Solar Power: Managing Uncertainty of Emerging Technologies

Submitted to the Mack Center for Technological Innovation under the Ford Motor Company MBA Fellowship

Michael Dreimann and
Raphael Speck
MBA Candidates - Class of 2010
The Wharton School
University of Pennsylvania

February, 2010

Wharton
University of Pennsylvania

Table of Contents

Acknowledgment

We would like to thank Professor Paul J.H. Schoemaker for his support and mentoring during this project at The Wharton School of the University of Pennsylvania. His time spent with us to understand implications of technological innovations and the impact on business strategy of high uncertainties related to this topic will prove highly valuable to us in the future.

Moreover, we would like to thank the Ford Motor Company for the generous MBA Fellowship and the Mack Center for Technological Innovation for its support in completing this project.

Last but not least we would like to thank two of our interview partners, Kostis Tselenis of Good Energies and Stephan Lissner of Q-Cells. They provided valuable first hand and up-to-date information about the solar industry and its challenges. Any parts of the project related to Q-Cells are based on public available information only. Hence, no insider information has been used for this research project.

Michael Dreimann and Raphael Speck

1. Summary

In this research project, we focus on strategic management under high uncertainty caused by new emerging technologies. The solar photovoltaic industry offers a first class example of an industry with major uncertainty related to the emergence of new technologies.

In this paper, we applied the tools of scenario planning and strategic option analysis from the view of an incumbent solar photovoltaic (PV) player. Both tools add significant value to managers, especially in the process of strategy building. Scenario analysis allows managers to understand the major drivers of value and to differentiate strategic imperatives among possible futures. For many companies, this is a paradigm change compared to strategies that often build on a narrow set of expectations (i.e., single point forecasting). Furthermore, viewing strategies as well as projects as strategic real options puts more emphasis on opportunities to react to the state of the industry in the future vs. average probabilities of a project.

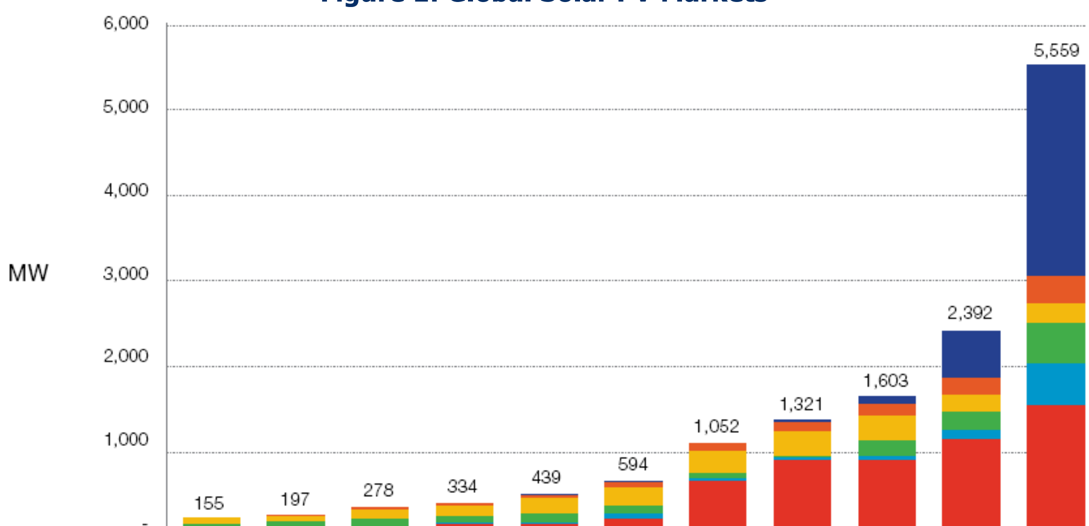
We formulated four scenarios for 2020, which are driven by two key uncertainties - the extent of new PV incentive programs and the relative technological advancement of Crystalline Silicon (c-Si) technology vs. alternative PV technologies. The scenarios range from solar PV as a niche market application ("Wallflower" scenario) to the "Golden Age" (high incentives, fast technological advancement) with each scenario posing distinct challenges as well as opportunities for incumbent players. When formulating a flexible strategy that can be effective across all scenarios, we recommend to focus on operational excellence (production and R&D), market access in sunny regions, downstream integration and brand building. In addition, there are scenario-specific strategies that need to be approached more flexibly using a real-options lens.

We applied such a strategic option analysis to Q-Cells, the current market leader, from a portfolio perspective. We conclude that Q-Cells' (publicly announced) option portfolio is quite robust for a future of new emerging technologies ("Delayed Technology Shock" scenario). In order to make the portfolio more effective in other scenarios as well, we recommend building options to increase market access in sunny regions and brand building.

2. Introduction

Renewable energies such as solar, wind, and geothermal have been a major success story in the first decade of the 21st century. The global installed capacity has grown more than sevenfold from 20 GW (Gigawatt) to 145 GW between 1998 and 2008. Wind power accounts for 20% of electricity generation in Denmark. About a fifth of the power produced in the Philippines, Kenya and Iceland is derived from geothermal resources[1]. Concerns about global warming have been the main cause for their explosive growth, another cause are government subsidies. With energy from sun abundant and predictable, solar photovoltaic has been one of the major markets that profited from the trend towards clean technologies. Today, the solar PV industry is a global, multibillion dollar industry. In 2008 5,559 MW (Megawatt) solar PV's have been installed. Assuming average system costs of 6 €/MW we estimate that size of the global solar PV industry was 33 billion Euros (47 billion USD) in 2008.

