Innovative solar cell technologies in the land of the rising sun

The promoting and limiting factors for PV development and diffusion in Japan and what we can learn for the Dutch case

Marjan Prent
TU Delft, master thesis report
Royal Netherlands Embassy, spring internship report

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Cover illustration: [Kanou, 2008]

Preface

When I first heard of the vacancy for a research internship on an energy-related topic at the office of science and technology (TWA) at the Royal Netherlands Embassy in Tokyo, I had already started work on a research proposal in a very different school of thought; the effects of culture on management qualities. Though the field of cross-cultural management is dear to me, once I heard of this opportunity I decided to take this 'once in a lifetime' opportunity and switch my final topic and apply to the TWA. In this I was fortunate to be acquainted with professors such as Robert Verburg and Roland Ortt, who were willing to aid me in finding the perfect research subject even when this lay outside of their own research area.
After a veritable quest of the faculty, speaking to a myriad of grad-students and professors, I slowly made my way to the section Technology Dynamics and Sustainable Development (TDSD). Here I was quickly directed to the office of Dr. Ir. Karel Mulder who introduced me to the world of Innovation Systems. I immediately fell in love with the ideas behind this framework and set about to write a research proposal for the TWA which was thankfully accepted.
Now after four months of research in Japan, followed by several more months of research in the Netherlands I am glad to be able to present you with results of my analysis. And I wish you a pleasant reading experience.

A large number of people were involved, in some shape or form, in the creation of this report who I would like to take the time to thank in this preface.
First, I would like to thank all my respondents for taking time out of their busy schedule to meet me and help me complete this research. Among these special thanks goes out to Katsumi Kushiya, Deputy General Manager of Showa Shell, for all his kind advice, brining me in contact with other respondents, and his endless patience.
Secondly, my external supervisor Rob Stroeks and my colleagues Mihoko Ishii, Thomas Bleeker, Kikuo Hayakawa, Daan Archer and Michiel de Lijster of the Office of Science and Technology of the Royal Netherlands Embassy, for making me feel at home and helping me with whatever small or large problem I was faced with during my stay in Japan.
I would also like to thank my main supervisor Linda Kamp, for all her assistance and feedback despite her busy schedule, Otto Bernsen and Job Swens for their insight into PV in general, and the Netherlands in particular, and Dr. Simona Negro for allowing me to use her research results.
Lastly I would like to thank my family and friends for their continued support and patience.

Contents

Abstract

The Netherlands is currently in the process of re-evaluating its energy structure. The Dutch government has set up the 'Task Force Energy-transition' to establish a plan of action for the development of sustainable energy in the Netherlands. One of the technologies under investigation is photovoltaic energy (PV), also known as solar cell technology, which is expected to contribute to the Dutch energy system in the years ahead. Japan is a frontrunner in the development and implementation of renewable energy technologies. One of the areas where Japan is highly proficient is in the field of PV technologies, where Japan until recently was the global leader in solar cell shipment and total installed capacity. As such it will be interesting to discover the promoting and limiting factors for the development and diffusion of PV in Japan, and see what can be learned for the Dutch case.
The goal of this research is therefore to discover the promoting and limiting factors for the development and diffusion of PV in Japan. This analysis was made by investigating the organization of, and processes within, several Japanese Technology Specific Innovation Systems (TSIS). We investigated how these Japanese PV TSIS are performing by evaluating the functioning of 7 functions or processes within each innovation system. After this we determined the existence of virtuous and vicious cycles. These can be compared to feedback loops which either speed up (virtuous cycle) or reduce (vicious cycle) the development and/or diffusion of the technology. After the analysis of Japan a comparison was made between the situation in the Netherlands and Japan. Based on the theory and the main promoting and limiting factors in both countries, three recommendations were given to the Dutch government how they could improve the functioning of their PV Innovation System.

Seven solar cell technologies were chosen in collaboration with SenterNovem to be investigated. One of these technologies, Solar Grade Silicon, proved too limited in Japan, and too separate from the other technologies, to be investigated fully. Eventually the following six technologies were chosen to be investigated: crystalline silicon solar cells (c-Si), thin-film silicon solar cells (tf-Si), stacked silicon solar cells, Cadmium-Indium-di-Selenide/di-Sulfide (CIS) solar cells, dye-sensitized solar cells (DSC) and polymer solar cells.

In the analysis of the innovation system we made a distinction between cycles which influence the development, and those that influenced the diffusion of the technology. The development of PV in Japan went very well and a virtuous cycle was found based on 'expectations'. The performed research increases expectations of the technology's capabilities to fulfill the government's reduction targets, which have also been proven (in part) in the large domestic market. As such the technology has gained a certain legitimization within the government as a valid option to attain the desired targets.
The diffusion of PV in Japan went very well during the period 1993-2005. A virtuous cycle was found, with the lobby activities of the PV branch organization reportedly facilitating, and promoting the continuation, of market support mechanisms by the government. The growing market in turn attracted new entrepreneurs which supported the lobby activities.
However since 2005 the amount of PV that is installed in Japan each year has decreased. We have identified multiple possible causes for this situation and it is possible the market is suffering a temporary dip. Nevertheless there is clear interest from the industry and government institutions for further market support, which is necessary to reach, amongst others, the greenhouse gas reduction targets. Strangely, in our analysis of the situation we identified a vicious cycle where

the seemingly unwillingness of manufacturers to lobby and lack of a specific government market policy appear to play an important part.

When looking at the different technologies we found several cycles for the different PV technologies. The *Crystalline silicon solar cells* TSIS suffers greatly from the current silicon shortage. Combined with insufficient attention of manufacturers to obtain a sufficient supply this has led to decreased interest from entrepreneurs in this type of cell, which has resulted in a vicious diffusion cycle. However research into and production of c-Si is still continuing. The technology's main promoting factors are its proven reliability and performance which will ensure them a large market share for quite some years.
In contrast to c-Si solar cells, *thin-film silicon solar cells* are profiting greatly from the current silicon shortage. The overlap in technological field with TFT is pushing development forwards and makes it easier for companies to enter the field. Combined, these two factors are the main factors promoting the tf-Si TSIS. The main limiting factor for PV diffusion is the competition on the domestic market. This makes it more difficult for new companies to enter and the only new entrant, Fuji Electric Systems, is focusing on specific applications for which thin-film silicon solar cells are currently especially well-suited.
Stacked silicon solar cells are only just entering the market but are expected to play an important future role with an increasing market share due to their potentially high efficiency. A virtuous research and development (R&D) cycle was found. The solar cells are now entering the market in specialized applications (high efficiency, low weight). The use of the solar cells in the market combined with the research that is performed shows the potential of the solar cells. Though they are currently in a niche market confidence is growing that they will play an important part in the future, and they are expected to have large share of the market. One of the main factors promoting entrepreneurs to use this technology is that they are based on fundamental thin-film silicon technologies but have higher efficiencies, allowing for fairly easy access to the technology while being better able to compete with the incumbent c-Si in the long run.
A vicious R&D circle was found for *CIS*, where the problems with knowledge diffusion are most likely preventing increased interest in the technology. CIS is potentially very appealing to entrepreneurs due to its high fabrication cost-reduction prospects, high efficiency and the fact that no silicon is required. However interest in CIS from entrepreneurs and research institutes is noticeably lacking, most likely due to the high costs associated with researching the technology, the very different background from the silicon and organic PV technologies and the Indium shortage. The small and scattered research community has led to problems with knowledge diffusion. There are no formalized exchange methods, the research groups are small and scattered, research is separated and the few companies in the industry do not collaborate. However there are some good prospects as the small research groups are expected to be combined into larger groups which should facilitate knowledge development and diffusion.
Dye-sensitized solar cells are not on the market yet however interest in this type of solar cell is very high as they are based on a new technological field (chemistry), and it is easy to start research and production as no expensive machinery is required. The main problems facing the many small DSC entrepreneurs are financial difficulties. The perception of the technology is varied, as it is expected market. It is not yet ready for power-applications though it will be used in consumer products soon.
Polymer solar cells are still in a very early stage of development. The main factor which promotes development of the technology is its overlap with DSC research field which promotes knowledge exchange and diffusion. Research into power-applications, which will take a fair

amount of time to realize, is promoted through the PV 2030 Roadmap.

When comparing the functioning of the Dutch and Japanese innovation systems we see both differences and similarities. *R&D* of PV in both countries is going strong and we can observe virtuous cycles in both countries. Knowledge development and diffusion activities in both countries are going strong and are supported by the government through research subsidies. However in the Netherlands learning by using does not take place in the domestic market which means products and procedures are not adapted to the Dutch institutional system. This problem does not exist in Japan as PV has a large market and the Field-Test projects which provide sufficient learning by using opportunities for the domestic market.

Where both countries are currently experiencing difficulties is in the *diffusion* of PV. However the starting position of the two nations differs. The Netherlands had some market growth in the past but at the moment has no market to speak of. The Japanese have one of the largest markets in the world but this market is stagnating.

In both countries the market shows a lot of potential, and past experiences with market subsidy schemes have proven home-owners are interested. The main difference between the Dutch and Japanese market subsidy schemes lies in their consistency. Japan’s main subsidy scheme (the Residential Dissemination Programme) continued uninterrupted for 12 years. During this time the Netherlands had several subsidy schemes with varying goals, lengths and set-ups, and some of these schemes were ended fairly abruptly. Both the varying subsidy schemes and the unexpected subsidy stops have negative effects on the Dutch PV market as it creates uncertainty with investors, customers and producers.

Both governments also lack a clear vision of the future market of PV on which they might base a new subsidy scheme. However Japan is slightly ahead in this area compared to the Netherlands. Japan has a well-known national energy strategy which already includes solar cell research, while the ideas and intentions of the Dutch government regarding the future of the energy supply are fairly unclear.

Based on our analysis we make three recommendations to the Dutch government:

1. Maintain a market subsidy scheme for a prolonged period of time, with a steady budget and fixed set-up.
2. Initiate a set of projects similar to the Japanese NEDO (Field Test) projects to allow for adequate market involvement and operational feedback.
3. Settle on a vision for the future of PV in the Netherlands in collaboration with industry and academia.

Glossary

AIST: National Institute of Advanced Industrial Science and Technology / 独立行政法人産業技術総合研究所

ANRE: Agency for Natural Resources and Energy / 資源エネルギー庁

BIPV: Building integrated photovoltaics

CIS: Cadmium-Indium-di-Selenide/di-Sulfide (solar cells)

c-Si: crystalline silicon (solar cells)

DSC: dye-sensitized (solar cells)

ECN: Energy research Centre of the Netherlands

EU: European Union

FIT: feed-in-tariff

HS: Holland Solar

IEA: International Energy Agency

IS: Innovation System

JPEA: Japan Photovoltaic Energy Association

mc-Si: multi-crystalline silicon (solar cells)

MEP: Milieukwaliteit Elektriciteitsproductie (subsidy scheme)

METI: Japanese Ministry of Economy, Trade and Industry / 経済産業

MEXT: Japanese Ministry of Education, Culture, Sports, Science and Technology / 文部科学省

MoE: Ministry of the Environment/ 環境省

NEDO: New Energy and Industrial Technology Development Organization / 新エネルギー・産業技術総合開発機構

NEF: New Energy Foundation / 新エネルギー財団

PV: Photovoltaic (energy) technology

PVTEC: Photovoltaic Power Generation Technology Research Association /太陽光発電技術研究組合

R&D: Research and Development

RPS: Renewable Portfolio Standard

SDE: Stimuleringsregeling Duurzame Energieproductie (subsidy scheme)

SESP: Sustainable Electricity Supply Platform

tf-Si: thin-film silicon (solar cells)

TSIS: Technology Specific Innovation System

VROM: Dutch Ministry of Housing, Spatial Planning and the Environment

1. Introduction

1.1 Introduction

The Netherlands is currently in the process of re-evaluating its energy structure. The Dutch government has set up the 'Task Force Energy-transition' to establish a plan of action for the development of sustainable energy in the Netherlands [Wijn, 2006]. Around thirty 'transition paths' have been defined within the transition program. Each transition path consists of an implementation trajectory related to a different renewable technology. [NWO, 2008] Recent research has taken place to help policy makers to decide on the best course of action, and now they are deciding on which paths should be supported and in what way. The research gained insight into the main limiting and promoting factors for the implementation of the renewable technologies, by looking at the current state of the technology's Innovation System. [NWO, 2008]

Each technology has its own unique network of institutions that enables a technological breakthrough to diffuse successfully in the market. Such systems are often referred to as 'Technology Specific Innovation Systems' (TSIS) and include actors such as: universities, R&D institutes, producers, users, branch organizations, government, interest groups and financial institutions.

One of the renewable technologies which the Dutch government sees as very promising is photovoltaic (PV) technology. And one of the countries which is internationally well known for its PV research and market is Japan. The country has been investigating solar cells for over 30 years and until recently was the global leader in solar cell shipment and total installed capacity. It is also the first country in the world to have established a sustainable PV market. On the basis of Japan's success rate in developing and implementing PV innovations, it is safe to assume that the Japanese PV innovation systems are well organized.

The Netherlands might learn from the way in which the Japanese organize the Innovation Systems of these technologies, to improve its own R&D and implementation processes. Therefore, an in-depth study of these Japanese PV Systems of Innovation will be of value. Furthermore, as the theory comes from the western world it will be of scientific value to apply the TSIS concept in an Asian setting. The goal of this research is therefore to investigate the organization of, and processes within, several Japanese photovoltaic Technology Specific Innovation Systems in Japan.

1.2 Research question

The aim of this research is to investigate the organization of, and processes within, several Japanese photovoltaic (PV) Innovation Systems in Japan. The research will focus on several different types of solar cells within the field of PV, and will answer the question; what are the promoting and limiting factors for the development and diffusion of PV in Japan? After the analysis a comparison will be made between the Dutch and Japanese systems, which may lead to recommendations to the Dutch government how they could improve their own Innovation System.

1.3 Research boundaries

Before starting the research we need to further specify the research which includes the choice of PV technologies and the TSIS system boundaries.

1.3.1 Choice of specific PV technologies

Seven technologies were chosen to be investigated in collaboration with SenterNovem of the Netherlands, which were considered to be the most important PV technologies at the time. These were: silicon feedstock, (multi-)crystalline silicon solar cells, thin-film silicon solar cells, high-efficiency solar cells, CIS solar cells, sensitized solar cells and polymer solar cells. In the initial analysis of the structure of the innovation system, this list was further refined where certain choices had to be made. High-efficiency solar cells were defined as those types of solar cells which had the potential to achieve more than 25% efficiency. This type of cells encompassed a large variety of different types of cells in different states of developments. Therefore we specified this type of cell to stacked silicon solar cells due to ease of access to information.[1] Furthermore, the activities regarding Solar Grade Silicon were limited in Japan and completely separate from the other technologies. Investigating this technology would require a large amount of additional work for which no time was available. As such the technology could not be investigated fully and no functional analysis was made of this technology.[2]

In the end six technologies were chosen to be investigated; crystalline silicon solar cells (c-Si), thin-film silicon solar cells (tf-Si), stacked silicon solar cells, Cadmium-Indium-di-Selenide/di-Sulfide (CIS) solar cells, dye-sensitized solar cells (DSC) and polymer solar cells. These will be explained in more detail in paragraph 3.3.

1.3.2 System boundaries

Next to knowing the specific technologies we will investigate, we need to define the starting point for the analysis by choosing the TSIS system boundaries. Bergek et al. (2008) outline three types of choices that analysts need to consider in this step; (1) the choice between knowledge field and product, (2) the choice between width and depth, and (3) the choice of spatial domain. We would like to make one small addition in the form of: (4) the choice of time period.

Of the seven selected PV technologies, one was a PV-supporting technology while the other six were related to different types of solar cells. Solar cell technologies stem from and are used in a large number of different industries. As we are only interested in the solar cell industry we will not focus on knowledge fields but on the specific product related to each of the 7 PV technologies (1).

As each of these products can also be used in a large variety of applications we choose to focus on a specific application of solar cells, namely 'solar cells for power applications' as this application forms the main challenge for government and industry circles[3] (2). Regarding the spatial domain, we will restrict ourselves to an analysis of the IS in Japan and the Netherlands (3). Lastly, though TSIS are path-dependent, investigating the entire 40 year history of PV in Japan would take a considerable amount of time. As we are mostly interested in what we can learn from the current situation, we will focus on current and recent developments of PV in Japan

[1] The theoretical limit of the efficiency of 'tandem' (double-junction) silicon solar cells has been calculated by F. Meillaud et al. (2006) as 35%.

[2] The information that was found has been included in appendix I.

[3] The product related to the supporting technology 'solar-grade-silicon material' is in and of itself already a specified application of a larger technological field (the production of silicon specifically for solar cell production).

and the Netherlands, roughly 2000-2008 (4). Research has already been performed about the historical evolution of PV in Japan [Kimura and Suzuki, 2006; Kurokawa & Ikki, 2001] and the Netherlands [Verbong et al., 2001] these will be used as reference when necessary.

1.4 Some technical background

1.4.1 Basic workings of PV

Solar cells work by turning the energy that the sun emits in the form of light, into an electric current. Different researchers have come up with a variety of ways of doing this. However the general principle behind solar cells remains the same, as can be seen in figure 1.1.

PV works by absorbing the energy which is emitted by the sun and transforming it into an electric current. Light enters the cell and releases electrons from the emitter which travel around an electric system as a current. An antireflective coating prevents the incoming light from being reflected, thereby increasing the amount of light entering the cell.

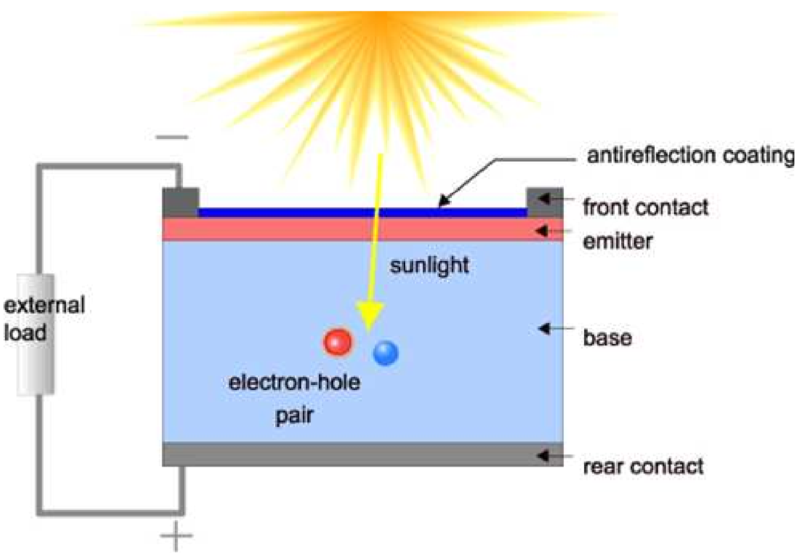

Figure 1.1: Workings of a solar cell
Source: http://teams.eas.muohio.edu/solarpower/WhatIsSolarPower.html

1.4.2 PV applications

The most widely known application of solar cells is on rooftops. However they are used in a large variety of applications, including: calculators, public lighting, windows, facades, recharges, emergency lighting and much more. In general a division can be made between ‘off-grid’ and ‘grid-connected’ PV applications, depending on whether or not the PV system is connected to the main electricity grid. In general four main applications for photovoltaic power systems are identified, [PVPS, 2007] other applications can be put into the often overlooked category of: solar integrated consumer products. For this research we restrict our analysis to grid-connected power systems, due to time constraints and the availability of data.

1 Off-grid domestic

This category entails the use of solar cells in stand-alone residential power systems, in general this translates into the installation of PV systems into rural housing.

Figure 1.2: Off-grid domestic example
Source: http://www.treehugger.com/files/2008/04/off-grid-homes.php

2 Off-grid non-domestic

These applications entail all uses of stand-alone power systems that are not meant for the residential market, such as; lighting, pumping, etc.

Figure 1.3: Off-grid non-domestic example
Sharp Corp.'s solar powered street lights
Source: http://i.treehugger.com/images/2007/10/24/sharp%20streetlight.jpg

3 Grid-connected distributed

The most widely known example of this category is the rooftop PV systems. An interesting new development is the creation of 'building integrated PV' (BIPV) systems, which entails using PV as buildings components such as: windows, facades and roofing material.

Figure 1.4: Grid-connected distributed example
Source: http://www.solorcorp.com/pictures/Premier_Gardens_from_above___GE_Neighborhood.JPG

Figure 1.5: BIPV example
MSK's see-through Photovoltaic glass
Source: http://www.kostak.si/dokumenti/lead/predstavitev_hanzic.pdf

4 Grid-connected centralized

The grid-connected centralized PV systems consist of large power systems.

Figure 1.6: Grid-connected centralized example
Source: http://www.chemistryland.com/CHM107/Energy/Energy.html

The PV technologies which are currently used for these four applications are: crystalline silicon solar cells, thin-film silicon solar cells and CIS solar cells. Thin-film silicon solar cells are especially popular for use in BIPV applications.

5 Solar integrated consumer products

Crystalline silicon solar cells and thin-film silicon solar cells are generally used for these applications. Consumer products employing dye-sensitized solar cells will enter the market this year (2008).

Figure 1.7: Solar integrated consumer products example
Source: http://www.soldius.com/index.htm

1.5 Restrictions & limitations of this research

After having specified our research and looking at the basic technical aspects of PV, we will now look at the main restrictions and limitations of this research.

The research was restricted to a six month **timeframe**, of which four months in Japan. This greatly limited the number of interviews which could be undertaken in both Japan and the Netherlands. As a result, several interesting **groups of actors** could not be included in the interviews, these include: financial institutions, utilities, project developers and end users (building owners). No financial institutions were contacted. Respondents were asked about their relationship with banks and other financial institutions and their perceived importance in the industry. Respondents indicated to have no special link to any financial institutions, not leading to any possible contact information. General information concerning the influence and interests of project developers and end users was received through a report from the JPEA (Japanese PV branch organization), and MNP (research institute consulting the Dutch government). A Japanese power company was contacted however they were unavailable for an interview. Due to time considerations no Dutch power company could be contacted.

First of, there was less **overlap between the TSIS** than expected, which led to difficulties in getting enough respondents for each technology. The activities regarding Solar Grade Silicon proved too limited in Japan, and too separate from the other technologies, to be investigated fully. No functional analysis was made of this technology. Furthermore, interviews with actors in the CIS solar cell and polymers solar cell TSIS were limited due to the limited number of actors involved and the difficulty in finding them, respectively. This has made the analysis of functions which rely largely on interview information, in particular knowledge diffusion, more difficult. Other sources were sought to compensate for this.

The research was limited to **grid-connected PV systems**, a.k.a power applications. This has made the investigation of PV technologies which are not ready yet for these types of applications, such as the organic solar cells, more difficult. Organic solar cells are currently being used in consumer products for the first time. However, as this lay outside of the scope of this research, this potentially very interesting field could not be investigated. In response more attention was paid to the large part of research into making organic solar cells suitable for rooftop applications.

Research into the development of **energy storage technologies**, i.e. lithium batteries and fuel cells, is in progress and is regarded as an important support-technology for the future of PV in Japan. However, as this lies outside of the scope of this research, it will not be included in this report.

Though the use of silicon in the PV industry is very important, this research will not expound on the **different types of silicon** materials which are in use. An analysis of the uses of silicon in the PV industry alone would be more than enough work for a complete master's thesis.

Several potentially highly valuable **sources of information** were unavailable. Important reports by the RTS and other sources of market information were unavailable due to high cost of access. Information in newspaper articles, magazines, and similar sources including specialized material were unavailable due to language difficulties on the part of the researcher.

The **language barrier** in general led to some difficulties. The degree of competency of English in the group of Japanese respondents varied greatly. Some of the later interviews, including those through e-mail were performed in Japanese and kindly translated by Rob Stroeks of the Royal Netherlands Embassy.[4]
Next to this there were several **cultural differences** regarding the way the interviews were conducted. The 'way of speaking' of respondents led to interpretation problems as Japanese use more circumvent ways of speaking than the researcher was accustomed to. Another important difference was that many of the interviews were held with multiple respondents at the same time while in the Netherlands it is more accustomed to have one-on-one conversations. Often respondents enlisted the help of others in the company with different expertise and/or a firmer grasp of English, which improved the quality of the responses.

Though the research aimed to incorporate potential **future developments** next to the current and recent developments, this proved more difficult than expected. Official announcements such as press releases are regarded as a 'commitment' in Japan, in comparison to other countries where it constitutes a matter of 'intent'. The result is that information on future developments is difficult to come by as organizations are very reluctant to release such information.

In some instances it was difficult to determine the **relationship between specific companies** due to reluctance in Japanese business culture to name organizations. Respondents were reluctant to name their suppliers and customers, as well as their partner company especially if it is not widely known or has not been announced yet; however this last factor is also in place in Europe.

Of the entire PV production line, this research will focus on those activities related to **solar cells and solar modules**. Though in general these terms are used interchangeably (even by experts), there is a significant technical difference between the term 'solar cells' and 'solar modules'. Solar cells refer to the small-size cells, which are the functional components of a solar power installation. These cells are placed in some type of frame and electrically connected to one another to form a 'solar module'. It is these modules which can be placed onto rooftops. In this research both terms are used to mean 'solar modules', except when discussing specific research results in Appendix I.

In the literature and news reports there were some difficulties with the term **'thin-film solar cells'** as this can refer to a large variety of solar cell technologies based on thin layers. These include: thin-film silicon solar cells, stacked silicon solar cells, CIS, GaAs, CdTe and thin-film organic solar cells. As the meaning of the term 'thin-film' was not always explained in reports and articles, cross-referencing was used as much as possible to determine the actual type of cell.

[4] The interview with Arno Smets from AIST was performed in Dutch however an English transcript was created and approved.

1.6 Thesis structure

The research starts in this chapter with an introduction to the research, starting with the research question. The section will include a short technological background of the workings of PV and special attention will be paid to the boundaries and limitations of the research.
The second chapter will provide the theoretical background of the research, explaining the Innovation System concept as well as the functions of innovation systems approach which will be used to analyze the different solar cell technologies. The concept of virtuous and vicious cycles will explained and the chapter will end with a precise description of the steps which have been taken to perform this research.
An overview of the current state of PV worldwide is given in chapter three in order for the reader to place the situation of Japan and the Netherlands into context. The basics of the selected PV technologies will be explained in the final paragraph.
The actors which are involved with the creation and diffusion of the selected technologies in Japan, e.g. the structure of the TSIS, will be discussed at the beginning of the fourth chapter. This will immediately be followed by the analysis of the TSIS using the seven functions from the functions approach described earlier. We will conclude this section with an evaluation of the existence of vicious and virtuous cycles for PV in general and for each of the technologies, where we will focus on discovering the main promoting and limiting factors of PV development and diffusion in Japan.
The comparison with the Dutch PV sector is located in chapter five. After a brief analysis of the Dutch PV IS and a comparison to the Japanese PV IS, several recommendations will be given to the Dutch government on how they may improve the Dutch PV IS.
The final chapter contains the main conclusions of the research, a discussion of the results and recommendations for further research.
Appendix I describes the current state of PV technologies in Japan as reference for readers or as a basis for further study. Appendix III contains a short analysis of the effects of culture on the willingness of government, companies and consumers to employ solar cell technologies. This document may be useful as background material before or during reading for those readers unfamiliar with Japanese and/or Dutch culture.

2. Theoretical framework

For any research the establishment of a sound theoretical base is paramount. This chapter will focus on this issue by looking at the various ways in which innovative processes can be analyzed and determining their suitability for this research. After this we will explain our chosen framework, the innovation system (IS), and the 7 functions we will use for our analysis. We will also explain the concept of virtuous and vicious cycles. This chapter will a step-by-step description of our research approach.

2.1 Innovation research

This research will answer the question; what are the promoting and limiting factors for the development and diffusion of PV in Japan? The research will focus on several different innovations within the field of PV. After the analysis of the Japanese PV IS a comparison will be made between the situation in the Netherlands and Japan, which could lead to recommendations to the Dutch government, how they could improve the functioning of their PV IS.

As such the theoretical framework to be used for this research needs to be aimed towards developments of a specific innovation. It needs to contain a method to investigate factors promoting and limiting factors for this development. However, though innovative research stretches across geographical boundaries, the analysis should be limited to that within specific countries. The framework should enable the investigation of socio-economical factors within a country. And, considering the Dutch and Japanese cases need to be compared, an important requirement of the framework lies in its ability to compare the two cases. Also, the research needs to be able to be performed within 6 months, as such the existence of an (initial) analysis for the Dutch case is important.

There are a variety of ways to investigate the processes surrounding innovations. We will look at several different frameworks, each employing a different perspective and level of analysis, and determine their suitability for this research. The six frameworks we will compare are: Socio-technical System, Strategic Niche Management, Large Technological Systems, Cyclic Innovation Model, Porter's diamond and Innovation Systems.

The term *Socio-technical System (STS)* was coined in the 1960s by Fred Emery and Eric Trist (1965) [Emergy and Trist, 1965 in Geels et al., 2004]. Socio-technical systems theory considers the interrelation of society and technology and has been used to discover the societal and technical factors that enable and prevent an innovation to be accepted on the market. The current theory distinguishes three different levels from which the development of a technology should be analyzed; macro level, socio-technical regime and niche, see figure 2.1. The macro level, or 'landscape', is mostly static and has a very large time frame. Regimes deal with competition for the technology in the form of the existing embedded technologies. The niche is the micro-level and consists of a new technology being developed, possibly protected by a merger of favourable circumstances under which the technology can flourish, also called a 'window of opportunity'.

The framework is very suitable for finding outside factors which could hinder or promote the development of an innovation. An analysis of the socio-technical regime would be very helpful in discovering (additional) promoting and limiting factors outside of the development of the technology itself. However due to time constraints such an analysis can not be performed. Furthermore not all factors found (namely those in macro level) are under control of any person. Though these would be very interesting to discover from a theoretical viewpoint these factors could not lead to any practical recommendations. Also the framework does not focus on factors dealing directly with the technology such as research and development activities.

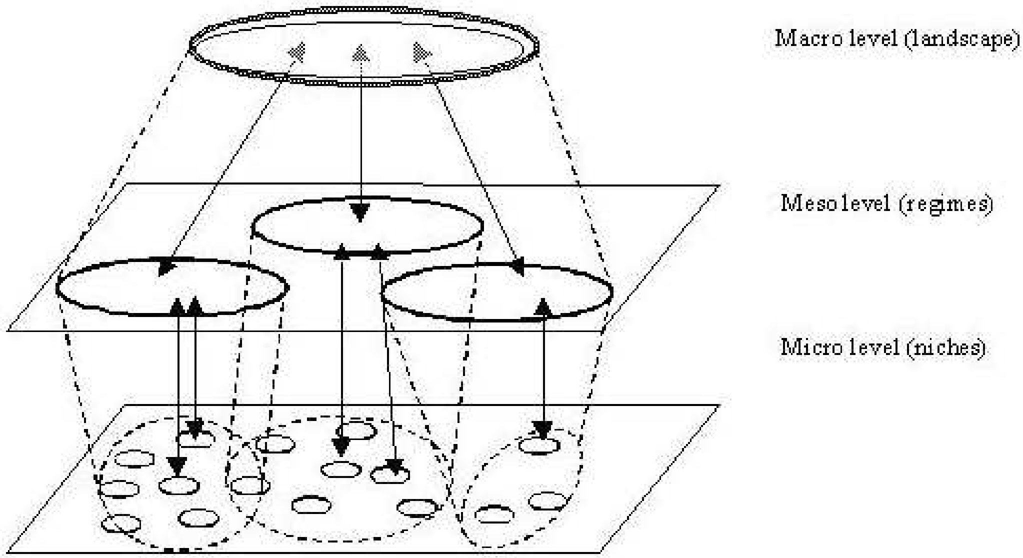

Figure 2.1: Multi-level perspective
Source: Rotmans, J., Kemp, R., van Asselt, M., 2001, 'More evolution than revolution: transition management in public policy', *Foresight 3*, 15–31.

Strategic Niche Management (SNM) is defined by Kemp, Schot and Hoogma (1998) as "the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology." [Kemp, Schot and Hoogma, 1998 in Raven, 2005] Three important processes were identified within the framework: voicing and shaping expectations, network formation and learning processes. [Raven, 2005] SNM has mostly been used for historical case studies to understand the process of technological development and there have been few practical guidelines for policy recommendations. [Caniëls & Romijn, 2006]
SNM focuses heavily on the creation of a protected market space for experimentation purposes and to promote future market diffusion. SNM does not look at entire countries and socio-technical circumstances are absent from the basic theory. As such the framework is not suitable for this research.

Large Technological Systems (LTS) theory as defined by Hughes (1983) focuses on changes within systems of large proportions and/or complexity, consisting of a seamless web of physical artefacts, organizations, and legislative artefacts (institutions). The goal of the system is to expand and a pattern of evolution is established which consists of several phases the system goes through: invention, development, innovation, transfer, and growth, competition, and consolidation. [Bijker, 1987] The framework has mostly been used to investigate radical changes in technology or major projects, such as the instigation of the telephone system and the shift from sailboat to steamboat.
The method is not suited for this research as it is mainly geared towards radical, large-scale system changes while this research focuses on current developments of existing or developing

systems. It is also very extensive; it incorporates physical artefacts such as power lines and the actual modules, and as such can not be performed for both countries in the available time.

The *Cyclic Innovation Model (CIM)* was developed in the nineties as an instrument for continuous reform. "It considers innovation processes as coupled 'cycles of change', connecting science with business, and technology with markets, in a cyclic manner." [Berkhout & v.d. Duin, 2007, p.294] It focuses on the mapping of 4 processes in public and private organisations which need to be managed in order for the innovation to reach the market. The model consists of 4 'nodes of change'; scientific exploration, technological research, product development, market transitions, which are connected by four interacting 'cycles of change'; technical oriented sciences cycle, systems engineering cycle, customized service cycle and society oriented science cycle. Each cycle can incorporate actions from multiple organizations and industries. [Berkhout & v.d. Duin, 2007]
Though the method focuses on processes that need to take place in order to bring a technology onto the market, it does not investigate several important outside processes, such as the need for the technology to fight for a place within the current structure, and how this can be achieved. Nor does it incorporate processes of institutional change. It is most suited for processes in public and private organizations while a more extensive picture is required to find outside factors which could limit or promote the innovation's development.

Porter (1990) was one of the first researchers to determine the economic and innovative success of a country based on structural factors. *Porter's diamond* model allowed for an understanding of the competitive position of a nation in global competition. The corners of the diamond consist of four factors: factor conditions, related and supporting industries, demand conditions and 'strategy, structure, and rivalry'. These factors affect four ingredients that lead to a nation's comparative advantage: the availability of resources and skills, information used by firms to decide which opportunities to pursue, goals and pressure on companies to innovate and invest. [Quick MBA, 2007]
Porter's diamond focuses on structural factors surrounding innovations and comparative advantages between companies or countries. It is not suitable for this research as it does not focus on the development of a specific technology. The theory is aimed at discovering the innovative strength of countries, which is a very high level of analysis for this research and would take too much time to explore.

The *Innovation System* framework is based on the premise that each technology has its own unique network of institutions that enables a technological breakthrough to diffuse successfully in the market. Such systems are often referred to as 'Technology Specific Innovation Systems' (TSIS) and include actors such as: universities, R&D institutes, producers, users, branch organizations, government, interest groups and financial institutions. Recently researchers such as Jacobsson & Johnson (2000) and Hekkert et al. (2007a) have put forward sets of 'functions', which are basically processes within the TSIS which must be fulfilled in order for the TSIS to function correctly. The interaction of these processes can lead to virtuous cycles which greatly promote the development and diffusion of the technology. Comparisons between countries have already been performed with this framework, examples are Kamp (2002) and Hekkert & Negro (2008).
As such the framework is very suitable for this research as these processes and cycles can be used to determine promoting and limiting factors of the development and diffusion of an innovation.

An additional reason is the ability with this framework to compare the Dutch and Japanese case, especially as the Dutch 'transition paths' are investigated through this method and the Dutch PV innovation system has been investigated. We will therefore use the Innovation System framework for our research. The IS framework will be further explained in the next section.

2.2 Innovation Systems

The term 'National Innovation System' was first coined by Christopher Freeman in his book 'Technology Policy and Economic Performance: lessons from Japan' [Freeman, 1987] where it was defined as "…the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies." The Innovation systems concept has become very popular among academics and policymakers due to its explanatory power. However there is currently no consensus on a definition. Since its inception a variety of definitions have been proposed (e.g. Lundvall 1992, Nelson 1993, and Metcalf 1995). For this research the definition of a TSIS as employed by Hekkert and Negro (2008) will be used "a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilise technology."

Researchers initially focused on the national level. However, for most researchers the national level added an unnecessary amount of complexity due to the vast amount of actors, institutions and relations involved. This has led to the creation of 'Sectoral Innovation Systems' (e.g. Malerba 2002), and 'Regional Innovation Systems' (e.g. Doloreux 2002), which as the names suggest focus on a sector or a region, respectively. [Sharif, 2006] Meanwhile recent researchers have proposed to focus on the development of specific technologies instead of regions or industries, since changes in Innovation Systems go hand-in-hand with technological change [Hekkert et al., 2007a]. These systems are called 'Technology Specific Innovation Systems" (TSIS).

An important difference between the TSIS and its sister concepts lies in its spatial aspect. While National, Regional and Sectoral Innovation Systems maintain strict geographical boundary, a TSIS transcends these boundaries as the technology is used in several sectors, and multiple countries are involved in the research and diffusion of the technology. See Figure 2.2. However, though they are international in nature when researching them, TSIS are virtually always restricted to national boundaries since they are affected by the national institutional framework. [Hekkert et al., 2007a]

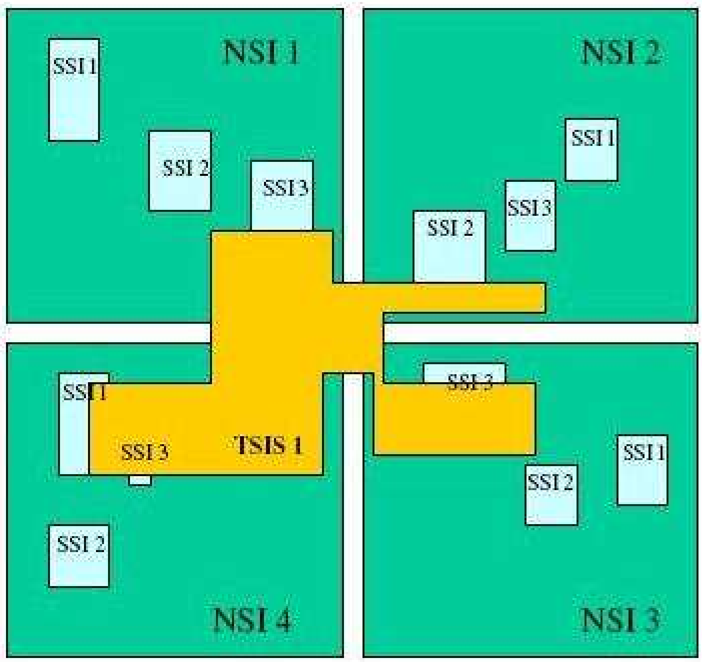

Figure 2.2: Boundary relations between National, Sectoral and Technology Specific Innovation Systems
Source: Hekkert et al. (2007a)

2.3 Functions of Innovation Systems

For an Innovation System to function correctly it is generally assumed it needs to fulfil a specific set of functions, where each function relates to a specific process or activity that takes place within the IS. Several of such sets have been proposed by e.g. Kern (2000), Hekkert et al. (2007a) and Jacobsson and Johnson (2000).[5] There is currently no agreement on the preferred set of functions. As stated by Hekkert and Negro (2008), "…another group of researchers with different backgrounds might highlight different processes and come up with a different categorisation of events and thereby to a different set of functions." [Hekkert & Negro, 2008] However there are two sets which are most prominent in the recent literature. Both Hekkert and Jacobsson have introduced a fairly similar set of 7 functions. Both are based on the newest insights and have been used in several case studies.

