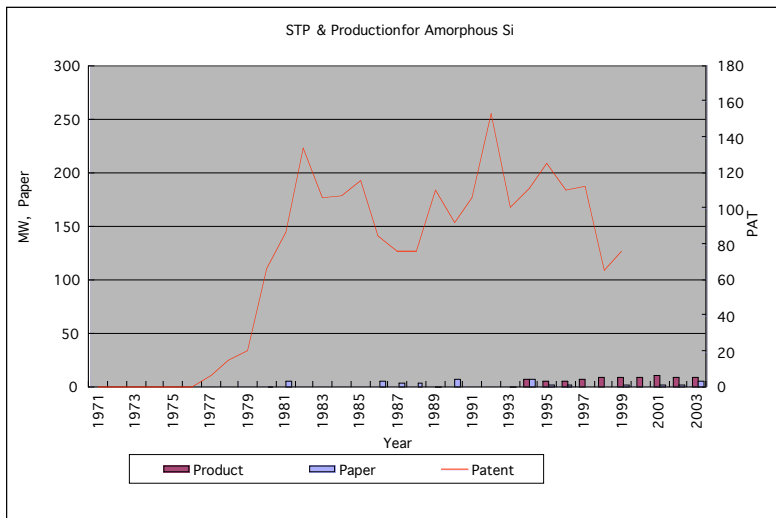
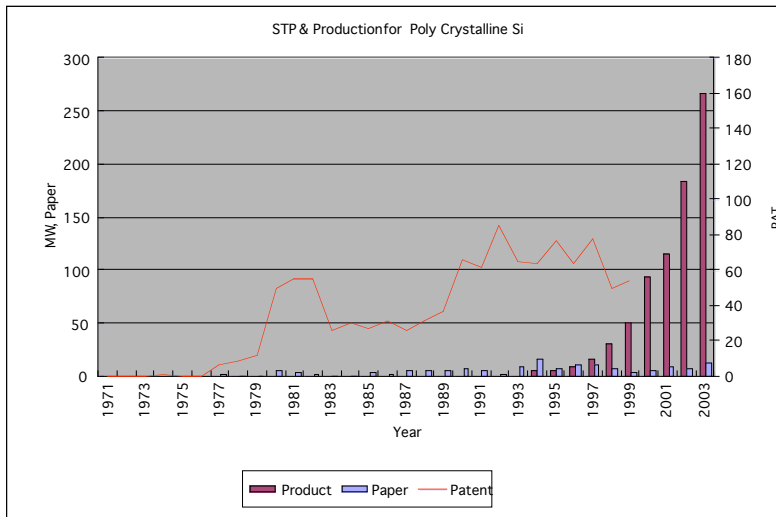
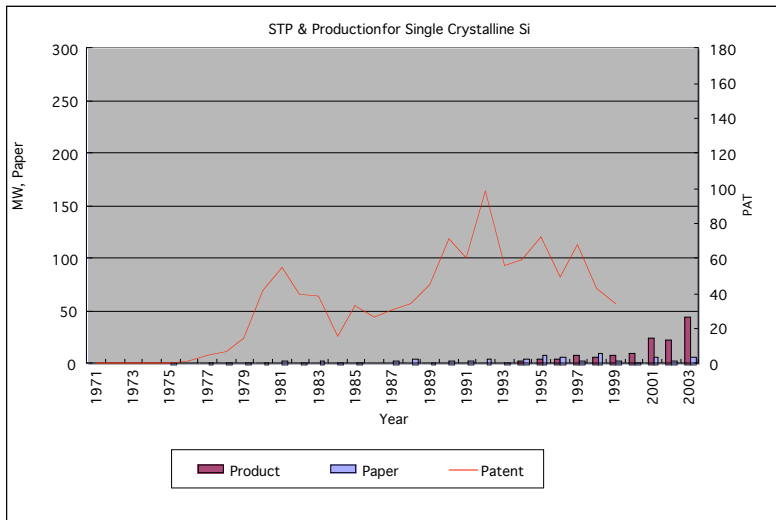
Although the quantity of production was small, patent applications of single crystalline and polycrystalline silicon were issued continuously. Even when applications for patents decreased, production increased slightly beginning in the second half of the 1990s.