Figure 1: Global Solar PV Markets[2]



MW	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Spain	0	1	-	2	9	10	6	26	88	560	2,511
USA	-	17	22	29	44	63	90	114	145	207	342
Japan	69	72	112	135	185	223	272	290	287	210	230
Rest of the world	68	84	94	75	104	98	53	12	196	207	485
Rest of Europe	8	11	10	16	16	50	30	30	37	108	492
Germany	10	12	40	78	80	150	600	850	850	1,100	1,500
TOTAL	155	197	278	334	439	594	1,052	1,321	1,603	2,392	5,559

[1] British Petrol, BP Statistical Review of World Energy 2009, June 2009
[2] European Photovoltaic Industry Association EPIA, Global Market Outlook, March 2009

A major characteristic of the industry is the continual technological advancement necessary to make solar PV a competitive energy source. Currently, crystalline silicon ("c-Si") cell is the dominant technology to produce power from solar sources. This technology is explained in section 4.2. The majority of companies in the solar power industry are active in this space. However, there are a large number of technologies that promise to be superior through a combination of cost efficiency, aesthetics and/or operational improvements. Some industry experts expect that sooner or later new technologies, such as thin film, will gain significantly in importance and might replace the dominance of c-Si technology.

3. Research Objective and Scope

This study investigates how uncertainties related to technological development and other relevant factors impact potential future scenarios within the solar industry. Key questions the study addresses are:

- Who are major stakeholders and what are the forces that will shape the future of the industry?
- What are predictable trends for the future of the solar PV market? How will each of them impact the solar PV market?
- What are the major uncertainties and how do possible outcomes for these uncertainties shape the future solar PV market?
- What are four possible and relevant scenarios for the solar market in 2020? What are implications of these scenarios for today's incumbents?
- How can business strategies be defined in terms of strategic options that will add value and prepare a company for all of these uncertainties?
- What are key variables to monitor in order to determine the most likely scenario in the coming years?

To answer these questions, we first introduce the relevant facts about the current solar PV market in Part 4. We continue by introducing the tool of scenario analysis (Part 5) which we apply to the solar PV market to build four relevant scenarios for the state of the solar PV market in year 2020 (Part 6). Furthermore, Part 7 analyses the current business strategy employed by Q-Cells, the PV solar market leader, with respect to potential strategic (real) options.

For our study we focus on the perspective of a leading solar PV player with its main activities in the c-Si technology. Given the market characteristics, we take a global perspective for the study.

4. Overview of Solar Power Market

The following section aims to give a short market overview of the global solar photovoltaic ("PV") market. The main focus will be on manufacturers of solar PV modules which are used to generate electricity from abundant solar radiation.

4.1 Solar PV Market 101: Economics

Similar to other renewable energy sources, the economic model for solar PV differs from traditional sources such as coal or gas. Once installed, solar PV modules produce electricity with little operating costs over their product lifespan. The main costs associated with generating electricity come from a sizeable upfront investment in the solar PV modules. The sustainability of solar PV as a viable electricity source depends on the cost competitiveness of solar PV given that electricity is a pretty much a commodity[3]. To make electricity generation costs comparable, full costs of electricity generation are expressed in $/MWh[4] produced. Cost per MWh is mainly depended on the system costs (solar PV module, additional components and installation) and the efficiency of the PV module (the number of MWh generated over the lifespan). The latter is also driven by the intensity of the sun, hence cost/MWh vary depending on the region where the particular modules are installed.

In 2009, the costs of solar PV were higher than the costs of traditional sources (defined as the grid-price[5]). Therefore, for most regions in the world, the attractiveness of solar PV projects is derived from government 'support'. This support can take different forms such as: (i) subsidies for the initial investments (e.g. tax breaks, credit, etc), (ii) guaranteed resale prices for the generated solar energy (through so-called feed in tariffs) and/or (iii) mandates for a minimal share of solar power in the power mix (e.g. renewable portfolio standards, certificate schemes, etc.). This policy support has allowed the market to grow steadily since 1994 when the first incentive scheme was introduced in Japan. The incentive scheme that Germany introduced in 2000 and amended in 2003/2004 in favor of solar PV

[3] In this paper, we focus on residential and utility scale market of solar PV. Niche markets (e.g. in space or off-grid application) for solar PV exist even if solar PV is not cost competitive.

[4]Throughout the paper, we use megawatt per hour for retail energy price comparison. The notion of MW or MWp (megawatt peak) refers to cost comparisons among different solar PV modules.

[5] Grid-price refers to the price of electricity charged by utilities to the end consumer of electricity

also led to high growth rates. The table below shows the types of incentives in place in the major markets for solar PV.

Figure 2: Incentives in different markets

Incentive Type	Example
Investment subsidies	USA, China, UK (until 2010), Japan
Feed-in Tariff	Germany, Spain, France, Ontario
Mandates	17 states of the USA as part of Renewable Portfolio Standards

Grid parity

For most industry experts the so-called "grid parity" reflects the inflection point for solar PV energy. At this point, the energy generated from solar PV will have the same marginal cost per MWh as other energy sources; additionally, subsidies will be less relevant to the industry and likely vanish. Two different definitions of grid parity exist. The first, retail grid parity, means that solar cost meets retail electricity price. The second, wholesale grid parity, refers to the point in time at which solar PV costs matches wholesale electricity price. On the one hand, retail grid parity is of great importance to all residential and industrial customers. On the other hand, the wholesale grid parity is important to utility generators. Given that retail prices are significantly higher than wholesale prices, retail grid parity will always be achieved earlier than wholesale grid parity. However, achieving grid parity will in both cases depend on these major factors: (i) the average selling price ('ASP') of solar PV modules[6], (ii) the solar irradiation at the specific location, (iii) energy efficiency[7] of solar PV and (iv) cost of competitive energy sources (incl. other renewables).[8] All of these inputs are exposed to great uncertainties and hence estimates of grid parity vary widely.