However it is important to note that in the choice of research methodology a major concern is the ability to compare results with other studies, especially as this research endeavours to make a comparison to the Netherlands PV industry. As the 7 functions of Hekkert et al. are currently used to examine the Dutch 'transition paths', this will facilitate translation. Furthermore, the framework has been used in several case studies in the Netherlands and abroad, including comparative studies.

For these reasons we will use Hekkert et al.'s (2007a) 'functions of innovation' framework to determine the strength of the Innovation Systems and points of improvement. Though the TSIS transcends national boundaries, we will focus our research on the Japanese and Dutch parts of the system. The framework consists of 7 functions. Each function relates to activities that take place in an Innovation System which are highly important for it performing well.

Function 1. Entrepreneurial activities

An entrepreneur turns the potential of new knowledge development, networks and markets into concrete actions to generate and profit from business opportunities. [Negro et al., 2007] Entrepreneurs are necessary to cope with the large uncertainties that stem from developing and diffusing new technologies. In general two 'types' can be distinguished. Entrepreneurs can be new entrants that see opportunities in new markets, or incumbent companies who diversify their business to take advantage of new developments. This function was analyzed by determining the number and type of new entrants, and their recent and future activities.

Function 2. Knowledge development

The development of new knowledge, or learning, is essential for the creation of new innovations. Four types of learning processes were distinguished by Kamp (2002); learning by searching, learning by doing, learning by using and learning by interacting. Of these the first three fall under the category of knowledge development. Learning by searching entails the creation of new knowledge at research institutes or companies. "It consists of the systematic and organised search for new knowledge, or the innovative combination of old and new knowledge." [Kamp, 2008, p.279] It was investigated by looking at the number and type of institutes doing research, and the type of research (basic/applied) they were performing.

Learning by doing consists of production skills which increase the efficiency of production operations. This process was mainly investigated by looking at how long production has been

[5] A thorough evaluation of the differences between the current sets of Innovation Systems Functions can be found in: Bergek et al. (2008) and Hekkert et al. (2007a)

taking place and the change in product cost during this period.
Using the technology also delivers specific knowledge such as feedback on the performance of the system in an actual application, as well as gaining experience with placing or installing the innovation. [Kamp, 2008] These all fall under the ‘learning by using’ process which was investigated by looking at the presence of test projects and methods for market feedback. For those technologies already in production we also briefly looked at the market size.

Function 3. Knowledge diffusion

The fourth learning process that was identified was learning by interacting, or knowledge diffusion. It entails the transfer of knowledge between different actors. With the large amount and variety of actors within the innovation system, the exchange of knowledge is very important. Formalized knowledge can be exchanged quite easily; however tacit knowledge which is difficult to formalise, needs to be transferred face-to-face. [Kamp, 2008]
For the analysis of this function attention was paid to collaborative efforts between the various actors, in particular between manufacturers and research institutes, as well as the existence of formalized exchange methods such as journals and seminars.

Function 4. Guidance of the search

Resources are limited making it is necessary to effectively distribute them by focusing on specific paths. There are several ways in which such guidance can be established. If a technology has proven itself, this will give the technology a higher level of credibility, which will propel development into this area. Similarly a technological breakthrough can motivate actors to focus on a specific field of study. Guidance can also be initiated by institutions such as the government through goal setting.
This function was analyzed by mapping specific targets set by governments or industries regarding the use of a specific technology, and determining the technological expectations of respondents.

Function 5. Market formation

A well functioning market is necessary in order to enable many of the other functions. It motivates and sustains entrepreneurial activities, motivates the application of new resources and enables support from advocacy coalitions. In general a Market is formed when the product fills a need or solves a problem. The establishment of niche markets are very important in this regard to allow new innovations to compete with embedded technologies. These niches are formed due to the presence of technology specific applications or through government action.
This function was analyzed by investigating the characteristics of each market, paying special attention to technology specific applications, and by examining government promotional activities.

Function 6. Mobilization of resources

To enable all the functions within the TSIS enough financial and human capital will need to be available. However there is another resource factor which is often overlooked, namely the fact that companies need to have access to enough physical resources to create their final products. I make a modest addition to the theory by clearly stating that ‘physical resources’ also need to be mobilized by actors within the TSIS. This function was analyzed through interviews, to discover whether or not core actors perceive access to sufficient resources as problematic.

Function 7. Support from advocacy coalitions [6]

New energy innovations need to make a place for themselves in the present energy system which is dominated by the oil industry. Current organizations have gained a large amount of power and influence and are often very reluctant to change. Creating legitimacy for the technology will facilitate a new technology to become part of an existing system, or overthrow it. Since interest groups are the key actors in creating legitimacy, this function will be analyzed by mapping the existence and activities of these groups.

For this function the existence of advocacy coalitions was analyzed. The views and activities of the coalitions were analyzed, including as much as possible an indication of their influential power, based on recent successes (or failures) and respondents' perceptions.

2.3.1 Virtuous and vicious cycles [7]

One of the central ideas of the 'functions of innovation' framework is that functions can influence one another. Entrepreneurs that see potential in a technology can start lobbying for special subsidy schemes from the government, thereby creating a niche market. This is one example of functions strengthening one another. A 'virtuous cycle' exists when the functions strengthen each other in a positive feedback loop. Negative feedback loops are known as vicious cycles. For example, we would have a virtuous cycle as soon as the creation of a niche market motivated more entrepreneurs to enter the market, thereby increasing the lobbying activities, getting more protection from government for the niche market, and so on. Determining the presence of cycles within an IS is very important. Virtuous cycles are considered the driving forces behind a good functioning Innovation System [Hekkert et al., 2007b], while vicious cycles will hamper the diffusion of technology and may even lead to the IS's collapse. [Hekkert, 2008] However it should be noted that a vicious cycle can be overcome and it is not uncommon for virtuous and vicious cycles to alternate over time within a single innovation system.

2.3.2 Relative importance of the functions

The last important point we will discuss relates to the relative importance of the seven functions. Though all seven functions are important for the functioning of the IS, recent research indicates that not every function is equally important. Research performed by Hekkert and Negro (2008) emphasizes the importance of three functions in establishing virtuous cycles; entrepreneurial activities, guidance of the search and market formation. However their analysis is only based on four case studies, two in Germany and two in the Netherlands. The only other authors which have discussed this issue are Bergek et al. (2008). A great deal is still unknown about the relation between the importance of functions and the phase of development of the technology under scrutiny, an issue which Jacobsson and Bergek (2004) greatly emphasize. Bergek et al. state that the importance of each function is expected to vary in time depending on whether the technology is in the formative or growth phase. [Bergek, et al. 2008] However their analysis is tentative and does not provide any practical guidelines. As the current research on this area is limited, we won't use the difference in importance of each function in this research.[8]

[6] This function is sometimes called 'creation of legitimacy/counteract resistance to change'. The terms are used interchangeably. We chose 'support from advocacy coalitions' as it was the clearest description.

[7] These types of cycles are also known as 'motors of change'.

[8] In paragraph 6.2 we will discuss our own findings regarding the relative importance of the functions.

2.4 Research approach

The research is divided into two main parts. First is the analysis of the functioning of the Japanese TSIS in order to determine the main promoting and limiting factors for the development and diffusion of the selected PV technologies. The second part is a comparison to the Dutch PV TSIS.

Part I – Analysis of Japanese PV technologies

To improve comparability between the Japanese and Dutch case, the Innovation system approach which was used to research the Dutch case has been used. [Hekkert et al, 2008] These involve the following 4 steps of analysis:

Step 1. Determining the phase of development of the technology

As mentioned before, the evaluation of an IS depends on the phase of development of the technology. Four possible phases are identified; pre-development, take-off, diffusion and stabilisation. The following table shows the criteria which are used to determine the phase of development. For a quick overview the phase will also be represented in a simplified diffusion graph, known as an S-curve.

Phase	**Criteria**
Predevelopment	Untill prototype is created
Take off	Few paying customers, small demand
Diffusion	Strong growing salesfigures
Stabilisation	Market saturation

Table 2.1: Phase of development of the technologies
Source: [Hekkert, 2008]

Step 2. Mapping the structure of the Technology Specific Innovation System (TSIS) [9]

In order to understand the processes happening within an Innovation System, it is paramount to first map the structure of the TSIS. Without a basic understanding of the structure, processes within the TSIS will be difficult to place and understand, leading to misinterpretations. For this reason, the research will start with an initial analysis to determine the basic structure of the PV sector. For this analysis the TSIS is divided into five parts: government system, supply, demand, intermediaries, and knowledge infrastructure, see figure 4.2. The allocation of the actors to each component can be found in the table below.

Structural component	**Parts**
Government system	National, regional and local governments
Supply	Manufacturers
Demand	Architects, project developers, building companies, retailers, installers, building owners (private, corporate, industry, real-estate, communities)
Intermediaries	Branch organizations, customer organizations, financial institutions, environmental organizations, specialized training institutes
Knowledge infrastructure	Universities, research institutes and company research centres

Table 2.2: Structure of the IS
Source: Adapted from [Hekkert, 2008] [10]

[9] A more extensive analysis of the Japanese PV sector has been made which is not limited to (though focussing on) the seven selected technologies. This analysis has been added as Appendix 1.
[10] Several actors were moved from the supply category to the demand category as this is more in line with the

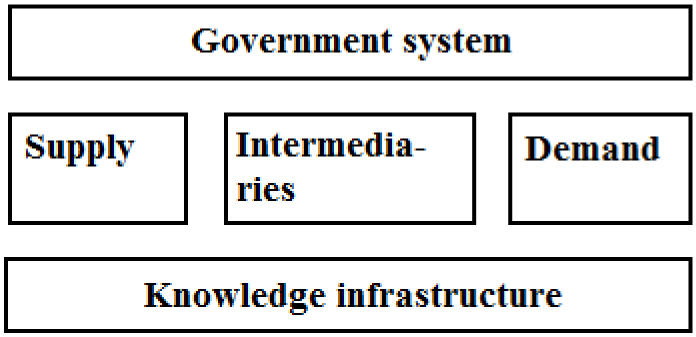

Figure 2.3: Structure of the TSIS
Source: Adapted from [Hekkert, 2008]

Step 3. Analysing the functioning of the IS
The next step is to assess the functioning of the innovation system through the evaluation of the seven system functions. These were evaluated through a mix of interviews with key actors in the TSIS combined with document search and literature review. In the evaluation of the Dutch energy trajectories, an appraisal was made of the structure of the IS and the fulfilment of the individual functions based on a 5-point scale. However considering these assessments are mostly based on 'common sense' and no fixed criteria currently exist for the evaluation of the functions, I will not employ this scheme for this research. Appendix II gives an overview of the indicators which were used to evaluate each function, and the type of actors which were questioned for each function.

Step 4. Determining the presence of virtuous or vicious cycles
The final step is to look at the interrelation between the functions. By observing positive and negative interactions we can determine the presence of virtuous and vicious cycles and their main causes. In the analysis of the innovation system we made a distinction between cycles which influence the development, and those that influenced the diffusion of the technology. The analysis focuses on investigating the main promoting and limiting factors for the development and diffusion of the technology.

Part II – Comparison to the Netherlands
The second part of the research consists of an evaluation of the Dutch PV innovation system employing the previous step-wise plan, and comparing it to the Japanese case. In this part we will not look at individual technologies but the PV industry as a whole. The Dutch PV IS was evaluated using a variety of empiric sources, including the analysis of the Dutch PV IS as performed by Dr. Simona Negro.
As the final step of this research several recommendations to the Dutch government will be given, based on the comparison. To establish these recommendations we will look at the strong points of the Japanese systems and analyze if implementing these factors would benefit PV development and/or diffusion in the Netherlands. Next to this we will look at the weak points of the Netherlands PV IS and investigate possible solutions based on the Japanese case. Experts have been consulted to determine the applicability of the Japanese solutions to the Dutch case.

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structure of this research, these are: architects, project developers, building companies, retailers and installers. Furthermore, 'company research centres' were added to the knowledge infrastructure category.

3. Current status of PV in the world and Japan

In this chapter we will look at the state of PV in Japan and abroad.[11] We will first look at the worldwide developments in order to put the situation in Japan and the Netherlands into perspective. Next we look at the current state of development of the selected PV technologies which we will investigate. The analysis of the TSIS of these technologies will take place in the next chapter.

3.1 PV Worldwide

PV is a blooming market, generating $17.2 billion in global revenues in 2007. [Marketbuzz, 2008] Especially the European market has seen an explosion in demand, after Germany initiated a feed-in-tariff (FIT) which gives home-owners a competitive price for the energy they deliver to the electricity grid. Italy and Spain have since followed its example. The current distribution of the world PV market is shown below.

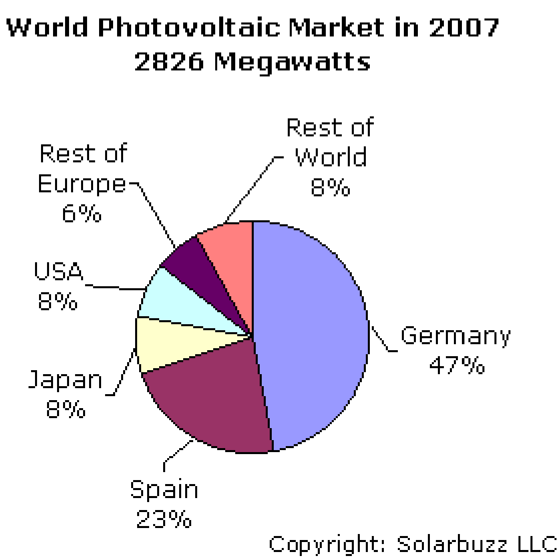


Figure 3.1: World Photovoltaic Market in 2007
Source: [Marketbuzz, 2008]

Linked to the increased market, there is massive growth in installed PV capacity, especially in Western European countries such as Germany, Italy and Spain, with Germany currently leading in cumulative installed capacity.

This increased demand has also led to an increase in production, especially in the European area. The main PV producing countries are Japan, Germany and the United States. The country of origin of the main PV producing companies is slowly shifting from Japan, which used to have the top positions, to European producers. The largest Japanese PV manufacturing company, Sharp Corporation, was the largest producing company from 1999 until 2007, when it was displaced by the German Q-Cells. [Prent & Stroeks, 2008] One of the main countries entering the PV market for the first time is China. China is producing a large quantity of solar cells but has no domestic

[11] For more detail per country please visit the IEA International Energy Agency website: http://www.iea-pvps.org/. Concerning the situation in Japan see Appendix I for more detailed information on current government, research and production activities.

market and is exporting over 90%. [Hui, 2008]

3.1.1 Global PV issues

There are two main issues facing the global PV industry; the silicon shortage, which constrains production, and grid stability issues, which hinder the diffusion of PV.

Silicon is the most widely used raw material for the production of solar cells. However, there is competition between the PV and semi-conductor industry for this precious commodity. Currently there is an enormous shortage of silicon on the market, making it difficult for some companies to get sufficient amounts. Production of many companies is not up to full capacity mainly due to shortage of silicon. Successful companies have managed to obtain long-term supply contracts, however new entrants are facing difficulties. Buying extra on the spot-market can be up to 5-6 times more expensive. The high costs form major problems for the PV industry since 20% of the current cost of solar system comes from silicon material. [Kim, 2008]
Many companies in China are seeing a business opportunity and are starting up silicon production plants. China aims to make solar cells using low cost wafers but manufacturers are facing instability issues. [Hui, 2008] In Taiwan institutes are busy trying to get ‘fast-grown’ cheap wafers of sufficient quality to be used. However despite silicon production for both solar and semiconductor use rising 30% in 2007, it remained the most capacity constrained part of the PV chain. Twenty-one new entrants started manufacturing silicon in 2007. [Marketbuzz, 2008] However there is good news as a rough estimate has shown that there will be a sufficient supply of silicon by 2010. [JPEA, 2008]

Another problem PV and other renewable energy sources face is that they are dependent on nature and are therefore considered supplementary power sources, and not energy power sources in their own right. This is mainly due to the fact that their reliance on nature results in an unstable power output. Incorporating large-scale projects can have negative effects on grid stability, as extra power is added and removed without warning. This increased the change of power outages, and therefore an increased chance of customer dissatisfaction. Research in Japan has pointed out that this instability will occur when up to 10% of the energy is delivered by solar cells. [JPEA, 2008] To get the needed stability to compensate for this, PV installations need to be combined with an adjustable power source or storage battery. [Watanabe, 2007] Research into these fields is underway in many countries, including Japan and The United States. The US government declared in the FY 2007 draft budget to focus on technological development of next-generation storage battery and hydrogen fuel. [Watanabe, 2007]

3.2 PV in Japan

Japan has practically no natural resources and is heavily dependent on imported oil. In fact, only 4% of Japan's energy comes from native sources. [ANRE, 2006] This weakness in the Japanese energy system became apparent during the first oil crisis of 1973. Ever since, one of the main goals of the Japanese energy policy is to gain independence from outside energy sources by investigating non-oil alternatives. The current principles of the Japan's energy policy are known as the 3E's:

1. Security of Japanese **E**nergy supply (alternatives to oil)
2. **E**conomic efficiency (market mechanisms)
3. Harmony with **E**nvironment (cut CO2 emissions)

[Jäger-Waldau, 2007]

As a result of the diversification actions of the government, the current energy mix of Japan consists of a variety of sources, including: nuclear, geothermal, LP gas, oil, LNG, coal and Hydro (see figure 3.2). The government is very supportive of the so-called 'new energy sources' which encompass a large variety of technologies; solar power generation, wind power generation, generation from waste products, biomass power generation, solar thermal energy, thermal energy from waste products, biomass thermal energy, ice thermal energy, production of fuel cells from biomass, temperature differential energy, electric vehicles (including hybrid cars), natural gas vehicles, methanol vehicles, natural gas co-generation and fuel cells. [ANRE, 2006, p.14]

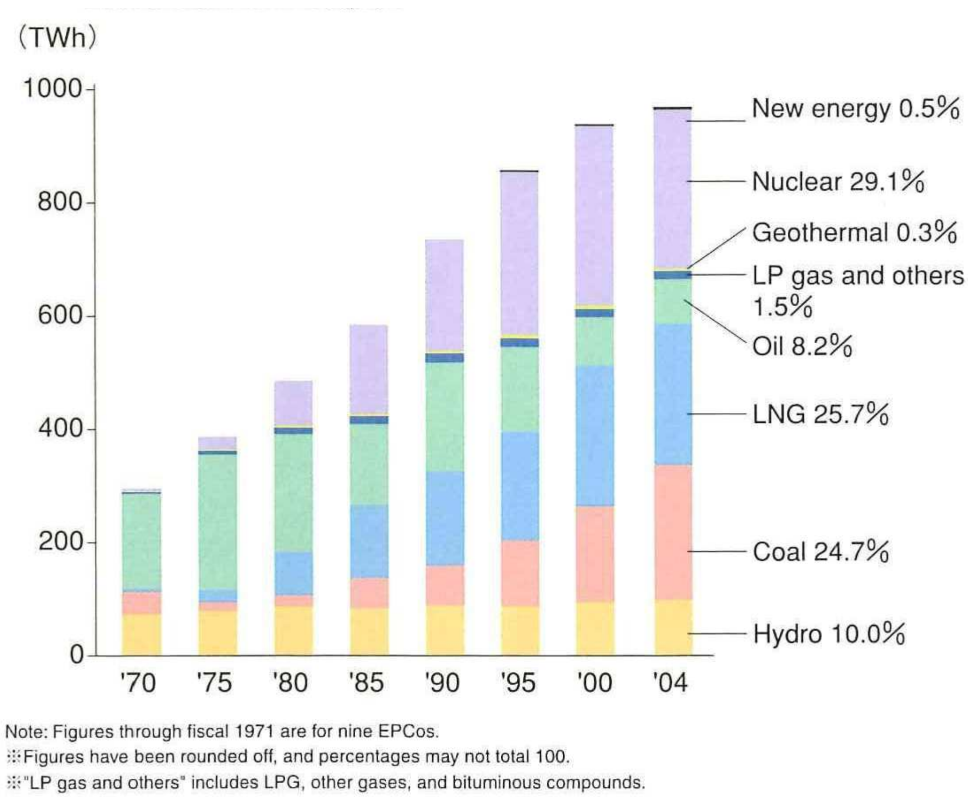
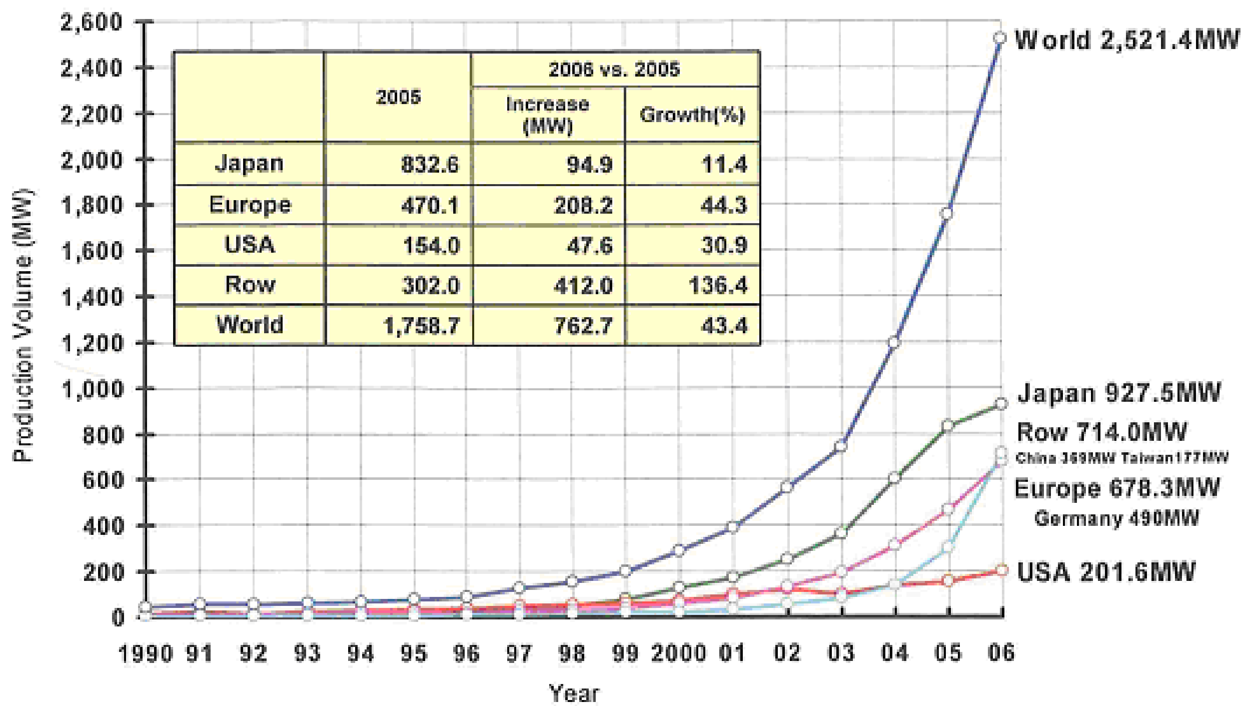


Figure 3.2: Trends in power generation in Japan
Source: [ANRE, 2006]

Japan is one of the ‘energy R&D-intensive’ leaders in the world together with: the United States, Canada, Germany, France, Italy, the Netherlands, Switzerland and the United Kingdom. However unlike the other leaders, only in the case of Japan does energy R&D account for more than 1.5% of the nation’s overall R&D enterprise. [Runci and Dooley, 2004] The government started the research and development of solar cell technologies in the ‘Sunshine project’ which lasted from 1974 up to 1993, after which it was replaced by the ‘New Sunshine project’. Though this new program ended in 2000, Japan it is still one of the largest spenders in the world regarding solar cell R&D. [PVPS, 2007]

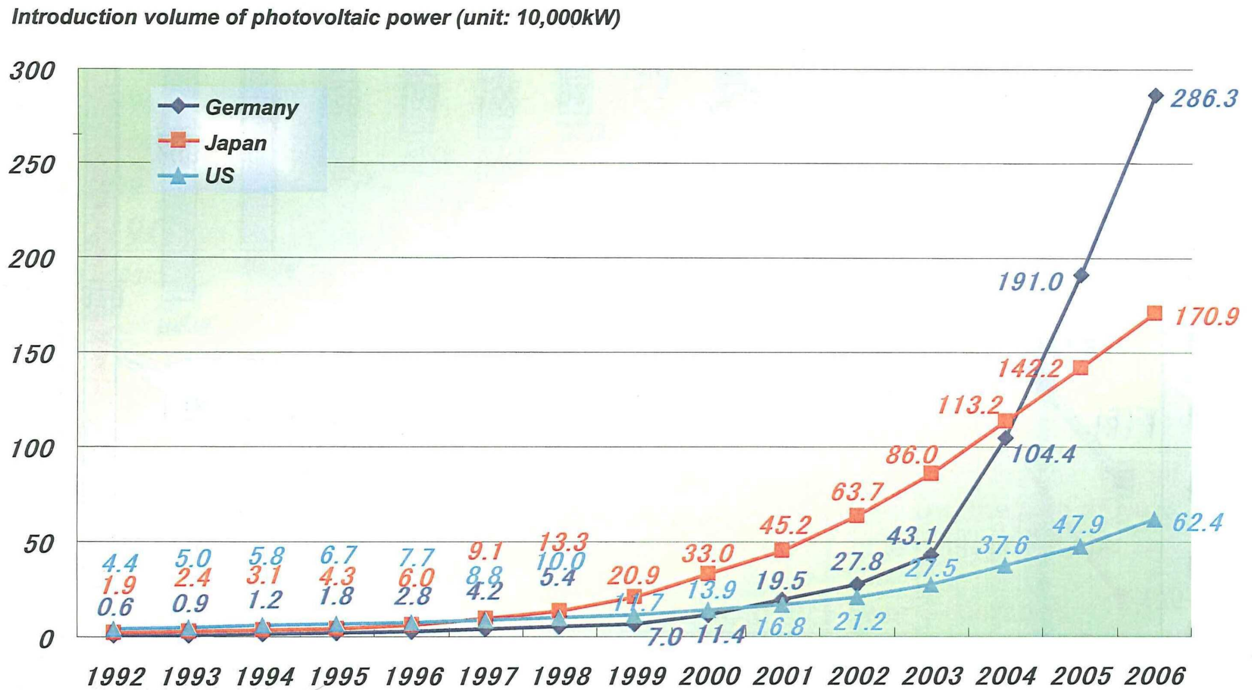
Japanese companies were quick to join in the government’s solar projects and a large solar cell industry has emerged. Japan became world No.1 ranked in production volume in 1999, and maintained this position until 2007. Japan produces about 40% (36.8%) of the entire world’s PV and Japanese PV manufacturers occupy 3 out of the 5 top five ranks. [Kaizuka, 2008] However Japanese producers are losing ground to new players such as Germany and China (see Figure 3.3). They only accounted for 26% of global production in 2007. [Marketbuzz, 2008]



	2005	2006 vs. 2005	
		Increase (MW)	Growth(%)
Japan	832.6	94.9	11.4
Europe	470.1	208.2	44.3
USA	154.0	47.6	30.9
Row	302.0	412.0	136.4
World	1,758.7	762.7	43.4

Figure 3.3: Production volume of PV cell
Source: [Kaizuka, 2008]

The Japanese have also lost their position as the country with the largest installed PV capacity in the world, see figure 3.4. The causes for this are the enormous growth in European countries such as Germany and the fact that the Japanese domestic market stagnated in 2006. The main reasons cited were the end of financial installation support through the government’s ‘Residential PV System Dissemination Programme’ in 2005, combined with indirect effects of tight silicon feedstock supply. [PVPS, 2007, p.11]



Note 1: Source: Trends in Photovoltaic Applications/IEA/PVPS (2006)
2: IEA PVPS participants: Australia, Austria, Canada, Switzerland, Denmark, Germany, Spain, France, UK, Israel, Italy, Japan, South Korea, Mexico, Netherlands, Norway, Sweden and the United States

Figure 3.4: Changes in Cumulative Introduction of Photovoltaic Power Generation
Source: [Watanabe, 2007]

3.3 Selected PV technologies

In this section we will present the selected technologies. We will explain the basics of each technology including the current research challenges and production status, ending with an evaluation of the current phase of development of the technology. We clustered the PV technologies into four groups based on the similarities of the technologies, linked to similarities and overlap within the innovation systems. The groups are: supporting technology, silicon-based technologies, CIS and organic technologies. As was explained before, no evaluation was made of the TSIS of solar grade silicon. Nevertheless we include a description of the technology in this section.[12]

3.3.1 Supporting technology

Solar Grade Silicon material (SoG-Si)

Solar Grade Silicon entails the production of silicon material which is suitable for use in Solar Cells. [U.S., 2008] Silicon is the second most available item in the Earth's crust as it is basically just sand. [U.S., 2005] Highly refined silicon is mostly used for the production of micro-processors (chips). Semi-conductors however require a high level of purity, 99.999999999%, and it takes a lot of energy to achieve this purity. Silicon for the production of solar cells on the other hand does not necessarily require this high level of purity, 99.9999% is sufficient. [Kawamoto & Okuwada, 2007]

Worldwide a lot of research is being done to determine the allowable levels of impurities for SoG-Si in order to lower the cost of producing silicon. Considering about 50% of the current costs of a PV module can be attributed to the high-purity silicon wafers, [ECN, 2008a] solar cell manufacturers are very interested in low-cost wafers.

Figure 3.5: Solar Grade Silicon material example
Source: http://www.greentechmedia.com/articles/ae-polysilicon-to-start-construction-457.html

The phase of development of SoG-Si is the take-off phase, as the worldwide production of SoG-Si is still very small, with a fairly small demand.

[12] Further information on the current state of solar grade silicon research and production in Japan can be found in Appendix I.

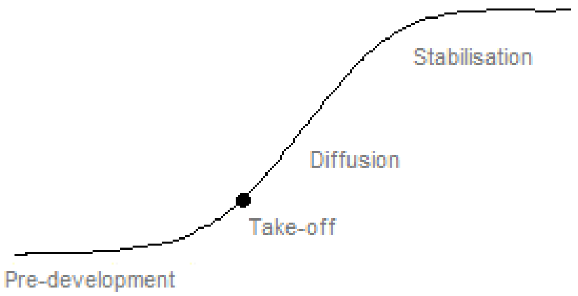


Figure 3.6: Phase of development of Solar Grade Silicon

3.3.2 Silicon-based solar cell technologies

Crystalline silicon solar cells (c-Si)

Crystalline Solar Cells are the most well-known solar cells, and also the most well researched. Nearly all of the solar cells that are currently being produced are of this type. They hold 90% of the total market. Due to their high efficiency and durability they are considered very well suited for roof applications.

Compared to the other technologies crystalline silicon has a high efficiency. The main problem lies in its relatively high silicon usage. Other technologies which use less silicon or no silicon at all are therefore becoming more attractive nowadays. Most of the current research into crystalline silicon solar cells is 'applied' instead of 'basic'.

Figure 3.7: crystalline silicon solar cell example
Source: http://www.kyocerasolar.com/products/mygen.html

World-wide the demand of this type of solar cell is on the rise, making the phase of development 'diffusion'.

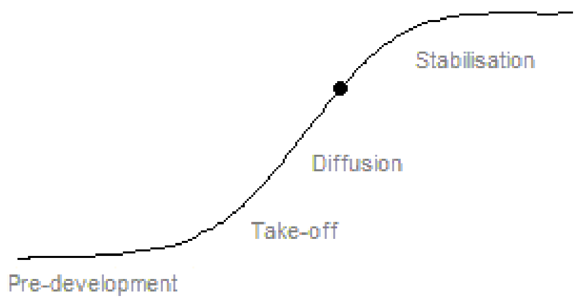


Figure 3.8: Phase of development of crystalline silicon solar cells

Thin-film silicon solar cells (tf-Si)

Considered the second generation solar cell, thin-film silicon solar cells were created with aim of reducing the amount of silicon that goes into each solar cell. Current products are becoming increasingly thin, up to 100th the thickness of conventional crystalline silicon solar cells. [ECN, 2008b] Their market share is growing, as ready-made production lines become available.
The main research goal in the PV industry is to make solar cells cheaper by using less silicon and increasing the efficiency. Current research focuses on making the wafers stronger as waver breakage due to thinner wavers is a big problem. Producers are creating unique applications such as see-through solar cells for in windows, and bendable solar cells which can be used in consumer products and on curving roofs.


Figure 3.9: thin-film silicon solar cells example
Source: http://www.fujielectric.co.jp/eng/news/2005/05082501.html

World-wide the demand of this type of solar cell is exploding, making the phase of development ‘diffusion’.

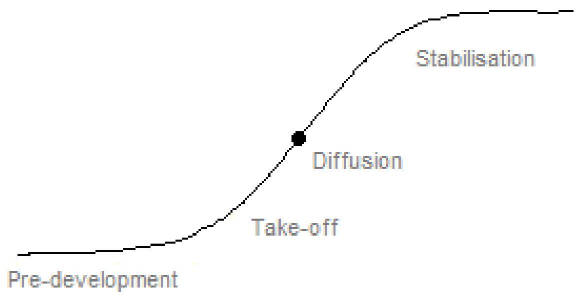


Figure 3.10: Phase of development of thin-film silicon solar cells

Stacked silicon solar cells

Stacked cells consist of multiple layers of different types of silicon. The most common variant consist of multi-junctions, like stacking multiple thin-film solar cells on top of each other. In general, each of these junctions is sensitive to a different part of the solar spectrum, allowing the solar cell to absorb a wider range of Solar Energy. Some of the highest efficiencies have been achieved by triple-junction solar cells. Current research is aimed at determining the optimum structure of the solar cell. Right now the structure that is used differs per research institute or company. The most common structure is those with two junctions called 'Tandem' or 'Hybrid'.[13]

Figure 3.11: Stacked solar cells example
Source: http://www.gizmag.com/new-technology-promises-solar-cell-efficiency-boost/8339/

Stacked solar cells only recently entered the market and production and sales are still very limited making the phase of development 'take off'.

[13] The basic structure of Sanyo's HIT solar cells differs however they have also been placed in this category as they consist of multiple layers of silicon-type material. HIT solar cells consist of a layer of crystalline silicon flanked by layers of polycrystalline silicon.

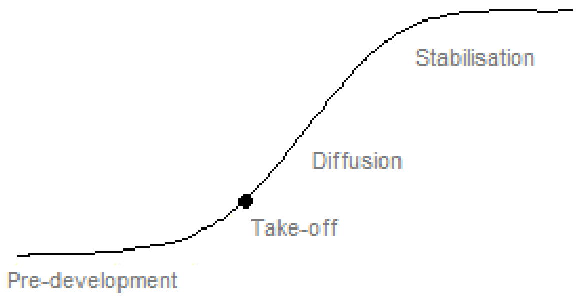


Figure 3.12: Phase of development of stacked silicon solar cells

3.3.3 CIS technology

Copper Indium di-Selenide/di-Sulfide (CIS) solar cells

CIS is the first technology we discuss here that does not incorporate silicon materials. 'CIS' is an abbreviation of the component of the solar cell and stands for Copper Indium di-Selenide/di-Sulfide.[14] There are not many manufacturers of CIS solar cells yet as it has only recently started to be commercialized. Since April 2003, the first pilot production for large area thin film solar modules based on CuInS2 (CIS) is under construction in Berlin. [Meyer et al., 2004] Many companies are in the process of up-scaling their test-installation into full production.

Current research aims at increasing the conversion efficiency, as it can not yet compete with the silicon-based technologies, and determining the optimal composition of the solar cells. [Powalla, 2008] The goals are to achieve 15% efficiency and establish robust manufacturing processes. [Kushiya, 2008b] The main problem lies currently with the switch from cell to module, which entails high loss of efficiency.

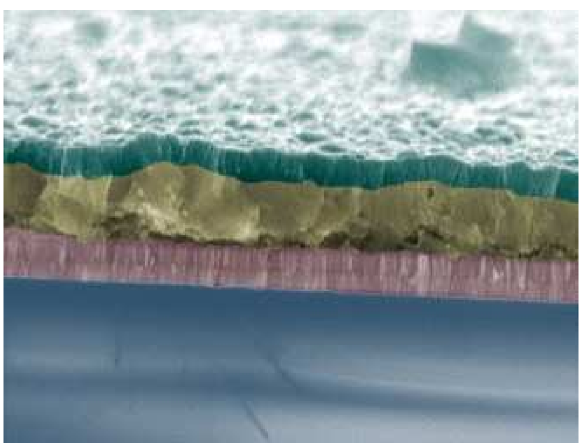


Figure 3.13: CIS solar cell cross-section
Source: http://www.pvresources.com/en/technologies.php

CIS solar cells only recently entered the market, no rapid diffusion yet, making the phase of development 'take off' moving towards 'diffusion'.

[14] The more complete term would be: Copper-indium/gallium-diselinide/disulphide (CIGSS)

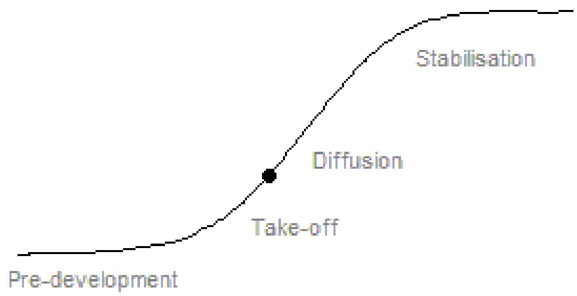


Figure 3.14: Phase of development of CIS solar cells

3.3.4 Organic solar cell technologies

Organic solar cells in general can be divided into two types; dye-sensitized cells and organic cells. These organic cells can have either a low or high molecular weight. Those with high molecular weight are polymers. [Yoshikawa, 2008]

Dye-sensitized solar cells

Dye-sensitized cells (DSC) use chemical dyes to capture the light and convert it into electricity. DSC solar cells are based on the ‘Graetzel Solar Cell’ which was created in 1991. However the first commercial products using sensitized oxides are only expected to appear in 2008 when the initial patents will expire. [Stroeks, 2006]

Dye-sensitized cells (DSC) are very cheap to produce. It takes only 1/3 to 1/5 cost of conventional solar cell production. This is due to the production process which uses low temperatures (500 C) and no vacuum. [Arakawa, 2008] The main problems now are long-term stability and the sealing of the material to prevent oxidation. Dye-sensitized solar cells can be used flexibly and can be made in many different colours. However different colours result in different efficiency levels since different parts of the light spectrum are absorbed. Black is the best since it absorbs all the light. A white dye will result in no power at all. [Arakawa, 2008]

Large scale commercial production of DSC solar cells is expected to start this year however this is only for consumer products, not for power applications.

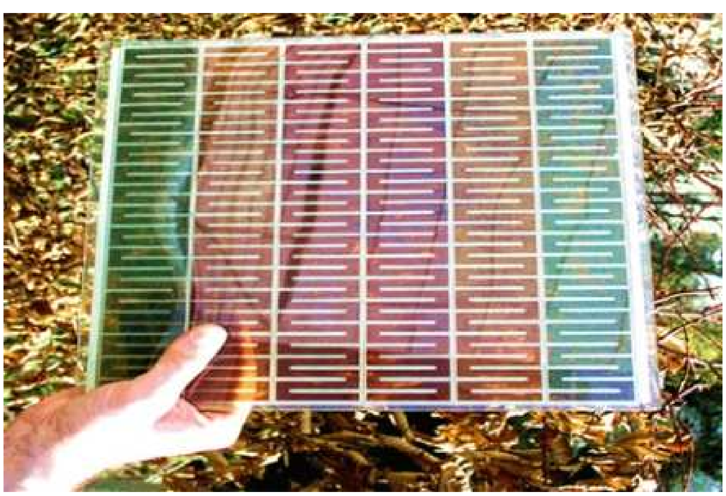


Figure 3.15: dye-sensitized solar cell example
Source: http://www.takeawayfestival.com/files/image/solar-panel-new-zealand.jpg

Looking at the rooftop applications for DSC solar cells, a prototype supposedly exists but is not on the market. Currently no plans have been announced for a test production facility or anything similar. For this reason we determine the phase of development of dye-sensitized solar cells to be pre-development.