In focusing on the number of patent applications, an index of innovation, the following features are summarized. Before going into mass production a considerable number of patent applications were issued, showing that the technological innovation emerged even though little feedback was received from markets. Significant patent applications have been issued compared to scientific or technological papers (STP). Many patent applications were submitted from 1971 to 1999 for amorphous silicon, polycrystalline silicon and single crystalline silicon. The trend of patent applications shows the rapid increase beginning during the first half of the 1980s. Although patent applications of single crystalline silicon and amorphous silicon reached a peak in 1991, patent applications of polycrystalline silicon were issued continuously.

⁴ Key word search in JST JDream data base

⁵ Key word search in NRI Cyber Patent data base

Residential Photovoltaic (PV) Systems in Japan



Source: Production data; NEDO

Residential Photovoltaic (PV) Systems in Japan

Figure 6. STP & Production transitions of solar modules

5.2.3 Technological trajectories

The technological trajectories of solar modules are illustrated in Figure 7. Developments of basic technologies were made before the Sun Shine Project⁶ of the 1970s, whereas single crystalline silicon modules, polycrystalline silicon modules and the amorphous silicon modules were supplied to the initial market in the 1980s. These developments were followed by improved developments in the 2000s. The technological innovations were made possible by means of the junction with amorphous silicon and single crystal silicon: their enhancing characteristic being obtained in the 1990s. Newly developed amorphous silicon with micro crystal modules or amorphous tandem structured module improved efficiency by saving materials in the 2000s. When the knowledge for manufacturing amorphous silicon was accumulated, enhanced technological innovation emerged from junction structure while pursuing complementarities.

			‡@	‡A	‡B	‡C	Development
Material	Thin Film	Amorphous & Nano Crystal Hybrid				↗ ?œ	High Efficiency High Productivity Enlarge
		Amorphous Si	?	→ ?œ	→ ?	→ ?	High Efficiency Preventive Degradation Flexible
	Bulk	Poly crystalline Si	?	→ ?œ	→ ?	→ ?	High Efficiency Enlarge Simple Production
		Single crystalline /Amorphous Si			↗ ?œ	→ ?	High Efficiency Double Side, Cell
		Single crystalline Si	?	→ ?œ	→ ?	→ ?	
	Period			1970	1980	1990	2000

? Basic R&D?@?œ?FInitial Market?@?>Imp
R&D

Figure 7. Technological Trajectories of Solar Modules

5.2.4. Conversion Efficiency

By these technological innovations, the present conversion efficiency of PV modules has been improved from the start-of-production time in the 1980s, and conserving resource material by utilizing the technological progress (Table 1)

⁶ The Sunshine Project Promoted by MITI was initiated in 1974 after the first oil crisis to develop the technologies for alternative energy sources to petroleum in Japan. In 1993, the New Sunshine Project started to develop the technologies for new energy and global environment integrating the Sunshine, the Moonlight (Energy-saving technology R & D) and the Global Environment Technology Projects.(NEDO,2007)

Residential Photovoltaic (PV) Systems in Japan

Table 1. Efficiency of Solar Modules

	Single Crystalline Si	Polycrystalline Si	Amorphous Si	Amorphous Si/ Amorphous SiGe	Amorphous Si / Micro Crystalline Si
1980S	14-16	13	6.5	-	-
2005	13-18	12-16	8	8	11-13

Source: Japan Ceramics Association 2006, PV maker catalog (Unit:%)

5.2.5 System Price

By comparing two periods, 1994 and 2004, production shows an exponential increase: system price shows an exponential decrease and unit running cost shows an exponential decrease. The production quantity by PV system has increased and the installation costs have been lowered due to the experience effect. At the same time, the economic value of owning a PV has increased by decreasing power operating costs (running cost) including PV system installation and maintenance fees. (Table 2)

Table 2. Experience Effect of PV

	1993	1994	2000	2004
Production (MW)	15	17	129	364
System Price (K JPY/kW)	3700	2000	840	580
Running Cost (JPY/kWh)	260	140	67	46

Source: PV news (data of1993), NEF

5.3 Effectiveness

We analyze motivational factors of PV in Japan, hypothesize and examine factors in terms of the diffusion process and estimate future introduction rates. Figure 5 shows the influence from stakeholders of PV.

Based on a result of the questionnaire in 2004 analysis of the motivational factors related to the user's adoption of PV system was made. The respondents had applied a subsidy for PV before the survey was made. The relation among suppliers, residential owners, buyer and the government is shown in Figure 8. The next analysis is based on how PV systems have been diffused by focusing on the relationship between stakeholders.