[6] Solar PV modules are typically priced in $/Wp. Wp peak is the power the module produces under standard test conditions (STC: Irradiance 1000 W / m2, Atmospheres 1.5, and cell temperature 25° C)
[7] The conversion of energy received from the sun to energy generated by the solar PV module.
[8] Jefferies Research, Clean Technology Primer, September 2009

As an example, the figure below shows grid parity estimates of HSBC[9]. In the best case, grid parity will be achieved in sunny places such as California and Italy in 2010. However, worst case estimates for the same markets (grid parity in 2018) show how uncertain these estimates are. In this worst case scenario, grid parity will not be achieved in the near future (>2020) in many markets.

Figure 3: Grid - Parity

Overview Grid-Parity by Technology and Region

	C-Si				Thin-Film			
	Wholesale		Retail		Wholesale		Retail	
Region	Best	Worst	Best	Worst	Best	Worst	Best	Worst
Germany	2018	>2020	2011	2015	2021	>2020	2011	2015
Spain	2018	>2020	2011	2015	2018	>2020	2011	2015
Italiy	2018	>2020	2011	2016	2018	>2020	2010	2016
California	2016	>2020	2010	2012	2018	>2020	2010	2012
New York	2019	>2020	2010	2014	2021	>2020	2010	2015
India	2018	>2020	2014	2018	2019	>2020	2015	2019

Source: HSBC

In off-grid applications, due to high grid connection costs, solar PV is already cost competitive with many other forms of electricity.

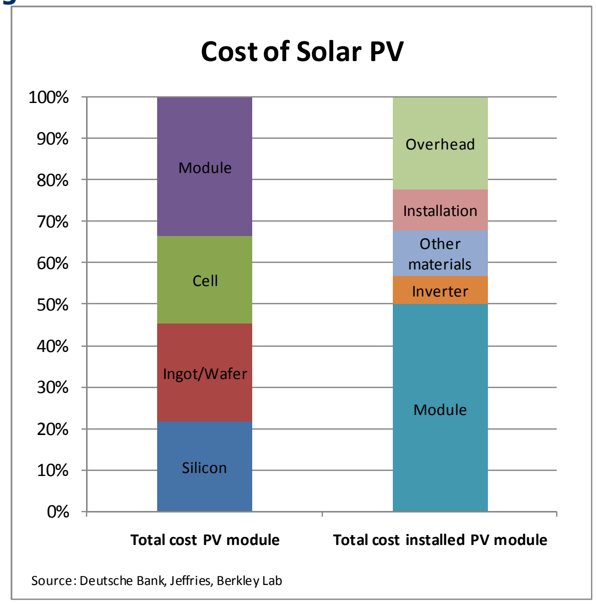
Cost of solar PV module

Only 50% of overall energy generation costs of solar PV are driven by the actual cost of the solar PV module. Additional costs come from the installation (labor and material) as well as the inverter and other system components.

For the PV module, raw materials make up around 45% of the total cost (for a c-Si module), the manufacturing of the solar cell and module another 25% and 30% respectively.

[9] HSBC, Global Solar Power, September 2009

Figure 4: Total Cost of an installed Solar PV module



Looking at the cost split helps to estimate the impact on cost-of-efficiency gains in different parts of the value chain. For example, efficiency gains in cell technology will only impact 12.5% of the total energy costs of solar PV generated electricity cost. On the other hand, manufacturing efficiency improvements (through economies of scale) address up to 35% of the total cost.

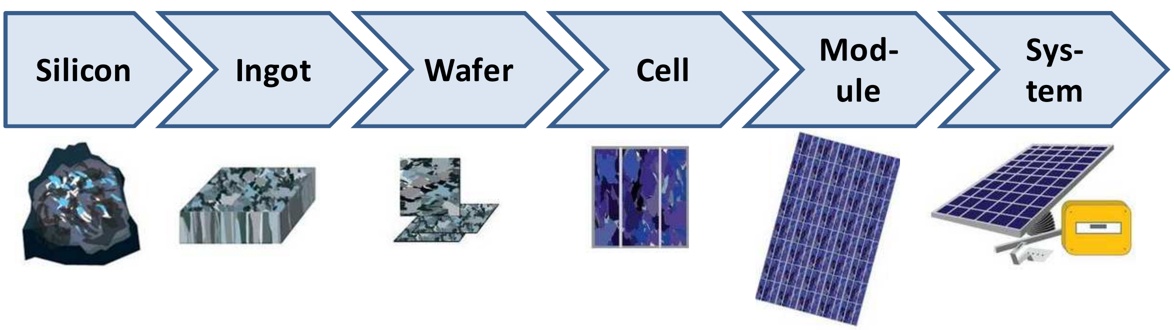
4.2 Technolgy (c-Si vs Thin Film) and Value Chain

Crystalline Silicon technology

Photovoltaic cells based on crystalline silicon (c-Si) were developed in 1954 by Bell Labs[10]. However it was not until the 1980's that the technology has been used on a significant scale for terrestrial application. Until now this technology has dominated solar electricity production with a total market share of 85% and higher[11].