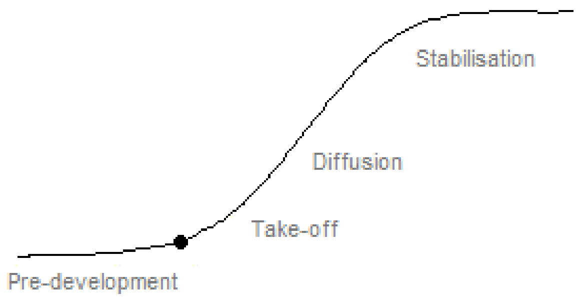


Figure 3.16: Phase of development of dye-sensitized solar cells

Polymer solar cells

Polymer solar cells, also known as ‘plastic solar cells’, use conducting polymer materials to produce electricity. Polymer solar cells consist of special plastic composites which produce electricity when light falls on them. This technology is only its early infancy [ECN, 2008c] however the research is progressing rapidly. In 2006, the conversion efficiency of the most efficient polymer solar cell was 4-5%. Five years before, it was less than 1%. [JSP, 2006]

Current research focuses on finding new materials and improving the structure of the polymer solar cells. There are also stability issues which need to be resolved, to ensure sufficiently long lifetimes for practical use. [ECN, 2008c]

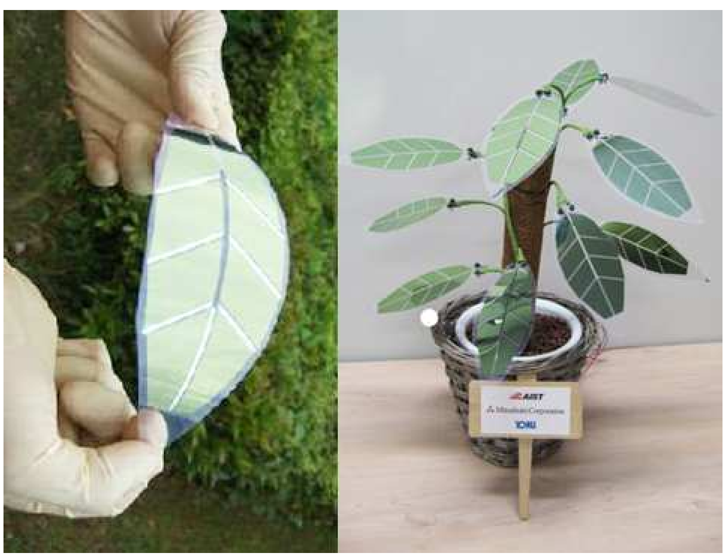


Figure 3.17: polymer solar cell example
Source: [Kanou, 2008]

As research into polymer solar cells for use in power applications is only in an early stage of development, we determine the phase of development of the technology to be ‘predevelopment’.

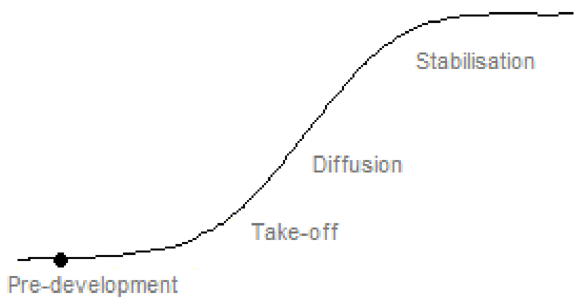


Figure 3.18: Phase of development of polymer solar cells

4. Functions of Innovation Systems Analysis

In this chapter we give an analysis of the innovation systems of the six selected types of solar cells; crystalline silicon solar cells, thin-film silicon solar cells, stacked silicon solar cells, CIS solar cells, dye-sensitized solar cells and polymer solar cells. We will begin this analysis with a snapshot of the structure of the PV TSIS in Japan by looking at the actors involved in the research, development and diffusion of the technologies. After this we will evaluate for each technology to what extent the functions have been fulfilled. We will discuss each of the seven function in turn, where we will focus as much as possible on the differences per innovation. At the end of this chapter we will determine the existence of virtuous and vicious cycles within the PV industry in general and for each innovation separately, focusing on the main promoting and limiting factors of PV development and diffusion in Japan.

4.1 Structure of the Japanese PV IS

This section will describe the structure of the TSIS of the 6 selected PV technologies in Japan, namely: crystalline silicon solar cells, thin-film silicon solar cells, stacked silicon solar cells, CIS solar cells, dye-sensitized solar cells and polymer solar cells. We will use a division into 5 parts; government system, supply, demand, intermediaries, and knowledge infrastructure.

4.1.1 Government system

The national government's energy policy is executed by the Ministry of Economy, Trade and Industry (METI). The Agency for Natural Resources and Energy (ANRE) within METI is responsible for maintaining a stable energy supply. Furthermore there are two institutes related to METI that perform specific functions for the PV sector. The National Institute of Advanced Industrial Science and Technology (AIST) is the national research institute, of which the 'Research Center for Photovoltaics' does research into practically all types of PV technologies. The New Energy and Industrial Technology Development Organization (NEDO) is the main subsidy provider of the government, for the most part research subsidies. It has several projects dedicated to PV research, development and dissemination.

Two other ministries that are involved in PV research and dissemination are the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of the Environment (MoE). MEXT finances research projects, and has a collaborative program to promote the use of solar installations in schools for educational purposes. The Ministry of the Environment started the 'Solar Promotion Programme', a package of several projects to advance countermeasures against global warming, including dissemination programmes within each project to promote the introduction of PV systems. [PVPS, 2006]

The New Energy Foundation (NEF) is focused on market introduction and was responsible for the market subsidy program, called the Residential Dissemination Program. It currently enforces market-oriented projects such as the Field Test Projects on New Photovoltaic Power Generation Technology [RTS, 2008] which is subsidized by half by NEDO.

Regarding local governments, the Metropolis of Tokyo has formulated an "Action program for Tokyo toward 10 years later" which includes a guideline for the installation of residential PV systems to 40,000 households. [RTS folder] Furthermore, over 319 communities provided a subsidy or preferential loan program for the installation of PV systems in 2006. [Ikki & Matsubara, 2007]

4.1.2 Demand

Most of the PV solar cells systems in Japan are sold to *home owners*. Over 80% of installed capacity lies in the residential market. [JPEA, 2006] There are also an increasing number of *companies* who are interested in PV. Seibu Railway is installing PV systems into several of its stations, as is Sagawa Express. Other companies that added PV to their buildings or installations in 2006 include: Kirin Brewery, Toyota Motor, Aeon, Seiyu and Asahi Shokuhin. [RTS, 2008] Also, nearly all PV manufacturers include them in their own offices and factories.

The *distribution* of PV systems is undertaken by a large number of companies, including Sekisui Chemical and Itochu. [RTS, 2008] In 2006, as many as 2,886 establishments were registered as system dealers and participated in NEF's project to promote residential PV systems, these include: remodelling companies, construction companies and architectural design firms, roofing companies, and electric work contractors. [JPEA, 2006] Door-to-door sales by PV system dealers have increased greatly since 2001. [JPEA, 2006]

Many *housing companies* such as Misawa Homes, Daiwa House Industry, PanaHome Corporation and Sumitomo Forestry are integrating PV into their homes. [RTS, 2008] Most of these companies sell prefabricated houses and have PV-integrated roofing as one of their options.

4.1.3 Intermediaries

The Japanese PV branch organization, the JPEA, provides marketing information, promotes collaboration between actors in the system and is an important speaking partner for the government. It co-organizes events such as the PV Expo to allow manufacturers and suppliers to meet and exchange contact details. There are no large well-known customer organizations, financial institutions or training institutes specialized in PV.

4.1.4 Supply

The following companies are manufacturing solar cells and modules.

Silicon solar cell manufacturers:

Fuji Electric Systems is part of the Fuji Electric Group and started manufacture of solar cells in 2006. It fabricates bendable thin-film silicon solar cells for use as non-straight roofing material and other curbing objects. Fuji Electric will start production of bendable solar cells worked into tent-cloth soon, and other applications are expected in the near future. The company is researching stacked solar cells.

Hitachi produces bifacial single crystalline silicon solar cell. It is focusing on improving the conversion efficiency of this type of cell (16.3% at the front, 15% at the back). Current production capacity is 10MW/year. [RTS, 2008] However the company has recently agreed to sell its technology to the Space Energy Corporation (SEC). [REW, 2008] Research and production activities are therefore expected to be continued by SEC. Hitachi has reportedly developed dye-sensitized solar cells which it had planned to commercialize in 2005. [Jäger-Waldau, 2007]

Kaneka is well-known world-wide for its thin-film silicon research. It started commercial production of thin-film silicon modules in 1999 with 20 MW/year, which has increased to 55 MW/year by 2007. The company has announced a doubling of its PV module production capacity to 130MW/year by 2010. [Kaneka, 2007; RTS, 2008] It started overseas sales in 2001, as well as moved into Tandem research. It has recently developed a 12% Hybrid module which it indicates it will put on the market in the near future. [Kaneka, 2008] Kaneka is focusing heavily on the foreign market, and it plans to expand the list of contract processing companies overseas for final products. [RTS, 2008]

Kyocera focuses solely on crystalline silicon solar cells. It produced 240 MW/year in 2007 and will increase its solar cell production in FY2010 to 500MW/year, approximately twice as much as the current production volume. [Kaizuka, 2008] The company is very interested in the world market and will produce modules at 4 sites around the world. [RTS, 2008] However the company focuses most of its attention on the developing countries. [Jäger-Waldau, 2007]

Mitsubishi Electric Company has achieved an 18.6% conversion efficiency of its multi-crystalline solar cells by employing a honeycomb texture structure to reduce surface reflectivity. The company plans to put it into mass-production by 2011.[15] [MEC, 2008] It expects a 30% increase in global shipment volume for FY2008 and invest to prepare for this. Mitsubishi Electric produced 150 MW in 2007, and aims to increase this to 600 MW/year by 2012. [Kaizuka, 2008; MEC, 2008b; ME, 2008]

Mitsubishi Heavy Industries (MHI) like Mitsubishi Electric Company, is a subsidiary of the Mitsubishi Group, however it focuses on a different type of solar cell. MHI produces thin-film silicon solar cells since 2002. [Jäger-Waldau, 2006] MHI started production of Tandem solar cells due to the efficiency gains over thin film silicon solar cells. [Yamauchi, 2008] Its first modules entered the market in April 2008. [Hirshman, 2008] The company has also started installing PV systems at all its plants. [RTS, 2008]

Sanyo Electric has produced HIT modules (stacked solar cells) since 1997, before that the company was working on thin-film silicon solar cells. [Jäger-Waldau, 2007] The company is in the process of improving its HIT technology. However, HIT does not reduce the company's dependence on silicon.[16] [Maycock, 2005] Sanyo Electric released a plan to establish a new "Advanced Photovoltaics Development Center" to promote the development of next-generation thin-film silicon PV module. [RTS, 2008]

Sharp Corporation is the largest PV manufacturing company in Japan, and until recently in the world, its current annual production capacity for solar cells is 710 MW/year (2007) [Sharp, 2008a]. It has the largest range of solar cell types of all the other companies as it produces crystalline silicon solar cells, thin-film silicon solar cells, stacked solar cells and GaAs, and is researching dye-sensitized and polymer solar cells.
The company started to develop solar cells in 1959 and succeeded in mass-producing them in 1963. It is the only Japanese producer to create solar cells for space application. Lightweight and flexible multi-junction cells have been developed for the next generation space solar cell (with the Japanese space agency JAXA). [RTS, 2008] The company also recently developed a triple-layered thin-film silicon solar cells with a high conversion efficiency of 13% [RTS, 2008], as well as a PV module using DSC with the world's highest conversion efficiency. [RTS, 2008]

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[15] For further explanation of the technological process: [MEC, 2008]
[16] Though HIT modules fall under the stacked silicon solar cell category, they are the only type in this category to not reduce silicon dependence as they have a layer of crystalline silicon as base.

Their recent new products include: a new large format thin-film polycrystalline solar cells since September 2005, a newly developed thin-film silicon Tandem cell, a see-through PV module which can act as a lamp at night called 'Lumiwall' and a new triple-junction GaAs solar cell which will go into production in May 2007. [Jäger-Waldau, 2007]
They started production of Tandem solar cells in 2005 for use as facades, see-through roofing material and rooftops. [Sharp, 2008b] And have announced the construction of a 1GW thin-film silicon solar cell plant in Sakai City in Japan, one of the largest in its kind and will cost 100 billion yen [Sharp, 2008a].

CIS solar cell manufacturers:
Honda Soltec Co. Ltd. has only recently entered the PV market. Their first factory in Kumamoto opened its doors in November 2007 and is expected to start with a production of 27.5 MW/year at the end of 2008. [Prent & Stroeks, 2008] This is the company's first entrance into the PV market and initially it will focus solely on the Japanese market. What sets this company apart is that they are the only company to not have developed their product in a government sponsored NEDO research project.

Showa Shell started production of CIS solar cells for use on rooftops in May 2007 and as such was the first Japanese company to put CIS-type solar cells onto the market. [Jäger-Waldau, 2007] It is currently planning to expand its production for the domestic market by building a new plant. Most of its sales are currently going abroad. The company plans to ramp up its current production capacity of 20MW/year to 1GW by 2011. [Doe, 2008]

Organic solar cell manufacturers
Peccell Technologies Inc. is a small spin-off company from Toin University in Yokohama and will be the first Japanese company to put dye-sensitized solar cells onto the market. It will start production of dye-sensitized solar cells for use in iPod-rechargers by the end of 2008. [Prent & Stroeks, 2008]

Other manufacturing companies
There are a fairly large number of companies which are researching DSC but have yet to indicate their intent to start production. These include both small companies such as Chemicrea Inc. (chemical company), and large companies such as: Fujikura, Nippon Sheet Glass Co., Nippon Steel Chemical Co., Ltd., Toyo Seikan Kaisha, Ltd. (container and package company), Koa Corp. (electronic parts manufacturer), and Hodogaya Chemical Co., Ltd.

4.1.5 Knowledge infrastructure
The following companies, universities and research institutes are investigating solar cells.

Crystalline silicon has a large research base. However the research is 'applied' instead of 'basic' and therefore more research is performed by the large manufacturing companies, sometimes in collaboration with manufacturing equipment companies. The main organizations that are performing research into crystalline silicon are: AIST (national research institute), Mitsubishi Electric (PV manufacturer), Kyocera (PV manufacturer), Hitachi (PV manufacturer) and Sharp Corp. (PV manufacturer). [RTS, 2008]
The list of current participants in NEDO's ultrathin crystalline silicon solar cells projects consist,

for the most part, of these companies (Mitsubishi Electric, Kyocera, Hitachi, Sharp), many research institutes (AIST, PVTEC, Tokyo Institute of Technology, Toyo Advanced Technologies Co. Ltd., Tohoku University, Okayama University, Toyota Technological Institute, Kyushu University and Meiji University) and companies producing manufacturing equipment (Daiichi Kiden and Nippei Toyama). [NEDO, 2008]

Research into *thin-film silicon* is a very ‘hot topic’ and as such many companies and institutes are investigating this technology. One of the main research institutes researching this technology is Osaka University. The current participants in NEDO thin-film silicon PV projects are: Sanyo Electric, Kaneka Corp., Mitsubishi Heavy Industries, Fuji Electric Advanced Technology Co., Ltd. (R&D company of Fuji Electric Systems), AIST and Nagoya University. [NEDO, 2008]
The main companies researching *stacked solar cells* are those that are also researching the thin-film silicon solar cells. The main researchers are: Sharp, Kaneka, Sanyo Electric, Mitsubishi Heavy Industries (MHI), Fuji Electric Systems and Tokyo Institute of Technology.

The main two companies involved in *CIS* research are Showa Shell and Honda Soltec. Matsushita Ecology Systems, now called Panasonic, has recently stopped its research activities into this technology. Participants in NEDO’s CIS projects are: Tokyo Institute of Technology, Showa Shell, AIST, Tsukuba University, Kagoshima University and Aoyama Gakuin University. [NEDO, 2008]

A large variety of companies is involved in *DSC* research, Fujikura is one of the most well known. Sharp Corp. is one of the only companies that is already in the PV industry. A surprisingly large variety of companies have started DSC research: Chemicrea Inc. (chemical company), Toyo Seikan Kaisha, Ltd. (container and package company), Kansai Pipe Industries, Ltd. (metal processing company), Nippon Sheet Glass Co., Nippon Steel Chemical Co., Ltd., Shinshu University, Koa Corp. (electronic parts manufacturer) and Hodogaya Chemical Co., Ltd. [NEDO, 2008] Even the Centre Research Institute of Electric Power Industry (CRIEPI) is involved.
Other research institutes that participate in NEDO’s DSC projects are: Tokyo University of Science, Fujikura Ltd., National Institute of Advanced Industrial Science and Technology (AIST), Gifu University, Graduate School of Kyushu Institute of Technology, Sekisui Jushi Technical Research Corp. (affiliated to a resin company), Kyushu Institute of Technology, and Osaka University. [NEDO, 2008; Tanaka, 2007]

Research into *polymer solar cells* is still in the basic research phase. The current participants in NEDO’s thin-film organic projects are: AIST, Matsushita Electric Works, Kanazawa University, Komatsu Seiren Co. Ltd. (a fabrics company), Nagoya Institute of Technology, Kyoto University and Nippon Oil Corporation (an oil company). [NEDO, 2008]

4.2 Function 1: Entrepreneurial activities

Entrepreneurs are crucial actors in the innovation system as they are the ones to translate research results into marketable products. As mentioned before, entrepreneurs exist in two forms. Entrepreneurs can be new entrants that see opportunities in new markets, or incumbent companies who diversify their business to take advantage of new developments. While the first one is more common in Europe, the second one is widespread in Japan. When looking at entrepreneurial activities in Japan it is therefore best to look at what the incumbent firms are doing.

4.2.1 Type of entrepreneurs

Though the Japanese PV production is enormous only a small number of companies are involved in production. Japan produces about 26% of the entire world's PV (2007) and Japanese solar cell manufacturers occupy 3 out of the 5 top five ranks. [Watanabe, 2007; Marketbuzz, 2008] In 2006, 10 companies were listed as PV cell/module manufacturers, namely: Sharp, Kyocera, Sanyo Electric, Mitsubishi Electric, Mitsubishi Heavy Industries (MHI), Kaneka, Hitachi, Fuji Electric Systems, Honda Motor and FujiPream/CleanVenture 21 (CV21)[17]. [Ikki & Matsubara, 2007]

Nearly all of these companies are part of large 'groups', such as the Mitsubishi Group, Kyocera Group and Hitachi Group. Ever since the industrialization period, Japan's industry has been governed by large conglomerates. These consortia are in general very conservative since they already have big production lines. If they would decide to change their production suddenly this would cost them a lot of money. However most companies have shown definite willingness to research and/or develop new technologies.

There appears to be a connection between the activities of the group company and the type of solar cells that are being produced. In general the silicon solar cell manufacturers come from groups who had invested in electronic equipment manufacturing. The CIS manufacturers, Honda Soltec and Showa Shell, stem from a car producer and an international oil concern, respectively. DSC solar cells are mainly investigated by companies from the chemical industry. These are also the only types of cell where small companies and new start-ups (such as Peccel Inc.) are involved in research and development.

4.2.2 Activities

An overview of the entrepreneurs and their activities was given in paragraph 4.1. Based on the information in this paragraph we make three observations. First of, the Japanese companies are very active. Nearly all companies have announced large production expansions, some up to three times their current production amount. Secondly, nearly all companies are focusing on foreign markets. In fact, Honda Soltec is the only manufacturing company to concentrate solely on the domestic market. Thirdly, the companies appear to be fairly specialized in one particular area, as can be seen from the table below. Only a few companies are researching or producing multiple types of solar cells. Most of these are the ones doing both thin-film silicon and stacked silicon solar cell research.

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[17] CV 21 focuses on spherical silicon solar cells which is not one of our selected PV technologies. As such this company and its activities will not be part of our analysis of entrepreneurial activities. Nevertheless, some information on this company and its technology can be found in Appendix II (paragraph 4.1.1).

Company	c-Si	tf-Si	stacked	CIS	DSC	polymer
Fuji Electric		R&D Production	R&D			
Hitachi	R&D Production				R&D	
Honda Soltec				R&D Production		
Kaneka		R&D Production	R&D Production soon (Tandem)			
Kyocera	R&D Production					
Mitsubishi Electric	R&D Production					
Mitsubishi Heavy (MHI)		R&D Production	R&D Production (Tandem)			
Peccell					R&D Production	
Sanyo Electric		R&D Production	R&D Production (HIT)			
Sharp	R&D Production	R&D	R&D Production (Tandem)		R&D	R&D
Showa Shell				R&D Production		

Table 3.1: Overview of Japanese PV manufacturers per technology
'R&D' incorporates research, development and prototyping activities, which are difficult to distinguish individually. 'Production' encompasses both niche and large-scale market introduction.

4.2.3 Per technology

The market for *crystalline silicon* solar cells is by now fairly established and highly competitive, there are no companies in Japan starting crystalline silicon production. Companies need a high amount of start-up capital in order to buy the necessary equipment. Production of *crystalline silicon* solar cells is in the hands of: Mitsubishi Electric, Kyocera, Sharp and Hitachi. [RTS, 2008] As part of a group these have that capital available. However the main Groups are already in this market and have already established their market and network. Japan is infamous for its close networks, which it is difficult to get into as an outsider.
Of the four companies involved, one has decided to sell its activities (Hitachi) and one is focusing increasingly on its thin-film activities (Sharp), showing a clear reduced interest from entrepreneurs in this innovation. However the remaining two companies (Mitsubishi Electric and Kyocera) show dedication and have announced production expansions of up to 3 times their current production volume.

Worldwide many companies have recently started in the *thin-film silicon* branch. The most mentioned reasons for this are the silicon shortage and the ease with which one can start. The silicon shortage makes thin-film silicon interesting as it uses far less silicon then crystalline-silicon solar cells. Furthermore, many of the consortia also have an electric appliances division

and produce TFT. As the technology is very similar, it is easier for these companies to move to the production thin-film silicon solar cells. Also equipment manufacturers are making good profit from selling manufacturing equipment for flat panel displays and LCD etc, and now want to sell their products to PV manufacturers. [JPEA, 2008] As such, tf-Si solar cell production equipment is readily available.
However in Japan, only one company has recently started production of thin-film silicon for the first time: Fuji Electric. The most likely reason for this lack of new entrants is the highly competitive Japanese domestic PV market.

The technology behind *stacked solar cells* builds on the basics of thin-film silicon production technology. As such it is easier for tf-silicon solar cell producers to start manufacture of this type of solar cell. Their higher efficiency as compared to thin-film silicon solar cells makes them very attractive to tf-Si solar cells manufacturers. It is therefore no surprise that the main stacked cell companies (Fuji Electric, Kaneka, MHI, Sanyo, Sharp), come from the thin-film silicon solar cell branch (Fuji Electric, Kaneka, MHI, Sanyo).
Sharp is the only company who ‘skipped’ the thin-film silicon stage and went straight into Tandem solar cell production in 2004, which, according to Sharp, was due to limited sales. “We started production of thin-film silicon solar cells in 1980 for use in calculators however we stopped production fairly quickly. The efficiency of the cells wasn’t high enough so sales were not very good. Afterwards we researched thin-film silicon for a very long time in order to raise the efficiency. In 2005 we started production of Tandem solar cells.” [Sharp, 2008b]
The companies are very active and many of the companies are expecting to put their products on the market in the near future. Only Sanyo Electric, MHI and Sharp are currently producing stacked solar cells, with MHI reportedly starting only a few months ago (October 2007).

There are only two *CIS* manufacturing companies in Japan; Showa Shell and Honda Soltec. Matsushita was until recently involved but has abandoned CIS development. Showa Shell and Honda have both only recently entered the market and they are also the only companies in Japan actively doing research into CIS. While large companies such as Sharp and Hitachi are also doing research into organic solar cell technologies, they are not doing any CIS research. This is most likely a combination of three factors. First of, as Professor Kushiya from Showa Shell stated; “it is expensive to do research into CIS”. [Kushiya 2008a] Secondly, there are concerns about the Indium supply which most likely makes those just dealing with a silicon shortage nervous. And thirdly, the production of silicon is expected to increase by 2009-2010 making the need to develop a technology which differs from the tried-and-tested semi-conductor and TFT technologies not so urgent.

Dye-sensitized solar cells are the only solar cells where both small and large companies are involved. As explained by Professor Arakawa; “Most of the current research is being done by big companies which are already in the business. They come from the electronic appliances sector. DSC is based on the chemical industry. In other words, DSC can create new business opportunities.” [Arakawa] This can also be seen by the large variety of companies that are doing research into DSC.
However there appears to be some problem in the TSIS as many small companies have reportedly stopped researching DSC. “3 to 4 years ago about 50 companies were involved in DSC research. However some have now left since their research was not successful. Others have successfully adapted and are continuing their research.” [Yoshikawa, 2008] as Professor Yoshikawa explains,

which he says is because “many parts of the process needed to be investigated; technology development, materials, devices, applications. It was a bit too much for the smaller companies. The groups have an established knowledge base which is necessary in order to perform all the research. Sharp has about 20 researchers for DSC and polymers.” [Yoshikawa, 2008; JPEA, 2008]

Polymer solar cells are not considered ready enough to be used in the market. Though the research into polymer solar cells is mostly basic research, which is usually the field of academic research, some companies such as Sharp are now also researching this type of cell. Sharp aims to produce a product incorporating plastic solar cells in 10 years. [Sharp, 2008b]

4.2.4 Conclusion

The current production of solar cells in Japan is controlled by companies which are part of large group companies. The exception are organic PV entrepreneurs which are mostly small companies entering the PV market for the first time. Nearly all companies have announced production expansions and are focusing on foreign markets. Most of the current entrepreneurs focus on one or two PV technologies, where the most overlap is between thin-film silicon and stacked silicon manufacturers.

- Incumbent companies are less interested in *crystalline silicon* due to the silicon shortage. The volatile market makes it difficult for new companies to enter.
- Interest in *thin-film silicon* and *stacked silicon* solar cells is increasing due to the silicon shortage and the ease with which one can start.
- Interest in *stacked silicon* is especially high due to their higher efficiencies than thin-film silicon solar cells and the overlap in technology with tf-Si.
- *CIS* is not as popular with new and incumbent companies as the thin-film silicon and organic solar cells. This is mostly due to the potential problems with the Indium supply, the high costs associated with researching this technology, and the fact the technology is very different from the ‘tried-and-tested’ silicon technologies.
- *DSC* is very popular as it is cheap to do research into this type of cell and many small companies from a variety of backgrounds are entering PV research. Small DSC entrepreneurs appear to have difficulty in gathering sufficient financial means, while the larger companies seem unaffected.
- Interest from incumbent and new companies in *polymer* solar cells is still fairly small as it is still in an early stage of development.

4.3 Function 2: Knowledge development

The development of new knowledge, or learning, is essential for the creation of new innovations, and as such is a key process in the innovation system. As mentioned before four types of learning processes were distinguished; learning by searching, learning by doing, learning by using and learning by interacting. Of these the first three fall under ‘knowledge development’. In this section we will look at each of the three processes in turn, after which we will look at the specific difference between the different types of cells. The fourth type of learning, learning by interacting, is part of the function knowledge diffusion and will be discussed in the next section.

4.3.1 Learning by searching

Japan is one of the countries in the world that does the most R&D into PV. [PVPS, 2007] The country has been researching solar cells since the Sunshine Project was initiated about 30 years ago, and has established quite a reputation for its PV research. Many respondents have stated that Japan’s knowledge base is very good, and is one of the things that puts Japan on the world PV map, as professor Kurokawa nicely illustrates “Japan has nothing but human resources. PV is created from technology, which means that if we have a good technology, we can produce energy and export the technology to make money. The government is always talking about creating a knowledge society.” [Kurokawa, 2008]

A large portion of solar cell R&D is done in companies. The main PV companies are all large consortia who each have their own research centre. Though most of this research is applied a fair number of respondents have indicated that the R&D of companies includes basic research and is usually better than that in Universities.

A large part of solar cell research is funded through the government-sponsored NEDO projects. Any university, company or group of companies can send in a research proposal for subsidy. These projects are both aimed at basic as well as applied research. In fact, Honda Soltec is currently the only PV manufacturing company that did not develop its main product within a NEDO project [Tanaka, 2007]. However the current government plan is to shift the focus of R&D as is stated in the PV 2030 Roadmap. “The activities of the national government will focus on high-risk R&D that is required for development of energy supply technology and on establishment of the highly public fundamental technological infrastructure. Responsibility for R&D closer to practical applications will be gradually shifted to the industrial sector.” [NEDO, 2004]

4.3.2 Learning by doing

The Japanese silicon companies have been producing solar cells for rooftop applications for more than 15 years. In this time manufacturers of solar cells have gained much experience with production processes. Part of this stems from the country’s large knowledge base as is explained by Mister Ooki from ULVAC, “R&D into PV started in Japan 30 years ago as part of a national program. So at the moment there are many specialists in Japan. In China, Taiwan and Korea they don’t know the process so they need to be taught.” [ULVAC, 2008] This is not limited to theoretical knowledge but also ‘know-how’ (learning by doing). “In ULVAC you have install-workers who install the machines at client’s factories. […] In Japan install workers are finished in 1 to 2 months. In China, Taiwan and Korea they have to stay up to 1 or 2 years!” [ULVAC, 2008]

That ‘learning by doing’ processes have taken place can also be seen from the large production cost reductions that have been achieved. The system price per kW dropped over 80%, from 3,700,000yen/kW in 1993 to 680,000yen/kW in 2006. [Watanabe, 2007]

This analysis naturally does not count for CIS, as CIS solar cells have only recently entered the market. These cells show great potential to achieve large cost-reductions [Iken, 2004] however there is some problem with ‘learning by doing’ for this type of cell as there are currently only a few research institutes which can actually fabricate CIS cells. [Kushiya, 2008a; Imoto, 2008] The most likely cause is the high cost of the required vacuum equipment. “Vacuum chambers and multisource sputtering guns are expensive, especially for the large process areas desired for solar panels.” [Derbyshire, 2008] This restriction coupled with the fact that large scale production has started only recently, makes ’learning by doing’ currently quite difficult for CIS.
In contrast, learning by doing processes for organic solar cells appear to be going strong. Despite the fact organic solar cells are not in production yet, any research group can fabricate the cells. Also, samples can already be obtained from many if not all of the companies and research institutes.

4.3.3 Learning by using

Japan currently has one of the largest markets in the world which is enabling many learning by using activities. Next to gathering knowledge from basic and applied research and the production of solar cells, it is also important for companies to get feedback on the actual performance of the system from end-users. A category of NEDO projects that clearly provides these types of learning by using opportunities are the ‘Field Test Projects’, the first of which was initiated in 1998 [Ikki & Matsubara, 2007]. The objectives of these projects are:

- Collection and dissemination of operational data
- Cost reduction
- Standardization of new type PV systems
- Demonstration of new type PV systems

The Field Test projects are beneficial for manufacturing companies as they allow for user feedback. In the Field Test projects half the installation costs of innovative modules and/or systems is reimbursed in exchange for feedback from users including performance evaluation up to 4 years which is released to the public. [NEDO, 2007; Ikki & Matsubara, 2007] Furthermore, installers, project developers and end-users gain experience with the system. And the set-up of the projects encourages companies to experiment with their products in different settings while simultaneously providing feedback on their operation. The field test projects have been quite successful, from 1998 to 2002, 740 PV systems were installed in industrial facilities under the program, for a total of 18,100kW. Other accomplishments include large reductions in the costs of PV systems. [Ikki & Matsubara, 2007]

However there are potentially inhibiting factors to good ‘learning by using’ processes. First of, not all the gathered data is made public, though a researcher or company can be allowed access based on their purpose on a case-by-case setting. [Imoto, 2008] Also, as the data is officially owned by NEDO, other parties may not be allowed to use it for promotional purposes or product improvement. [Suntech/MSK, 2008] Furthermore, it should be noted that the subsidy is only valid for power applications and specific markets. As such organic solar cells, which can not yet be used in these types of applications can not profit from this scheme. Also, there is currently no scheme for the residential market only for the industrial and public markets.

4.3.4 Per technology

Japan has been researching and developing *crystalline silicon solar cells* since before the start of the sunshine project, over 30 years ago. Crystalline silicon solar cells are fairly advanced and as such nearly all the research revolves around product development, not basic research. However a fair number of groups are still doing research into crystalline silicon solar cells, as such learning by searching is still going strong.
Crystalline silicon solar cells have also been in production for a long time which has led to large cost reductions in production cost (learning by doing). And as the main type of cell being produced they have benefited most from the Field Test Projects for learning by using.

Of all the PV technologies currently the most popular research field is *thin-film silicon solar cell*, and by extension s*tacked solar cells*. Research into thin-film started in 1977 when a researcher discovered possible new applications for amorphous silicon such as for TFT's and solar cells, as such current research into TFT benefits tf-Si solar cells, and vice versa. One of the first applications for this type of cell was in solar powered calculators. Many respondents agree that this was a good learning bed for working with the technology (learning by using). Research in this field is for a large part still basic research (learning by searching) however more and more companies are switching from basic to applied research.
Thin-film silicon solar cells have been in production for quite some time. As such companies have gained a lot of experience in producing thin-film silicon solar cells (learning by doing). As thin-film and stacked solar cells have entered the market they are benefiting from the Field Test Projects for opportunities to test their solar cells and gain experience with usage in a real-life setting (learning by using).

While the silicon solar cells appear to be very popular among research groups, the same is not true of *CIS*. The number of research institutes doing research into CIS is fairly small. There are only 2 companies currently doing research into CIS (Honda and Showa Shell), and a handful of universities and research institutes. Both these companies are also not as large as their silicon counterparts and are therefore most likely limited in their research abilities. Professor Kushiya from Showa Shell has indicated that the amount of research the company can do is limited since it is still growing. [Kushiya, 2008a]
There are also some problems with the 'learning by doing' function, as mentioned before, as only a few of the research institutes can fabricate cells. This is most likely due to the costs of the fabrication equipment which small groups can't afford. However there is some good news on the horizon as there are indications that the government aims to incorporate all the groups into large research centers. [Kushiya, 2008a] There is also good news regarding 'learning by using' as they have started production they will be able to benefit from the Field Test Project.

There is a large variety of companies and institutes currently doing research into *organic solar cells* (DSC and polymer solar cells). Most of the research consists of basic research in order to achieve rooftop applications and as such a surprisingly large number of research institutes is involved.[18] However since the main problems with the organic cells lie in their stability, aiming for power applications which require long term stability (up to 15 to 20 years for rooftops) will require much research and a lot of time. [Arakawa, 2008]
Regarding learning by searching, many scientists are working on organic solar cells in order to

[18] For a list see paragraph 3.4.5 Knowledge infrastructure

improve their efficiency, however the development is currently still in a small experimental stage [JPEA, 2008]. As such they cannot yet profit from the Field Test Project (learning by using). However, although the organic solar cells are not in full-scale production yet, DSC solar cells can easily be made by all the research groups, and samples can already be obtained from many of the companies and research institutes. With this they are gaining experience with producing these types of cells which enables them to improve the production process (learning by doing).

4.3.5 Conclusion

Japan is well-known for its solar cell research which is considered by most to be very strong. A large part of the research is performed by companies, including basic research. PV research is funded through the government-sponsored NEDO projects which include basic and applied research. However this is expected to change to mostly basic research in the near future (learning by searching).

Production of solar cells has been going strong for over 15 years in Japan and large production cost reductions have been achieved indicating that ‘learning by doing’ processes have taken place.

Learning by using is promoted through the large domestic and international market and the NEDO Field Test Projects, in which market feedback in the form of operational data is gathered and published. However the feedback is not perfect.

- *Crystalline silicon* research is mostly applied but is still going strong (l by s). Large production cost decreases have been realized (l by d) as it has been on the market for a very long time (l by u).
- *Thin-film silicon* research is very popular (l by s). The cells have been in production for a long time (l by d), first being used in calculators (l by u).
- *Stacked silicon* solar cells are based on fundamental thin-film technology. The cells are only recently going in production (l by d) and as such will benefit greatly from the current international market growth and the Field Test projects as many new panels and system configurations can be investigated (l by u).
- *CIS* research is mostly performed by scattered research groups and the two main manufacturing companies (l by s). CIS show great potential for cost-reductions however there are problems with learning by doing as not all research groups can fabricate cells, which is related to the high costs of research mentioned earlier (l by d). However good news is on the horizon as the small groups will be incorporated into large research centers. Similar to stacked silicon solar cells CIS will profit from the Field Test projects and the current international market growth for learning by using processes (l by u).
- Many companies and institutes are involved in *DSC* and *polymer* research (l by s). However it will be some time before they are ready for power applications due to stability issues. As such learning by using processes for power applications is not yet taking place (l by u). However DSC (and polymer) cells are cheap to produce, facilitating learning by doing processes. Many if not all of the companies and research institutes offer samples (l by d).

4.4 Function 3: Knowledge diffusion

Following from the previous section we now look at learning by interacting, which entails the transfer of knowledge between different actors. With the large amount and variety of actors within the innovation system, the exchange of knowledge is very important. For this reason we will first focus on collaborative efforts between the various actors, in particular between manufacturers and research institutes. After this we will look at the presence of formalized exchange methods such as journals and seminars. We will end with an evaluation per type of solar cell.

4.4.1 Collaboration

As a large portion of PV R&D is done in companies, knowledge exchange between universities and companies, and between companies, is especially important. However it appears that companies' willingness to cooperate with others, especially competitors, depends to a large extend on the phase of development of the type of cell they are working on. As the main crystalline silicon and thin film silicon solar cells are already fairly mature technologies there is an overall decline in the willingness of manufacturers to collaborate.

A good indication of this is the discontinuation of PVTEC. PVTEC started as a collaborative effort of PV producing companies, aimed at doing joint research. However starting this year it has fallen in decline and will effectively vanish. Mister Ishimura from PVTEC stated that the main reason for this is that "PVTEC depends on the support of its members which is currently lacking. […] Now, when the technologies are more developed and there is more worldwide competition, cooperation is less interesting than before". [Imoto & Ishimura, 2008] The same thing was found during NEDO research projects. NEDO sponsors and manages many research projects. Some are granted to individual companies some to representatives of companies and universities "but it was difficult when the PV makers were involved into the same team." as Mister Imoto of NEDO explains. [Imoto, 2008]

The main reason for the decline in willingness is the risk of exposing production secrets. As technologies move closer to applied research there are also fewer issues where multiple parties would benefit from the research.

4.4.2 Patenting and Licensing

One of the ways in which companies and research institutes can exchange knowledge is through patenting and licensing agreements. Patenting is very popular in Japan and even small additions can qualify as a new patent. This mostly resolves around the need of researchers to show their productivity. As Arno Smets of AIST explains: "In Japan the amount of work you do is very important. Japanese researchers have to get patents and publicize their work as much as possible, to show that they are productive." [Smets, 2008]

However licensing is not popular in the PV industry. None of the respondents indicate any wish to license. Some respondents had concerns regarding patent protection due to bad experiences, though this view was not widespread in the innovation system. Another reason for the lack of interest in licensing is related to the aforementioned patenting based on small increments. As Kaneka explain; "Each patent only covers a small part of the system. For another to use the patent we would need to license a cluster of patents". [Kaneka, 2008]

Many collaborations within the industry, take place within the government-sponsored NEDO projects. The project's patenting structure is beneficial to knowledge exchange while keeping in line with companies' secrecy requirements. The projects are national projects and as such the

research results need to be made public, “as the research is funded by the government the results should belong to the community.” [Ohta, 2008] Unfortunately this also means that interesting research results are also publicized and the company that made the discovery will lose its advantage.
In the past the government had a system where the patents from NEDO projects were 100% owned by NEDO, which led to the strange situation where the company that had made the discovery had to pay to use it. Between 1992 and 1996 this was changed to: 50% owned by NEDO, 50% by the company that developed it. Since the Baido law of 1996 the patents are 100% entrusted to the company. [Kushiya, 2008a] However even before that the companies that did the research were favored as Professor Kushiya explains: “Whether the entire patent is owned by NEDO or not, the company that did the research has priority. Honda wanted to use our NEDO patent but we had priority so NEDO had to turn them down.” [Kushiya, 2008a] In general we can say the NEDO system ensures that companies can use interesting research results, while still promoting knowledge exchange by publishing research information.