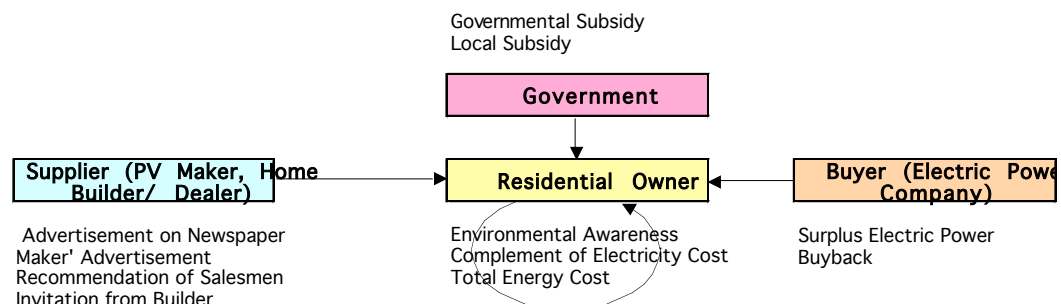


Figure 8. Influence from Stake Holders

5.3.1 Analysis of motivational factors

Regarding the questionnaires⁷, results are shown in Table 3 and Table 4. Answers are classified in terms of reasonable price for residential PV owners in Table 3. Answers are adjusted by giving a weight⁸ in Table 4.

1) Residential owner's factor

⁷ 1,000 questioners were issued. Response rate was 56%.

⁸ Weight of 5,4,3,2,1point is given for each answer corresponding with strong (5) to weak (1).

Residential Photovoltaic (PV) Systems in Japan

Economic advantage is not a negligible factor for deciding participation into a business, since economic priority is dominant in usual firms. Based on this way of thinking and focusing on economic profitability consideration of residential owners, we are going to verify if similar models are applicable in setting up the hypotheses.

Hypothesis 1: Residence owners introduce PV expecting economical advantage.

Table 3 shows classification of reasonable price zones for potential adopter of PV. This price has been classified by JPY400,000/kW⁹ (economical revenue balance point) and JPY700,000/kW (average sales price of PV system at the time of the questionnaire's issuance). The analysis of motivation for installation based on economical factor dismisses the hypothesis, since about 40 % of respondents responded that they intended to install PV, disregarding economical factors. This suggests existence of any other possible installation motivational factor than economic advantage.

Table 3. Residential owner's Economical Factor for PV

	Reasonable System Cost (JPY)		
	<400,000	400,000~700,000	>700,000
Answer	54.1%	39.2%	0.2%

We then analyzed aspects of environmental awareness, domestic electric cost and energy cost. The relative significance is shown in Table 4. Generally, environmental measures and economical factors are said to be confronting concepts. The result shows that environmental awareness is a stronger motivational factor than domestic electric or energy cost, however economical factors are also considered. PV businesses can be invested even disregarding commercial profit. Hence, environment awareness influences installation of PV similar to economical factors.

2) Buyer's factor

Revenue of residential owner is calculated as buy back tariff from electric companies plus saved electricity charge by using PV system minus running cost. Here, we are setting up a hypothesis regarding power buy back tariff and environmental awareness because unit price of buy back tariff and electricity charge is the same in Japan.

Hypothesis 2: Residential PV owners find stronger motivation in environmental awareness than revenue from power buy back program.

The relative significance is shown in Table 4. "Surplus electric power buy back" is a stronger motivational factor than "Environmental awareness" although both factors are strong motivational factors. The hypothesis is dismissed, as it might be a reason for many residential PV owners to prefer power buy back generated by their own PV system.

⁹ The price is estimated, profit is about JPY1, 000, assuming a construction subsidy of \45,000/kW of fiscal 2004, an interest rate of 4 %, a term of depreciation for 20 years and 11 % of available factors for power generation.

Residential Photovoltaic (PV) Systems in Japan

Table 4. PV installation motivational factors

Question	Weighted total	Relative intensity
(Residential owner's factor)		
Environmental awareness	1704	1.41
Complement of electricity cost	1682	1.25
Total energy cost	1729	1.29
(Buyer's factor electricity power)		
Surplus electric power buy back	2098	1.56
(Equipment supplier's factor)		
Advertisement on Newspaper	721	0.538
Maker's advertisement	989	0.737
Recommendation of salesmen	1746	1.302
Recommendation of builder	732	0.546
(Policy factor)		
Governmental subsidy	1847	1.38
Local subsidy	948	0.71
(Reference)		
Average	1341	1.00

3) Supplier's Factor

Sales promotion activity is important for stimulating the diffusion of innovation. It is said that "Advertisement by suppliers improve incentives for installation" based on marketing theories (Kotler, 1996). We then set up a hypothesis to verify, if PV installers are influenced by sales promotion activities.