A c-Si system is based on a silicon wafer. The wafer can be made from mono-crystalline silicon or multi-crystalline silicon. Single crystal silicon wafers are slightly more expensive to produce but lead to higher efficiencies. The wafer is given semiconductor properties through diffusion of selected ions. Together with surface treatment, various coatings and in some cases grid printing, this process makes a photovoltaic cell. Multiple cells are connected to each other and assembled into a module. The module is then installed with other system components such as inverters, and an installation support system. The figure below illustrates the value chain of a c-Si system.

Figure 5: – Value Chain c-Si Photovoltaic[12]



An important characteristic besides cost is the energy efficiency[13] of a solar PV module. The higher the efficiency the more electricity will be produced by a module. Industry

---

[10] Stefan Hirschberg et al., "Renewable Energies and Nuclear Energy", Paul Scherrer Institute, Villigen, 2005

[11] "Thin film's Share of Solar Panel Market", Renewable Energy World, November 13 2009 and "Market Share of Solar PV technologies", Photon Magazine, April 2007

[12] Illustration from European Photovoltaic Industry Association www.EPIA.org

average efficiency of modules was 16% in 2008[14]. Sunpower Corp. claims that its premium product "315 solar panel" achieves an efficiency of 19.3%. In the NREL's[15] labs, efficiencies of close to 24% have been achieved.[14]

Thin film technologies

In this report the term "thin film" technologies applies to all solar photovoltaic technologies that use a thin layer of semiconductor materials applied to a support material to produce electricity from sunlight. The most common thin film technologies are:

Amorphous silicon (a-Si): Where a thin film of silicon in an amorphous structure is applied to a substrate such as glass or a foil. The technology is best known for its application in solar powered calculators. For application in solar electricity production it is often combined with a microcrystalline silicon layer to increase efficiency. a-Si modules achieve efficiencies of 6%[16].

Microcrystalline silicon (μ-Si): A thin film of microcrystalline silicon is applied to a substrate. A module with a combined a-Si and μ-Si film achieves efficiencies of 8%[17].

Cadmium Telluride (CdTe): Instead of a silicon-based semiconductor, cadmium and telluride are used. The first commercially successful application of the CdTe technology was made by FirstSolar. Until now, FirstSolar does not only dominate the CdTe technology but also the thin film market. FirstSolar's modules achieve efficiencies of slightly more than 10%[18]. Average selling price (ASP) in the fourth quarter 2009 is estimated to be 1.7 $/Wp[19] which is significantly lower than the price of c-Si modules. Due to its lower efficiency CdTe must be priced lower than c-Si modules. However, production

[13] Efficiency: Output of the cell
[14] Ben Isaacson, "Alternative and Renewable Energy", Scotia Capital, August 2008
[15] NREL = National Renewable Energy Laboratory (United States)
[16] Bosch Solar Module a-Si plus specification, October 2009
[17] Bosch Solar Module μ-Si plus specification, October 2009
[18] First Solar FS Series 2 PV Modules Specification, January 2009
[19] Credit Suisse Equity Research, November 2009

costs of CdTe are significantly lower than those for c-Si. This helped FirstSolar to earn a gross margin of 56%[20] in the third quarter of 2009.

Copper Indium Gallium Selene (CIGS): This technology uses a semiconductor material based on copper, indium, gallium and selene. In terms of efficiency, this technology is most promising among the thin film technologies (see Part 4.6). Currently commercial products achieve efficiencies of just above 10%[21]. Firms using this technology claim that costs are even lower than those for CdTe.

The value chain for thin film technologies has less value generating steps (see figure below).

Figure 6: Value Chain Thin film Photovoltaic

The majority of value is generated in the cell/module part of the value generation.

c-Si versus thin film

Both thin film and c-Si based technologies allow consumers to generate electricity through solar PV. However, the two technologies differ in some aspects:

- c-Si modules need much less area (i.e. land) to produce the same amount of electricity compared to thin film technologies. This is due to the difference in energy efficiency: ~16% for c-Si vs. ~6-10% for thin film. This is an important benefit to c-Si modules as system installation costs make up a lower percentage of total system costs. Similarly, if space constraints exist, c-Si based applications offer a better alternative.

[20] First Solar SEC filing, October 2009
[21] Würth Solar Gene CIS Photovoltaic Modules specification, June 2008

- Thin film technologies offer a drastic improvement in material efficiency (thin film vs. silicon wafers) vs. c-Si technology. This leads to potentially significantly lower cost of PV modules. The trade-off for the much lower cost per module is the lower efficiency grade.