4.4.3 Formalized knowledge exchange

One of the main ways in which respondents are keeping themselves up to date on knowledge development activities and results in Japan and abroad, has been through formalized knowledge exchange methods such as symposia and seminars. The importance of these events is not restricted to the actual information which is presented, but also the opportunity to meet new people. ‘Who you know’ is very important in Japan as Mister Smets of AIST explains: “Especially in Japan everything revolves around who you know. But you build your network by going to meetings, so it is all connected.” [Smets, 2008]
There are a large number of events where actors can meet one another. “The conferences are a major source of information.” as professor Yoshikawa explains, “There are many groups and meetings. The ‘society for PV systems’ is really big; it has about 200 to 300 people from industry and universities. We meet once a month. For organics specifically there is only one group which meets once every 3 months. At these meetings we exchange information, mostly research results.” [Yoshikawa, 2008]
There are also seminars and symposia which are organized by the JPEA. They provide good practical information to companies and research institutes on such topics as: Japanese government policy, installation technology, application results and production safety. There are also special seminars for beginning companies [JPEA, 2008]. Recently a lot of focus has been put on political information such as financing mechanisms, regulations, subsidies and the green certificate. [JPEA, 2008] The seminars are organized several times a year while the symposia are held every year in June. A wide range of people attend the Symposia about 300 to 400 people from JPEA’s member companies, non-member companies, universities, installers, etc. [JPEA, 2008]

Next to the events there is a large selection of magazines which provide information to the industry and research institutes on a large variety of topics. Magazines such as ‘Solar Energy and Materials’ and the ‘Japanese Journal of Applied Physics’ provide specialized research information. There are several bulletins or newsletters that provide companies and research institutes with regular updates on the current developments in Japan. In this regard two companies are key actors in knowledge distribution. The RTS is a consultancy company that provides regular bulletins with the latest research results, production figures and production announcement, for a steep price. The JPEA provides a quarterly newsletter, which is distributed

to member companies and government authorities. It provides information on previous and upcoming events, as well as production statistics. [JPEA, 2008]
For international news, there is Photon Magazine which is fairly well known with respondents. It is an international magazine with the latest on PV around the world. As this newsletter has a strong base in Europe, they are an important source of information for the Japanese entrepreneurs interested in this market.

4.4.4 Per technology

Crystalline silicon solar cells are a very mature technology, most of the research is applied and as such the companies are not very inclined to cooperate. However collaborative research between research institutes, and between research institutes and companies, is still progressing, as can be seen from the current NEDO project list for ultra-thin crystalline silicon solar cell research:

Nr	Participants list
1	Kyocera
2	Mitsubishi Electric, Tokyo Institute of Technology
3	AIST, Toyo Advanced Technologies Co. Ltd.
4	Daiichi Kiden (manufacturing equipment company)
5	Sharp, Tohoku University, PVTEC, Okayama University, Nippei Toyoma (manufacturing equipment company)
6	Toyota Technological Institute, Kyushu University, Meiji University

Table 4.2: Participant list of NEDO’s ultranthin crystalline silicon solar cell research project
Source: [NEDO, 2008]

An intriguing point in the list is the number of equipment manufacturing companies that are involved, which is not as prevalent in the other types of cells. This is most likely due to the fact that nearly all research is applied. The silicon solar cell manufacturers need to collaborate heavily with their equipment suppliers as nearly none are producing the fabrication machinery themselves. As Mister Oosaki from ULVAC (equipment manufacturer) explains: “If the customer wants something new we will need to get information about the technology from the customers.” [Oosaki, 2008]
As the main type of cell currently in production, a lot of information is exchanged through the formalized exchange methods. Most of this information relates to patents or new products and production technologies. The large number of groups and meetings allow the researchers in companies and research institutes to meet.

Thin-film silicon is a very hot topic, which is in part due to the current interest in TFT which is highly related to thin-film research. Though it is a fairly mature innovation there are still many opportunities for researching common problems, mostly in the form of processing technologies to create thinner layers. There is a large base in the literature dedicated to this subject.
Many collaborative efforts exist, especially between companies and research institutes, an example of this is the collaboration between Fuji Electric Systems and Kumamoto university and Kumamoto Techno Industrial Foundation. [Tsukioka, 2005] As Kaneka, a worldwide expert in thin-film silicon says: “There is still a network of institutions that keep in touch in this field and exchange information. We hold academic conferences twice a year in spring and fall. They are held by the Applied Physics Society.” [Kaneka, 2008b] At these conferences research results and

patents are explained.

The *stacked silicon* solar cell community is fairly small as compared to the other types of cells. However they are related to thin-film silicon solar cells, as they are also dependent on processing technologies to create thinner layers. As such there is a large amount of overlap in the fundamental knowledge base between stacked and thin-film silicon solar cell. As the same actors are involved it is indicated that research information is discussed at the same events as for tf-Si solar cells, such as the “International Workshop on Thin-film Silicon solar cells”. And through the same contacts: “Many thin-film silicon institutions investigate the stacked silicon solar cell technology as well. I think each technology is exchanged via a network of thin-film silicon institutions.” [Kaneka, 2008c] The research community appears to see stacked silicon solar cells as a continuation of thin-film silicon research and not as a separate field of study.

CIS is not such an advanced innovation and as such we would expect knowledge exchange to be somewhat easier. However there are indications that this is not the case. The CIS research base is fairly small with only two companies and several research groups involved. The only two companies producing and researching CIS have limited their collaborative activities. Honda Soltec has developed their main product by themselves, the only major Japanese PV company to do this. Showa Shell has been researching CIS the longest but does not collaborate with any other institute as it considers its own knowledge level too advanced. “We do have some common issues we could research together, however we do not feel inclined to collaborate.” [Kushiya, 2008a] The only company Showa Shell collaborated with was Shell Solar, since there were no secrecy issues as they are part of the same multinational. [Kushiya, 2008a]
Collaborative efforts with other actors were also hindered by NEDO as Mister Kushiya from Showa Shell explains: “We are not allowed to collaborate with other players within a NEDO project. It is because this is mostly done to separate projects. We can only work with those outside of the project and then we first have to consult with NEDO if they will allow it.” [Kushiya, 2008a]
On the other hand, research institutes and universities do collaborate. For instance, there is a NEDO project with AIST, Tsukuba University and Kagoshima University. [NEDO, 2008] Unfortunately the CIS research community consists of many small separated groups, which does not facilitate knowledge exchange. As Professor Kushiya explains “The research groups are all very small and focus on specific parts of the cell. NEDO keeps them very separated to prevent research being done by a duplicated form.” [Kushiya, 2008a] The basic technology that each of these groups uses differs as well which makes it likely that performed research will not benefit the other groups. However there are indications that this will improve in the future as NEDO will set up two PV research centers, one at the University of Tokyo, the other at AIST, which aim to combine these small groups. [Kushiya, 2008a]
Unfortunately formalized exchange methods that specifically target CIS are limited. There are no special bulletins or journals targeted at CIS. However in this regard the small research community might actually be an advantage, as Mister Kushiya mentions: “There are no difficulties for me to get information on Japanese CIS research activities. The research community is very small with only a few groups, so it is easy to keep in touch with everyone.” [Kushiya, 2008a]

Regarding *dye-sensitized* solar cell research many varied companies and research institutes are involved and are collaborating quite heavily. When looking at the NEDO project list there are

distinctly more companies per project with DSC than with other types of solar cells (see table below). However there are some indications that knowledge exchange will be more difficult in the near future, as DSC approaches commercialization. As explained by Professor Yoshikawa: "The technology is more mature so knowledge exchange is more difficult. There are many researchers but their interests differ. They are becoming more interested in applications and commercialization. For instance, some are working on large modules durability testing." [Yoshikawa, 2008]
There are no special papers and such to exchange information, however as mentioned before, there is a group for organics that meets once every 3 months and exchanges research information. [Yoshikawa, 2008]

Nr	Participants list
1	Tokyo University of Science, Fujikura Ltd.
2	Sharp Corp., AIST
3	CRIEPI
4	Gifu University, Chemicrea, Sekisui Jushi Technical Research Corp. (affiliated to a resin company)
5	Kyushu Institute of Technology, Nippon Steel Chemical Co., Ltd.
6	Osaka University, Toyo Seikan Kaisha, Ltd. (container and package company), Kansai Pipe Industries, Ltd. (metal processing company)
7	Shinshu University, Koa Corp. (electronic parts manufacturer) and Hodogaya Chemical Co., Ltd.

Table 4.3: Participant list of NEDO's DSC research project
Source: [NEDO, 2008]

Polymer solar cells are only at basic research and as such there are many items on which companies can collaborate. It appears that some small companies have grouped together to start research into polymers and that here are also small companies that collaborate with Universities by themselves. [Yoshikawa, 2008]
There is also a large amount of overlap between DSC and polymer research which aids knowledge creation and diffusion. Professor Yoshikawa states that "30-40% of the researchers are doing both DSC and organic/polymer solar cells research." [Yoshikawa, 2008] Considering DSC knowledge diffusion is doing well this has positive implications for polymer knowledge diffusion. A good example of this is the group specialized in organics which meets once every three months. "The conferences are a major source of information. Also there are journals for our field such as 'Solar Energy and Materials' though none are specialized for organic solar cells. For polymers there are conferences and related journals such as 'Electronic Devices', which discuss TFT and DSC." [Yoshikawa, 2008]

4.4.5 Conclusion

Interest in research collaboration between companies is decreasing as PV technologies become more advanced. Though patenting is popular in the industry, licensing is not. However collaboration in government sponsored NEDO projects is continuing. The project's patenting structure is beneficial to knowledge exchange while keeping in line with companies' secrecy requirements. Formalized knowledge exchange methods such as journals, seminars and symposia are plentiful in Japan. The seminars and symposia are important not just for the presented information but also the opportunity to get in touch with other researchers. Specific practical market information is readily available.

- *Crystalline silicon* solar cells are very mature and companies are reluctant to cooperate. However research activities between research institutes, and between research institutes and companies, is still progressing.
- *Thin-film silicon* solar cells are fairly mature but there are many opportunities for research from which all could benefit. Many formalized exchange methods are in place and institutions 'keep in touch'.
- The *stacked silicon* solar cell research field overlaps with tf-Si meaning there are areas where both would benefit from research (creation of thin layers/deposition technology). This also allows stacked solar cell researchers to benefit from the formalized knowledge exchange methods of, and contacts with, the tf-Si research area.
- Knowledge exchange within the *CIS* research field is more difficult as there are no specific journals or seminars. The CIS research groups are kept separate by NEDO to reduce doubling of research. This also means the basic technology used by each group differs which means not all research might be beneficial to other members. However there are good prospects as the small groups will be combined into larger research centers.
- Many varied companies and research institutes are involved in *DSC* research and are collaborating quite heavily. Knowledge exchange takes place at group meetings and through 'regular' PV journals. However there are some indications that knowledge exchange will be more difficult in the near future, as DSC approaches commercialization.
- *Polymer* solar cells are only at basic research and as such there are many items on which companies can collaborate. There is also a large amount of overlap between DSC and polymer research which aids knowledge creation and diffusion.

4.5 Function 4: Guidance of the search

This function is based on the fact that resources are limited, making it necessary to effectively distribute them within the innovation system by focusing on specific paths. There are several ways in which such guidance can be established. We will look at the guidance that is provided in two ways.

First of, guidance can be provided by institutions such as the government, by setting goals. We will look at this type of guidance by looking at the research and market targets set by government, academic and industry organizations for the different types of solar cells.

Secondly, we will look at the perception of the different types of solar cells. If an innovation has proven itself in the past, this will give the innovation a higher level of credibility, which will propel development into this area. Similarly a technological breakthrough can motivate actors to focus on a specific field of study.

4.5.1 PV Roadmap 2030

In Japan the one document that is cited the most when discussing the future direction of PV in Japan is the PV2030 Roadmap. The Roadmap was initiated by Professor Kurokawa of Tokyo University of Agriculture and Technology and created by an investigating committee consisting of representatives from government, industry and academic circles[19], through six discussion sessions [NEDO, 2004]. And as such has a broad support base within. According to the Roadmap, PV is expected to fulfill 50% of the residential energy requirement of Japan, approximately 10% of Japan's total energy consumption [NEDO, 2004]. It describes two main objectives for PV:

1. Improvement of the economic efficiency of PV power generation

The first goal of the Roadmap is to lower the cost of PV to 7 yen/KWh by 2030, see Fig 4.1, which is the current cost level for industrial use.[20] Within the Roadmap the cost goals are transformed into specific efficiency targets for each technological field as can be seen in Fig. 4.2.

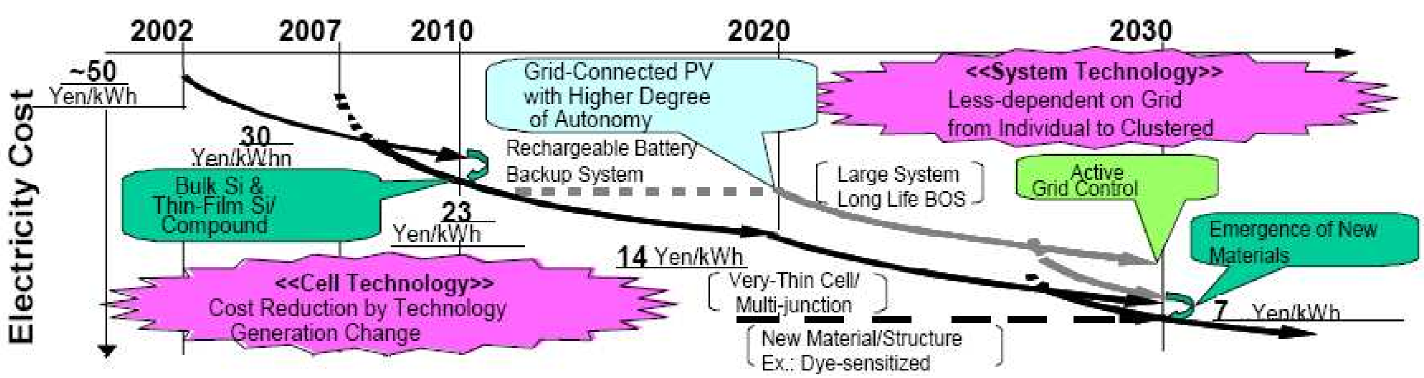


Figure 4.1: PV Roadmap 2030
Source: NEDO, [NEDO, 2004]

[19] The committee consisted of: JPEA, Sharp Corp., Kaneka Corp., Sekisui Chemical Co. Ltd., Kajima Corp., Nikkei Science, Tokyo Institute of Technology, Toyota Technological Institute, AIST, NEF, PVTEC and METI

[20] The intermediate targets of 2010 (23 yen/KWh) and 2020 (14 yen/KWh) are related to the cost level for residential use and business use, respectively. [NEDO, 2004]

2. Enlargement of PV application areas

The second objective relates to increasing the market adaptation of PV in more areas. The focus here is on a shift to more stand-alone capabilities such as community-based clustered PV systems with electricity storage functions. In addition, a wider variety of PV modules for diverse functions is promoted. This includes the development of technologies to overcome the grid stability issues, such as storage batteries.

Item	Present Status	Target by 2010 - 2030
Production cost of PV module	Production: 250 yen/W (2003) Expected development: 14 yen/W (2007)	100 yen/W (2010) 75 yen/W (2020) <50 yen/W (2030)
Conversion-efficiency of PV module		
Durability of PV module	20 years	Service life 30 years (2020)
Silicon feedstock consumption	10～13 g/W	1 g/W (2030)
Inverter (power conditioner unit)	～30,000 yen/kW	15,000 yen/kW (2020)
Accumulator battery	～10 yen/Wh (for automobile)	10 yen/Wh (2020) Durability: 10 years

Solar Cell Type	Present Status	Conversion efficiency target (%)		
		2010	2020	2030
Crystalline silicon solar cell	13～14.8 *(18.4)*	16 *(20)*	19 *(25)*	22 *(25)*
Thin-film silicon solar cell	10 *(14.7)*	12 *(15)*	14 *(18)*	18 *(20)*
"CuInSe" solar cell	10～12 *(18.9)*	13 *(19)*	18 *(25)*	22 *(25)*
"III-V" solar cell	Concentrator *(38.9)*	28 *(40)*	35 *(45)*	40 *(50)*
Dye-sensitized solar cell	*(10.5)*	6 *(10)*	10 *(15)*	15 *(18)*

PV module conversion efficiency targets *(cell efficiency targets)*

Figure 4.2: PV Roadmap goals
Source: Adapted from [NEDO, 2004][21]

In general this Roadmap provides good guidance for the research of PV in Japan for three reasons. First of, the roadmap is specified for each technological field, providing specific guidance for each and focusing on the contribution each technology can deliver to achieve the final goal. Secondly, the roadmap is supported and used by actors from government, industry and academic circles. The PV goals are followed by NEDO which makes them the basic research targets of all government sponsored R&D projects. Companies such as Sharp state that they "set our own company targets according to the PV Roadmap 2030." [Sharp, 2008b] As such the Roadmap forms the basis of actual actions instead of being a mere 'concept'.

Lastly, the main goal of the roadmap is part of the government's overall energy policy which

[21] "III-V" solar cells are compounds made from elements in the III and V columns of the Periodic Table of Elements

increases its credibility. The government's New National Energy Strategy aims at energy security and sustainability and includes the New Energy Innovation Plan. The main target of this plan is: "The reduction of solar energy power generation cost to the level of solar thermal power generation by 2030" [ANRE, 2006] As energy security has always been an important issue for the Japanese government, the inclusion of solar cell research in its energy policy gives confidence to the PV research community that they will continue to receive support.

However the Roadmap is not optimal as the guidance is not related to actual technological capabilities. The 2030 cost goal was conceived by the government without reference to technological feasibility; back casting and calculations were used to establish the efficiency targets. As Kushiya has indicated, this makes the targets very difficult to achieve "The 2030 target is, honestly speaking, very difficult to reach as it is close to the theoretical maximum efficiency." [Kushiya, 2008a]
However there is hope to improve this as the goals will be reviewed regularly to incorporate the latest trend, with the first review scheduled for FY 2009. [NEDO, 2004] There are indications that in this review the efficiency goals for each technology will be lowered. This is likely due to the unexpectedly large production facilities of PV manufacturing companies which will lead to lower production costs, reducing the need to achieve high efficiencies. [Kushiya, 2008a] Also, with the current rise of the price of oil the target of grid-parity may be reached sooner. "The target is not necessarily 7 yen per kW, but a competitive level to grid power. If the electricity price increases, we might reach our goals faster. However it is a waiting game with the Utilities as they do not announce price increases. We need the cooperation of the Utilities to get PV introduced into the market without batteries." [JPEA, 2008]

4.5.2 Market guidance

One of the things we notice from the Roadmap and other sources is that there no widely-supported market or installation goals for PV in Japan. The Roadmap focuses exclusively on research targets. Though it provides a 'possible' installation target it solely offers research targets to allow the technology to reach this target. The JPEA's "Vision of the Future of the Photovoltaic Industry in Japan 2006, 'Aiming to be the World's Leading PV Nation'" is limited to predictions regarding market developments. It does not give any targets. [JPEA, 2006]

4.5.3 Perception of the different types of solar cells

Crystalline silicon has been used for a very long time and as such has created a large amount of credibility, the industry is confident in its abilities and reliability. As such, crystalline silicon is expected to remain an important type of solar cell in the industry, despite the current silicon shortage. Sharp says: "Companies are not moving away from crystalline silicon. We are doing both crystalline silicon and thin-film silicon technologies and we will continue to do so. As the market will grow we will need both technologies in order to keep up with the demand." [Sharp, 2008b]

The industry sees a lot of promise in the *thin-film silicon* technologies (thin-film, stacked) as they are expected to enable efficiency improvements and cost reductions and have the benefit of lower solar module weight. The development of thin-films was launched through a 'breakthrough' when in 1977 a researcher that was trying to see if amorphous silicon was suitable for the semi-conductor industry discovered that it could be used for several other purposes, such as TFT's and solar cells. [Kaneka, 2008b] Thin-film silicon technology is used in calculators and in TFT so there is confidence in the continued development of this type of cell.

For *CIS* the potential for cost reductions are considered very large as the creation of the solar cell is easier and large efficiency increases are expected in the near future. However there are concerns within the PV industry regarding the supply of Indium for the fabrication of solar cells making people nervous about investing in this type of cell. Those already in the industry claim that they are aware of this problem and that it will not be a problem as the amount they use is quite small. [Kushiya, 2008a] [22]

There is mixed confidence in *organic solar cells* for use in power applications. In general it is expected that it will take quite some time before they are ready for long-term applications, especially polymer solar cells as they are in an early stage of development. As professor Arakawa says regarding DSC power applications; "We expect to achieve the wanted efficiency in 10 years but it depends on the stability. It might be only 5 to 6 years if there is a major breakthrough." [Arakawa, 2008]
Organic cells are fairly unstable as the materials oxidize in air and therefore require some advanced lamination technology. They also have a very short lifespan. For these reasons some believe they might never be able to be used in power applications. As Arno Smets of AIST says: "I don't see much of a future in organic solar cells yet, unless they find a way to seal the cells properly." [Smets, 2008] However due to these characteristics, even these skeptics believe the organic cells are very suitable for use in consumer products. "They would be suitable for use in disposable products. It all depends on the application. Every technology has its advantages for certain applications." [Smets, 2008]

4.5.4 Conclusion

There are no widely-supported market or installation goals for PV in Japan however the government has a strong research policy. The PV 2030 Roadmap provides specific research goals for each PV technology and is widely supported in government, academic and industry cycles. The Roadmap's target to make PV generation cost equal to the level of solar thermal power generation by 2030 is even incorporated in the government's New National Energy Strategy and used as a basis for the NEDO research projects.

- *Crystalline silicon* has been used for a very long time and as such has created a large amount of credibility, the industry is confident in its abilities and reliability.
- The industry sees a lot of promise in the *thin-film silicon* and *stacked silicon* technologies as they are expected to enable vast efficiency improvements and cost reductions. The interest in thin-film silicon stems from a technological breakthrough in 1977. As thin-film silicon technology is used in calculators and in TFT there is confidence in their continued development.
- *CIS* shows a lot of potential for cost reductions which motivates development of this type of solar cell. However the concerns within the PV industry regarding the supply of Indium make people reluctant to invest.
- There is mixed confidence whether *organic* solar cells will ever be ready for power applications. However their suitability for consumer products has gone unquestioned.

[22] See also paragraph 4.7.3

4.6 Function 5: Market formation

The possibility to obtain economic benefits is important to motivate entrepreneurs and other actors in the TSIS to invest in the different types of solar cells. As such it is paramount for a market to be formed and maintained. The establishment of niche markets is very important in this regard to allow new innovations to compete with embedded technologies. These niches are formed due to the presence of technology specific applications or through government action.

In Japan a market for PV power applications has existed for quite some time and is in fact one of the largest of the world. We divided the market into 3 parts in correspondence with the JPEA and government: a residential market (home owners), an industrial market (companies) and a public market (public organizations). We will look at each in turn, looking at the buyers' motivation for purchasing PV, the market prospects and government support. As the different types of solar cells share the same market space they are competing with each other for room. At the end of this section we will therefore look at the different types of solar cells, analyzing their expected market share and the existence of technology specific applications which enable the formation of niche markets.

4.6.1 Residential market

The residential market consists of home-owners and is the oldest and largest PV market in Japan with over 80% of installed capacity. The market is characterized by a large number of small installations [JPEA, 2006]. The Japanese government supported home-owners through the 'Residential PV System Dissemination Programme' for 12 years.

The government stopped the installation subsidy in 2005 because it claims it has achieved its goal of creating a self-sustaining market. [Ikki & Matsubara, 2007] The dissemination program provided home-owners with a reduction of the installation cost of a PV system up to a specified level of around 3 million yen for a 4kW system. As can be seen from the following figure, under this scheme the actual price home owners have had to pay has remained fairly constant since 1995 since the subsidy was reduced when the system cost went down. In fact the past few years the subsidy was no more than a token amount.

Since then the focus of the government has shifted its focus onto the industrial and public PV markets. However, though central government market support has stopped, local government support remains with over 319 communities providing a subsidy or preferential loan program in 2006. [Ikki & Matsubara, 2007]

An important scheme which has promoted home-owners to buy solar cells is the voluntary buy-back of energy by the energy companies since 1992 [PVPS, 2007]. Under the scheme the utilities buy the excess energy that home-owners produce under current energy rates.

Interest from home-owners greatly increased under the Residential Dissemination Programme, as can be seen from Figure 4.3, and the market grew enormously. However there is some uncertainty in Japan concerning: why home-owners buy solar cells? The motives for home-owners to install a PV system were investigated by NEF and are ranked as followed: [JPEA, 2006]

1. because electric power companies buy surplus power
2. because they have strong environmental awareness
3. because they can use a national subsidy system
4. sales efforts (because the salesperson recommended to do so)
5. commodity value

From this list we might conclude the main motivation of customers is financial in nature.

However it should be noted that the amount of money that home-owners had to pay for a PV installation has barely changed under the scheme, see figure 4.3. Even with the rates paid by utilities for the surplus power is equal to that of grid power. [PSPV, 2007] As such, even with the buy-back of electricity, the expected pay-back period for a PV installation has always been 20 years. For reference, the expected lifespan of a house in Japan is also 25 to 35 years.[23] [Jäger-Waldau, 2007] As such we believe the Japanese domestic solar cell market is based on environmental consciousness.

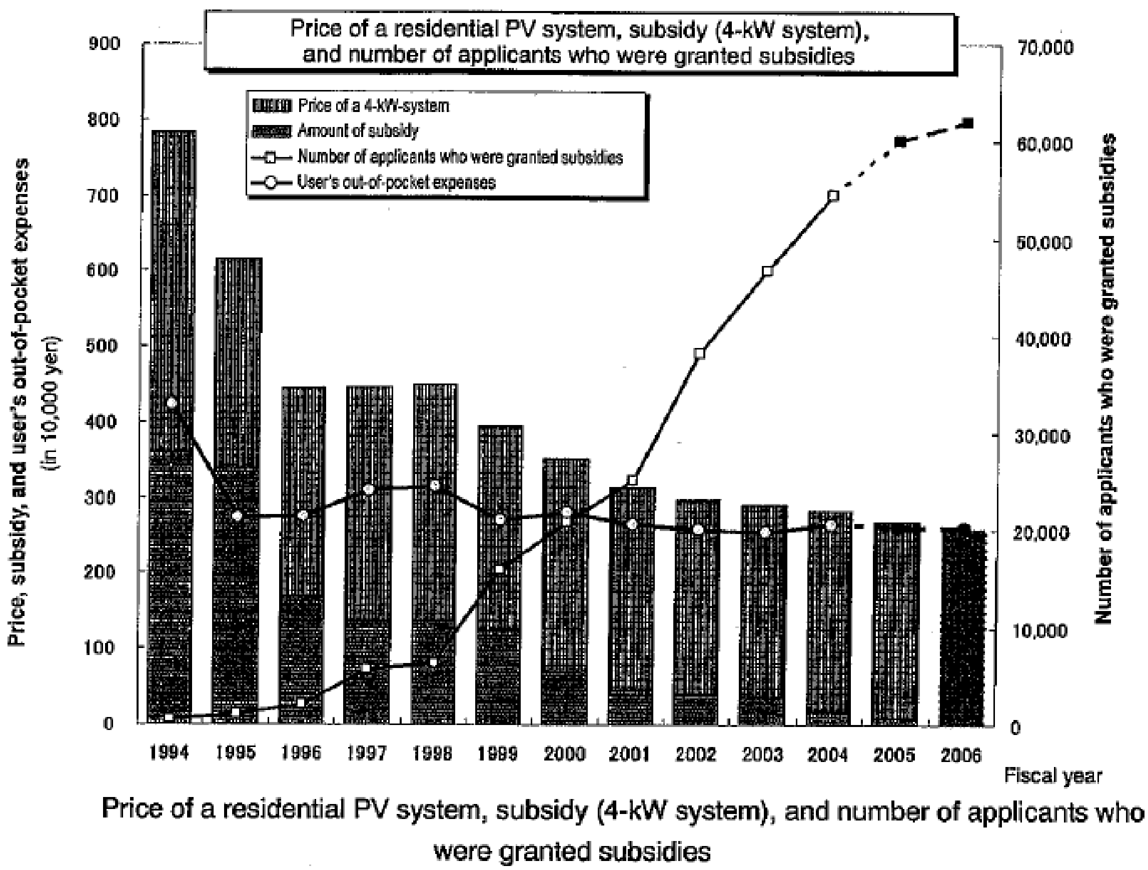


Figure 4.3: Price of a residential PV system
Source: [JPEA, 2006]

4.6.2 Industrial market

The industrial market in Japan is currently still small. However it is expected to grow as the government is increasing its focus on this and the public market. The market is characterized by a small number of larger installations and can be divided into three main parts: companies, large scale projects and power stations. [JPEA, 2006]

One of the reasons the market is still small is explained in a JPEA market analysis. It showed introduction problems existed for the industrial and public market due to procedural and

[23] We believe this expectation of the durability of buildings is due to the frequent earthquakes that affect Japan. Though most of these quakes are very small, their large number (several per week on occasion) would eventually start to affect the structural integrity of the building. As land prices are high in Japan, it is not uncommon for houses to be rebuilt every few decades in the same location.

installation difficulties, such as the timing of actions to accommodate the companies' financial year, and the high costs associated with designing and approving systems which can not be standardized. [JPEA, 2006] A Field Test Project exists for the industrial and public market called the "Field Test Project on New Photovoltaic Power Generation Technology" which might help with the procedural and installation difficulties but this is not its actual goal. [PVPS, 2007] The project is aimed at the adoption of new technologies into PV systems for public and industrial facilities and accelerating further developments while promoting further introduction of medium and large-scale PV systems. Applicants collect data for 4 years and demonstrate the performance of the PV systems. Half the installation cost is subsidized and it is considered a very successful program with 22.08MW installed in 2006. [PVPS, 2007]

There are also good prospects regarding the interest from *companies*. A JPEA study indicates the interest of companies in PV is increasing. As there is a special industry energy tariff which is lower than that for residents there is less of an economic motive for companies to invest in PV. In general the motives for companies to invest in PV installations are: environmental consciousness, corporate image, advertising and CSR (corporate social responsibility). [JPEA, 2006] There is an installation subsidy specifically aimed at companies: the "Project for Supporting New Energy Operators". This METI project aims to accelerate new energy introduction by supporting businesses that launch the introduction of new energy, from the perspective of energy security and global environmental protection. A maximum of one third of installation cost is subsidized, and debt is also guaranteed. [PVPS, 2007]

The situation differs for *large-scale projects*. Large-scale projects are in general rare in Japan when not initiated or organized by the government. Especially large-scale housing programs are nearly non-existent in Japan [JPEA, 2006]. A possible reason for this is the lack of financial incentive to initiate such a scheme.

Power plant type PV installations are also very rare. Some believe Japan is simply not suitable for large-scale power plants as the space available is very limited and land prices are very high and there have been no new power plant type PV installation since 1995. However, now through government intervention interest appears to be finally increasing. In 2007 construction of a 2MW and a 5MW power plant were started through the government's "Verification of Grid Stabilization with Large-Scale PV Power Generation System" program. [Ikki & Matsubara, 2007]

4.6.3 Public market

The public market, like the industrial market, is still small however there is increasing interest from the communities in installing PV in public buildings. [JPEA, 2006] A variety of subsidies are available for this market. For instance the 'Eco-school Promotion Pilot Model Project' which is a collaborative effort from several ministries and METI. It aims at implementing pilot model projects to promote the introduction and demonstration of environmental-friendly schools, providing students with environmental education and improving school facilities. Up to now 387 eco-schools have been created, a further 44 schools were approved in 2006. [PVPS, 2007] For local governments there is the "Project for Promoting the Local Introduction of New Energy" which aims to accelerate new energy introduction by supporting the efforts of local governments and non-profit organizations. In 2006, 1130 kW in total was accepted. [PVPS, 2007]

There are also several top-down initiatives from the central government. For instance the fact that renewable energy has to be put in all new government buildings.

4.6.4 Renewable Portfolio Standard (RPS)

There is one other important government scheme aimed at improving the amount of renewable energy installed in Japan, the Renewable Portfolio Standard (RPS). Utilities are obligated through the RPS to use renewable energy sources through, which states that a specific percentage of the produced energy must come from renewable energy sources. It has been quite successful in promoting renewable energy sources, as can be seen from figure 4.4, which shows that utilities have more energy sources than the RPS minimum. This extra can be 'banked' and used in later years.

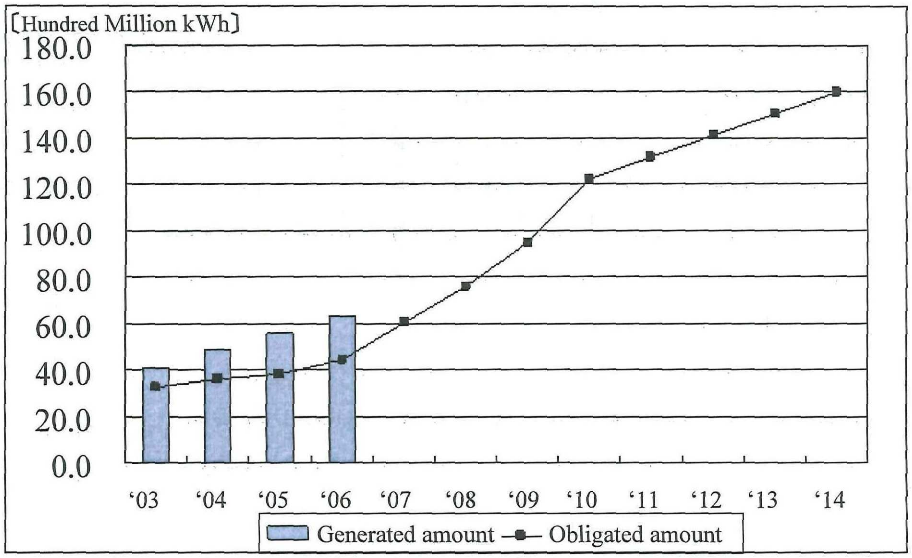
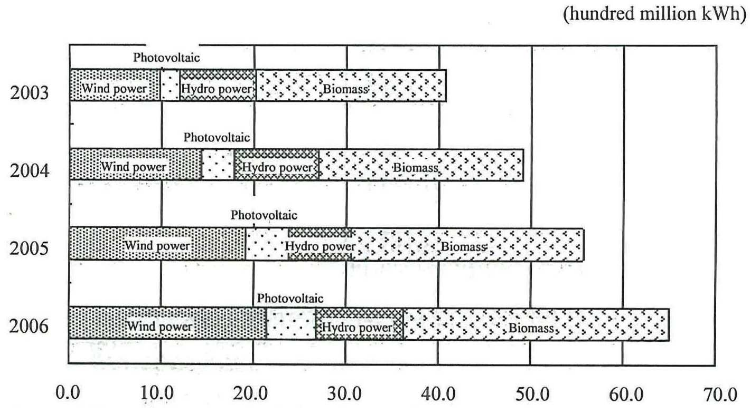


Figure 4.4: RPS Obligation fulfillment
Source: [Watanabe, 2007]

Unfortunately the RPS law is not technology specific. All 'new energy sources' can be used to fill in the limit. From Figure 4.5 we can see the amount of PV that falls under the RPS has increased, however the buy-back of energy from home-owner also falls under this scheme. As such the program is not so good for the promotion of PV specifically, whose costs are still fairly high and does not promote utilities to invest in PV them selves. Fortunately this problem has been recognized by the government and the RPS is undergoing a revision. A special preferred measure for PV is added where installed PV power is counted double. [Ikki & Matsubara, 2008]



	Wind power	Photovoltaic	Hydro power	Biomass	Others	Total
2003	9.9	2.0	8.4	20.4	0.0	40.6
2004	14.4	3.5	9.1	22.1	0.0	49.1
2005	19.1	4.6	7.0	25.0	0.1	55.8
2006	21.4	5.4	9.4	28.6	0.1	65.1

Figure 4.5: The total supply amount of RPS-related new energy
Source: [Watanabe, 2007]

4.6.5 Market developments

Since 2005 the amount of solar power that is installed every year in Japan has leveled-off, with a sudden decline in 2007, as can be seen from figure 4.6. In general this trend is assumed to be due to the stop of the Residential Dissemination Program in 2005 which made PV less popular with home-owners. However, considering the fact that the program did not provide any financial incentives, we would not expect the discontinuation of the subsidy program to have that much of an impact on market demand. There are several other likely reasons for the reduced demand.

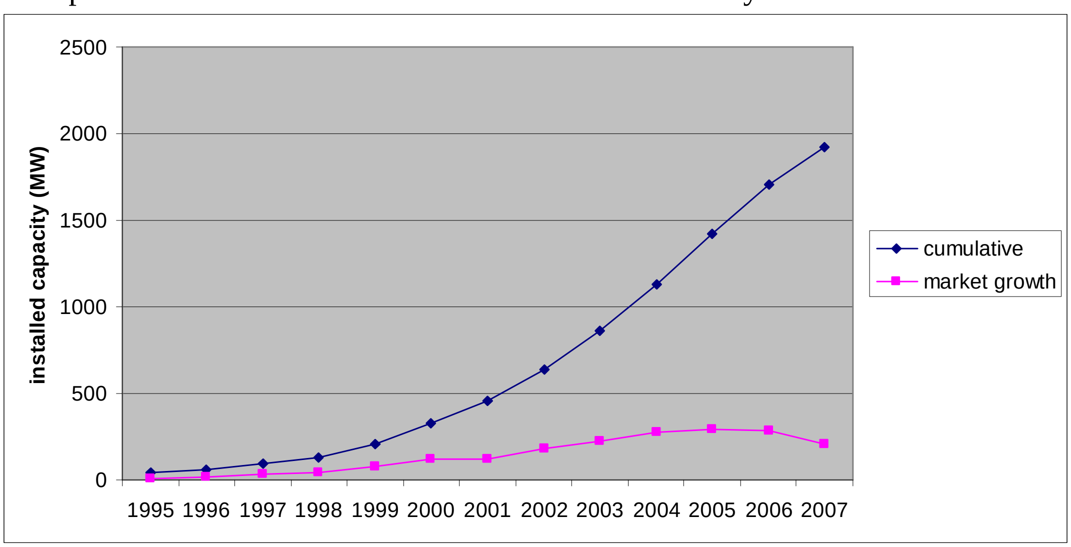


Figure 4.6: Japanese market developments[24]
Source: data used from http://www.iea-pvps.org/

[24] Market growth is the additional installed capacity per year.

Firstly, the prices of solar modules have risen recently due to the silicon shortages. The rise in silicon price and other materials has pushed up the price of PV installations for the residential market in Japan by 1.3% in 2006.[25] [Ikki & Matsubara, 2007] Next to this is the focus of companies on foreign markets, which causes shortages on the domestic market and pushes up the prices of modules [Kurokawa, 2008]. Furthermore, it is likely that the discontinuation of the residential program had a psychological effect on home-owners. As Akio Suzuki of Sharp Corp. explained "'the government is supporting this product' seemed to be a very persuasive factor to convince consumers of the social value of PV" [Kimura & Suzuki, 2006, p.17-18]. As such the stop might indicate to potential buyers that the government does not value solar cells anymore, or not as highly as other technologies which are still getting support.

It is likely that these factors combined, have caused the recent domestic market developments. As such, though the installed capacity decreased in 2007, this does not necessarily mean this trend will continue. In fact at the 17th International Photovoltaic Science and Engineering Conference (PVSEC-17) the JPEA stressed that "a sustainable residential PV market is being created without subsidy in Japan, even after Residential PV System Dissemination Program was completed and rate of growth slowed". [RTS, 2008] In other words, the market may be suffering no more than a temporary dip due to recent market developments and as such may improve in the coming years, once global market conditions change.