Hypothesis 3: Sales promotion activities for PV by the supplier are effective.

The answers in questionnaire for "Advertisement on Newspaper," "Maker's advertisement," "Recommendation of salesman," "Recommendation of the builder," were compared with the average of all items (Table 4). It shows that the degree of appeal for installation motivation is largely determined by sales persons' recommendations; a smaller amount is influenced by home builder's advertisements and a small amount by newspaper advertisements. Therefore, the hypothesis is supported only by direct influence. It is presumed that the cause for the strong influence of "Recommendation of salesman" addresses the owner's questions and increases incentives for installation.

4) Governmental factor

Inducements by governmental dissemination programs are effective. Framework for governmental deployment concerning residential PV is shown in Figure 9.¹⁰

¹⁰ The RPS law was introduced, however the effect on the residential PV is not considered as of 2004

Residential Photovoltaic (PV) Systems in Japan

Year	Instruments	Outline
1994-2005	Residential PV system dissemination program	National government subsidize individual housing owner with a part of installation cost. The subsidy is step by step gradually reduced from 1/2 to 1/3 or a fixed value of the amount in the specified year.
1997 -	Promotion of local new energy introduction	Local government subsidize small part of the installation costs.

Figure 9. Deployment of PV systems by Government

We set up a further hypothesis and verify, if PV owners are influenced by governmental dissemination activities, and if subsidies work along with supplier incentives, a subsidy is the same as lowering the purchase price.

Hypothesis 4: The existence of a subsidy for installation of PV composes strong motivational incentives for installation.

The result of analysis using questionnaires shows that the hypothesis 4 is supported since “Governmental subsidy” is similarly as strong as “Environmental awareness”, although many PV owners do not always find lower system costs (see hypothesis 1) as a strong motivational factor. Respondents cited a strong expectation of national subsidies which is an equally strong motivational factor as owner’s environmental awareness.

5.3.2 Summary of motivational factors

Based on the market research, analysis regarding motivational factors of the stakeholders is summarized below:

- (1) 40 percent of individual homeowners are willing to introduce PV systems not taking into consideration economical profit balance. Through residential PV systems, human nature shows a sense of responsibility for the environment as well as a sense of achievement of electric power generation.
- (2) Residential PV owners have the option of selling surplus electricity obtained from their PV using a buy back program, which is a strong motivational factor in purchasing the system. They have strong motivational factors regarding environmental protection and saving energy although not all consumers have such strong motivational factors in regard to the purchase price of the PV system. Since the above mentioned buy back program can also be a factor of dissatisfaction in Herzberg's motivational-Hygiene theory, it is important to not make it worse.
- (3) Legislation for power buy back of the PV system and the preferential tax treatment for the PV system will contribute to motivate consumers, although buy back is now carried out by power companies voluntary programs.
- (4) A maker's advertisement campaign using general marketing technique is not a strong motivational factor. Similar results from the research questionnaires using correspondence analysis method for accelerating adoption shows “Public Enlightenment”, ” Sales Promotion” and “ Public Advertisement” of PV have a weak effect on motivation (Figure 10). Simply advertising this product in a traditional way will not motivate owners enough to purchase this system. It is better to incorporate messages that raise environmental awareness, which may have similar affect as national subsidies do.