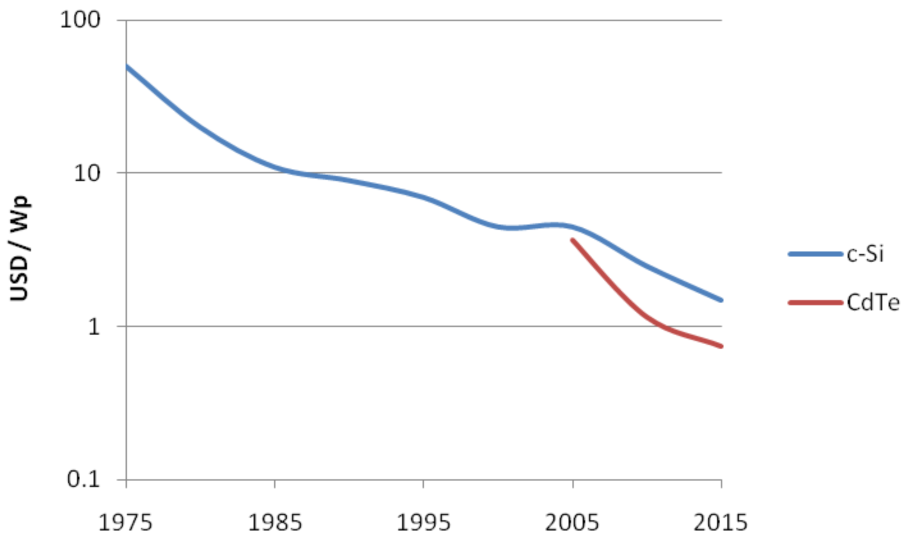
The table below summarizes the main advantages of c-Si versus thin film technologies. A "+" indicates a relative advantage.

Figure 7: Main advantages of c-Si versus thin film

Attribute	c-Si	Thin film
Cost per Wp		+
Efficiency	+	
Weight		(+)
Degradation	+	
Long term track record	+	

Thin film or c-Si - which will be the dominant PV technology? This question remains one of the main uncertainties in the solar PV industry. Most industry participants differ in their views about the relative prospects of these technologies based on different assumptions about material costs, improvements in production, technology and in installment systems. Given the complexity, many experts agree that this question will only to be solved in the next five to ten years. Comparing the development of specific costs of the two technologies suggests that thin film has a steeper learning curve, as the figure below shows. However, there is only limited data available about the evolvement of costs for thin film technologies. The figure below uses costs of CdTe modules by First Solar as a proxy for the costs of thin film. Furthermore cost is not the only important attribute. As important, if not more, are efficiency (see Figure 13) and other attributes such as scalability, aesthetics, etc.

Figure 8: Historic costs of solar modules[22]



4.3 Market Development and Outlook

Market Volume

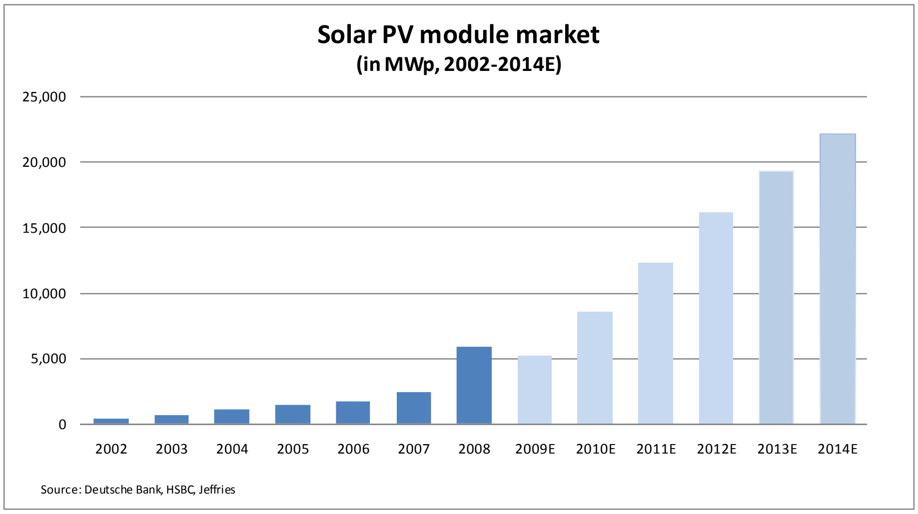
The solar PV market has been a success story since taking off in the beginning of this century. The start of the solar PV market was driven by government subsidy program in Japan in 1994 and in Germany in 2000 (EEG[23]). In 2004, an amendment to the EEG increased the incentives for solar PV energy through compensation rates for the higher cost of generation. As a result, the solar PV market increased to around 1.4 GWp by 2005 (see figure below). Increasing awareness of climate change and subsequent policy changes caused many countries to follow suit. Most notable are programs in Italy (2005), California (2006) and Spain (2008). These subsidy programs together with decreasing generation costs caused a boom in the solar PV market. Installations tripled in only three years to around 5.8 GWp in 2008. Overall, the volume of the solar market experienced a compounded growth rate of 57% since 2002.

[22] Based on numbers from Robert U. Ayres, Eco-restructuring: Implications for sustainable development, United Nations University press 1998 , SolarBuzz module market review and First Solar Corporate Overview 2009

[23] Erneuerbare Energien Gesetz (Renewable Energy Law): For a good overview of the law and the feed-in tariffs please see http://politics.pege.org/2008-d/photovoltaic-eeg.htm

2009 has been a rough year for the solar PV industry. Instead of a 20% volume growth, installation declined by ~12%. This was driven by the delay of large-scale projects (due to the lack of financing) and the cap of incentives in Spain[24].