Nevertheless there is interest from industry and several government institutes to support the market and speed up the diffusion of PV in Japan. The JPEA is trying to obtain new market incentives. They hope to install about one million PV systems on detached houses by 2010. However they argue that to reach the installation goals requires the inclusion of home-owners who are not just concerned with the environment but also employ economic considerations. [JPEA, 2006] A similar consideration lies behind the call of the Osaka Chamber of Commerce and Industry (OCCI), for a reinstatement of a subsidy scheme for the residential market in order to achieve the greenhouse gases reduction targets. [Jäger-Waldau, 2007]

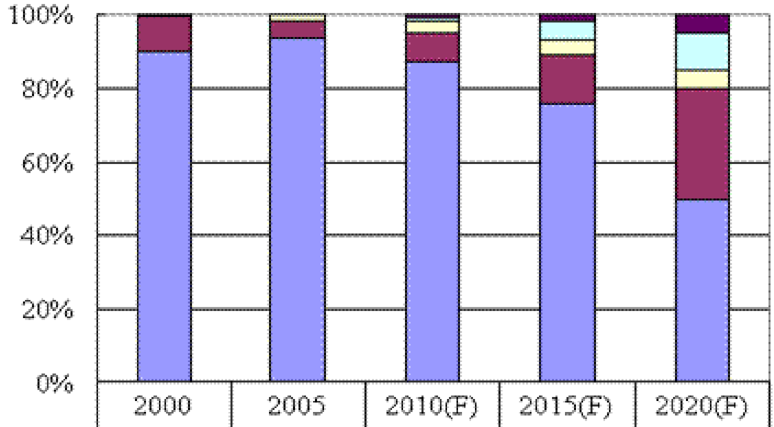
In all, we can identify four good prospects for the Japanese domestic PV market. First of, the silicon supply is expected to meet demand by 2009-2010 in the coming years which is expected to lower the domestic solar cells prices. [Suntech/MSK, 2008] Secondly, there are reports the Japanese government is in fact planning to initiate a new subsidy system for home owners aimed at halving the costs of buying solar power systems in Japan, in order to meet the prime minister's new goal of cutting greenhouse gas emissions by 60-80% from current levels by 2050. [Reuters, 2008] However, whether the budget will actually be allocated is still uncertain as previous calls to reinstate the residential subsidy were rejected by the Finance Ministry. [businessGreen, 2008]

Thirdly, the JPEA is promoting the installation of a Green certificate, aimed at increasing legitimacy with the customer. As the JPEA explains; "A product that is considered 'green' (aka renewable) can get a green certificate. This adds extra value for customers, since the energy from renewable sources is still very expensive. However this certificate has not yet been put into effect. Like many other things we are waiting until the G8 summit." [JPEA, 2008] Lastly, though the sizes of the industrial and public market are still negligible at the moment, interest from companies and communities is increasing. And these markets are expected to start having a significant impact on the domestic market by 2020. [JPEA, 2006]

[25] The price of residential systems is based on a 3- to 5-KW installation. The price of PV systems for public and industrial facilities (more than 10kW generation capacity) increased by 2.7%.

4.6.6 Per technology

Crystalline silicon solar cells already have a good established market. As indicated in figure 4.7, c-Si has roughly 90% market share. The near future prospects are looking fairly good with the increase of silicon supply, however the long term projects are fairly bleak. Though c-Si cells are expected to maintain a major share of the PV rooftop market for some time due to their high efficiency and proven reliability, it is expected to lose about half of its market share, as can be seen from the figure. No drastically new products or new crystalline silicon manufacturers are expected to enter the market.



	2000	2005	2010(F)	2015(F)	2020(F)
New Type(incl. GaAs, DSSC, Organic, etc.)	0.0%	0.0%	1.0%	2.0%	5.0%
CIS/CIGS	0.2%	0.2%	1.0%	5.0%	10.0%
CdTe	0.3%	1.4%	3.0%	4.0%	5.0%
a-Si/mc-Si	9.6%	4.7%	8.0%	13.0%	30.0%
c-Si(incl. mono, multi, ribbon, sheet)	89.9%	93.6%	87.0%	76.0%	50.0%

Figure 4.7: Expected world market share of several types of solar cells
Source: http://www.pvtaiwan.com/presscenter/news_view.shtml?docno=2278

Thin-film silicon solar cells are drastically increasing their market share. The current interest mostly stems from the silicon shortage and the ease with which companies can add tf-Si production lines. They can be bought as a whole from an increasing number of equipment manufacturers. However due to the lower efficiency than c-Si, some manufacturers are aiming at specific applications, in particular BIPV. BIPV stands for ‘building integrated photovoltaics’, which entails the use of solar cells as building components such as windows, facades, roofing materials etc. Fuji Sun Energy stands out as the most creative, creating a lightweight flexible solar cell which can be integrated into non-straight roofing material, or even tent-cloth.

Stacked solar cells manufacturers are mainly aiming at the ‘standard’ rooftop applications. Due to their high cost they are currently aiming at a specialized part of this market. With their high efficiency and low weight they are focusing on areas where customers need to use the limited area they have optimally.

Only two companies in Japan research and produce *CIS*. Both companies, Showa Shell and Honda, are new to the PV industry and started production in 2007. Their market share is expected to increase steadily. Currently only one company, Showa Shell, has announced production expansion. Regarding applications, CIS is competing directly with crystalline silicon in that they are aiming at rooftop applications. However the silicon technologies pretty much dominate the market, making it hard to enter. Especially as CIGS holds no clear advantage yet over crystalline regarding pricing and efficiency. However as Professor Kushiya of Showa Shell says "Customers can not see any difference among the crystalline-Si PV products prepared by Mitsubishi Electric, Kyocera and Sharp except Sanyo Electric (HIT) however they can see that Showa Shell's products are completely different on the appearance. This makes our product more attractive as a brand-new PV product. Also there is currently only a limited supply of CIS PV modules in the world wide so it looks like a status symbol." [Kushiya, 2008a]

In general the *dye-sensitized solar cells* and *polymer solar cells* are not considered ready enough to be used in the power applications market. The main advantages of organic solar cells are the potential low production costs, high efficiency and diversity in color. In general many consumer applications are currently becoming possible for DSC and worldwide many companies are planning innovative DSC products. However the focus of the Japanese government and thereby the research in Japan is on rooftop applications. As such there seems some doubt with PV manufacturing companies what to do with the organic solar cells right now. Sharp notes that "We still need to decide a final application as the market is very uncertain at the moment. A power plant is our final application but we are also considering other applications. We can't set a date yet for market introduction." [Sharp, 2008b] Regarding polymer solar cells, "We expect to start production of polymer solar cells about 10 years from now, maybe for a mobile phone or another application." [Sharp, 2008b]

4.6.7 Conclusion

We distinguished three markets: residential, industrial and public market. The residential market is the largest of the three and has increased enormously under the government's installation subsidy, which was ended in 2005. As the program together with the voluntary buy-back of power of the utilities did not provide any significant financial advantage for home-owners, the residential market appears to be based on environmental consciousness.

The industrial and public markets have some procedural and installation difficulties, which might be solved through the Field Test Project. There are good prospects for businesses however large-scale projects and power plant type installations are rare. The public market is mainly being promoted through several government projects. Another important government project is the RPS law which motivates utilities to use renewable energy sources which is now being revised to be more beneficial to PV.

The overall market growth has leveled-off since 2005. In general this is assumed to be due to the stop of the residential dissemination program however this seems unlikely. The market may be suffering no more than a temporary dip due to recent market developments and as such may improve in the coming years, once global market conditions change. Nevertheless there is interest from industry and several government institutes to support the market and speed up the diffusion of PV in Japan.

- *Crystalline silicon* solar cells have 90% of the solar cell market. Though c-Si solar cells are expected to maintain a major share of the PV rooftop market for some time, it is expected to lose a large part of its market share to the other PV technologies.
- *Thin-film silicon* solar cells are quickly increasing their market share due to the silicon shortage and the ease with which companies can add tf-Si production lines. They are especially used for the niche of BIPV applications.
- Of the *Stacked silicon* solar cells are currently on the market. They are aiming at a specialized part of the market based on their high efficiency and low weight.
- *CIS* is new on the market but is increasing its market share. The manufacturers are not aiming at any specific applications.
- *DSC* and *polymer* solar cells are not yet in production. There is some uncertainty about what type of market would be most suitable. Though research focuses on rooftop applications, not all believe they will be suitable for this application and DSC solar cells are now 'ready' for consumer products.

4.7 Function 6: Mobilization of resources

To enable all the functions within the TSIS enough resources need to be available to the actors within the innovation system. These resources are divided into three types: financial capital, human capital and physical resources. Here we will look at the presence of each in turn. We will end with an evaluation per technology.

4.7.1 Human capital

Japan has an extensive solar cell research community and as such the amount of specialists available is large. However there are no specialized PV education programs at universities. Experts are trained at universities through the presence of NEDO research projects. As a university does research under the project it automatically teaches the students who participate about the basics of the technology. This means that the types of solar cells where the academic research base is larger also have more students who graduate with expertise in the technology. However, while there are many researchers at universities for the silicon and organic types, there are not that many research groups for CIS. One would expect that this would have led to problems for CIS manufacturing companies in getting the researchers they need. However this is not the case, according to Mister Kushiya of Showa Shell. [Kushiya, 2008a]

In fact respondent companies have stated they get most of their researchers from within their own company and not from universities. As Kaneka explains: “It is rare for us to get researchers that are already specialized in the PV field. Most of the time graduates join Kaneka after having studied chemical engineering and then switch to solar cells. We then train them in house through on-the-job training.” [Kaneka, 2008b] This does not just count for Kaneka but appears to be the norm in Japanese PV manufacturers. As such, general knowledge is valued more in the PV community. As Arno Smets explains: “For researchers knowing the basics of science (chemistry, natural sciences, etc.) would be good enough. What is really important is being able to think on an academic level, the details of the PV material, technology and production processes are learned in practice.” [Smets, 2008]

In this system new employees require extensive on-the-job training. However as this is customary for new employees in Japan it is not perceived as a big problem. In fact no company reported problems finding researchers though some indicated that training them to become good researchers was quite an effort as researchers need to be informed about many technological fields. “Specialists for thin-film silicon need to know many kinds of areas so it is very difficult to get good researchers.” [Kaneka, 2008b]

The only problem in the availability of human capital in Japan lies with the country’s very low birthrate.

4.7.2 Financial capital

The main PV companies are part of large Group companies and as such they can bear the burden of the research and development activities that are necessary to bring PV products onto the market. Research capital is also provided through the NEDO research projects. Respondents agree that the long-term aspect of these projects has facilitated research and development of PV in Japan. As Professor Kurokawa stated; “Usually MITI[26] plans are only 5 years long, but in this case it lasted for 25 years. Long term plans and projects were one of the ’good things’ that made Japan strong in the PV field.” [Kurokawa, 2008]

[26] Former abbreviation for the ministry now known as METI

These projects have also helped to overcome the expensive development period between research results and prototype or product, as all of the main PV companies with the exception of Honda, developed their product in a government sponsored (NEDO) project. [Tanaka, 2007] However this may change in the future as the plan is to gradually shift responsibility for R&D closer to practical applications to the industrial sector. [NEDO, 2004]
Another promoting factor is the apparent Japanese habit that once research subsidy is given it is continued for quite some time, regardless of the research results. As Arno Smets of AIST says: "As soon as it has been established that a group or person gets funding, they will continue getting funding for quite some time. Compared to Europe, they are a bit 'spoiled', since they will get the funding anyway. Also it seems like not a single project fails, if the results are lacking, the project is subsumed or changed into another project." [Smets, 2008]

4.7.3 Physical resources

We now look at two raw materials which are very important for the production of PV and which have been indicated may lead to, or are already leading to problems. These are silicon and Indium. The main limiting factor for PV production lies in the current silicon shortage. Many factories are not producing at full capacity due to shortages, and getting a steady supply of silicon is deemed one of the major challenges currently facing solar cell manufacturers. Its importance is exemplified in the case of Sharp, as Professor Kurokawa explains: "Sharp had no strategy for securing a steady supply of silicon feedstock. Today, Sharp is the only large Japanese PV manufacturer whose production curve is leveling off." [Kurokawa, 2008] However there are good prospects in this regard as the number of silicon manufacturers is increasing greatly. It is expected that there will be a sufficient amount of silicon on the market around 2009-2010 [Suntech/MSK, 2008].

The second material we will look at is Indium, which is a key component of CIS solar cells. Indium is a rare metal and PV experts have therefore raised concerns regarding the Indium supply. As Arno Smets of AIST explains: "It is not yet available in large quantities, and I guess if many companies move to this type of cell, it would create an Indium shortage and the prices would rise quickly. The current supplies are just too limited." [Smets, 2008]
However the CIS researchers and producers themselves are adamant that the supply of Indium will not be a problem, as the amount they require is still very small as compared to the flat-panel display (FPD) industry, which is the main consumer. As Professor Kushiya from Showa Shell explains; "Our current need of Indium does not have a large impact on the Indium market. If we started a 1GW plant, we need 10 to 20 tons of Indium. Flat panel displays now require roughly 500 tons per year. There is also a very good working recycling system in Japan. CIS-PV manufacturers will only have a big impact on the Indium market price once we reach 10GW production per year." [Kushiya, 2008a] They are also expecting the FPD industry to replace the Indium need with an alternative which would greatly impact the Indium market. [Kushiya, 2008a] Either way, CIS manufacturers will need to ensure an adequate Indium supply to guarantee the future of CIS solar cell production.

4.7.4 Per technology

Silicon-based solar cells are mostly investigated by large group companies and as such can bear the burden of research and development, as well as the training of new researchers. Many companies and research institutes are involved and as such many specialists in the industry are available. The main problem for the silicon-based solar cells lies in the silicon shortage which forces technical innovations and a move towards thinner technologies.

The *CIS* research community is fairly small as compared to the other PV fields. There are reportedly only three universities that participate in NEDO research, these are:

- Tokyo Institute of technology (Tokyo Tech)
- Ryukoku University (Buddhism group owned private university)
- Aoyama Gakuin (Christian university) [Kushiya, 2008a]

However since companies train new employees themselves this does not appear to be that much of an issue for the producing companies. Showa Shell has indicated that even if they were to employ CIS university students, they need to retrain them as the technologies differ. “It takes at least 6 months to one year based on the graduation level and which university they graduated.” [Kushiya, 2008a] There are also concerns that students have worked for their competitors or will join their competitors company later on which would lead to secrecy issues. [Kushiya, 2008a]
Honda and Showa Shell are part of large group companies and as such have access to sufficient financial resources for R&D and production activities. The main problem for CIS manufacturers lies in ensuring a sufficient Indium supply. The companies appear confident this will not form a problem however they are also dependent on foreign companies. If many companies suddenly start CIS production it will still be an issue.

The *Organic* research field is large, there are a large number of research groups and companies involved. As such we can assume there is enough human capital present. The problem apparently lies with access to financial capital. Many small companies have reportedly stopped due to financial difficulties in researching and developing a new product. [Arakawa, 2008] They are likely dependent on NEDO projects for financing, as Arakawa explains “We still get money from the Sunshine project through NEDO, though it is called differently now. That is why we can still do R&D.” [Arakawa, 2008] However which financial means are available to small companies is currently unclear.

4.7.5 Conclusion

Japan seems to have no major problems with the supply and quality of staff in research organizations and companies. The only main problem in the availability of human capital lies with Japan’s low birthrate.
Regarding financial means, the main PV manufacturing companies are part of large Group companies and as such can bear the burden of research and development. Long-term government research projects have proved good sources of funding. The NEDO projects also helped companies with product development activities, though this is expected to change in the near future.
The main physical resources which are or might become constraint in the market are silicon and Indium. The silicon shortage is a major issue for companies and has already led to problems for some companies. However the shortage is expected to be resolved by 2009-2010. Indium is used for CIS and is a rare metal, however experts say there won’t be a shortage until production increases exponentially.

- *Silicon-based* solar cell manufacturers and researchers are not experiencing any problems with the supply of people and money. The main problem lies with the shortage of silicon making them move towards thinner technologies.

- *CIS* has few university trained researchers however there does not appear to be a shortage of company researchers. There seems to be sufficient financial resources. For manufacturers the Indium supply might become a problem if many (foreign) companies suddenly start CIS production.
- The *organic* solar cell community seems to have adequate human capital and no clear material shortages. However small companies apparently have a problem with access to financial capital.

4.8 Function 7: Support from advocacy coalitions

New energy innovations need to make a place for themselves in the present energy system which is dominated by the oil industry. Actors within the current system have gained a large amount of power and influence and are reluctant to change. Creating legitimacy for an innovation will facilitate that innovation to become part of an existing system, or overthrow it. Since interest groups are the key actors in creating legitimacy, we will consider several of these groups, in particular their activities and influence.

The groups we will look at are important actors in the development and diffusion of PV in Japan, these are: the government, the industry, utilities, universities, end-users and suppliers. However we would first like to start with explaining the process of interest groups influencing government policy, known as 'lobbying', which differs in Japan from the direct 'make yourself publicly heard' approach. We will not make a distinction per type of solar cell as we did not find a difference in support between the different types of solar cells.

4.8.1 Lobbying

Government regularly receives input from outside actors such as industry and academia through advisory committees. Working together to achieve a common goal is considered very important in Japan, as is explained by the JPEA: "We do not have a strong green party. Discussion with the government is very important since we are all in the same boat. We serve as consultants for future policies and participate in government committees, mostly on market-related issues." [JPEA, 2008] The government's goals and policies in general are not top-down but are made in conjunction with industry and academics.

For instance the creation of the PV2030 Roadmap was initiated by Professor Kurokawa when the previous goals were getting old [Kurokawa, 2008]. In response NEDO organized a sub-committee to the set these future PV targets. The Investigative Committee for the Roadmap consisted of: Kosuke Kurokawa (chair), JPEA, Sharp Corp., Kaneka Corp., Sekisui Chemical Co. Ltd., Kajima Corp., Nikkei Science, Tokyo Institute of Technology, Toyota Technological Institute, AIST, NEF, PVTEC and METI (observer). [NEDO, 2004] In other words representatives from all important fields were present (research institutes, universities and individual companies) and also from all technological fields. This means that the goals can rely on wide support within the innovation system. Furthermore, some of the goals come from calculations of earlier agreed upon points, making the goals logical conclusions of earlier agreements.

A good example of the way advice-giving is incorporated in the structure of government offices can be found in NEDO. NEDO is not staffed with specialists from specific technological fields. As such the institute does not have the necessary knowledge to judge the highly technical proposals that come in. The organization chooses which projects to fund based on expert advice. A committee of independent experts is set up of academics and institute researchers, mostly from the academic world, which decides which advises NEDO which of the various proposals to fund. [Arakawa, 2008; Kurokawa, 2008] This gives academic and industry researchers a large amount of influence over the future direction of PV in Japan.

4.8.2 Government

The government has always been a main player in the promotion of solar power as an important renewable technology. Since the beginning of the Sunshine Project, solar powered technologies have been part of the government's future energy plans. As such the government has always greatly promoted research into PV. PV is currently part of important government programs such as the New National Energy Strategy for 2030 and Cool Earth 50. The government's current PV research budget (2007) has 3 themes: [Watanabe, 2007]

1. Technology development; reducing cost and improving performance
2. Demonstration testing; identify and resolve problems that may hamper commercialization and verify effectiveness
3. Promotion of introduction; create initial demand and promote use etc. (half total budget)

In general government attention is now on market adoption. It is increasing its focus on research to make solar cells suitable for the market. [JPEA, 2006] and most NEDO projects are aimed at research to improve the technology to achieve grid-parity, or to facilitate installation. The government is also shifting its focus from the residential market to the industrial and public market which relates to the second target of the PV Roadmap. Up till now the government was focusing most of its attention of the residential market with the residential dissemination program. [JPEA, 2006]

While the guidance for PV research activities is strong there is a distinct lack of guidance and support from the government regarding the market. Many research projects exist to make PV competitive and able to support itself in a variety of markets (PV 2030 Roadmap) however subsidized projects mostly provide research funds and not installation aids. With the exception of the field test programs, aimed at gaining experience with installing PV systems, there are currently few market aids. Since the end of the Residential Dissemination Program in 2005 no general market support has been given to the industry for the formation of a market nor are there any installation targets. The aim of the PV2030 Roadmap is to make PV competitive with the current energy technologies. As such the players, including the government, agree that PV is currently not financially competitive.

Although the government has no installation targets for renewable technologies, it does have high reduction goals such as cutting greenhouse gas emission and reducing the country's oil dependence. However the current PV market is not large enough to actively contribute to these goals. Government officials appear to realize this and recent reports indicate the Japanese government is planning to initiate a new subsidy system for home owners aimed at halving the costs of buying solar power systems in Japan. [Reuters, 2008] "We don't want to depend on subsidies," as Shoji Watanabe, who leads the ministry's new energy policy team, explains. "We are hopeful that technology would eventually lower solar energy prices far enough that people will have an incentive to use it. Until then, subsidies or other state support, such as tax breaks, are necessary." [businessGreen, 2008] This is in response to Prime Minister Yasuo Fukuda's new target to cut greenhouse gas emissions by 60-80% from current levels by 2050. [Reuters, 2008] However, whether the budget will in fact be allocated is still uncertain as previous calls to reinstate the residential subsidy were rejected by the Finance Ministry. [businessGreen, 2008]

4.8.3 Industry

The PV industry is represented in the PV branch organization JPEA. However, not only PV manufacturers are members of JPEA, also: utilities, suppliers and equipment manufacturers. The organization has existed for a long time and is an important speaking partner of the government. They have reportedly managed to persuade the government to focus on market introduction instead of research in the 1990's, and convinced the government to extend the Residential Dissemination Program for an additional two years after it was supposed to end in 2003. [JPEA, 2008] It is the main consultant of the government regarding market related questions.

The JPEA agrees with industrial and academic circles that the price of PV is still too high to allow the market to expand to users who buy on financial considerations. As such the organization has been trying to obtain new market incentives. [JPEA, 2006] PV manufacturing companies have indicated that they would like market incentives but most don’t expect one to be initiated since the government states the original goal of the subsidy (creation of sustainable residential market) has been reached.

Also the manufacturers themselves seem to be less interested in the Japanese domestic market then in the foreign markets. As a result they might not be working as hard as they could to convince the government to initiate a new scheme. These concerns are shared by the JPEA and RTS. [JPEA, 2006] “…Japan’s PV industry should more and more strongly urge not only METI and MoE but also all the other ministries and agencies as well as 47 prefectures to direct the country toward further dissemination of the PV system.” [RTS, 2008, p.7]

4.8.4 Utilities

In Japan, the ten largest utilities are gathered in the Federation of Electrical Power Companies (FEPC). Utilities are very powerful in Japan and are not so keen on the large-scale diffusion of solar cells in the market. The Japanese energy companies dislike PV for 2 main reasons. The first deals with grid stability concerns because the power output from renewable sources is unstable. However recent research has pointed out that this is only a problem if more than 10% of the energy comes from PV. [JPEA, 2008] As the JPEA points out; “Currently we are at less than 1%, so why do we need to discuss the 10% case? For the most part it is the cost. They loose profit because of lost customers due to PV, as well as that they are required to buy the surplus energy from the house.” [JPEA, 2008] The second reason is due to the inherent loss of customers associated with PV dissemination. Home-owners that have PV installed take less energy from the electricity grid while at the same time the power companies buy the extra electricity the homes generate. However as this energy also counts towards their RPS quota, this installed capacity also has its advantages.

Judging from the main utilities’ websites (TEPCO, Kansai Electric Power, Tohoku Electric Power …), the utilities appear to favor nuclear power. Nuclear, like PV, is one of the technologies the Japanese has high hopes for. The ‘Nuclear Power National Plan’ in the New National Energy Strategy gives a target of 30% to 40% nuclear power by 2030. [ANRE, 2006] The power companies appear to work with PV to satisfy the RPS law and for public approval. As explained by the JPEA: “The utilities are also members of the JPEA but they are not so active in the PV field. Their core interest is nuclear power. However in order to use nuclear power they first need the consensus of the people, and they need to do PV in order to get this consent.” [JPEA, 2008]

4.8.5 Universities

At the moment researchers at universities and research institutes are adapting the technology to allow energy stability. Mostly this is done through creating small areas of PV which are connected to the grid separately (buffers and storage). They are focusing on micro-grids and separating PV from the grid through batteries. However there are indications that the adaptation of the technology is mostly to satisfy the utilities. As Professor Kurokawa explains “I'm being clear of what I want, but there is tough opposition from the utilities. [..] We now need to change the technology (make the PV systems autonomous from the Energy grid) in other to let it work in the market.” [Kurokawa, 2008]

These system design processes are also being supported by the government through research budgets. Considering the influence of the industry on government research goals and budget allocation, this could be a way of industry to work around the utilities

4.8.6 End-users

There are no large, well-known consumer organizations to promote PV. However there are no indications that this forms a problem. Specific interest organizations such as environmental groups are in general not common-place in Japan.

4.8.7 Suppliers

As mentioned in the previous sections there is a fight for silicon between the micro-electronics and PV industry. Most of the respondents considered the lack of silicon a market issue in which companies and institutes do not have much control, also because it depends on other industries like semi-conductors and TFT's. As Arno Smets of AIST explains: "In the past, the solar cell industry has always had to work with the leftovers from the semiconductor industry. So, this field was not really connected to the solar cell word. That's maybe also one of the reasons of the current shortage of silicon." [Smets, 2008] However at the moment a large number of suppliers are announcing the construction of factories specifically for solar cell production. The large increase of demand from PV has made suppliers aware of the (potential) benefits of supplying to this industry, if they weren't already beforehand.

Many other respondents pointed out the need of manufacturers to not just focus on silicon but to take all parts of the supply chain into consideration. "The PV industry should invest in Si feedstock, but also watch out for more downstream products such as sheet glass. Investments should be done here since the surface area of PV is expanding. For thin-film technologies, a very special type of glass is used, which only a limited number of manufacturers can produce. In the future, also keep an eye on the power electronics industry, e.g. the production of suitable inverters." [Kurokawa, 2008] Kaneka has also noted that the competition with other industries is not limited to silicon but also the production technology. "The process technology for these industries is fairly similar but if the TFT's or semi-conductors get more attention from researchers, the process technology for amorphous silicon will start to fall behind." [Kaneka, 2008b] However how the manufacturing companies react to these concerns is unclear.

4.8.8 Conclusion

Lobbying activities are formalized; the government mostly receives input from outside actors such as industry through advice-giving sessions which are incorporated into the basic government structure.

The *government* has been a main promoter of solar cells and has been supporting research activities for over 30 years. PV is included in the major government energy plans. However regarding market promotion, the government focuses on research to reach parity. The government stopped the market subsidy program in 2005 and appears unwilling to institute a new scheme.

The *industry* is organized in the JPEA, which appears to be quite successful in convincing the government to initiate and continue market incentives. However at the moment the individual PV manufacturing companies are not paying much attention to the domestic market which is perceived as a major problem for the domestic market by the JPEA and RTS.

The *utilities* are more interested in nuclear than PV. They are more interested in grid-stability and

therefore dislike PV. They promote renewable energies for corporate image.
University researchers appear to see utilities as a hindering factor as they are adapting the technology to make the technology mostly independent from the utilities.
There are no *user* organizations however there are no indications that this forms a problem.
The need for manufacturers to pay attention to their *suppliers* has been mentioned by many actors. Suppliers of the silicon industry can and have put more attention to other industries (micro-industry for silicon, TFT for thin-film machinery) which might cause problems for the PV industry in the long run.

4.9 Virtuous and vicious cycles

In this chapter we will look at the presence of vicious and virtuous cycles and look at the main promoting and limiting factors for the development and diffusion of PV in Japan. We will start with an analysis of the PV sector in general and then continue with analyses of the specific technologies.

4.9.1 Development

There is strong guidance in Japan for PV research activities. The future direction of PV is presented in the PV2030 Roadmap through clear research targets and is incorporated in the government's New National Energy Strategy (F4 guidance). The PV2030 Roadmap (F4) was a collaborative effort of governmental, academic and industry cycles (F7 advocacy). To achieve the targets the government provides financial support to the solar cell industry, mainly through the NEDO research and field test projects (F6 resources).

These projects have four positive effects on three other processes within the innovation system and thereby greatly promote the functioning of the innovation system.

1. Entrepreneurial activities (F1) are promoted, as through the NEDO research projects companies are involved in the development process. Also, the projects have helped companies overcome the large technical and financial difficulties that become prominent when transforming a technology into a prototype.
2. Knowledge development (F2) is greatly promoted as due to these long-standing research activities Japan has a large knowledge base (learning by searching), which has facilitated the expansion of production (learning by doing). The NEDO Field Test projects also help the research activities by providing learning by using opportunities.
3. The projects facilitate the dissemination of knowledge (F3). Also cooperative research improves knowledge exchange as do the publishing of information within the projects.

As such we can identify a virtuous R&D cycle based on expectations. The performed research increases expectations of the technology's capabilities to fulfill the government's reduction targets (F4), which have also been proven (in part) in the large domestic market. As such the technology has gained a certain legitimization within the government as a valid option to attain the desired targets (F7).

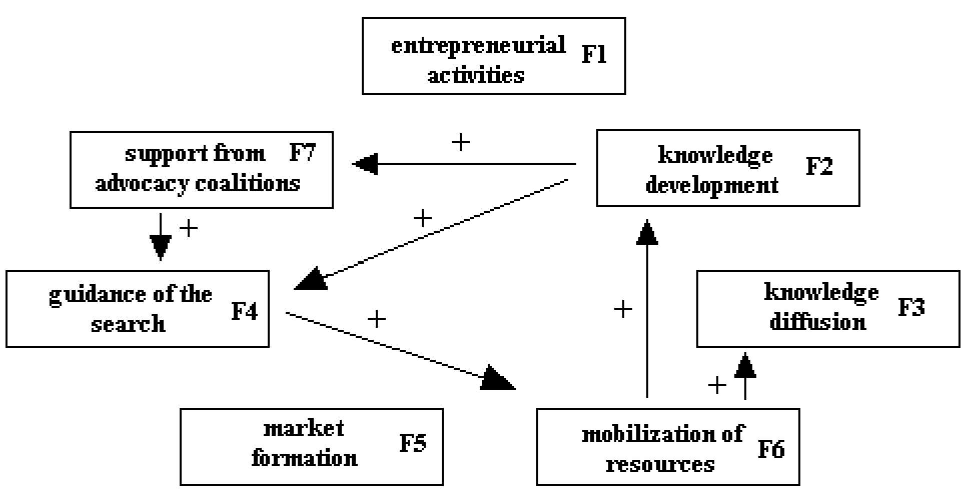


Figure 4.8: Japanese virtuous R&D cycle

4.9.2 Diffusion

We can also identify a virtuous cycle when looking at the diffusion of PV during the period 1993-2005. Lobby activities of the JPEA (F7) reportedly facilitated the initiation of the Residential Dissemination Programme (F6). This programme led to the creation of a large domestic PV market, which became the largest in the world (F5 market formation). As the market grew more entrepreneurs were attracted to the market; Sanyo (1997), MHI (2002), etc. (F1). Due to the lobby-type activities by the entrepreneurs through the JPEA (F7) the Residential Dissemination Program was continued for an additional 2 years (F6).

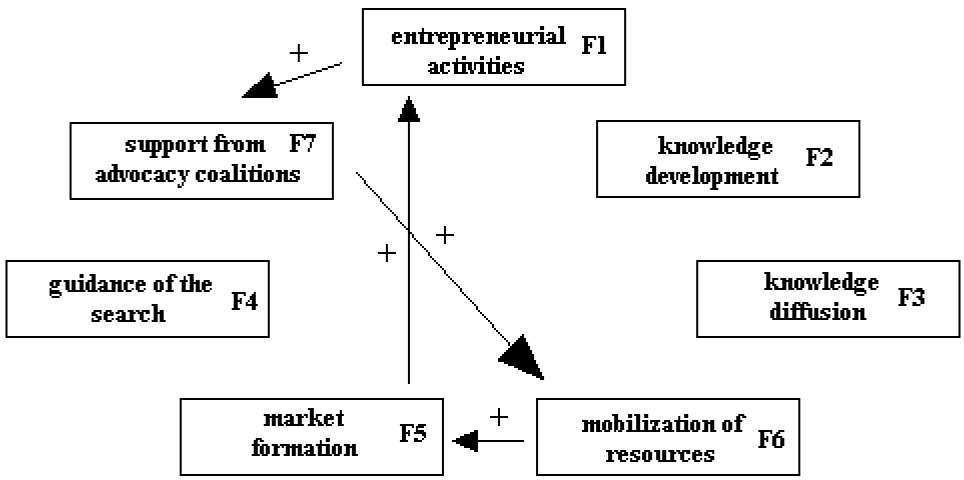


Figure 4.9: Japanese virtuous diffusion cycle

The situation is different for the present. Since 2005, the end of dissemination programme, the Japanese PV market growth has stagnated. However before we analyze this problem we need to ask ourselves whether the lack of a large market actually constitutes a problem. It is not the government's job to make 'unprofitable' technologies financially attractive by keeping them on a 'subsidy drip'. Is it really necessary for Japan to have a large domestic market of its own? Might the government be content with selling its products abroad? Or perhaps the Japanese government would prefer to wait until the technology has become financially attractive before initiating a subsidy scheme. Achieving grid-parity is after all the goal of the PV 2030 Roadmap, which the government supports and funds through the NEDO research projects.

However for our analysis we will assume a large domestic market is currently desirable. Recent reports indicate that several government institutes, as well as the prime minister, wish to initiate a new scheme in order for the government to reach its ambitious greenhouse targets. However the Finance Ministry appears reluctant as it has rejected previous calls to reinstate the residential subsidy system. The environment has always been high on the Japanese political agenda. Although the government has no installation targets for renewable technologies, it does have high reduction goals; cutting greenhouse gas emission by 60-80% by 2050, reducing oil dependence and so on. As PV has proven itself as a valid option to achieve these goals it appears logical for the government to wish to use this technology to reach its reduction goals, and in order to reach these goals action would have to be taken as soon as possible.

While the guidance for PV research activities is strong there is a distinct lack of guidance from the government regarding the market. The Japanese government has set strict targets for greenhouse gas reduction but no clear implementation targets for renewable energy sources (F4). There is also currently no market support (F6) even though it is accepted by all parties including the government (incorporated in New National Energy Strategy and PV2030 Roadmap) that solar cells are not yet competitive in the market (F5).

Activities from industry and academic circles could turn this around by motivating the government to set targets for PV (in collaboration) and reserve funds for market support (F7). Their activities have proven to be quite effective in the past; the PV2030 Roadmap was initiated and governed by Professor Kurokawa, before it was picked-up by NEDO, and the JPEA managed to extend the Residential Dissemination Program an additional two years. Unfortunately the foreign markets are growing so fast the Japanese PV manufacturers are focusing highly on these markets (F1). As explained by the JPEA and RTS, the focus on foreign markets means that the Japanese PV manufacturers do not try to promote the domestic market as much (F7). Entrepreneurs are selling increasing number of solar cells abroad and are increasing production to meet foreign demand (F1). The production increases further constrain the silicon supply (F6) pushing up the prices of solar cells, and since so many PV cells are sent abroad domestic prices are rising even further. The increased prices combined with the stop of the residential dissemination program appear to reduce interest in solar cells (F5). The reduced market means entrepreneurs are less interested in it, leading to reduced lobby activities (F7). This means no alleviation measures for the market are promoted and put in place (F5) which further constrains the market, meaning more entrepreneurs will focus on the market abroad (F1).

The situation appears to be causing a vicious cycle at the moment. However this situation should be resolved in the near future as the silicon supply will no longer be constraint by 2009-2010. There are also reports the Japanese government is planning to initiate a new subsidy system for home owners aimed at halving the costs of buying solar power systems in Japan which should improve the domestic market (F5). However, whether the budget will in fact be allocated without lobby activities by the industry is still uncertain as previous calls to reinstate the residential subsidy were rejected by the Finance Ministry (F7).

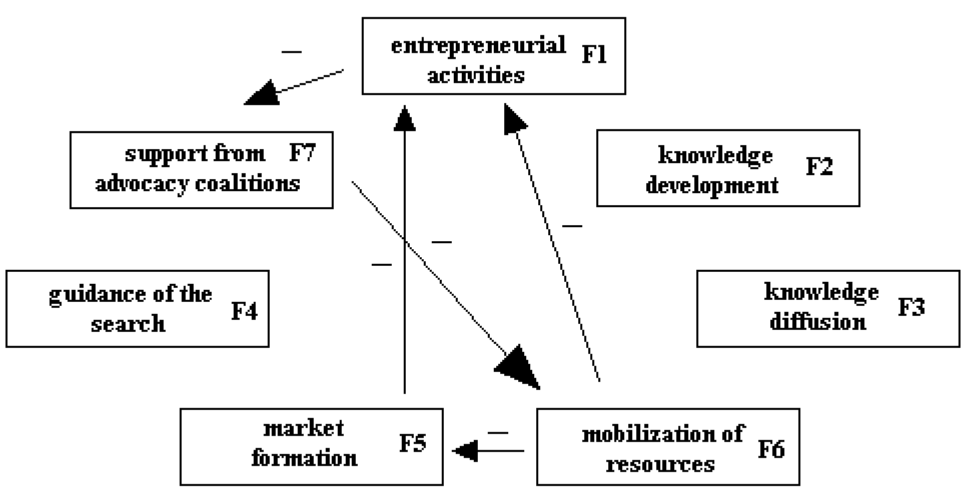


Figure 4.10: Japanese vicious diffusion cycle

4.9.3 Crystalline silicon solar cells

Crystalline silicon is the main type of solar cell in use today and as such a lot of knowledge is being gained through the production (learning by doing) and diffusion (learning by using) of crystalline silicon solar cells. The knowledge base in Japan is large (F2) however as the technology is quite advanced most of the research is applied which means most of the research lies with the manufacturing companies (learning by searching). These companies are more reluctant to collaborate regarding research however collaboration with research institutes and their equipment suppliers is continuing within NEDO projects. And there are many seminars, symposia and journals where knowledge is still exchanged (F2). Unfortunately due to the fact that the production of c-Si solar cells requires large amount of silicon, whose supply is constraint (F6), this type of solar cell is becoming less popular with entrepreneurs (F1). As is evidenced by the fact that out of the four producers, Hitachi has sold its c-Si activities and Sharp is mostly increasing its thin-film silicon production. The main promoting factor of c-Si solar cells is their proven performance and reliability (F4), as such the innovation is expected to remain an important part of the market even though its market share will drop (F5). In general we can say the lack of access to silicon is the main constraining factor for the c-Si innovation system, a situation which is most likely due to lack of effort by entrepreneurs to ensure a sufficient supply (F7). The shortage has turned entrepreneurs away from this type of solar cell leading to reduced market shares (F4) and thereby less prospects for potential new entrepreneurs (F1).

There appears to be a vicious cycle. The lack of effort by entrepreneurs to ensure a stable supply of silicon (F7) has (amongst other factors) led to problems for entrepreneurs to obtain a sufficient supply (F6) which has pushed entrepreneurs away from this technology (F1) towards technologies that use less or no silicon. Even though the silicon supply is expected to increase within a few years, entrepreneurs have already shifted and are not expected to return (F1) as development in the other types of solar cells are making them competitive with crystalline silicon solar cells.