Residential Photovoltaic (PV) Systems in Japan

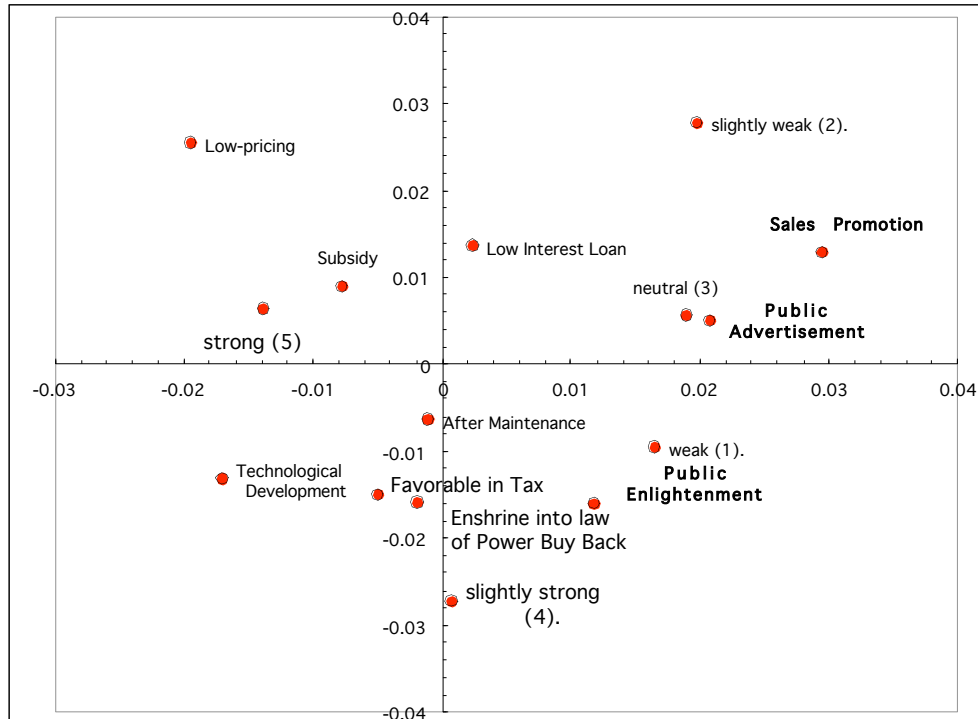


Figure 10. Residential Owner's Installation Motivational Factors for PV Systems

6. CONCLUSION

Analysis of the diffusion of PV power generation in Japan, in terms of its efficiency and effectiveness, shows that efficiency of the PV system is increased by progressive technological innovation, making it possible to reduce the costs of running the system. Low cost develops incentives for potential adoption of the system so many people will therefore introduce this residential PV system.

First, even if there are technological imbalances in terms of material performance and shortages in solar modules, they will be resolved with technological innovation. Existing research discusses the decrease of profitability which causes technological change with natural trajectory (Nelson, 1977). In our study of the development process of solar modules, material shortages allow an opportunity for an emergence of further innovations. Technological trajectories demonstrate the pursuit of substitutable material. Enhanced development utilizing low quality material along with the innovation of thin-film solar cell using amorphous silicon for conservation of natural resources to electricity is being pursued. The performance of the product system has improved gradually, in consequence, the transformation from renewables to electricity can be accomplished more efficiently.

Second, through technological evolutionary processes, technological diversification has progressed without falling into core rigidity problems by leading the development of the Sun-Shine Project. Generally firms tend to depend on core competence for increasing competitive advantage. As a result of the absence of perspective on knowledge creation, they cannot cope with the firms' environment changing from time to time so the core competence easily transforms into core rigidity (Leonard, 1995). Core rigidity is the fear of letting current knowledge and skills become devalued, and from leadership's reluctance to perform in the market resulting in a loss of political authority. However for PV systems, the core capability is accumulated in the amorphous silicon in parallel to the crystalline silicon before it falls into core rigidity. The technology for PV systems has been developed in technological seeds-leading way owing to national R&D project for the last 30 years, investing a cost of about JPY200 billion (NEDO, 2004). The reason behind this: This allowed firms to tackle every new technological development continuously, along with not having to experience profitability depreciation in markets, as is the case with typical firms. Moreover, many firms addressed technology developments at the same time; this

Residential Photovoltaic (PV) Systems in Japan

fact promotes diversification of technology. The psychology of engineers is that they may lose the chance for addressing future technology, if they do not challenge it now, it seems to affect the diversification of technology innovation initiated by leading development in the future.

Third, analysis of motivational factors points out that many homeowners are willing to introduce PV systems not taking into consideration economical profit balance and human nature shows a sense of responsibility for the environment as well as a sense of achievement of electric power generation. However, these owners have a strong motivational factor for selling surplus electricity obtained from their PV. It is important for us to encourage the strengthening of satisfaction factors and prevent the aggravation of dissatisfaction factors. It is also mentioned that public relations activities working on individual environmental awareness and establishing an institutional electricity power buyback program are necessary.