Figure 9: Solar PV module global market (volume)



The long-term growth prospects of the industry remain positive. The industry is expected to grow by over 40% p.a. in the next two years. New installations are expected to reach 16 GWp by 2012. This growth expectation is based on new policy programs, like those in China, and the increasing competitiveness of solar PV through lower prices. In sunny regions with high electricity prices, such as Italy, grid parity will be achieved by 2011 (see Figure 3).[25]

Module Prices

As mentioned before, solar PV module prices play an important role in the future of the solar PV industry as they determine, among others, the competitiveness of solar PV. Several factors put long-term price pressure on manufacturers:

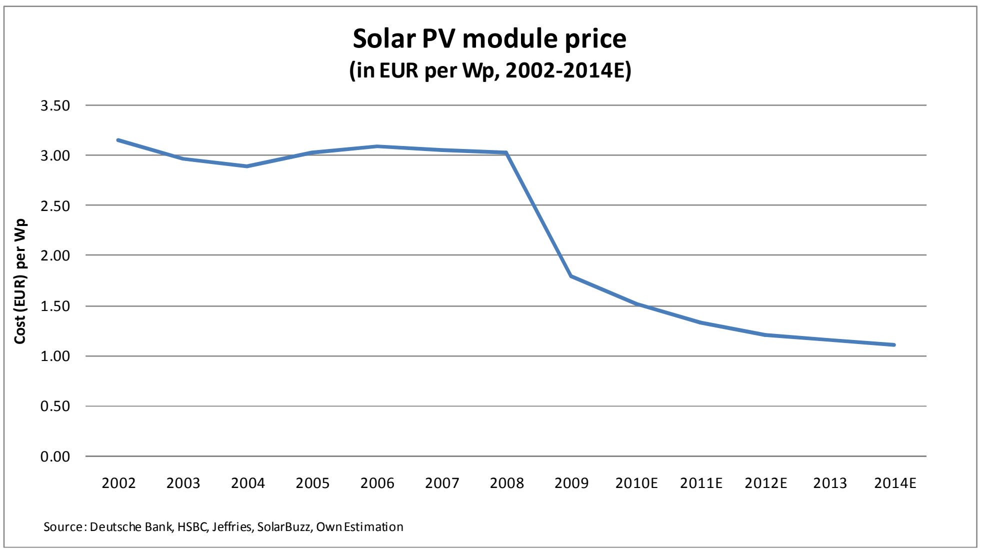
- lower subsidies per MW,

[24] SolarBuzz, www.solarbuzz.com
[25] HSBC, Global Solar Power, September 2009

- technological advances and new technologies,
- higher yields per MW through improved manufacturing and economies of scale and
- competitive pressure from low-cost production countries (e.g. China).

However, looking at the (wholesale) average selling price (ASP), we can see the industry managed to keep prices constant from 2002 to 2007[26]. The main reasons are the time lag in capacity ramp up to meet increased demand and the increase in input cost such as silicon, which have been passed on to the consumer.

Figure 10: Solar PV module market (price)



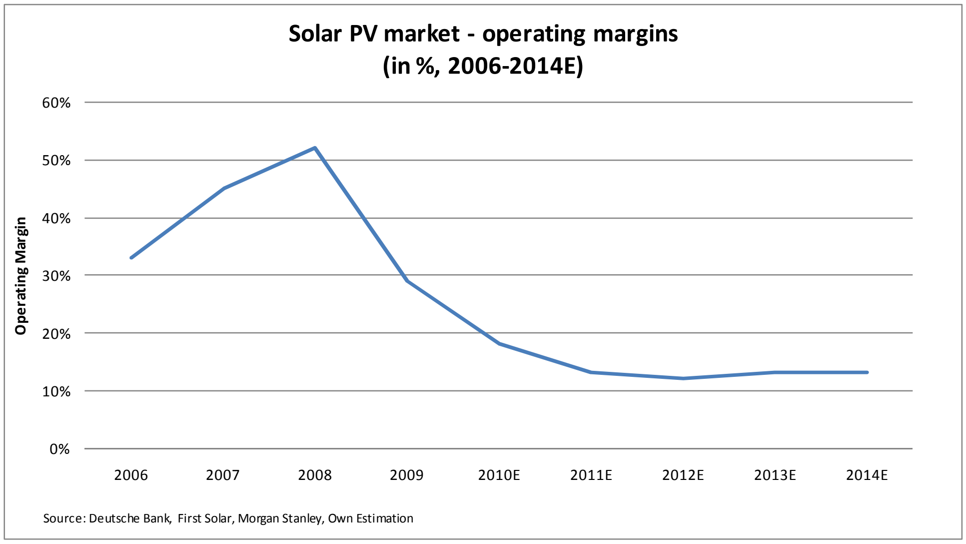
Since 2008, this trend has reversed and the industry faced a price decline of 30-40% (mainly due to overcapacity in the market). For the near future, analysts and industry experts expect a further price decline of 15% (2010), 12% (2011) and 10% (2012)[27]. Based on these estimates, the average manufacturing selling price will reach around 1.10 EUR/Wp in 2014.

[26] SolarBuzz, www.solarbuzz.com
[27] HSBC, Global Solar Power, September 2009 and Deutsche Bank, Solar PV industry update, October 2009

Market profitability

The solar PV industry was extraordinarily profitable in 2007 and 2008 with operating margins of 45%-50%. It was able to profit from lower manufacturing cost and stable prices. Analysts forecast a decline in operating margins driven by price decreases as reaction to oversupply and further commoditization of the product over the next years. The decline in module prices has shifted margins from module manufacturers to developers and installers. For 2009, the operating margins for module manufacturers decreased 20%-points to ~30%. Furthermore, analysts expect industry profitability to decline by 12% in 2011. Until 2014, analysts consider this the sustainable operating margin of the PV solar industry. Of course, the margins will vary widely by technology, size and geographic focus of each player.

Figure 11: Solar PV module market (operating margins of integrated manufacturers)



With declining operating margins from PV wafer, cell and module manufacturing, many players are moving downstream the value chain and acquiring system installers. Besides market access, this move allows manufacturers to decrease distribution cost and hence become more cost competitive.