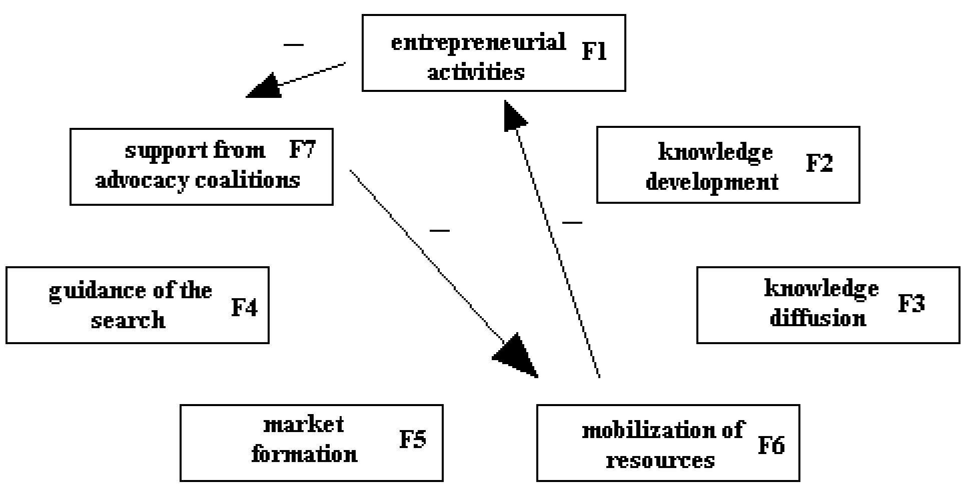


Figure 4.11: Crystalline silicon vicious diffusion cycle

4.9.4 Thin-film silicon solar cells

No specific cycles were found for the tf-Si TSIS, though several factors were determined to be important in the development and diffusion of the technology. While the silicon shortage has

negative effects on the c-Si TSIS, it is the main motivating factor for tf-Si solar cells. The silicon shortage has increased attention to thin-film silicon solar cells which uses only about 1/100th of the amount of crystalline silicon (F6). Thin-film silicon solar cells first became a hot research topic after a technological breakthrough in 1977 showed its uses for a variety of applications, including solar cells and TFT (F4). This overlap promotes the further development of the solar cell and also allows new players to enter production and research fairly easily (F1). The main problem for new entrants is the fierce competition on the Japanese PV market. This mostly likely has prompted, the only new entrant, Fuji Electric Systems, to aim at specialized applications (F5). There is also the fact that all of the current tf-silicon manufacturing companies are also investigating stacked solar cells. In general it appears that interest into thin-film silicon solar lies with short-term production increases, while stacked solar cells are deemed more important in the long-term due to their higher efficiencies.
As thin-films silicon cells have been in production for quite some time, a lot of information has been gathered through production and diffusion (F2). Though the technology is getting more advanced which is making knowledge exchange more difficult there are still points where all would benefit and collaborative research efforts are continuing (F3).

4.9.5 Stacked silicon solar cells

A virtuous cycle was found for the development of stacked silicon solar cells. As stacked silicon solar cells have a higher efficiency coupled with an equivalent low silicon need (F6), they are more attractive than thin-film silicon solar cells for entrepreneurs. Also because they are based on fundamental thin-film technology it is easy for the entrepreneurs producing tf-Si solar cells to move into stacked silicon solar cells, as they are doing (F1). This also allows them to benefit from tf-Si research activities which are being researched and discussed extensively (F2). Also as the same actors are involved, knowledge exchange is occurring through the same network and at the same events, greatly promoting knowledge exchange (F3). The solar cells are now entering the market in specialized applications (high efficiency, low weight). The use of the solar cells in the market combined with the research that is performed shows the potential of the solar cells. Though they are currently in a niche market confidence is growing that they will play an important part in the future, and they are expected to have large share of the market (F4).

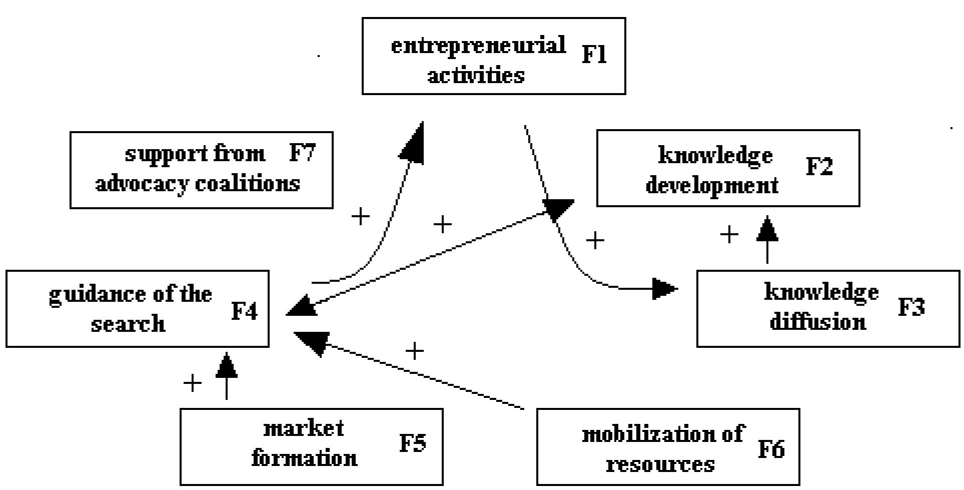


Figure 4.12: Stacked silicon virtuous R&D cycle

4.9.6 CIS solar cells

CIS solar cells recently entered the market as a direct competitor to Silicon solar cells and are gaining ground (F5). The cells have good cost reduction prospects which would make them very suitable for achieving the industry's goals of cost competitiveness (F4), which is their main motivating factor. However in the current climate of silicon shortages concerns have been raised regarding the availability of Indium (F6). The uncertainty surrounding this issue, combined with the large costs associated with researching CIS, is the most likely reason (potential) entrepreneurs are put off of this type of cell (F1). The fact that CIS differs so much from other types of cells is also not a beneficial factor. The CIS research community is fairly small in Japan with only two companies and several small scattered groups involved (F2). These companies do not collaborate, afraid to lose their advantage when exposing their technology (F3). The fact that the research community is small and scattered also results in two issues hindering knowledge processes. First of, learning by doing is difficult as only a few research groups can fabricate their own cells. Secondly, knowledge exchange in this TSIS is vital as the small research groups are scattered, however no formalized exchange methods are present (F3). Thirdly, the small number of groups has prompted the government to keep the groups separate to ensure no work is being done twice, however this also means that their basic technologies differ, making research that is being performed not necessarily beneficial for all other CIS researchers (F3).

As such we can find a vicious R&D cycle where the small scattered research community (F2) is not allowing for good knowledge diffusion (F3). This in turn is causing problems with the perception of the technology and thereby less interest (F4). However there are some good prospects as the small research groups are expected to be combined into larger groups which should facilitate knowledge creation and diffusion.

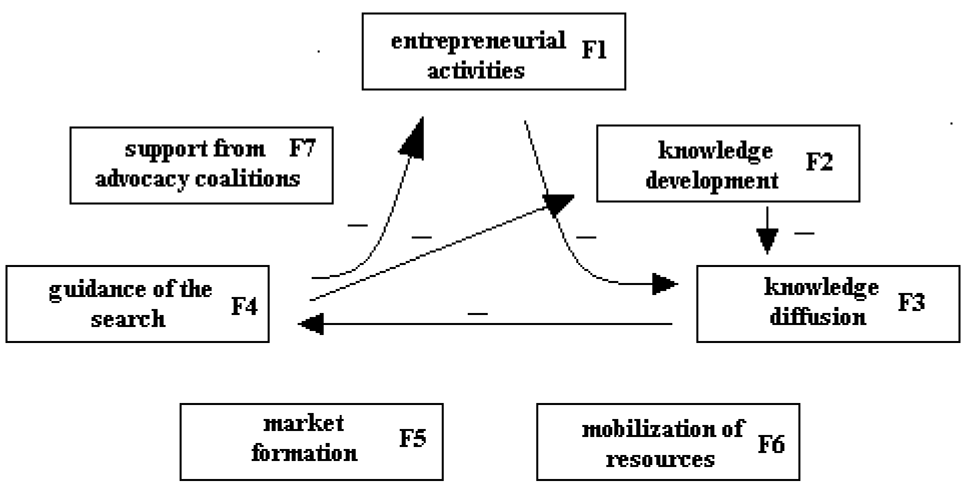


Figure 4.13: CIS vicious R&D cycle

4.9.7 Dye-sensitized solar cells

No cycles were found for the DSC TSIS however several factors were found to be important in the diffusion and development of the technology. According to DSC researchers, DSC solar cells show a lot of potential to achieve the target of grid parity through the reduction of production cost. (F4) As they are not based on the semi-conductor industry, DSC solar cells offer business openings for companies from different fields, such as the chemical industry. Also it is easy for small companies to start as no heavy machinery is required for production. The combination of a new technological field and ease-of-production is what has attracted many companies and research institutes to this type of solar cell and are its main promoting factors. As a result many small companies have entered the PV market for the first time (F1). One effect of this is that collaboration between companies is more common place, to share the costs of research and development (F3). Even so many small companies have stopped DSC research due to financial difficulties (F6).

The main technological problem with DSC solar cells is that they still suffer from long-term stability issues, which makes them unsuitable for power applications at this time. However, there are concerns in the PV industry that DSC solar cells will never be ready to enter the power application market. Nevertheless, the general consensus is that these types of cells are very well suited for consumer products (F4), and they will be put on the market in this form for the first time this year (F5). However research into DSC mostly focuses on power-applications, since this is the government's main area of focus. As such companies will most likely not receive much aid from the government when starting in these applications (F2).

4.9.8 Polymer solar cells

No cycles were found for the polymer TSIS however several factors were found to be important in the development of polymer solar cells. The second type of organic solar cell, the polymer solar cell, is currently in an early stage of development. As there is overlap between the research fields of DSC and polymer, they profit from each other's research. As such the situation is a bit similar to thin-film silicon and stacked silicon solar cells as research is exchanged through the same media and experts, the 'organics group' is a good example of this (F3). Most of the research is only in the basic research stage which is the field of academic research (F2). As such its inclusion in the PV 2030 Roadmap is an important factor stimulating development of the technology though it is still far from power-type applications. As it is expected to take quite some time before a sufficiently large efficiency, stability and durability is reached (F4) to be able to compete with other types of solar cells, they are not as popular with companies as DSC. However large companies such as Sharp are researching polymer solar cells (F1) and are expecting to put them onto the market in the future (F5). As these are part of large group companies they have the necessary resources to perform such basic research activities (F6).

5. Comparison to the Dutch PV IS

In this chapter we will make a comparison between the Dutch and Japanese PV Innovation Systems. The Dutch PV IS was evaluated using a variety of empiric sources, including the analysis of the Dutch PV IS.[27] We will start this chapter with an evaluation of the Dutch PV. First we will look at the structure of the Dutch PV IS, then the fulfilment of the processes within the IS and we will finish with an analysis of the main promoting and limiting factors of PV in the Netherlands by determining the presence of virtuous and vicious cycles. Next we will compare the Dutch and Japanese PV IS. Based on this comparison we will end with three recommendations to the Dutch government.

5.1 Structure of the Dutch PV IS

5.1.1 Government system

There are two ministries which are most involved in the Dutch PV IS; the Ministry of Housing, Spatial Planning and the Environment (VROM) and the Ministry of Economic Affairs (EZ). Of these, EZ is responsible for both monetary issues and energy policy.
SenterNovem is the *subsidy provider* of the government. This agency has been responsible for the renewable energy subsidy programs.

The Sustainable Electricity Supply Platform (SESP)[28] members represent the energy industry and other important groups, including: the Ministry of Economic Affairs, Tennet (electricity grid owner), NUON, ECN, Greenpeace and EnergieNed. The platform distinguishes four complementary main routes to make the electricity supply in the Netherlands sustainable.
In 2006 the platform appointed PV as one of the energy transition paths. [Swens, 2006] This led to the formation of a PV transition working group, working group for Solar Photovoltaic Systems, the 'Committee on Solar PV'. This work group specified the details of the transition path and formulated a strategy for deployment of PV in the Netherlands, including a recommendation for a market implementation support scheme.

Local governments such as the municipalities of Zeist and Alkmaar are providing additional subsidy schemes.

The government is also dependent on the decisions of the European Union (EU) when establishing its energy policy. The International Energy Agency (IEA) is responsible for international energy policy. Its solar heating and cooling programme has continued since 1977. [Montfoort & Ros, 2008]

5.1.2 Demand

The Dutch housing market can be categorised as a supply-driven market. *Project developers* realize many large-scale housing projects in which local governments usually play an important

[27] The research results of the analysis of the Dutch PV transition path were provided by Dr. Simona Negro in confidence and were used as background information for our own investigation and analysis. Referenced as [Negro, 2008]
[28] Platform Duurzame Elektriciteitsvoorziening (PDEV). For more information: http://www.senternovem.nl/energytransition/themes/sustainable_electricity_platform/index.asp

part. Home owners simply buy what is available on the market. In general consumers are not very familiar with durable living concepts. [Montfoort & Ros, 2008]
Unfortunately *architects* are not very enthusiastic about PV. Many are only incidentally involved in architectural design in which solar powered modules need to be incorporated and when they do most of the architects feel constraint in their creativity. Only a few always incorporate solar power into their designs. [Montfoort & Ros, 2008]
Distributors and *installers* are present in the market, such as the company Stroomwerk Energy BV. However their activities are lacking customer services and system guarantees. [Negro, 2008]

5.1.3 Intermediaries

The Dutch PV *branch organization* is Holland Solar (HS). HS is growing due to the improved prospects of PV in the Netherlands and an increasing number of parties are becoming members. The organization is becoming an important speaking partner for the government. HS is co-founder of the Dutch Renewable Energy Association.
This association, also known as 'De Koepel' (Duurzame Energie Koepel) aims to stimulate the development of renewable energy technologies in the Netherlands by influencing governmental policy and to increase political and public support. Pushing for more consistent and stimulating policies and for the removal of administrative barriers for renewable energy generation are the main priorities. [DE Koepel, 2008]
Several other industry branch organizations have been involved in the PV industry in the past, such as Uneto VNI (Branch Organisation Electro-technical Installers), VEBI-DAK (Branch Organization for Roofers), Association of Dutch architects ('Bond van Nederlandse Architecten (BNA)), and the 'Groene installateur' (Green installer). However these have retreated due to the small market. The expertise they have gained is therefore slowly disappearing.

There are also several organizations aimed at the *owners* of PV systems. These have been very active the last few years to fill the information gap left by the PV manufacturers, retailers and installers. [Negro, 2008]

Interest in PV from the *financial world* is increasing however the financial world is still limited in its knowledge of the rapidly developing solar cell market. ABN-AMRO bank, in collaboration with Seinen Construction and the municipality of Groningen, developed a financing scheme, in which financing of energy efficiency and renewable energy applications in buildings could be included in the mortgage, and could be financed on top of the calculated allowable maximum of the mortgage. [Swens, 2006]

5.1.4 Supply

Most of the Dutch PV manufacturing companies are small to middle sized. Companies that are active on the market include:

APA (Advanced Photovoltaic Applications) was founded in 2006. It will produce solar cells at 2 locations in Leeuwarden. The company's first solar panels will be produced in the 2nd quarter of 2009. The production facilities are currently under construction. By 2015 APA aims to cover 20% of the market shares for solar cells.
APA belongs to a group of companies that jointly cover the whole range from solar cells development to market implementation, the 'A group', together with i.e. Advanced Surface Technology BV (AST) and Advanced Water Splitting BV (AWS). [APA, 2008]

Helianthos became a full subsidiary of Nuon in 2006. At the end of 2007 the construction of a pilot plant was started in Arnhem, it is expected to start producing in the third quarter of 2008. [Nuon Helianthos, 2008; Nuon, 2008]

Scheuten Solar invests in Germany in silicon solar cells but has recently started a test-factory for CIS-technology in the Netherlands. [Nieuwsbank, 2006]

Shell stopped production of silicon solar cell in the Netherlands in 2003. At the moment they aim for thin-film solar cell (in collaboration with glass-giant Saint-Gobin) and CIS solar cell production abroad. [Montfoort & Ros, 2008; Energieraad, 2007]

Solland Solar is a German/Dutch company. It started production of silicon solar cells in 2005 with 20 MW/year, which has been increased to 60 MW/year by 2007. [Montfoort & Ros, 2008]

Ubbink Solar produces 2.6 MW of solar cell modules. [Swens, 2006]

Lastly, the power company Delta invested in a new ECN spin-off company called *GS Development*. [PVPS, 2007]

5.1.5 Knowledge infrastructure

The main *universities* working on PV research are: Technical University Eindhoven (TU/e), Technical University of Delft (TUD), University of Utrecht (UU) and the University of Groningen (Rijksuniversitiet Groningen (RuG)). [Montfoort & Ros, 2008]

The *research institutes* involved in solar cell research include: TNO, Energieonderzoek Centrum Nederland (ECN), and Front-End Silicon Technology for Photovoltaics (FEST).

There are also several *companies* doing into PV, such as: Solland Solar, Sunergy, Nuon/Helianthos, Scheuten Solar, AST (Advanced Surface Technology), Shell [Montfoort & Ros, 2008]

5.2 Functional analysis of the Dutch PV IS

After looking at the structure of the Dutch PV IS in the previous paragraph, we will now look at its functioning by evaluating the seven system functions.

5.2.1 Entrepreneurial activities

A relatively large number of companies are active in the Dutch PV industry considering there is currently not much of a domestic market. The entrepreneurs are small to medium-sized companies which are mostly new entrants into the PV industry. In fact many of the current companies have been founded in the last five years. The only multi-national company involved in PV in the Netherlands is Shell.

In general, entrepreneurs are very active as they are starting and/or expanding production. Solland Solar is currently the fastest growing company in the Netherlands, and companies such as Scheuten, Nuon/Helianthos and AST/APA have announced the construction of production lines in the Netherlands. As the Dutch market is small, the manufacturers are focusing on foreign markets, in particular Germany.

5.2.2 Knowledge development

Learning by searching

The Netherlands is very strong in solar cell research. Though the country is small, it is an important player in the international research community. The Netherlands is a technology provider for a large part of the worldwide PV industry. ECN delivers production and process-technology to both Dutch and foreign producers, and the country also plays an important role in the EU PV Technology Platform. ECN coordinates CrystalClear, a large EU-project. TNO and universities such as TU/e, TUD, UU, etc, take part in Dutch development activities and participate in many EU-PV projects.

The most active knowledge institutes are ECN, TNO and universities. There are also several companies which invest heavily in research however these focus mostly on applied research. As professor Zeman states “Dutch PV companies are not yet doing fundamental research.” [Zeman, 2008]

Learning by doing

The first PV factory in the Netherlands was built by Holecsol Components BV in 1981. [Verbong et al., 2001] Over the years the industry has managed to achieve quite some price reductions (see figure below), which indicate learning by doing activities have taken place. Though prices increased around 2005 due to the silicon shortage, the module prices have regained their decreasing line. However as they production volumes are still fairly small the market can not yet benefit from reduced prices due to economies of scale.

Learning by using

Dutch PV companies are installing their products in foreign markets and are thereby able to gain experience to adapt their products to a real-life setting. However the small Dutch market means Dutch PV installers are not gaining much experience with installing solar cells in the Dutch system. The Netherlands has a specific building tradition and as such requires development of standardization criteria specifically aimed at the Dutch situation, development of prefab applications and the built of knowledge and experience of construction risks. [Menkveld et al., 2004 in: Montfoort & Ros, 2008]

There have been several projects aimed at gaining experience with installing solar systems in the

Netherlands. Examples are the large-scale projects in Heerhugowaard and the Nieuwland neighbourhood in Amersfoort. Through these projects important information was gained concerning construction risks, such as water leakage on slanted roofs, fire hazards, and the disappointing life-expectancy of invertors and thin-film solar cells in real-life situations. [Montfoort & Ros, 2008] Research at vacation park 'de Groene Leguaan' (the Green Iguana) in Stavoren shows that the installation and the placing of the inverter are just as important as the conversion efficiency of the solar panel. [Montfoort & Ros, 2008] The main technical problems architects and installers are faced with are; covering the solar module edges, and connecting the panels to the other roof materials. [Montfoort & Ros, 2008]
In the building community there are many players, however of these only a fraction has participated in these types of demonstration projects and gained experience. [Montfoort & Ros, 2008] Unfortunately no government budget was available for demonstration of field trials in 2006, to improve this situation. [PVPS, 2007] Furthermore, with the small domestic market, important branch organizations from the built environment have retreated from the PV market and expertise gained during previous market subsidy programs is disappearing.[29]

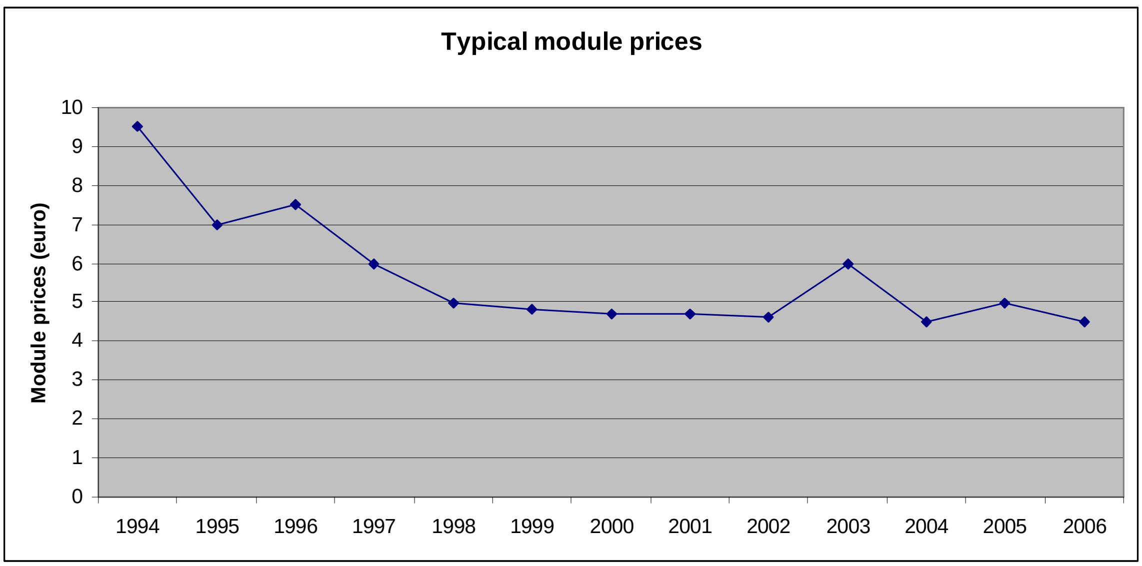


Figure 5.1: Typical module prices
Small flat- or pitched roof mounted systems (not integrated) of 0.1 to 1.0 kW
Source: [Swens, 2006]

5.2.3 Knowledge diffusion

Collaboration

There are many collaborative efforts within the research community. The three technical universities collaborate heavily. As Professor Zeman of TU Delft explains; "We have many joint projects. At the moment we have about three or four projects together with TU/e funded by SenterNovem. Twente has a different research focus from us so we collaborate less with Twente than with TU/e. Twente is interested in systems technology." [Zeman, 2008]
There are also many collaborative efforts between the different universities and research institutes, usually combined with companies. As Professor Zeman explains: "We have two types

[29] See paragraph 5.1.3

of research projects: basic research and more applied research. Most of our research projects have an industrial partner. I would say the division between the two types is about 50-50. However, even in the basic research projects an industrial partner is usually involved." [Zeman, 2008]
The PV-section of the TU Delft collaborates with two Dutch PV companies: NUON and OM&T. [Zeman, 2008] Scheuten Solar collaborates with ECN and TNO. [Scheuten, 2008] ECN and TNO cooperate on research for the built environment titled "building future". [Montfoort & Ros, 2008; Building Future, 2008] One of the most successful collaborations is the Helianthos project which was executed by TU Delft, TU Eindhoven, University of Utrecht and TNO-TPD, Shell Solar and Akzo-Nobel and resulted in a new fabrication technology for flexible solar cells. Nuon has now taken over the project and its subsidiary Helianthos will start production soon. [NODE, 2008]

Formalized exchange methods
There are several Dutch events where knowledge exchange can take place, these include: 'Landelijk De Zonneceldag' (The National Solar Day) and the Joint Solar Program (twice a year). The type of knowledge that is exchanged during these events mostly consists of research information. Unfortunately feedback from practice is lacking, especially monitoring of existing systems is not arranged in the Netherlands. [Negro, 2008]
Similar to Japan, the events are not just meant for information exchange but are also important as they are an opportunity to meet others in the field of PV. The importance of events and personal contact for researchers can be seen from Professor Zeman's list of ways he keeps up-to-date of research activities in the Netherlands, which all revolve around meeting others in contrast to written sources. "I keep informed in four ways. First and foremost through the research project meetings and big conferences. The project meetings are once every half year and a great way to meet people, exchange information and ideas and in general just keep in touch. Secondly, there is the National PV day. Thirdly, the workshops. Lastly, I keep up-to-date by just keeping in touch with my fellow researchers." [Zeman, 2008]

5.2.4 Guidance of the search
Vision
The Sustainable Electricity Supply Platform (SESP) has put down a vision towards a sustainable energy supply; the document 'New Energy for Climate Policy'. This document articulates the Clean and Efficient (Schoon en Zuinig) work programme which describes how the Netherlands is aiming to have one of the most efficient and cleanest energy systems in Europe by the year 2020. [SESP, 2006]
The SESP distinguishes four complementary main routes to make the electricity supply in the Netherlands sustainable. In 2006 the platform appointed PV as one of the energy transition paths. [Swens, 2006] The PV transition workgroup of the SESP created a vision for the future of PV. The workgroup formulated a transition path for Solar PV which specified a strategy for deployment of PV in the Netherlands and included a recommendation for a market implementation support scheme. [Solar Workgroup, 2006] The workgroup's vision is widely supported by the sector, in fact several companies were involved in its creation.[30] It also unites the existing Dutch and European vision documents:

- A Vision for Photovoltaic Technology - Report by the Photovoltaic Technology Research Advisory Council PV-TRAC

[30] The group consisted of representatives from: SenterNovem, ECN, SolandSolar, NUON, Stichting De Koepel, Eindhoven University of Technology and Econcern.

- Improving the European and National Support Systems for Photovoltaics - PV Policy Group
- *Zonneklaar* - the Advisory Council for Research on Spatial Planning, Nature and the Environment (RMNO)
- Transition Path for Solar Electricity- The Roadmap of Holland Solar

Overall, the SESP are counting on a 'modest' contribution of PV of 1TWH by 2020. The agreed upon installation goals are: 500 MW of installed capacity by 2015, and 6 GW by 2030, which translates to 3% of the total electricity use by 2030. [SESP, 2006; Holland Solar, 2005; Work Solar, 2006]

The document should have been an input for a new solar cell subsidy program. Unfortunately the vision of the platform was not adopted by the government and the new subsidy scheme (SDE) no longer has any relationship with the ambitions of the platform or the proposed market approach. [Negro, 2008] This has made the industry very sceptical about the upcoming arrangement.

For PV solar energy the government mainly sees a role in the longer term, after 2020, as the expectation in the report is that PV will reach consumer price levels within ten years. However some question whether this level can be reached in such a short time. [Montfoort & Ros, 2008]

Targets

The government has no research or installation goals specifically for PV. However the Dutch government has set targets for renewable energy, which are partly based on European agreements. The main targets are:

- 20% renewable energy in 2020
- 2% energy savings per year
- 20-30% CO2 emission reduction 2020 as compared to 1990

[DE Koepel, 2007a]

Technological expectations

The technological expectations for PV development are large price reductions, up to the residential tariff for solar power in 5 to 7 years. There will be increasingly cheaper systems based on new or old technologies. As soon as the market will grow, competing technologies and systems will enter the market which is expected to reduce the cost even further.

5.2.5 Market formation

Market characteristics

The Dutch PV market is very small accounting for only 1,5MW in 2007. Due to the reasonable market growth in the nineties the Netherlands is currently on par with countries such as Sweden and Spain in installed capacity. However as market growth in other European countries is much larger, the expectation is that the Netherlands will go further down in the ranking without further impulses. [Montfoort & Ros, 2008] As the Dutch market is fairly small and the foreign large, the export market is very important to Dutch companies.

Motivation to buy

There is a lot of potential in the market as many companies and home-owners are interested in this form of energy. This has been shown by the explosion of applications during a previous PV subsidy programs and the interest shown in the upcoming subsidy scheme for renewable energy sources.[31] On the second day of the application period for the new subsidy already 3.900

[31] For more information: http://www.senternovem.nl/sde/index.asp (Dutch only)

individuals had requested subsidy, more than half of the about 7.000 applications which can be honoured. [NRC, 2008] In the period 1990-2003 the yearly growth in the number of realized system has always lain above 20%. [DE Koepel, 2007b]
The general consensus is that consumers in the Netherlands buy solar cells based on financial motivation. When buying a home, consumers are in general willing to pay extra for PV; the most mentioned amounts correspond with a pay-back period of four years. Renters are willing to pay no more than what the solar systems deliver per year. [Montfoort & Ros, 2008] Without a market introduction subsidy there is barely any power being installed. The total power has increased less than 15% since the end of the previous subsidy system in 2003. [Montfoort & Ros, 2008]

Inconsistent market support
A large problem in the formation of a Dutch domestic market lies with the sporadic government market support. Many different schemes have replaced one another over the years, and in some periods in the past no replacement subsidy was initiated for several years. Furthermore some of these schemes were stopped fairly abruptly. In 2001 the renewable subsidy scheme, EPR (Energiepremieregeling) was expanded with an installation subsidy for the sales of solar panels by consumers. However in 2003 this scheme was stopped as the maximum total amount was exceeded. [Montfoort & Ros, 2008] The next subsidy scheme, MEP (Milieukwaliteit Elektriciteitsproductie) was initiated in the same year with the goal of improving the sustainability of the Dutch electricity production. However the scheme was not very successful, with only a minimal amount of PV installed during its run. [Montfoort & Ros, 2008] Then, in 2006, the minister of Economic Affairs suddenly stopped the subsidies for renewable energies, the MEP, when predictions indicated the Kyoto protocol goals (9% by 2010) would be achieved. “Closed due to success”, as the Minister said. [Nu.nl, 2006] Now a new subsidy scheme, the SDE (Stimuleringsregeling Duurzame Energieproductie), will be initiated in the near future. [Montfoort & Ros, 2008]
This starting and stopping of subsidy schemes of the government is not limited to solar power, solar thermal has also been subject to this behaviour, which has been dubbed the government’s ‘stoplight behaviour’ by Holland Solar. [Montfoort & Ros, 2008] This behaviour has very negative effects on the Dutch PV market as it creates a lot of uncertainty with investors, customers and producers. According to Rein Willems, leader of the Energy Transition Taskforce it is paramount that government policy is set for the long-term, stretching across multiple cabinet periods. “That is the only way in which enough confidence is built to enable investing in the long term.” [Nu.nl, 2006] Entrepreneurs, together with energy companies and political parties such as the SP (‘Socialistische Partij’) have announced their discontent with the government’s erratic behaviour. [ODE, 2008] As a spokesperson of Essent stated “there is no consistent policy. You’ll have to be extra careful with new projects.” [Nu.nl, 2006] Two companies, Solland Solar and Scheuten, have actually indicated their intention to move production out of the country due to the uncertainties surrounding market introduction subsidies. [Montfoort & Ros, 2008]
The upcoming SDE subsidy program proves to be promising for the market. The scheme does not only promote PV but also other renewable energy sources however it contains a special budget for PV. As solar cells are still fairly expensive as compared to other technologies this will be beneficial for diffusion. [Nu.nl, 2008] However the scheme is very limited, for 2008 only between 10 and 20 MW of subsidy is available. [PVPS, 2008]

5.2.6 Mobilization of resources

Financial capital

Financing for research is readily available from a large variety of sources. A large portion of the research support stems from European programs such as: Crystal Clear, European PV Technology Platform, FullSpectrum, Performance, PV-catapult, PV Policy Group, PVSAT-2, and PV-TRAC (Photovoltaic Technology Research Advisory Council). Government means are primarily used for R&D, the total national spending on research and development in 2006 was 9,40MEUR (94% of total budget). Only 0.6% and 5.4% were spent on tax and green certificate incentives for implementation respectively. No budget was available for demonstration projects or field trials. Additionally 2.5 million Euros (MEUR) of investment subsides were provided by local and regional authorities. [PVPS, 2007]

As is the case in the rest of Europe, venture capital is hard to obtain for entrepreneurs however capital is available to start a factory. Producing companies can get enough money on the capital market. The main bottleneck lies in the large technical and financial difficulties that become prominent when transforming a technology into a prototype. [Negro, 2008]

Human capital

There is currently a lack of sufficiently well-educated people in the PV branch and this problem will only increase once the market grows. “The biggest limitation is manpower. We have good contacts in the industry, enough money, but not enough manpower.” As professor Zeman explains, “We are pleased with the subsidies we receive from SenterNovem, however the research projects that receive funding need people to carry them out.” [Zeman, 2008]

Recent initiatives such as the founding of a ‘Solar Academy’ are aimed to deal with this problem. Initiator ECN works together with Solland, LIOF and The Institute of Semiconductor Electronics (RWTH Aachen University). The academy offers practical and theoretical courses for operators, engineers and managers, working in the solar cell industry. [Montfoort & Ros, 2008] However with the expected growth of the PV industry due to upcoming subsidy scheme, the availability of PV specialists is expected to remain constraint in the coming years.

Physical resources

The worldwide shortage of silicon has had its effect on Dutch manufacturers, as could be seen from the price rises that took place.[32] There is also no silicon feedstock production in the Netherlands itself, making actors dependent on the foreign market.

5.2.7 Support from advocacy coalitions

Government

The government has not had a consistent policy regarding solar cells. The Netherlands has been researching solar cells since the 1970’s and the technology became part of the National Research Programs in 1985. [Verbong et al., 2001] Between 1997 and 2000 the government and industry made a covenant aimed at creating a PV market. However in 2001 the government indicated it wished to stop negotiations for a new covenant. [Montfoort & Ros, 2008] In that year with the ‘4th National Environmental Policy Plan’ (NMP4), the government decided solar energy was a too costly option and would not be able to contribute to the 10% renewable energy goal for 2020. Maintaining a specific government policy for solar power was therefore considered not meaningful by the Ministry of Economic Affairs. [Montfoort & Ros, 2008] Since 2000 solar

[32] see figure 5.1

energy has not taken a prominent place in Dutch policy. [Montfoort & Ros, 2008]
When looking at the domestic market the government mainly sees a role for solar PV in the longer term, after 2010, when the technology has become financially profitable. However technology-wise PV is most likely seen as an important possible ‘export product’. An often stated goal of the government is to make the Netherlands a ‘knowledge country’; a country which exports knowledge in the form of technology, not products. In this regard, PV research shows a lot of potential. The Netherlands is internationally very strong in PV research, and organizations such as ECN are already technology providers for companies both in the Netherlands and abroad.

Though the government has, from time to time, supported market introduction, it is not very successful in its market subsidy policy. Though it is initiating a new market subsidy system for renewable energies, there is not much confidence in this scheme in the industry as it is not based on the SESP proposed vision. Furthermore, the government’s previous ‘unreliable’ behaviour, as described in 5.2.5, have resulted in the situation where part of the sector fears the subsidy scheme may be changed or stopped suddenly.

Utilities
In general Dutch utilities are not interested in renewable energies or any other ‘behind the meter’ activities. This is most likely due to the institutional changes which took place at the start of the century when the Dutch energy system was privatized. In the resulting competitive market, renewable energy sources are not as interesting to power companies, especially PV as it is currently still a very ‘expensive’ technology. As such most of the utilities only employ renewable technologies for promotional value towards their customers, to show that they are ‘green’ suppliers.
However several power companies promote the use of PV even after the liberalization, for instance Nuon and Eneco Energy introduce extra subsidy on PV. [Negro et al., 2008b] Furthermore, two power companies are also active in solar cell manufacturing. In 2006, NUON took over the Heliantos thin film silicon cell pilot plant from AKZO and Delta invested in a new ECN spin-off company called GS Development. [PVPS, 2007]

Industry
There are several industry coalitions aimed at promoting PV in the Netherlands however their success has been varied. Holland Solar has put forward a vision for the future of PV and this vision was one of the documents used as a basis for the PV transition path.
The HS is also one of the co-founders of the Dutch Renewable Energy Association (Stichting DE (Duurzame Energie) Koepel), along with the Netherlands Bio Energy Association (Platform Bio Energie), the Wind Energy association NWEA (formerly know as the FME groep windenergie, PAWEX and NEWIN) and the Heat Pump Association. [DE Koepel, 2008] The association aims to stimulate the development of renewables in the Netherlands by influencing governmental policy and to increase political and public support. Pushing for more consistent and stimulating policies and for the removal of administrative barriers for renewable energy generation are its main priorities. [DE Koepel, 2008] De Koepel was one of the members of the workgroup which wrote the Solar PV transition path document.
However the lobby power in favor of PV is limited. The created documents appear to be ignored by the government and their wishes and ideas regarding market strategy are not followed. There is a common message towards the government from the PV-sector but it is not being heard. Even the threat of relocation by Solland Solar and Scheuten did not lead to any significant

improvements. [Montfoort & Ros, 2008]

End-users
ODE is one of the customer organizations that wish to promote the diffusion of renewable energy sources. ODE attempts to achieve this by distributing information through their website, magazine and newsletter, and by participating in public discussions. The organization has a special solar section.
The amount of impact these organizations have on public perception or government policy is unclear at the moment. However they play an important role in the industry as they provide customers with reliable customer information and support, functions which are missing from the manufacturing and distributing side of the industry.

5.3 Virtuous and vicious cycles

In this paragraph we will determine the existence of virtuous and vicious cycles in the Dutch PV Innovation System.

5.3.1 Development

Research in the Netherlands is going strong. The country is very active in PV research and has strong international ties (F2). There are many collaborative efforts in the Dutch research community and between Dutch companies and research institutes (F3). This research is supported through national and international research programs (F6). The government has no clear vision for the future of PV (F5) however it expects PV to make a significant contribution to achieving the 20% renewable energy supply goal after 2010. And continuing its research support activities would be in line with its wish to make the Netherlands a 'knowledge country' (F7). As such we can identify a virtuous cycle.

The only limitation of the knowledge processes lies in the connection with the market. Learning by using processes aimed specifically at the Dutch institutional framework (F2), and learning by interacting processes between end-users and other actors in the system are lacking (F3).

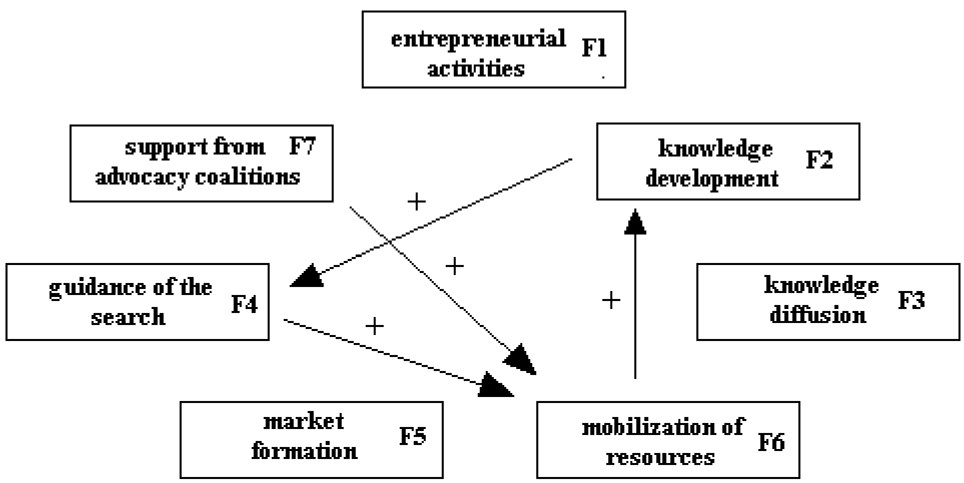


Figure 5.2: Dutch PV industry virtuous research cycle

5.3.2 Diffusion

The current Dutch PV market is negligible. However, before we start our analysis of the Dutch PV market we will need to consider the same question as for the Japanese case: Does the lack of a large market actually constitute a problem? Considering the many activities of industry to advance a large PV market we can say that (for them) this is certainly a problem. However the Dutch government has indicated it only sees a role for PV after 2020, once the technology reaches grid-parity, and as such the current small market does not constitute a problem. On the other hand the Dutch government has set high targets for itself for the year 2020 regarding emission reduction and renewable energy, which will be difficult to reach without employing all the technology currently available to them. Considering the fact that the opinions of the entrepreneurs strongly influences their behaviour in the IS, and that the government will likely need to employ PV, to some extent, to reach its 2020 goals, we will make the following assumption. For our analysis we will assume that the preferred situation is for PV to offer a significant contribution to the government's 2020 reduction and renewable energy targets. As such a much larger than the current 1.5MW would be desired, closer to the range of 30-50 MW.[33]

The Dutch domestic market is currently very small but shows great potential (F5). Though Dutch entrepreneurs are focusing on foreign markets (F1), they are interested in a domestic market and are lobbying to get the government to implement market subsidy schemes (F7). The PV industry has created a vision of the future of PV in the Netherlands which was used as an input for the vision towards a sustainable energy supply (F4). However the government has not taken over these visions the created documents appear to be ignored by the government and the industry's wishes and ideas regarding market strategy are not followed (F4). As such the lobby power in favor of PV appears limited (F7).
The guidance provided by the government is also lacking as it does not have its own vision of the future of the Dutch energy supply and its market subsidy policy has been erratic (F4). Though the government has supported market introduction in the past and will do so again in the near future through the upcoming SDE arrangement, support has not been constant over the years (F5). With the many switches in subsidy programs and the sudden discontinuation of several subsidy schemes both end-users and manufacturers are unsure if they can trust in new schemes, which will have negative effects on the formation of a domestic market (F5). The sporadic support has already caused two entrepreneurs to threaten to relocate their installations abroad (F1). In this way a vicious cycle can be distinguished as can be seen in the figure below.