Now policymaking, which helps ensure the success of the electricity buy back program by the electric power companies, is necessary with the redesign of electricity pricing schemes for further diffusion of PV. Besides, Japanese government has already introduced the RPS law in 2003 for attaining the target value of renewable energy. In order to attain this target, a green certificate (which gives securities in terms of renewable energy) was introduced to fulfill the required quantity of renewable energy with the price determined by using the electricity market. However in the case of wind power, a tug of war took place between the existing electric power companies and the wind power proprietors since it became crucial to attain the aggregate supply of renewable energy (Saijo, T., 2002; Inoue & Miyazaki, 2005). To support a mid and long term renewable energy system it is necessary to stimulate supply and demand by requiring the setup of the aggregate targets by the government. Moreover, institutional reforms such as reforming the RPS law or introducing an environmental tax are recommended.

7. IMPLICATIONS

It is a suitable time to reform the energy system, since it was created during the growth phase of a highly industrialized society. Our society is on the brink of an energy crisis and faces multiple global environmental problems. These allow a great opportunity for technological innovation in our society. To implement this innovation effectively it is important to carry out promotions of energy and environmental conservation policies by recognizing the negative effects on the external economy. As mentioned previously, financial supports of the government helped many homeowners to introduce the PV system. As a result, technological innovations have been further developed and utilized with expectations of economical rent. This will pave the way to build large-scale PV technologies for various facilities.

The advantage of PV lies in the fact that power can be generated from natural resources from already readily available instead of the existing high efficiency power generation systems. However, going with increased PV electricity, quality problems due to natural weather fluctuations will occur. In terms of the quality issues, one possibility is to install and use batteries at the PV system site and alternating between these two systems when the weather conditions are not favorable. Based on this, systemic solutions incorporated with the existing power system should be taken into account. Electrolyte solution cells, redox flow cells, and NAS cells (cells having highly frequent charging and discharging function) are promised as a power smoothing technology. However, their construction costs are at a similar level as those of PV facilities and are economically problematic. On that basis, systemic solutions incorporated with the existing power system should be taken into account. It is necessary to examine the installation of accumulator batteries in the PV system infrastructure. Without solving this problem, further diffusion of PV cannot be expected.

In Japan, PV has just reached the takeoff phase. The interaction between technology and the market needs to be strengthened for a successful takeoff phase. It is necessary for the actors to receive incentives, which provide an incentive to create the market from electric consumers by addressing a resolution to this social problem. Therefore, if technological innovations of PV would be allowed to make further progress, problems associated with economical inferiority could be resolved in the future, meeting demand expansion with positive effects.