4.4 Competitive landscape

The solar PV market is dominated by a few players. The top three players - Q-Cells, First Solar, and Suntech – have production capacity of over 1 GW per year[28]. Overall, the top 10 producers own 50% of the market[29].

Most of the production sites are based in China, where around 33%[30] of all PV modules are produced; another 20% of the PV modules are produced in Germany.

Figure 12: Overview major Solar PV players

Company	Market Share	Technology	
		Main	Comments
Q-Cells	8.3%	C-Si	Also in CIGS and other thin-film
First Solar	7.2%	CdTe	Special Thin-Film technology
Suntech	7.1%	C-Si	Also in a-Si
Sharp	6.8%	C-Si	Also in a-Si/µ-Si
JA Solar	4.3%	C-Si	
Kyocera	4.1%	C-Si	
Yingli	4.0%	C-Si	
Motech	3.9%	C-Si	
SunPower	3.4%	C-Si	
Sanyo	3.1%	C-Si	JV for Thin-Film
Top-10	**52.2%**		

Source: Own research, Jeffries and Company, SolarBuzz

4.5 Emerging New Technologies in the Solar PV Market

One characteristics of the solar PV market is that new promising technologies seem to constantly arise on the horizon. We view three (none thin film) technologies as promising to potentially play a role in the solar PV market by 2020:

a) *String Ribbon*

This technology pulls a thin ribbon out of molten polysilicon using high temperature resistant filaments. These ribbons are cut into squares which can be

[28] HSBC, Global Solar Power – Solar eclipsed?, September 2009
[29] Jefferies Research, Clean Technology Primer, September 2009
[30] www.solarbuzz.com

used instead of polysilicon wafers. This avoids the wafering process and its material inefficiency. The technology uses only half of the silicon of a traditional c-Si cell. On the downside, the cell efficiency is slightly lower compared to the traditional c-Si.

b) *Gallium Arsenide (GaAs)*

The rare Gallium is used in the semiconductor compound. While highly resistant to radiation and heat, GaAs modules deliver very high efficiency level of up to 40%[31]. The disadvantages of the technology are its higher cost, the short supply of Gallium and the toxicity of Arsenide. Hence, major application of GaAs technology is in space and solar concentrators.

c) *Organic Solar Cells*

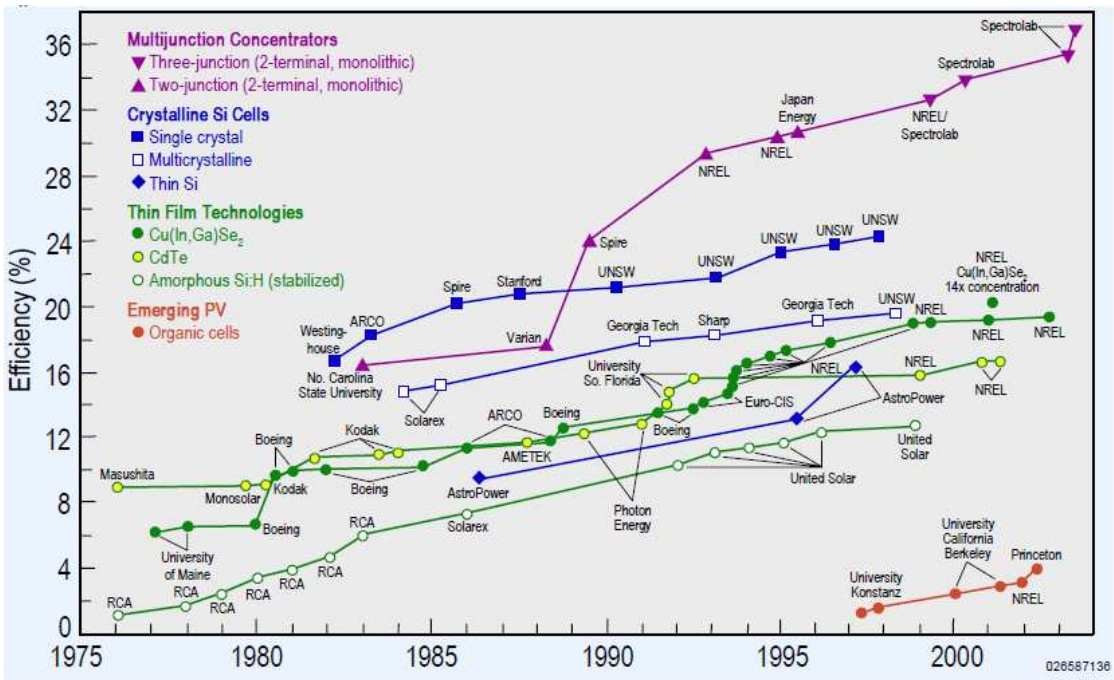
This technology is based on organic receptors that act as semiconductors (similar to c-Si technology). While the technology promises many advantages (light, flexible, cheap production through printing process), no commercial production has started or been announced by any of the players that are developing this technology (e.g. BP Solar and Nanosys).

Industry platforms such as SolarBuzz often report new quantum leaps in existing or new technologies. Many of these reports are based on successful experiments at universities or government research centers. Such news generates the notion that the PV industry must expect a major disruptive technology in the near future. However, based on past data of technology evolution (see figure below) and interviews with market participants, we infer that continuous incremental improvement of existing technologies is the most severe threat to market participants. The graph below shows efficiency improvements of different solar PV technologies. It can be concluded that technology evolution in solar PV is happening rather slowly. Almost all improvements were incremental in the past and there were no fast disruptive discoveries in that space.