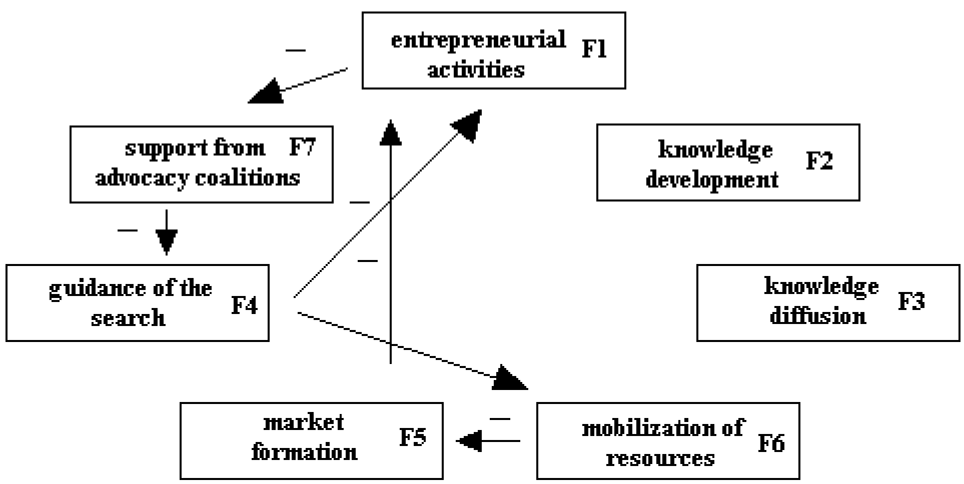


Figure 5.3: Dutch PV industry vicious diffusion cycle

One last problem for initiating a domestic PV market still needs to be mentioned. Namely that with the functions of knowledge development (F2) and diffusion (F3), knowledge processes related to the domestic market are lacking. Learning by using does not take place in the domestic market which means products and procedures are not adapted to the Dutch institutional system. Without this experience the installation cost will not be as low as abroad and the quality will suffer until such experience can be gained. Also, experience that had been gained with the previous subsidy systems is slowly being lost. Without consistent domestic market support this trend will continue (F2).

[33] See also the calculation we made in the description of our first recommendation in paragraph 5.5.1.

5.4 Comparison

Now that both the Japanese and Dutch PV Innovation Systems have been evaluated, we will compare both IS in this section. We will first start with a structural comparison of the IS, after which we will look at the differences in the fulfilment of the functions.

5.4.1 Structural comparison

There are many differences and similarities between the Netherlands and Japan. First of, both countries have limited natural energy supplies and are heavily reliant on external energy sources. For this reason both countries are very interested in renewable energy sources and are investing in renewable energy research. As such both countries have a very strong PV research base. Though the Netherlands is only a small country it is an important player in the international research community. However in contrast to Japan, the country is also dependent on European rules and regulations for its PV policy.

Category	**factor**	**The Netherlands**	**Japan**
Production	Estimated PV labour places in 2006	232	18.000
	Total cell and module production in 2006	20.6 MW	1,565 MW
Installed power	Total installed PV power	53,300 kW	1,918,894 kW
	Total installed per capita	3.3 W/capita	15.0 W/capita
	Cumulative domestic off-grid PV capacity	5,300 kW	1,884 kW
	Cumulative non-domestic domestic off-grid PV capacity		88,266 kW
	Cumulative distributed grid-connected PV capacity	43,500 kW	1,823,244 kW
	Cumulative centralized grid-connected PV capacity	3,500 kW	5,500 kW
	PV power installed	1,605 kW	210,395 kW
Public budgets	Public budgets for PV R&D in 2006	9.4 MEUR	21.80 MEUR
	Public budgets for Demonstration/field trials in 2006	–	93.5 MEUR
	Public budgets for market stimulation for PV in 2006	3.0 MEUR	28.5 MEUR
Pricing	System prices in 2006 (grid-connected)	4.8-5.5 EUR/W	4.7-5.2 EUR/W
	Module prices in 2006	3.3-4.5 EUR/W	3 EUR/W
	Price of an PV kWh	0.50 euro	

Table 5.1: Comparison between Japan and the Netherlands
Unless indicated otherwise figures represent end of 2007
Sources: http://www.dekoepel.org/documenten/factsheets%202007%20DE%20Koepel4.DE%20in%20Ned.pdf, [PVPS, 2007; Swens, 2006], www.iea-pvps.org/

The main aspect where the two countries differ is the size of their industry and market, as can be seen from the table above and figures below. Japan is one of the largest producers in the world, stimulated by the subsidy program which created a substantial market for PV. Though the domestic market is now stagnating the country still has one of the largest markets in the world,

and is one of the main producers. The Netherlands on the other hand has no domestic market to speak of. However interest from customers is present and previous subsidy programs of the government have resulted in a respectable amount of installed solar power in the country.
Differences are also present in the type of market that is favoured. The off-grid non-domestic market in Japan has already been established as a commercial market that does not require subsidy. [PVPS, 2007] However as the Dutch electricity grid covers almost the whole Dutch territory, off-grid domestic systems are rarely installed in the Netherlands. [Swens, 2006] Compared to Japan, the Netherlands has relatively more centralized grid-connected systems. This type of system is in general more popular in European countries. They are not always considered appropriate in Japan due to the limited space which is available nevertheless the government is now also supporting the development and diffusion of this type of application.

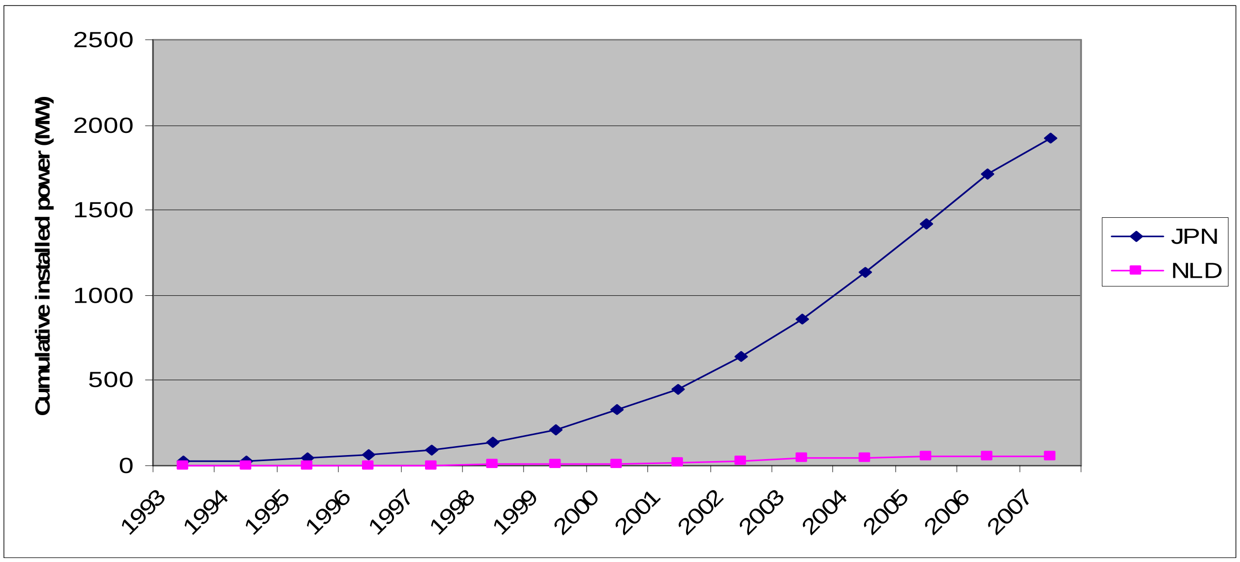


Figure 5.3: Cumulative installed PV power in Japan and the Netherlands
Source: data used from http://www.iea-pvps.org/

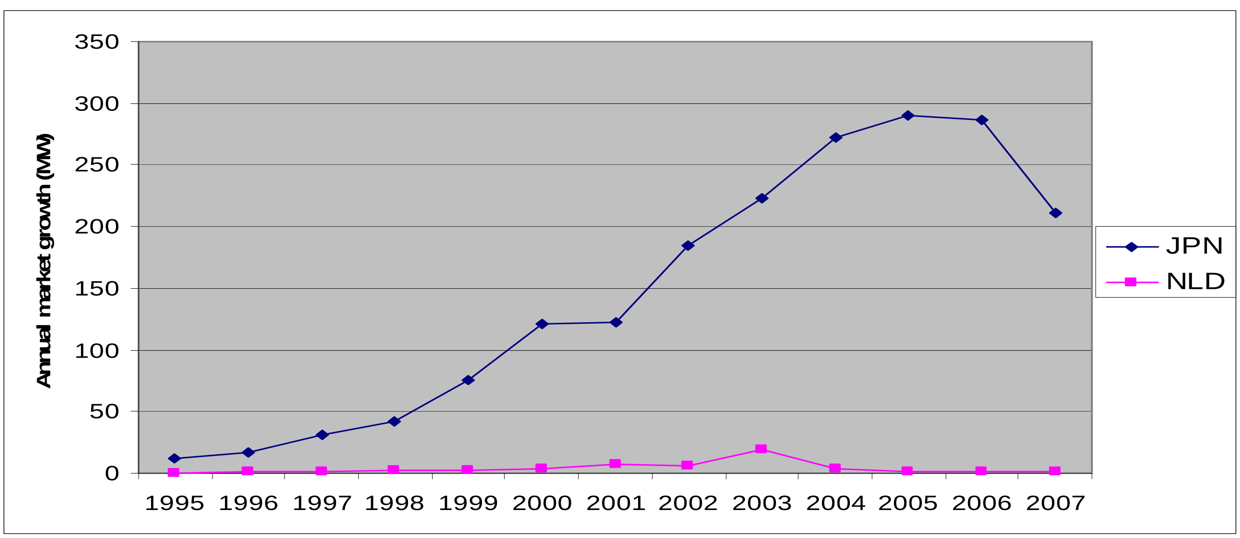


Figure 5.4: Annual PV market development in Japan and the Netherlands
Source: data used from http://www.iea-pvps.org/

5.4.2 Functional comparison

When comparing the functioning of the innovation systems we see both differences and similarities. *Development* of PV in both countries is going strong and we can observe virtuous cycles in both countries. Knowledge development (F2) and diffusion (F3) activities in both countries are going strong and are supported by the government through research subsidies (F6). In both countries the government provides research subsidies as it believes the technology can provide a significant contribution in attaining specific reduction targets (F7). However the Japanese appear to be surer of this than the Dutch government.

Where both countries differ most is in the *diffusion* of PV. Japan has one of the largest domestic PV markets in the world which is based on environmental consciousness. The Netherlands had some market growth in the past but at the moment has no market to speak of (F5). In contrast to Japan, the Netherlands' market is based on financial considerations, as such financial incentives schemes are very important.

In both countries the market shows a lot of potential, and past experiences with market subsidy schemes have proven home-owners are interested (F6). The main difference between the Dutch and Japanese market subsidy schemes lies in their consistency. The Japanese subsidy scheme continued uninterrupted for 12 years and worked with a pre-defined goal; reducing installation costs up to a certain level until the system price reached this level. During this time the Netherlands had several subsidy schemes with varying goals, lengths and set-ups, and some of these schemes were ended fairly abruptly. Both the varying subsidy schemes and the unexpected subsidy stops have negative effects on the Dutch PV market as it creates uncertainty with investors, customers and producers.

Both governments also lack a clear vision of the future of PV on which they might base a new subsidy scheme (F4). However Japan is slightly ahead in this area compared to the Netherlands. Japan has a well-known national energy strategy which already includes solar cell research, while the ideas and intentions of the Dutch government regarding the future of the energy supply are fairly unclear.

In both countries there are problems with the lobby activities of the industry however the exact problems differ (F7). In the Netherlands the PV sector is unable to make itself heard with the government. A vision for the future of the energy supply was created but was not taken over by the government. In Japan the PV industry managed to achieve market support mechanisms for 12 years (F6), which have led to the creation of a very large market (F5). However the companies are now losing interest in the domestic market due to the favourable foreign market.

In both countries manufacturers are aiming towards foreign markets, however as Japan is already one of the largest producers in the world and has an established (domestic) distribution network, it has a much better starting position for export than the Netherlands.

5.5 Recommendations

In this section we will look at the promoting factors for PV in Japan and the limiting factors for PV in the Netherlands with the aim of discovering possible recommendations for the Dutch government or industry. As we wish to learn from the Japanese situation we will focus on the period in which we identified virtuous cycles for both development and diffusion (1993-2005) for our analysis. Furthermore, as the main problems with the Dutch PV innovation system are related to the diffusion of solar cells we will focus on this area.

5.5.1 Consistent subsidy schemes

After comparing the two innovation system in the previous section, we can see at least one point where the Dutch IS may learn from the Japanese IS: maintaining a long-lasting, consistent subsidy scheme.

In the Netherlands, many different schemes have replaced one another over the years, and some of these schemes were ended fairly abruptly. Both the varying subsidy schemes and the unexpected subsidy stops have negative effects have negative effects on the Dutch PV market as it creates uncertainty with investors, customers and producers.

In contrast in Japan the Residential Dissemination Program created one of the world's largest markets. The subsidy program ran for uninterrupted for 12 years and provided consumers with an installation subsidy which reduced the cost of a PV system up to a pre-defined level. Though the chosen level was fairly arbitrary, the program was very successful. It also had the effect that the subsidy costs per installation were reduced for the government. In short, the scheme led to the creation of a large domestic PV market which in turn attracted more entrepreneurs.

The recommendation to the Dutch government is therefore to maintain a market subsidy scheme for a prolonged period of time, with a steady PV budget and fixed set-up, to reduce uncertainty with customers, manufacturing companies and investors.

The government can create a *steady PV budget* by ensuring a fixed income source for the subsidy scheme, for instance by assigning a fixed percentage of the fuel tax to feed directly into this subsidy scheme, or by creating a special tax solely for this purpose.

To ensure that the *set-up* of the subsidy scheme is consistent over the year, the organization or body of people that determine the set-up of the subsidy should be consistent as well. This would be best implemented by allowing a separate (semi-) governmental organization, such as SenterNovem, to be responsible for setting up and maintaining a suitable subsidy scheme. However for this to function correctly, the organization will need a clear mandate describing what goals it needs to achieve and when. It would be best if this mandate fits into the overall government policy, such as a vision of the future energy supply.[34] If the subsidy scheme's goal was part of a larger goal or vision this would validate its budget allocation and promote commitment from all parties.

As such, the *duration* of the program and the *budget* allotted to such a scheme should fit into the size of the market which is desired. For instance, the Sustainable Electricity Supply Platform and the HS Roadmap are counting on a 'modest' installed capacity of 500 MW by 2015, and 6 GW by 2030, which translates to 3% of the total electricity use by 2030. To allow the initial 2015 target, at least 55 MW will need to be installed every year between 2008 and 2015.[35] The

[34] See the third recommendation in paragraph 5.5.3

[35] Installed capacity in the Netherlands at the end of2007 is 53.3 MW (see table 5.1), to achieve 500 MW by 2015, a

upcoming SDE will last to at least 2011 and will allow for an annual installed capacity of 10 to 20 MW. To achieve the SESP targets the amount of PV subsidy under the SDE will need to be doubled, and the duration of the program should be expanded to at least 2015.

Although we recommend a consistent subsidy scheme to be implemented, we realize that the Netherlands is a changing country and *changes* in the set-up of the scheme might need to be made at some point. However we recommend that such changes be gradual, preferably decided on in collaboration with the relevant parties (industry and market) and with enough advanced notice to all involved parties.

For customers it is important that the amount of subsidy and the duration of the program will not be reduced suddenly. This is particularly important when large projects are set up as this requires many administrative issues (such as acquiring building permits) to be resolved before actual construction can take place (sometimes up to several years). It might be some time before the initial investment is earned back. Luckily, the upcoming SDE scheme is meant for private home-owners who generally require less administrative work and thereby less time. Especially with the 'pre-registration' scheme, where customers can request subsidy up to four years before having to install the system.

However the main actors which are affected by policy changes are not the customers but the manufacturers. Large changes in the amount of total provided subsidy will make it difficult for PV producing companies to anticipate demand and change their production accordingly. Solar cell production is a capital intensive business. As Dutch PV companies are very small, investing in a new production plant is a very costly affair. Not mentioning the time-lag between the decision to create a new plant and actual start of production. Dutch manufacturing companies will look for guarantees that their market will not disappear before their investment has paid itself back.

5.5.2 Market-related knowledge development

The second recommendation stems from specific problems that exist in the Netherlands regarding the connection of knowledge creation activities with the market. Learning by using does not take place in the domestic market which means products and procedures are not adapted to the Dutch institutional system. Experience that had been gained with the previous subsidy systems is slowly being lost. Without consistent domestic market support this trend will continue (F2).

This problem does not exist in Japan as it has a large market and the Field-Test projects which provide sufficient learning by using opportunities for the domestic market. The NEDO research and Field Test projects incorporate the market and companies in research in an early stage. In the NEDO research projects, companies, researchers and collaborations thereof, can submit research proposals. A subcommittee of specialists judges these proposals within 6 research fields depending on the technology and decides which proposals to honour. The Field Test projects enable the installation of test projects and incorporate market feedback and 4-years of operational analysis. This data is also published, enabling players in the industry to compare results of different installations.

The recommendation to the Dutch government would therefore be to initiate a set of projects similar to the Japanese NEDO (Field Test) projects to allow for adequate market involvement and operational feedback. For instance half the installation price will be paid back in exchange for the

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yearly production of 55.8 MW is required (2008-1015).

placement of a monitoring system, with the requirement that system owners will provide monitoring data for four years.
This recommendation is most appropriate if the government should decide not to initiate a large market subsidy to initiate a large market right now but wait until the technology has reached grid-parity. As such the industry can still gain experience with the technology in the specific Dutch institutional framework. Without this experience the installation cost will not be as low as abroad and the quality will suffer until such experience can be gained.

5.5.3 Vision of the future

What we can learn from the theory and the Japanese case is that though research targets are important, a clear vision of the future of the market is also necessary. Setting up a future vision could jump start a virtuous cycle, by motivating all actors to pool all their resources into one clear direction. These activities will attract new actors who will contribute their own resources and abilities, further promoting the chosen direction.

The recommendation to the Dutch government is therefore to settle on a vision for the future of PV in the Netherlands in collaboration with industry and academia.
To establish this vision the government has three options:

1. Adopt one of the existing visions

Several visions currently exist in the industry. The Dutch government has missed an opportunity in not basing its policy decisions on the vision of the 'Sustainable Electricity Supply Platform', or taking over the vision of the PV-workgroup as these are widely supported in the branch.

2. Adapt one of the existing visions

If the current visions do not meet the government's standards, they can either adapt one of the visions or create a new vision. Adapting one of the visions so that they are acceptable to all parties (including the government) would save the government a lot of time and money.

3. Create a new vision of the future of PV [36]

One of the most basic forms of a future market vision is by setting an installation target and supplementing this with a roadmap or other implementation plan. However the most important question the vision will need to answer is what role PV will play in the future Dutch energy system.
The vision will need to be set up in collaboration with the most important parties (government, industry, academic) to ensure a wide support base and a feeling of 'commitment'. This could be done by setting up a covenant between industry and government, such as existed for PV between 1997 and 2000.
However the vision does not have to be span 50 years. Even a 15-20 year vision will help the IS by giving direction to government policy, and motivating entrepreneurial activity. A vision with such a medium long timeframe might also provide a good learning ground for future visions.
However the success of this recommendation relies on the stability of the government in maintaining this vision. A vision can only work as long as all parties support it, belief it can be reached and have confidence it will not be changed suddenly so they can use it to anticipate future developments.

[36] Independent from this research, Dr. Simona Negro has also given the recommendation for the government to set up a long-term vision in collaboration with market parties.

6. Conclusions, discussion and recommendations

6.1 Conclusions

This research was aimed at investigating the promoting and limiting factors of the development and diffusion of several PV technologies in Japan. In all, seven solar cell technologies were chosen to be investigated, in collaboration with SenterNovem, which were further refined to achieve the following list: solar grade silicon (SoG), crystalline silicon solar cells (c-Si), thin-film silicon solar cells (tf-Si), stacked silicon solar cells, CIS solar cells, dye-sensitized solar cells (DSC) and polymer solar cells. The activities regarding Solar Grade Silicon were limited in Japan and completely separate from the other technologies. Investigating this technology would require a large amount of additional work for which no time was available. As such no functional analysis was made of this technology.

To discover the promoting and limiting factors for each of the six solar cell innovation we investigated the functioning of their Innovation Systems. This assessment was performed by evaluating the functioning of seven functions or processes within each of the six IS, and observing the existence of virtuous and vicious cycles. In the analysis of the innovation system we made a distinction between cycles which influence the development, and those that influenced the diffusion of the technology.

Overall, the *development of PV in Japan* went very well and a virtuous R&D cycle was found based on expectations. The performed research increases expectations of the technology's capabilities to fulfill the government's reduction targets (F4 guidance), which have also been proven (in part) in the large domestic market. As such the technology has gained a certain legitimization within the government as a valid option to attain the desired targets (F7). In particular the NEDO projects were found to have a positive effect on PV development in Japan.
Regarding the *diffusion of PV in Japan*, a virtuous development cycle was found during the period 1993-2005. Lobby activities of the JPEA (F7) reportedly facilitated the initiation of a national market subsidy scheme (F6). This scheme led to the creation of a large domestic PV market (F5), which attracted more entrepreneurs (F1). Due to the lobby-type activities by the entrepreneurs through the JPEA (F7) the subsidy scheme was continued for an additional 2 years (F6).
Since 2005 the Japanese PV market growth has levelled-off and Japanese entrepreneurs have turned towards foreign markets. This has resulted in a vicious diffusion cycle, where the reduced market means entrepreneurs are less interested in it, leading to reduced lobby activities (F7). This means no alleviation measures for the market are promoted and put in place (F5) which further constrains the market, meaning more entrepreneurs will focus on the market abroad (F1). However there is clear interest in Japan from the industry and government parties to initiate a new market scheme to accelerate the home market in order to achieve reduction emission goals. And there are good prospects for the domestic market; the silicon shortage will ease in coming years and there are reports a new subsidy scheme may be initiated.

The analysis of the PV technologies led to the discovery of several very different cycles. Even when no cycles could be found, several factors could be identified which were promoting or limiting the development or diffusion of the different technologies.
The *Crystalline silicon solar cells* TSIS suffers greatly from the current silicon shortage (F6).

Combined with insufficient attention of manufacturers to obtain a sufficient supply this has led to decreased interest from entrepreneurs in this type of cell (F1), which has resulted in a vicious diffusion cycle. However research into and production of c-Si is still continuing. The technology's main promoting factors are its proven reliability and performance which will ensure them a large market share for quite some years.

In contrast to c-Si solar cells, *thin-film silicon solar cells* are profiting greatly from the current silicon shortage. The overlap in technological field with TFT is pushing development forwards and makes it easier for companies to enter the field. Combined, these two factors are the main factors promoting the tf-Si TSIS. The main limiting factor for PV diffusion is the competition on the domestic market. This makes it more difficult for new companies to enter and the only new entrant, Fuji Electric Systems, is focusing on specific applications for which thin-film silicon solar cells are currently especially well-suited.

Stacked silicon solar cells are only just entering the market but are expected to play an important future role with an increasing market share (F5) due to their potentially high efficiency (F4). A virtuous R&D cycle was found. The solar cells are now entering the market in specialized applications (high efficiency, low weight). The use of the solar cells in the market combined with the research that is performed shows the potential of the solar cells. Though they are currently in a niche market confidence is growing that they will play an important part in the future, and they are expected to have large share of the market (F4). One of the main factors promoting entrepreneurs to use this technology is that they are based on fundamental thin-film silicon technologies but have higher efficiencies, allowing for fairly easy access to the technology while being better able to compete with the incumbent c-Si in the long run.

A vicious R&D circle was found for *CIS*, where the problems with knowledge diffusion are most likely preventing increased interest in the technology. CIS is potentially very appealing to entrepreneurs due to its high fabrication cost-reduction prospects, high efficiency and the fact that no silicon is required. However interest in CIS from entrepreneurs and research institutes is noticeably lacking, most likely due to the high costs associated with researching the technology, the very different background from the silicon and organic PV technologies and the Indium shortage. The small and scattered research community has led to problems with knowledge diffusion. There are no formalized exchange methods, the research groups are small and scattered, research is separated and the few companies in the industry do not collaborate. However there are some good prospects as the small research groups are expected to be combined into larger groups which should facilitate knowledge development and diffusion.

Dye-sensitized solar cells are not on the market yet however interest in this type of solar cell is very high as they are based on a new technological field (chemistry), and it easy to start research and production as no expensive machinery is required. The main problems facing the many small DSC entrepreneurs are financial difficulties. The perception of the technology is varied, as it is expected market. It is not yet ready for power-applications though it will be used in consumer products soon.

Polymer solar cells are still in a very early stage of development. The main factor which promotes development of the technology is its overlap with DSC research field which promotes knowledge exchange and diffusion. Research into power-applications, which will take a fair amount of time to realize, is promoted through the PV 2030 Roadmap.

After the analysis of Japan a comparison was made between the situation in the Netherlands and Japan, based on the main promoting and limiting factors in both countries, in order to discover possible recommendations for the Dutch PV IS.

Development of PV in both countries is going strong and we can observe virtuous cycles in both countries. Knowledge development (F2) and diffusion (F3) activities in both countries are going strong and are supported by the government through research subsidies (F6). In both countries the government provides research subsidies as it believes the technology can provide a significant contribution in attaining specific reduction targets (F7). However the Japanese appear to be surer of this than the Dutch government. Where the Netherlands in particular is facing trouble in its knowledge development activities is with its connection to the market. Little experience is being gained with the particular Dutch institutional system which means products and procedures are not being adapted.

Where both countries differ most is in the *diffusion of PV*. Japan has one of the largest domestic PV markets in the world which is based on environmental consciousness. The Netherlands had some market growth in the past but at the moment has no market to speak of (F5). In contrast to Japan, the Netherlands' market is based on financial considerations, as such financial incentives schemes are more important.

In both countries the market shows a lot of potential, and past experiences with market subsidy schemes have proven home-owners are interested (F6). Where they differ is in the execution of these subsidy schemes, in particular their consistency. The Japanese subsidy scheme was constant for 12 years and worked with a pre-defined goal, while the Netherlands had several subsidy schemes with varying goals, lengths and set-ups during this time. Also, several subsidy schemes were cut-off unexpectedly and there were times in which no subsidy was given at all. This has impacted the faith the industrial sector has in the reliability of the government's future subsidy schemes.

Both governments lack a clear vision of the future of PV on which they might base a new subsidy scheme (F4). However Japan is slightly ahead in this area compared to the Netherlands. Japan has a well-known national energy strategy which already incorporates PV research, while the ideas and intentions of the Dutch government regarding the future of the energy supply are fairly unclear.

In both countries there are problems with the lobby activities of the industry however the exact problems differ (F7). In the Netherlands the PV sector is unable to make itself heard with the government. A vision for the future of the energy supply was created but was not taken over by the government. In Japan the PV industry managed to achieve market support mechanisms for 12 years (F6), which have led to the creation of a very large market (F5). However the companies are now losing interest in the domestic market due to the favourable foreign market. As Japan is already one of the largest producers in the world and has an established (domestic) distribution network, it has a much better starting position for export than the Netherlands.

Based on the comparison and theory, three recommendations were given to the Dutch government.

1. Maintain a market subsidy scheme for a prolonged period of time, with a steady budget and fixed set-up.
2. Initiate a set of projects similar to the Japanese NEDO (Field Test) projects to allow for adequate market involvement and operational feedback.
3. Settle on a vision for the future of PV in the Netherlands in collaboration with industry and academia.

6.2 Discussion

While performing this research we encountered several important points related to our theoretical framework which we will discuss in this paragraph. First of, we found several aspects external to the TSIS to be important in its functioning: the silicon supply and institutional change. Secondly, we noticed that the difference between the goal of the IS and the goal of actors within the IS has an impact on the evaluation of the functioning of the IS. Thirdly, we looked at the applicability of this set of seven functions in an Asian setting. Next we looked at two factors dealing with cycles; the split of the IS into two parts with each their own cycle, and the importance of several functions creating virtuous and vicious cycles. Next we relate our research to the existing Japanese research into the PV industry. Lastly we will discuss our own experiences with using the functions of Innovation System approach.

We found several *aspects external to the TSIS* to be important in its functioning: the silicon supply and institutional change. The world-wide supply of silicon is not under the control of any one actor within the PV TSIS. However, though this factor is external to the PV TSIS of Japan and the Netherlands, it does have an important effect. The crystalline TSIS has a negative R&D cycle caused by the supply shortages, while the shortages have propelled development of thin-film silicon and non-silicon technologies. Though the availability of raw materials, such as silicon can be investigated within the TSIS context by looking at mobilization of physical resources, this analysis is limited. The analysis only looks at the immediate causes of manufacturing companies within the TSIS not receiving a sufficient supply, and simplifies all causes that lie outside of the influence sphere of the actors.

The other external aspect we found important was institutional change. In the Netherlands, the liberalization of the energy market has had a profound impact on the willingness of actors, in particular power companies, to work with and support renewable technologies. However, despite their influence, institutional changes are difficult to place in the functions analysis framework as it exists now.

The Socio-Technical System framework could have been used (combined with the IS) to investigate these important issues. As mentioned in paragraph 2.1, the STS framework is very good for finding outside factors and investigating them more thoroughly. Of its three levels, niche, regime and landscape, the later two would have been particularly beneficial to investigate in this case. Within the landscape problem fall such worldwide situations such as the silicon shortage and its effects on an innovation. While, the effects of institutional changes on an innovation are part of the regime level of analysis.

We also noticed that the difference between the *goal of the IS* and the goal of actors within the IS has an impact on the evaluation of the functioning of the IS. It should be noted that whether a TSIS functions well, according to the definition would be when the technology is being developed and diffused. However this is not always the wish of the actors within the system. For instance, the government might be quite happy with only developing a technology and exporting technology or products abroad, and not have a (large) domestic market. Or it might be content to simply import the products and not be burdened with high R&D costs (which for such new innovations are at least partly government funded). These wishes may also change over time, as can be seen from the Dutch government's changing viewpoint on the desirability of PV in the Netherlands over the years. As such the perceptions of the actors in the system are important factors for a researcher to consider when determining whether a TSIS is functioning ‘well’.

The third point we will look at is the applicability of this set of seven functions in an *Asian setting*. Our research constituted the first time this specific set of functions was used in an Asian setting. We found the set of seven functions to be well suited and could relate all events and relationships to a specific function. As such we did not find any factor or function specific to the Asian setting was missing. However we did find that we had to focus on different indicators for the functions due to cultural differences.[37]
When looking at entrepreneurial activities, in Europe the focus lies mostly on young start-ups, however as we explained in paragraph 4.2 for Japan we focused all our attention on incumbent firms, as young start-ups are less common.
When analyzing ‘advocacy coalitions’, ‘market formation’ and ‘guidance of the search’ we looked at the existence, efforts and accomplishments of councils. Councils or committees are used extensively in Japan as we explained in paragraph 4.8.1. One of the specifics of Japanese culture is that a lot of value is placed on maintaining harmony and ‘saving face’. As such, though strong opinions are present, they are not voiced as openly as in Western Europe, and activities in which opinions are given or received, such as lobbying, take place through fixed councils to minimize unexpected conflict.
When analyzing ‘advocacy coalitions’ we also looked at groups rather than opinionated individuals. As Japan is group-oriented, the opinion of one person (nearly) always reflects the opinion of the group (i.e. organization) he belongs to.
In ‘advocacy coalition’ and ‘market formation’, we paid particular attention to government views and actions. In Western views the authorities are there to serve the citizens and there are strong feelings of citizen competence. In Japan there is a greater dependence of citizens on authorities and the government has a larger part in guiding the country. This is related to the need for more security, as conflict and competition lead to unpredictability and are therefore considered undesirable. As such the government has more of a leading role than in the Netherlands, which means that their views are important to other actors in the IS such as the public, which is reflected in the fact that government support has an impact on public buying behaviour, as we discussed in paragraph 4.6.5.

During our research we found that we could *‘divide’ the IS into two parts*, development and diffusion, and identify separate cycles in each part. Such a split of the IS into two ‘parts’, has not explicitly been done before. In several IS we found a cycle in only one part of the IS. For example we found R&D cycles for Stacked silicon and CIS solar cells in Japan but no cycle for their diffusion. Next to these ‘single cycles’ we also found ‘opposite cycles’, meaning we found a virtuous cycle in one part of the IS and a vicious cycle in the other. Specifically we found virtuous R&D cycles combined with vicious diffusion cycles, in both the Japanese and Dutch PV IS. These situations seem to showcase the problem of transferring research results onto the market.

We also noticed during our analysis that *several functions were particularly important* in the creation of both virtuous and vicious cycles. These are: ‘guidance of the search’ (F4), ‘mobilization of resources’ (F6) and ‘advocacy coalitions’ (F7).
Guidance of the search (F4) was a key factor in the creation of the virtuous R&D cycles in Japan,

[37] See Appendix III for a description of Dutch and Japanese culture and its effects on the implementation of PV.

while the lack of consistent market guidance in was a main factor in the vicious diffusion cycle of the Dutch PV IS.
Mobilization of resources (F6) or the lack thereof, was the most important factor in the creation of vicious cycles. Lack of physical resources caused a vicious R&D cycle for CIS and a vicious diffusion cycle for c-Si in Japan.
The function 'advocacy coalitions' (F7) was key in the creation of several virtuous and vicious cycles. The lobby activities of manufacturers created a virtuous diffusion cycle for the Japanese PV industry. However lack of support for c-Si caused a vicious diffusion cycle for this particular type of solar cell. Furthermore, in both the Netherlands and Japan the virtuous R&D cycles were kept going by government support based on expectations that PV research and development could solve the government's problems.

Our research was not the first to look for the reasons behind the Japanese success with solar cell development and diffusion. Several Japanese researchers have investigated the history of Japan in PV and the causes for its success.[38] In the historical analysis of Kimura & Suzuki (2006) several factors were identified which enabled and promoted the development of PV in Japan in the past 30 years. These were: providing a stable environment for research communities, long-term commitment by the government, market creation policies, market acceptance in spite of high price and the efforts of ambitious private firms with strong commitment. One can see the first two of these factors deal with Japan's long-lasting policies. In fact it is generally agreed in Japan and abroad that the long-term timeframe of the government's policies was one of the most important factors in the success of PV.
Watanabe et al. (2000) identified a virtuous cycle based on the interrelation of R&D, market growth and price reduction. For their research they did not apply Innovation System theory but used techno-economics. They found that in the period 1976-1995 government actions promoted the creation of technology knowledge stock with companies, which contributed to a dramatic increase in solar cell production, leading to a reduction in production price, promoting further production and thereby knowledge development.
All of these factors returned in our research, though some to a lesser extent. In our analysis the importance of long-term policies was underscored by the short time frame of our research, however it was an important factor in our virtuous development cycles through the PV Roadmap. The virtuous diffusion cycle was based on a combination of a successful Residential Dissemination Program, customer's interest based on environmental consciousness and lobby activities of firms. The main difference between Kimura and Suzuki's results and our analysis lies in our observation that the lobby efforts of the main PV companies seem to be waning.
We also found a similar positive relation as Watanabe et al. (2000) between the market and development, under the heading of 'learning by doing' (see paragraph 4.3.2). Though it was found to be an important factor, especially in the comparison with the Dutch situation, in our analysis of Japan's PV development cycles it did not come forward as an integral part of any virtuous cycle.

Lastly we will discuss our own personal experience with using functions of Innovation System approach for our research. Overall we very much enjoyed using the seven functions of Hekkert et al. (2007a). The fact that no consensus currently exists on the indicators to be used for each

[38] Unfortunately not many of these researchers wrote down their results in English, which severely hampered our comparison.

function, allowed us the freedom to choose appropriate indicators. When specific information for one indicator could not be found this indicator could be dropped or altered. However it also created some difficulty as it was sometimes difficult to find appropriate indicators. Especially the seventh factor ‘advocacy coalitions’ is very vague and finding indicators which could be used in the Netherlands and Japan was challenging. Also, at times the choice felt slightly arbitrary. Until the indicators are established it will be difficult to compare our results to those of other researchers, as some of the indicators we chose could be placed under a different function by another researcher. Especially the functions knowledge development and knowledge diffusion appear to have a lot of overlap as both concern research activities and results.
Nevertheless we feel that, once properly defined, the seven functions form a good basis for the analysis of the functioning of an innovation system. Problems in the IS could very easily be identified by relating them to a specific function or combination of functions. However we found that the most insight could be gained when analysing the presence of virtuous and vicious cycles. By looking at the interrelation of the functions it was easier to find which factors in particular were important for the technology. Unfortunately it was often difficult to determine the exact nature of the virtuous and vicious cycle. For some technologies we would have expected there to be a virtuous R&D or diffusion cycle but could not find a coherent sequence of functions that initiated a self-supporting cycle. This might have been solved with additional research, however no time was available for this. Still, even when no cycle could be found, the analysis of cycles was a very helpful tool in discovering the main promoting and limiting factors of the development and diffusion of the technologies.

6.3 Recommendations for further research

During our research we found that the analysis of the IS could be split up into two parts, development and diffusion, where a virtuous (or vicious) cycle in one part not necessarily lead to a virtuous (or vicious) cycle in the other part. We identified ‘single cycles’ where a virtuous or vicious cycle only exists in one part of the IS, and ‘opposite cycles’ where one part has a virtuous cycle and the other a vicious cycle. However more research will need to take place to determine whether these single and opposite cycles can be maintained over time.

In our research we were forced to limit our investigation to power application, however not all the technologies we researched were suitable for this market. In particular DSC is now entering the consumer products market. As this research indicated there is a lot of interest of Japanese PV manufacturers in this market, including small firms. However many small companies were reportedly forced to stop research and development activities due to financial difficulties. As such, this would be a very interesting field of study when analyzing the difficulties in bringing a new innovation onto the market.

Furthermore, research into the development of energy storage technologies, i.e. lithium batteries and fuel cells, is in progress and is regarded as an important support-technology for the future of PV in Japan. Since the problems with the silicon shortage, several actors have indicated the need to look at all technologies related to solar cell manufacturing to ensure none can restrict PV’s development in the future. Unfortunately the activities surrounding these technologies lay outside of the scope of this research. However we find that research into the development of energy storage technologies, and their effects on the future of PV would be of value.