Residential Photovoltaic (PV) Systems in Japan

REFERENCES

- Abernacy, W.J., Clark K.B. (1985), Innovation: Mapping the Winds of Creative Destruction. *Research Policy*, 14.
- Abernathy, W.J., Utterback, J.M. (1978) , *Patterns of Industrial Innovation*.
- Baldwin, C.Y., Clark K.B.,(2000), *Design Rules, Massachusetts Institute of Technology*.
- Brandenburg, A.M., Stuart, H.W., (1996), Value-Based Business Strategy, *Journal of Economics Management Strategy*, 5, 5-24.
- Christensen, C.M. , (1997), *The Innovator's Dilemma.*, President and Fellows of Harvard College.
- Dosi G., 1982, Technological Paradigm and Technological Trajectories: A Suggested Interpretation of the Determinant and Directions of Technical Change. *Research Policy* ,11.
- European Renewable Energy Council,(2004), *Renewable Energy in Europe*, James & James.
- Foster, R., (1986), *Innovation - The Attacker's Advantage*. Mckinsey.
- Fujimoto, T., (1997), *Evolutionary theories of Production Systems*, Yuuhikaku.
- Gould, S J., (1982), *The Panda's Thumb of Technology*, Natural History.
- Henderson, R.M., Clark, K.B.,(1990), Architectural Innovation: The Reconfiguration of Existing Product,Technologies and the Failure of Established Firms, *Administrative Science Quarterly*, 35.
- Hamakawa, Y., (2004), *Photovoltaic*, Corona.
- Herzberg, F., (2003), what is Motivation, *Diamond Harvard Business Review*, April.
- Hughes TP., (1983) *Networks of Power Electrification in Western Society*, Johns Hopkins University Press.
- Iba,T., (2004), Model Framework of Complexity and evolution, In: Nishibe, M., (Eds.), *Frontier of Evolutionary Economics*, Nippon Hyooronn Sha.
- Hobday, M., 1998, Product complexity, innovation and industrial organization, *Research policy*, 26.
- IEA,(2005),*OECD Electricity Statistics*,2005.
- Ikki, O., Tanaka, Y., (2003), *National Survey Report of PV Power Applications in Japan*, IEA.
- Inoue, Y., Miyazaki, K.2006, Diffusion Process of Wind Energy in Japan, *ASIALICS*.
- Japan Ceramic Association, 2006, *Material of Photovoltaic*, Nikkann Kogyou.
- Japan Photovoltaic Association, (2006), *PV symposium*.
- Kagono, T., Inoue, T., (2004), *Business System Strategy*, Yuuhikaku.
- Kim, B., (1985), The interaction of design hierarchies and market concept in technological evolution. *Research Policy* , 14.
- Kline, S.J., Rosenberg, N., (1986), An Overview of Innovation, In: Landau, R., Rosenberg, N., (Eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, National Academy Press.
- Kotler, P., (1996) *Marketing Management 7th*, Prentice Hall College Div.,
- Kuwata, K., Tao, M., (1998), *Organizational Theory*, Yuhikaku.
- March., J.G., Simon, H.A., (1958), *Organizations*, John Wiley & Sons.
- MITI,(1993), *Hand Book of New Sunshine Plan*, MITI.
- MIYAZAKI, K., (1995) *Building Competences in the Firm lessons from Japanese and European Optoelectronics*, Macmillan.
- Mowery, D., Rosenberg, N.,(1979), The influence of Market Demand upon Innovation: A critical Review of some Recent Empirical Studies, *Research Policy* , 8.
- Mowery, D., Rosenberg, N., (1998), *Path of Innovation*, Cambridge University Press.
- NEDO,(2007), Accessed on the Web at <http://www.nedo.go.jp/english/index.html>.
- NEDO, (2004), *Roadmap for PV toward 2030*,NEDO
- NEF, (2004), Questionnaire Survey Report for Residential PV System
- Nelson, R., Winter, S., (1982), *An Evolutionary Theory of Economics Change*, The Belknap Press.
- Nelson, R., (1996), *The Link between Science and Invention: The case of the Transistor: The Source of Economic Growth*, Harvard University Press.
- Nelson R., (1977), In Search of Useful Theory of Innovation, *Research Policy*, 6,
- European Renewable Energy Council, (2004),*Renewable Energy in Europe*, James & James
- OECD, (1974), *Terms and conditions of Technical Innovation*, MITI chousakai.
- Nelson, R and Winter, S., (1977), Natural Trajectory : In search of useful theory of Innovation, *research policy* 1 36-75.
- Porter, M.E., (1987), Technological Dimension of Competitive Strategy, In: Burgelman, R.A.,

Residential Photovoltaic (PV) Systems in Japan

- Maidique, M.A., (Eds.), *Strategic Management of Technology and Innovation*, Japan Production Center.
- Rogers E., (1982), *Diffusion of Innovation 3rd ed.*, The Free Press.
- Rosenberg, N., (1976), *Perspectives on Technology*, Cambridge University Press.
- Rosenberg, N., (1982), *Learning by Using. Inside the Black Box: Technology and Economics*, Cambridge university Press.
- Rosenberg, N., (2000), Innovators and mere imitators, in: *Schumpeter and the Endogeneity of Technology*, Routledge.
- Saijo, T., (2002), Expectancy for Wind Energy: RPS and Purchase at Fixed Prices Institution. Wind Energy,
- Schneiberg, A. & Gould, K. (1994), *Environment and Society: The Enduring Conflict*, St. Martin's Press
- Simon, H., (1945), *Administrative Behavior*, The Free Press.
- Simon, H., (1978), *The Science of the Artificial*, MIT Press.
- Teece, D.J.,(1986), Profiting from Technological Innovation for Integration, Coordination, Licensing and Public Policy, *Research Policy*, 15.
- Tidd, J., Bessant, T., Pavit, K., (2005), *Managing Innovation 3rd Edition*, John Wiley & Sons.
- Utterback, J.M., (1994), *Mastering the Dynamics of Innovation*, President and Fellows of Harvard College.
- Uzawa, H. (1995), *Think about Global Warming*, Iwanami Shoten.
- von Hippel, E., (1978), *Users as Innovators*, Technology Review.
- Watanabe, C., Miyazaki, K., Katsumoto, M., (1998), Theory of Techno-Economics, Nikkagiren.