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List of interviews

Person	Company	Position	Date
Arno Smets	AIST	Research Center for Photovoltaics, Novel Silicon Material Team	18 April
Dr. Hironori Arakawa	Tokyo University of Science	Faculty of Engineering, Department of Industrial Chemistry, Professor	4 April
Takayuki Nakajima	JPEA	International Department, General Manager	16 April
Tetsuzo Kobayashi	JPEA, Eko Instruments Co.	Eko Instruments Co., General Manager, Production Engineering Dept.	16 April
Junichi Honda	JPEA, Kyocera Corp.	Kyocera Corp., Corp. Solar Energy Group, Manager Sakura Solar Center	16 April
Masahiro Sakurai	JPEA, Fuji Electric Systems Co.	Fuji Electric Systems Co., Staff General Manager, Energy systems Dept.	16 April
Dr. Akihiko Nakajima	Kaneka Corp.	Kaneka Corp., Solar Energy Div., Tech. & Dev. Group, Manager	11 April, 11 July
Toshiaki Sasaki Ph.D.	Kaneka Corp.	Kaneka Corp., Research, Solar Energy Div.	11 April, 11 July
Masahiro Gotoh	Kaneka Corp.	Kaneka Corp., Solar Energy Div., Research	11 April, 11 July
Susumu Fukuda	Kaneka Corp.	Kaneka Corp., Solar Energy Div., Research	11 April, 11 July
Professor Kurokawa	TUAT	Strategic Research Initiative for Sustainability and Survival, Graduate School	7 April
Atsuhiko Kurihara	METI	ANRE	30 May
Isamu Ohta	Misawa Homes	Energy and Environmental Research Department	8 April
Junpei Imoto	NEDO	Project Coordinator	19 March, 26 May, 28 May
Masanori Ishimura	PVTEC, NEDO	Technical department, chief researcher (PVTEC)	19 March
Izumi Kaizuka	RTS Corporation	Manager, Overseas Division	4 April
Tatsuo Saga	Sharp Corporation	New Technology Development Center, Solar systems group, Group Deputy General Manager and Division General Manager	9 May
Takao Konishi	Sharp Corporation	New Technology Development Center, Solar systems group, Division deputy general manager and department general manager of Development Department I	9 May
Naoki Asano	Sharp Corporation	New Technology Development Center, Solar systems group, Junior Manger Development Department I	9 May
Katsumi Kushiya	Showa Shell Sekiyu K.K.	New Business Development Div., CIS Development Group Chief Researcher, Deputy General Manager	7 May
Fumiko Kato	Suntech	Marketing, Manager	1 April
Hiromichi Kuroda	Suntech	Marketing, Senior Manager	1 April
Yukako Muramatsu	MSK	Sales & Marketing, Business Development Specialist	1 April
Takayuki Oosaki	ULVAC	Advanced Electronics Equipment Divison, Sales Department, Senior Staff	17 March
Dr. Susumu Yoshikawa	Kyoto University	Institute of Advanced Energy, Professor	14 April
Dipl. Ing. Ingrid Weiss	WIP-Renewable Energies	Senior Project Manager	28 March
Dr. Miro Zeman	TU Delft	DIMES, ECTM Laboratory, Solar Cell Group Head	9 September
Dr. Simona Negro	Universiteit Utrecht	Faculty of Geosciences, Innovation Studies Group, Postdoc	29 January, 15 August
Job Swens	SenterNovem		16 January

Appendix I: Current status of PV technologies in Japan

This appendix will give an outline of the current state of PV technologies in Japan to be used within the PV scan 2008 of SenterNovem. We structured this appendix based on the categorization of solar cell technologies used by the 'European PV Technology Platform'.[39] However we made three small changes to this categorization related to the focus of our research. First, we added 'silicon feedstock' as an additional category. Second, within the category 'thin-film silicon' we specified 'single-junction' and 'multi-junction' based on the difference between 'thin-film silicon solar cells' and 'stacked silicon solar cells'. Thirdly, we made a distinction between 'dye-sensitized' and 'polymer' when looking at organic solar cells. Each technology consists of 4 parts: a very short description of the technology,[40] government action to promote the technology, current research activities and current industry activities (production). We do not claim the information in this chapter to be all-encompassing or complete. We include it as appendix as reference for readers or as a basis for further study.

1. Supporting technology

Silicon feedstock/ Solar Grade silicon

Solar Grade Silicon entails the production of silicon material which is suitable for use in Solar Cells. [U.S., 2008] Silicon is the second most available item in the Earth's crust as it is basically just sand. [U.S., 2005] Highly refined silicon is mostly used for the production of micro-processors (chips). Semi-conductors however require a high level of purity, 99.999999999%, and it takes a lot of energy to achieve this purity. Silicon for the production of solar cells on the other hand does not necessarily require this high level of purity, 99.9999% is sufficient. [Kawamoto & Okuwada, 2007]

Worldwide a lot of research is being done to determine the allowable levels of impurities for SoG-Si in order to lower the cost of producing silicon. Considering about 50% of the current costs of a PV module can be attributed to the high-purity silicon wafers, [ECN, 2008a] solar cell manufacturers are very interested in low-cost wafers.

Government

There is currently no clear government support program for the research and/or development of Solar Grade Silicon.

Research

Tokuyama is in the process of verifying and improving its 'vapor to liquid deposition (VLD)' [41]production process technology which can reportedly make the silicon deposition rate more than 10 times higher. [Tokuyama, 2005]

Chisso Corporation has been developing a zinc-reduction method to achieve 99.9999% purity. [42]It has established a joint-venture company 'Japan Solar Silicon (JSS)' in 2007 with Nippon Mining Holdings and Toho Titanium, to promote joint development and commercialization of SoG-Si. [Chisso, 2006; Chisso, 2006b]

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[39] See: [EU PV Platform, 2007]

[40] Please see [EU PV Platform, 2007] for a more detailed description.

[41] For further explanation of the technological process: Satoru W. and Oda Hiroyuki, 2005, "Development of Solar Grade Silicon Manufacturing technology by Vapor-to-Liquid Deposition Method", Nippon Kagakki Koen Yokoshu, vol.85, no.1. p.510

[42] For further explanation of the technological process: http://www.chisso.co.jp/english/news/pres060920.html

Production

Tokuyama Corp. has delayed commercial SOG-Si production until late 2008, stating that “the plant capable of 200 tons per year is still in the validation phase for commercial production.” [Hirshman, 2007]

M.Setek started construction of SoG-Si plant with a 500t/year capacity in 2006.

Nippon Steel Corporation also announced to enter SoG-Si manufacturing and established “NS Solar Material”. [Ikki, 2007]

The JSS is planning to construct a pilot plant with a capacity of 100 ton/year in middle 2008. [Ikki, 2007]

2. Wafer-based crystalline silicon solar cells

Though crystalline silicon has been used in a variety of new applications, wafer-based crystalline silicon solar cells is still the most common. This type of cell has dominated the PV industry since the beginning. [EU PV Platform, 2007] Nearly all of the solar cells that are currently being produced are of this type. They hold 90% of the total market. Due to their high efficiency and durability they are considered very well suited for long-term power applications.

Compared to the other technologies crystalline silicon has a high efficiency. The main problem lies in its relatively high silicon usage. Other technologies which use less silicon or no silicon at all are therefore becoming more attractive nowadays. Most of the current research into crystalline silicon solar cells is ‘applied’ instead of ‘basic’.

Government

Research subsidies are provided under the NEDO project “Research and Development of Next-generation PV Generation System Technologies” FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme ‘technologies and associated processes to produce highly efficient next-generation ultrathin crystalline silicon solar cells”. [NEDO, 2007]

Installation subsidies are provided for innovative applications or systems, up to 50% of the installation costs, under the “Field Test Project on New Photovoltaic Power Generation Technology” FY2007-FY2014, project budget: 7:86 billion yen. [NEDO, 2007]

Research

Current participants in NEDO ultrathin crystalline silicon solar cells projects are: Kyocera, Mitsubishi Electric, Tokyo Institute of Technology, AIST, Toyo Advanced Technologies Co. Ltd., Daiichi Kiden (manufacturing equipment), Sharp, Tohoku University, Nippei Toyama (manufacturing equipment), PVTEC, Okayama University, Toyota Technological Institute, Kyushu University and Meiji University. [NEDO, 2008]

AIST is one of the few research institutes still doing basic research, in general most companies focus on development.

Mitsubishi Electric Corp. has achieved 18.6% conversion efficiency with a honeycomb texture structure to reduce surface reflectivity, which it plans to put into mass-production by 2011.[43] [MEC, 2008]

Kyocera has achieved 18.5% conversion efficiency. [RTS, 2008]

Hitachi developed a bifacial single crystalline silicon solar cell with improved conversion efficiency of 15%. The company is focusing on improving the conversion efficiency of this type

[43] For further explanation of the technological process: [MEC, 2008]

of cell (16.3% at the front, 15% at the back). [RTS, 2008] However the company has recently agreed to sell its technology to the Space Energy Corporation (SEC). Research activities are therefore expected to be continued by SEC. [REW, 2008]
Sharp Corp. has achieved 20.1% efficiency. [RTS, 2008]

Production
Mitsubishi Electric Corp. produced 150 MW in 2007, and aims to increase this to 250 MW/year by 2010. [Kaizuka, 2008]
Kyocera is producing 240 MW/year in 2007 [Kaizuka, 2008]
Sharp is the largest PV manufacturing company in Japan, and until recently the world, its current annual production capacity for solar cells to 710 MW/year (2007) [Sharp, 2008a] About 695 MW is expected to be crystalline silicon solar cells. [Kaizuka, 2008]
Hitachi currently produces 10 MW/year (2007). [RTS, 2008]

3. Existing thin-film technologies

3a. thin-film silicon

Considered the second generation solar cell, thin-film silicon solar cells were created with aim of reducing the amount of silicon that goes into each solar cell. In contrast to wafer-based silicon solar cells, the silicon is not cut into wafers but deposited directly on large area substrates, such as glass panels (square metre-sized and bigger) or foils (several hundred meters long). [EU PV Platform, 2007] Current products are becoming increasingly thin, up to 100^{th} the thickness of conventional crystalline silicon solar cells. [ECN, 2008b] Their market share is growing as ready-made production lines become available.
The main research goal in the PV industry is to make solar cells cheaper by using less silicon and increasing the efficiency. Current research focuses on making the wafers stronger as waver breakage due to thinner wavers is a big problem. Producers are creating unique applications such as see-through solar cells for in windows, and bendable solar cells which can be used in consumer products and on curving roofs.

Government
Research subsidies are provided under the NEDO project “Research and Development of Next-generation PV Generation System Technologies” FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme: ‘Technologies to enable higher productivity and to improve the efficiency of thin-film silicon solar cells.”. [NEDO, 2007]
Installation subsidies are provided for innovative applications or systems, up to 50% of the installation costs, under the “Field Test Project on New Photovoltaic Power Generation Technology” FY2007-FY2014, project budget: 7:86 billion yen. [NEDO, 2007]

Research
<u>Single-junction:</u>
Current participants in NEDO thin-film silicon PV projects are: Sanyo Electric, Kaneka Corp., Mitsubishi Heavy Industries, Fuji Electric Advanced Technology Co., Ltd. (R&D company of Fuji Electric Systems), AIST and Nagoya University. [NEDO, 2008]
AIST created 6.33% μc-$Si_{(1-x)}Ge_{(x)}$ p-I (1μm)-n single junction cells. [RTS, 2008]
Osaka University created 6.30% μc-Si single junction cell with a growth rate of 8.1 nm/s. [RTS,

2008]
Sanyo Electric created 7.6% single-junction cells using Localized Plasma Confinement CVD with 1.5 nm/s and uniform deposition. [RTS, 2008]
Kaneka performs research on solar cells on glass substrates.
Sanyo Electric Co., Ltd. achieved a conversion efficiency of 22% in practical sized HIT solar cells. [RTS, 2008]

Multi-junction
Sharp developed triple-layered thin-film silicon solar cells with conversion efficiency of 13%. [RTS, 2007]
Kaneka developed thin-film Hybrid PV module with conversion efficiency of 12%. [RTS, 2007] Its Hybrid modules have a unique intermediate layer which greatly improves the conversion efficiency. Kaneka focuses its research activities on the optimization of the Hybrid structure. [Kaneka, 2008]
Sanyo Electric created 11.4% tandem (multi-junction silicon based thin-film solar cells) by Localized Plasma Confinement CVD with 1.5 nm/s and uniform deposition. [RTS, 2008]
Tokyo Institute of Technology developed a-SiC for a top cell i-layer material in triple junction solar cells. [RTS, 2008]
Fuji Electric is reportedly working on fabrication technology of a-Si/a-SiGe/a-SiGe triple-junction plastic film substrate solar cells.

Production
Single-junction
Kaneka completed a new production line of thin-film silicon PV module with the capacity of 55 MW/year, [RTS, 2007], aims at increasing this to 70MW by fall 2008 and 130MW by 2010. [Kaneka, 2008]
Fuji Electric is creating highly bendable thin-film solar cells. They can be used in arching roof surfaces or in consumer product. In 2009 it will be incorporated into tent-cloth.
Mitsubishi Heavy Industries and Sanyo Electric are also reportedly producing thin-film silicon solar cells.

Multi-junction:
Sharp began mass production of Tandem thin-film solar cells with 10% efficiency in September 2005. The company produced 15 MW in 2007, which will be increased to 160MW in 2008. [Kaizuka, 2008] Sharp announced the construction of a thin-film silicon PV module plant with a 1GW/year capacity in Sakai City, Osaka Prefecture. [RTS, 2007]
Sharp also developed triple-layered thin-film silicon solar cells, with a conversion efficiency of 13%. [RTS, 2007] Mass production is slated to begin in May 2007 at Sharp's Katsuragi Plant in Nara Prefecture.
Mitsubishi Heavy Industries previously manufactured and sold amorphous solar cells, but embarked on the production of microcrystalline (μc-Si) tandem solar cells from October 2007, due to the substantial gain in efficiency over amorphous type cells. The company is producing 14 MW 12% (tandem) solar cells in Nagasaki which it will expand to 100MW in 2009.
Sanyo Electric produces HIT modules, 260 MW/y in 2007, increased to 650 MW/year in 2010. [Kaizuka, 2008]
Kaneka will introduce their Hybrid PV modules to the market in the near future in the form of BIPV.

3b. Copper-indium/gallium-diselinide/disulphide (CIGSS) and related I-III-VI compounds

This category consists of a variety of thin-film technologies that do not employ silicon as a basic component. Of these, CIGSS compounds, which include CIS, exhibit the highest cell and module efficiencies of all inorganic thin film technologies. [EU PV Platform, 2007]

Government

Research subsidies are provided under the NEDO project "Research and Development of Next-generation PV Generation System Technologies" FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme: 'Technologies to improve the efficiency of CIS thin-film solar cells and elemental technologies to form solar cells on lightweight substrates.". [NEDO, 2007]

Installation subsidies are provided for innovative applications or systems, up to 50% of the installation costs, under the "Field Test Project on New Photovoltaic Power Generation Technology" FY2007-FY2014, project budget: 7:86 billion yen. [NEDO, 2007]

Research

Showa Shell Sekiyu has created 14.3% on a 30x30cm cell. [RTS, 2008]

Honda Engineering has created 13.9% on a 73x92cm cell. [RTS, 2008]

Several institutes are involved in the development of novel CIGS deposition techniques employing: [RTS, 2008]

- Se-radical source (AIST)
- thermally cracked Se source (Tokyo Institute of Technology)
- Laser-assisted deposition (Aoyama Gakuin University)
- Particle-based technology (Ryukoku University)

Technologies for flexible cells: [RTS, 2008]

- Low-temperature process; 11.8% at 330 ºC, 14.1% at 400ºC (AIST)
- 17% flexible CIGS cells (Aoyama Gakuin University)

Participants in NEDO's CIS projects are: Tokyo Institute of Technology, Showa Shell, AIST, Tsukuba University, Kagoshima University and Aoyama Gakuin University. [NEDO, 2008]

Production

The only Japanese companies that are producing CIS modules in Japan are Honda and Showa Shell. [JPEA] Honda Soltec and Showa Shell Solar are in a stage that the production volume is steadily ramping up towards full capacity of, 15 to 30 MW/y.

Honda will open its first factory in Kumamoto in November 2007, and is expected to start production of 27.5 MW/year by the end of 2008. [Prent & Stroeks, 2008]

Showa Shell started production of CIGS solar cells in May 2007. The production is slated to increase from 20 MW/y to 80 MW/year in 2009, with the construction of a new factory in Miyazaki. [Prent & Stroeks, 2008]

3c. Cadmium telluride (CdTe)

The attractive features of CdTe are its chemical simplicity and stability. The cells are fairly easy to manufacture with potential low costs. [EU PV Platform, 2007]

Government

The Japanese government has initiated a Cadmium restriction due to regional contamination in the past.

Research
No research is currently taking place into CdTe solar cells.

Industry
No CdTe solar cells are produced in Japan due to the Cadmium restriction. AnTech, BP Solar and Matsushita Battery closed down their CdTe production in 2002.

4. Emerging and novel PV technologies

"Emerging" technologies and "novel" technologies are at different levels of maturity. The label "emerging" applies to technologies for which at least one "proof-of-concept" exists or can be considered as longer - term options that will disrupt the development of the two established solar cell technologies - crystalline Si and thin-film solar cells. The label "novel" applies to developments and ideas that can potentially lead to disruptive technologies, the likely future conversion efficiencies and/or costs of which are difficult to estimate. [Taken from: EU PV Platform, 2007, p.41]

4.1 Emerging PV technologies

4.1.1 Advanced inorganic thin-film technologies

Advanced inorganic thin-film technologies stem from the thin-film technologies in the previous section. Examples are the spherical CIS solar cells and thin-film polycrystalline silicon solar cells deposited at high temperatures (above 600Cº).

Government
Research subsidies for emerging technologies are provided under the NEDO project "Research and Development of Next-generation PV Generation System Technologies" FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme: 'Search for next-generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar power generation systems.". [NEDO, 2007]
Installation subsidies are provided for innovative applications or systems, up to 50% of the installation costs, under the "Field Test Project on New Photovoltaic Power Generation Technology" FY2007-FY2014, project budget: 7:86 billion yen. [NEDO, 2007]

Research
Clean Venture 21 has developed an 11%-efficiency spherical silicon PV module. The firm has conducted its fundamental research with the National Institute of Advanced Industrial Science and Technology (AIST). [Tanaka, 2007]

4.1.2 Organic solar cells

In this categorization, the active layer of the solar cell consists at least partially of an organic dye, small, volatile organic molecules or polymers. Two main technology branches exist within the 'organic solar cells' category. One is the hybrid approach in which organic solar cells retain an inorganic component (e.g. the Graetzel cell, dye-sensitized solar cells). The other is full-organic approaches (e.g. bulk donor-acceptor heterojunction solar cells, polymer solar cells). For both branches the main challenges relate to increasing efficiency, improving stability and developing an adapted manufacturing technology. [EU PV Platform, 2007]

Government

Research subsidies are provided under the NEDO project “Research and Development of Next-generation PV Generation System Technologies” FY2006-FY2009 Project budget: 2.38 billion yen, under two research themes: ‘Technologies to enable highly efficient, modular, and durable dye-sensitized solar cells’ and ‘Technologies to improve the efficiency and durability of organic thin-film solar cells’. [NEDO, 2007]

Installation subsidies are provided for innovative power applications or systems, up to 50% of the installation costs, under the “Field Test Project on New Photovoltaic Power Generation Technology” FY2007-FY2014, project budget: 7:86 billion yen. [NEDO, 2007]

Research

Dye-sensitized solar cells

Sharp Corp. developed a PV module using DSC with the world’s highest conversion efficiency 7.9%. [RTS, 2007; RTS, 2008] The company also created a 11% cell.

Tokyo University of Science in collaboration with Fujikura, Sharp Corp, Sumitomo Osaka Cement Co., Ltd. and AIST, achieved the world highest 11% conversion efficiency with a 5mm-square DSC by controlling the disposition of titanium dioxide molecules at a nano-scale to raise light absorption. [Tanaka, 2007]

Aishin Seiki Co., Ltd. in conjunction with Toyota Central R&D Labs., Inc., (affiliated to Toyota Motor) created a 6mm x 9mm cell that has an 8.2% efficiency and is durable up to 85°C by replacing electrolyte with gel-state substance. A long-term open-air durability test is currently being conducted. [Tanaka, 2007]

Professor Miyasaka’s group in the Toin University of Yokohama, in conjunction with its spin-off company Peccell Technologies Inc., has developed a large film-type dye-sensitised module of 30cm-square with a 2% efficiency. The university has also been developing alternatives to flammable electrolyte, using carbon materials. These developments contribute to improvements in the safety and durability of DSC. [Tanaka, 2007]

Professor Arakawa’s group in the Tokyo University of Science has achieved an 11% efficiency DSC cell and is also developing a bendable dye-sensitised PV cell, using a film as a substrate, in conjunction with Nissan Motor Co., Ltd. Its conversion efficiency reached 7.1% with a 5mm-square cell, the world highest level amongst bendable types. In addition, the university has developed a non-metallic ruthenium dye and a dye effective for infrared radiation. [Tanaka, 2007]

Other companies which are performing research into this technology include: Sony Corp., Mazda, Nippon Kayaku, Nippon Sheet Glass Co., Koa Corp., Daiichi Kogyo Seiyaku, Toyo Seikan Kaisha, Ltd., Nippon Steel Chemical Co., Ltd., Dai Nippon Printing, Kansai Pipe Industries, Ltd., Chemicrea Inc. and Hodogaya Chemical Co., Ltd. [Tanaka, 2007; NEDO, 2008]

Other research institutes performing research include: Centre Research Institute of Electric Power Industry (CRIEPI), Graduate School of Kyushu Institute of Technology, Kyushu Institute of Technology, Gifu University, Shinshu University, Osaka University, Sekisui Jushi Technical Research Corp. [Tanaka, 2007; NEDO, 2008]

Polymer solar cells

A high efficiency cell of 3.8% at 1 cm^2 was created by Sharp and certified by AIST. [RTS, 2008]

The participants in NEDO’s thin-film organic projects are: AIST, Matsushita Electric Works,

Kanazawa University, Komatsu Seiren Co. Ltd. (fabrics company), Nagoya Institute of Technology, Kyoto University and Nippon Oil Corporation (oil company). [NEDO, 2008]
Kyoto University is currently investigating “Super hierarchical nano structure organic thin-film solar cells”. [Yoshikawa, 2008]
Other organizations and institutes which are known to investigate this technology are Sony Corp. and AIST.

Industry
Peccell Technologies Inc. is a small spin-off company from Toin University in Yokohama and will be the first Japanese company to put dye-sensitized solar cells onto the market. It will start production of dye-sensitized solar cells for use in iPod-rechargers by the end of 2008. [Prent & Stroeks, 2008]

4.1.3 Thermophotovoltaics (TPV)
The principle of Thermophotovoltaics (TPV) is the conversion of heat into electricity. A basic thermophotovoltaic system consists of a thermal emitter and a photovoltaic diode cell. In the long term, this third approach could be used in concentrating solar thermal power applications (CSP). Before that happens, the technology could be used in CHP systems.

Research
The technology is being studied by Ube Research Laboratory of Ube Industries, Ltd.[44]
R&D on Thermo photovoltaic Generation (TPV) is conducted mainly in Europe and US research institutes, and not well known in Japan. [45] However, based on an article search there are indications TPV is being studied at: Tokyo Institute of Technology, Kyoto University Graduate School of Engineering, University of Tokyo, Gifu University and Tohoku University.

Industry
N/A

4.2 Novel PV technologies

4.2.1 Novel Active layers
Nanotechnology allows features with reduced dimensionality to be introduced in the active layer: quantum wells, quantum wires and quantum dots. There are three different approaches using these features. The first aims at obtaining a more favourable combination of output current and output voltage of the device. A second approach aims at using the quantum confinement effect to obtain a material with a higher band gap. The third approach aims at the collection of excited carriers before they thermalise to the bottom of the concerned energy band (e.g. hot carrier cells). [EU PV Platform, 2007]

Government

[44] For specifics see article: Nakagawa Narihito & Shibata Koji, “The present state of the thermophotovoltaic system and its selective emitter materials technology”, Oyo Butsuri, Vol. 76, no.3, p.281-285
[45] Source: kumano Tomoyuki, “Energy. Themophotovoltaic (TPV) Generation.”, Journal of the Japan Society of Mechanical Engineers, Vol.108, No.1045, p..904-905(2005)

Research subsidies for emerging technologies are provided under the NEDO project "Research and Development of Next-generation PV Generation System Technologies" FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme: 'Search for next-generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar power generation systems.". [NEDO, 2007]

Research
LBNL, Tsukuba University, TTI and Fukui University have made progress in the research on quantum dots and nitride materials for multi-junction cells. [RTS, 2008]
The University of New South Wales in collaboration with Toyota Central R&D Labs has made a quantitative analysis, revealing the way to realize hot carrier solar cells. [RTS, 2008]
Toyota research group also reported the first example of commercialized nanocomposites.

4.2.2 Boosting structures at the periphery of the device

Technologies in this category are aimed at tailoring the solar spectrum to boost existing PV technologies, through up-down conversion layers and plasmonic effects. [EU PV Platform, 2007]

Government
Research subsidies for emerging technologies are provided under the NEDO project "Research and Development of Next-generation PV Generation System Technologies" FY2006-FY2009 Project budget: 2.38 billion yen, under the research theme: 'Search for next-generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar power generation systems.". [NEDO, 2007]

Research
N/A

5. Concentrator technologies (CPV)

CPV is aimed at concentrating sunlight, through optical devices like lenses, to improve the increase the amount of sunlight entering the solar cell, thereby increasing their efficiency.

Government
Research subsidies are provided under the NEDO project "Research and Development of Next-generation PV Generation System Technologies" FY2006-FY2009 Project budget: 2.38 billion yen, most likely under the research theme: 'Search for next-generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar power generation systems.". [NEDO, 2007]

Research
Sharp has achieved 40.0% with an InGaP/Ga(In)As/Ge cell. [RTS, 2008]

Industry
Sharp Corp. has been developing a three-junction cell including a GaAs cell, applying it to a solar concentrating system for power generation. Sharp is conducting demonstrations in foreign countries. The conversion efficiency has reached 38%, but the system needs to be improved to demonstrate stable performance under varying conditions.

Sharp is the only Japanese producer to create solar cells for space application. Lightweight and flexible multi-junction cells have been developed for the next generation space solar cell (with JAXA). [RTS, 2008]
A high-concentration system using III-V solar cells, created by a collaboration of Solfocus and Daido, is currently entering the market. [RTS, 2008]

Appendix II: Indicators for each function

This appendix gives an overview of the indicators which were used to evaluate each function, and the type of actors which were questioned for each function. Information from Milutin Jerotijevic's report "The Netherlands: Sociotechnical Analysis of Wind Energy in the Built Environment" was used in the construction of this table.

Functions	**Factors**	**Indicators**	**Stakeholders/actors**
Entrepreneurial activities		Change in the number of entrepreneurs Type of entrepreneur Recent activities Future (announced) activities	Branch organization, Manufacturers
Knowledge development	Learning by searching	Size of research (budget) Type of organization performing research Type of research activities (basic/applied)	Manufacturers, Research institutes
	Learning by doing	Duration of production (starting year) Production cost changes Know-how	Manufacturers, Research institutes, Branch organization
	Learning by using	Market size Feedback from market Presence test projects	Manufacturers, Users, Utilities
Knowledge diffusion	Learning by interacting	Collaboration between organizations on R&D Patent or license exchange Formalized exchange methods	Manufacturers, Research institutes, Branch organization
Guidance of the search	Goals	Targets set by government or industry Type of targets (research/ market/ installation) Support for goals	Branch organization, Manufacturers, Research institutes, Government
	Credibility	Technological expectations Technological background (historical breakthrough) Expected continuation of development	Research institutes, Manufacturers (R&D)
Market formation		Characteristics of the market (size) Motivation (why they buy) Financial market incentives Environmental market incentives ('Green' certification etc.) Technology specific applications	Branch organization, Government, Manufacturers, Users
Mobilization of resources	Financial	Government research budgets Market incentives Specialized financial institutes Availability venture capital	Financial institutes, Manufacturers, Government, Research Institutes
	Human	Availability of (research) employees Availability specialized education programs	Manufacturers, Research Institutes
	Physical	Availability of raw materials Use of rare materials	Manufacturers, Suppliers
Support from advocacy coalitions		Existence of advocacy coalitions Activities of coalitions Recent results of activities	Government organizations, Utilities, Branch organization

Appendix III: Effects of culture on willingness to employ solar cell technologies

This appendix looks into the effects of culture on the perception, development and diffusion of Photovoltaic technology (PV) in the countries Japan and the Netherlands.[46] We will start off with a short description of the framework we will use for our analysis; the Hofstede dimensions, then a description and comparison of the Dutch and Japanese culture. We will end with an evaluation of the effect of cultural differences on the perception, development and diffusion of PV in the two countries.

Defining Culture

Culture is a difficult concept which can have many interpretations. What some people might see as part of a country's or group's culture, others may perceive as no more than mannerisms. Many different views on 'culture' exist. Some focus on its perceivable aspects, by defining it as "the tastes in art and manners that are favored by a social group" [Princeton]. While others focus on the ideas that go behind those 'tastes' and 'manners', defining culture as "the predominating attitudes and behavior that characterize the functioning of a group or organization" [Lexico].

Hofstede has created a set of 5 cultural dimensions, with which one can analyze a country's culture. Hofstede's definition of culture is multi-layered. The first layer, called 'culture one', deals with 'refinement of the mind' and encompasses things such as education, art and literature. While his 'culture two' is much broader and encompasses all of peoples' actions. His focus is on this second layer. He perceives culture as being a process of learning, similar to a computer's, where 'mental programs' are created based on a person's experience and social environment. His definition of culture: "[Culture two] is the collective programming of the mind which distinguishes the members of one group or category of people from another." [Hofstede, 1991, p.5]

Since this appendix is more interested in practical applications, this section will not focus too heavily on providing a precise definition of the word 'culture'. Instead, we will introduce Hofstede's set of cultural aspects, called the Hofstede dimensions, with which one can analyze a country's culture and which will provide the necessary framework for the final evaluation.

Hofstede Dimensions

The Hofstede dimensions are a set of 5 aspects of culture that together explain differences between different countries. The aspects are determined by questioning people in the different countries and discovering their disposition according to these 5 aspects.[47] Each is ranked on a scale of 0 (low) to 100 (high). These aspects will now be explained in turn, where the information has been taken from "The Five Dimensions Pocket Guide". [Result, 2005]

Power Distance Index (PDI)

This index indicates the extent to which the less powerful members of society accept that power is distributed unequally.

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[46] The initial part of this appendix consists of chapter 2 of an internal report written by Jun Wu, Mo Zhang, Marjan Prent and Ronald Franco Delgadillo called "Knowledge and innovation management decisions in different cultures", written for the course 'Knowledge Management and R&D Management'. Re-used with permission.

[47] It should be noted that Hofstede's dimensions give an average of the cultural group. The figures should never be related to any one individual within the group as large differences exist.

Low	High
Low dependence needs	High dependence
Inequality minimized	Inequality accepted
Hierarchy for convenience	Hierarchy needed
Superiors accessible	Superiors often inaccessible
All should have equal rights	Power holders have privileges
Change by evolution	Change by revolution

Individualism (IDV)

The two extremes of this dimension have separate names. A low IDV score is called 'Collectivism' and a high IDV score is called 'Individualism'. Collectivism indicates that people belong to groups such as families, clans and organizations that look after them in exchange for loyalty. In a society with a high level of Individualism, people only look after themselves and their immediate family.

Low	High
"We" consciousness	"I" consciousness
Relationships have priority over tasks	Private opinions
Fulfill obligations to family, in-group, society	Fulfill obligations to self
Penalty: Loss of "face" and shame	Penalty: Loss of self-respect and guilt

Masculinity (MAS)

This dimension also uses two different names for its extremes. 'Femininity' corresponds to a low MAS factor, and indicates that caring for others and quality of life are the dominant values in society. A high MAS factor, 'Masculinity' indicates that the dominant values are achievement and success.

Low	High
Quality of life, serving others	Performance ambition, a need to excel
Striving for consensus	Tendency to polarize
Work in order to live	Live in order to work
Small and slow are beautiful	Big and fast are beautiful
Sympathy for the unfortunate	Admiration for the successful achiever
Intuition	Decisiveness

Uncertainty Avoidance Index (UAI)

The extent to which people feel threatened by uncertainty and ambiguity, and try to avoid such situations.

Low	High
Relaxed, less stress	Anxiety, greater stress
Hardwork is not a virtue per se	Inner urge to work hard
Emotions not shown	Showing of emotions accepted
Conflict and competition seen as fair play	Conflict is threatening
Acceptance of dissent	Need for agreement
Flexibility	Need to avoid failure
Less need for rules	Need for laws and rules

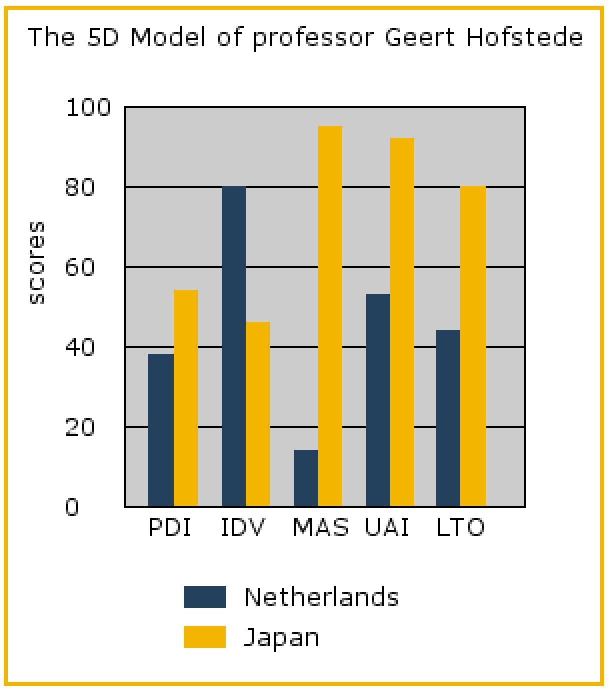
Long-Term Orientation (LTO)

The extent to which a society shows a pragmatic future-oriented perspective rather than a conventional historical or short-term point of view.

Low	High
Absolute truth	Many truths
Conventional/traditional	Pragmatic
Concern for stability	Acceptance of change
Quick results expected	Perseverance

Japan and Netherlands comparison

Japan and the Netherlands have large cultural differences as can be seen from picture III-1. Japanese culture can be characterized by high MAS, UAI and LTO, and above average PDI and IDV. The country's PDI factor is fairly high which displays itself in the reliance of the Japanese people on hierarchy, as well as the expectation that people in high positions show their status. One of the key characteristics of Japanese society is its group-orientation, which might not be so apparent from its above average IDV. In Japan's this group orientation is towards companies, meaning that each person identifies itself through the company he/she works at. Organizations are expected to look after employees like family and in general (still) offer life-long employment.



Picture III-1: Japan and Netherlands Hofstede factors comparison
Source: http://www.geert-hofstede.com/hofstede_dimensions.php?culture1=62&culture2=50#compare

Within the Japanese culture there is strong emphasis on maintaining harmony among group-members. One of the most important factors in this culture is to avoid 'loss of face' as this reflects on the entire group not just the individual. Group decisions are considered better than individual decisions. This is also reflected in the country's UAI score.

The country has high UAI which means people try to avoid uncertainty as much as possible. As such the society has a high degree of rules and regulations, the citizens maintain more ritual behaviour and social conduct is highly ritualized. Citizens feel dependent on these regulations and place a high level of trust in the authorities.

This need for stability and harmony might seem to contradict with the culture's very high MAS score,[48] which indicates that showing ambition, trying to excel and working hard are key qualities in the culture, and displaying your status is a sign of success. However to maintain the desired harmony, the ambitions of employees should not lead to much conflict and one should not openly trample over others to 'reach the top'. One of the solutions that appear to exist in Japan is its fairly strict policy of basing promotion on seniority (related to PDI).
As a final important factor Japanese culture is very much forward looking. People maintain a long-term perspective, regularly saving up money for their grandchildren instead of their own retirement. There is perseverance towards results which cannot be readily achieved and a willingness to subordinate oneself for a (common) purpose. Change is accepted, however due to the high Uncertainty Avoidance, a well thought out slow approach would naturally be preferred.

The Netherlands is characterized by very low MAS (Femininity), low PDI and LTO, fairly high UAI and high IDV. The Netherlands is a highly Feminine country with one of the lowest MAS scores in the world [Hofstede, 2003]. This is shown by overlapping roles for men and women and a need for consensus, which can be seen in the well-known 'polder-model'. Power holders are not expected to show their status and are considered equal to others and are overall accessible to subordinates (low PDI). Status is not so important to show success (low MAS).
The Dutch community is very Individualistic, with a strong emphasis on autonomy and variety. People are expected to defend their own interest and purport their own opinions. However the low MAS score ensures that no person is left to his/her fate. A caring society exists, where there is a lot of sympathy for the unfortunate and support structures to ensure adequate quality of life. In fact trying to be better than others is neither socially nor materially rewarded.
Hard work is not a virtue on its own, and Dutch individuals mostly 'work to live' rather than 'live to work'. The country has an average UAI score which has resulted in the situation where people rely on rules and regulations while maintaining strong feelings of citizen competence. As such though people rely on rules they are willing to change them if they cannot be kept anymore.
Along with the average LTO score we can say that Dutch people are more willing to take unknown risks, than for instance the Japanese. However they are looking for results more quickly, either in the short- or medium-term.

Effects of culture on willingness to employ solar cells

Solar cells are still being developed and are not yet profitable. Also, the newest technologies could take a long time to be ready for the market. However they show great future potential. Of the two countries under investigation, the Netherlands and Japan, the Japanese society with its long-term orientation would therefore seem more eager to develop and employ PV.

This is the case in Japanese companies, consumers and the government. It takes a lot of time and money to develop new solar cell products and technologies. Nevertheless, Japanese companies maintain their PV subsidiaries because they expect long-term profits and opportunities. The companies are willing to sacrifice some short-term profit with the goal of having a large market share in the future. It has been mentioned that some Japanese PV subsidiaries only recently started making profit, even though some have existed for over 10 years.

[48] Japan was the most masculine country in Hofstede's original survey. [http://www.geert-hofstede.com/hofstede_dimensions.php].

The government is also more inclined to support renewable energy technology. Since the oil crisis the need for Japan to become energy independent has been widely discussed and the government has shown itself to be big a supporter. In Japanese culture, society places a lot of confidence in the government.

One factor in particular stood out as being beneficial; the longevity of policy. Due to the cultural tendency to maintain the status quo (high UAI), companies and research institutes etc. are assured of continued support in research and development. In many cases research subsidy is maintained even though the research has proven unsuccessful [source?]. This also relates to government's and industry's inclination to set up and employ a long-term strategy or vision(LTO).

We can also identify several cultural factors that influence Japanese citizens to buy solar cells, namely:

- Buy to save the environment and allow a good future for their children and grand-children, which is related to society's long-term orientation (LTO)
- Buy as a long-time investment. The investment will pay itself back in 20 years, there is no need to get returns on investment quickly (LTO)
- Buy for use as a status symbol. Showing your status is very important in Japan and buying such an expensive item shows your financial capabilities. It has even been suggested that fully integrated roofs are less desirable in Japan as they 'hide' the technology too well.

We would have expected that the high risks associated with developing innovative technologies would have made renewable energy technologies such as PV less attractive in Japanese society. However the expected future benefits and status they enjoy in Japan appears to off-set this. Society is not worried about change in the long-run.

Dutch society is more oriented towards the short- or medium-term, expecting and requiring quick results. Companies and their subsidiaries need to prove themselves and make a profit within a few year timeframe. Those employing 'unprofitable' technologies are weeded out. Though this process fits Dutch society well, it might inhibit the successful diffusion of innovative technologies.

The government also needs to show results fairly quickly, in particular within the 4 years they rule. Though society is focused more on quality of life than performance, this does not mean officials will not be judged. The government is expected to serve the people, not the other way around. As such ministers need to prove that they spend their money wisely while at the same time profiling themselves. Though they belong to a political party they are individuals who will be held accountable individually. Government is mostly striving for consensus, they are expected to serve the people and can not decide things unilaterally.

Consumers are also focused on the short- or medium term. They wish for quick returns on investments with limited risks. The most mentioned amounts correspond with a pay-back period of four years. Renters are willing to pay no more than what the solar systems deliver per year. [Montfoort & Ros, 2008] Dutch society does not have the long-term orientation of the Japanese or the need to use it as a status symbol.

On the other hand the Dutch social system is more flexible and can probably execute changes in a much shorter time-span than the Japanese system. Companies and individuals are also more likely to take risks than in Japan which might lead to more companies starting research or development of renewable energy technologies. Furthermore, as Dutch society is highly feminine there is a lot of focus on quality of life and the living environment, which could potentially promote renewable energy technologies amongst customers.