[31] NREL achieved a record efficiency of 40.8%

We estimate the time to market from a successful first lab experiment to a cost competitive technology is seven to ten years.

Figure 13: PV Technology Map



Source: National Renewable Energy Lab

5. Theoretical Frameworks for Analysis

The main frameworks we use in this study are:

- **Scenario Planning Analysis and**

- **Strategic Options Analysis**

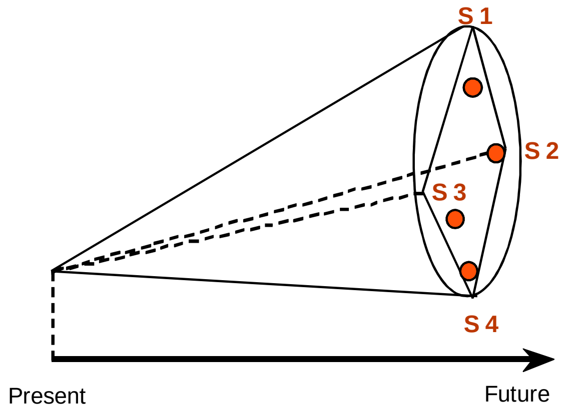
Scenario analysis will help to better understand possible future worlds. Strategic options are a way to prepare for a future with major uncertainties.

5.1 Scenario Planning Analysis

The future in many markets is often highly uncertain. The energy sector and its subsector solar PV energy are no exception. Scenario planning is a framework that helps people and organizations structure their thinking about the future. Instead of predicting one single possible future, scenario planning considers several possible futures. Scenarios address the challenges of: i) uncertainty, ii) complexity and iii) paradigm shift. [32]

Scenario planning considers a distinct number of possible future worlds (scenarios) that lay in a range of feasible outcomes. The figure below illustrates the concept of scenario planning in a three-dimensional graph. In reality this graph would have as many dimensions as there are uncertainties and trends.

Figure 14: Concept of Scenario Planning[33]



[32] Paul J.H. Schoemaker and V. Michael Mavaddat, "Scenario Planning for Disruptive Technologies" in "Wharton on Managing Technologies", G. S. Day and P. J. H. Schoemaker, Wiley, New York, 2000
[33] Paul J.H. Schoemaker, "The Future of Bioscience", The Wharton School, Philadelphia, 2008

Scenario planning is a continuous process. Once a first set of possible futures is defined, the main forces that shape the future are monitored. This information is used to make an educated guess about further developments and about the likelihood of different scenarios. In summary, scenario planning is a tool to better manage an uncertain future.

A typical scenario planning process looks as follows[32]:

1. Define the issue that is to be better understood
2. Identify stakeholders and actors who influence the issue or are affected by the issue
3. Identify and analyze main forces that shape the future
4. Identify trends (a trend is a consistent, unidirectional change over time)
5. Identify uncertainties (unlike trends, uncertainties have no known direction of change)
6. Key trends and uncertainties are selected and scenarios are built
7. Scenarios are analyzed on their impact and outcomes for the stakeholders
8. Strategies are developed to cope with uncertainties. Potential organizational structures have to be adjusted as well
9. Key trends and uncertainties are continuously monitored and scenarios and their implications are updated

Application in the research project

Scenario planning appears to be a highly relevant framework for managing uncertainties in the solar energy industry. The number of key uncertainties is potentially high and the range of scenarios seems to be wide. We conduct a scenario planning analysis by taking a view of an incumbent player in the solar energy industry. By doing so, we demonstrate the mechanism and usefulness of the methodology. The outcome shall furthermore build the basis of a strategic real options analysis for a c-Si player.

5.2 Strategic Options Analysis

Strategic options (or real options) are an alternative method to evaluate investment decisions. While a classical NPV calculation considers only outcomes that are modeled from the very beginning to the end with a focus on expected values in each period, strategic options attach a value to the variance around this expected value via the creation of contingent plans for future use.[34] Besides being a pure investment decision-making tool, strategic options provide a framework for creating and thinking about the value of flexibility embedded in many decisions. The main steps in the management of strategic options are:

- **Options Generation:** A large number of options are considered potentially useful and are in line with the entity's strategy
- **Assessment:** The value of the generated options is assessed
- **Selection:** A set of options is selected for funding and execution. A further step is selection based on a portfolio approach. This will allow the company to hedge themselves against unwanted outcomes in certain scenarios.
- **Monitoring:** The execution of the options is monitored and adjusted to reflect changes in the market and the competitive environment.

Application in the research project

Strategic options analysis is highly relevant in a fast-changing environment in which the solar energy industry is the framework of managing. Incumbent firms as well as dedicated sector investors could potentially benefit significantly from taking a real options view. In this specific case, strategic options and especially a portfolio of strategic options can have very different values in each scenario. Analyzing these options for each scenario will add significant insight to the importance of each strategic option.

[34] A real-option is defined by the right, but not the obligation, to perform a specific action. In contrast to DCF models, which are often based on averages and medium expectations, options have higher values as certain actions do not need to be performed if they will generate negative value.

6. Scenario Analysis

We base our scenario analysis on a time horizon of 10 years. Hence, all our scenarios will be built for the year 2020. We think that over this time frame, the solar market will change significantly compared to today's market structure given the many strong forces we detected in the market (Chapter 6.3).

6.1 Issues

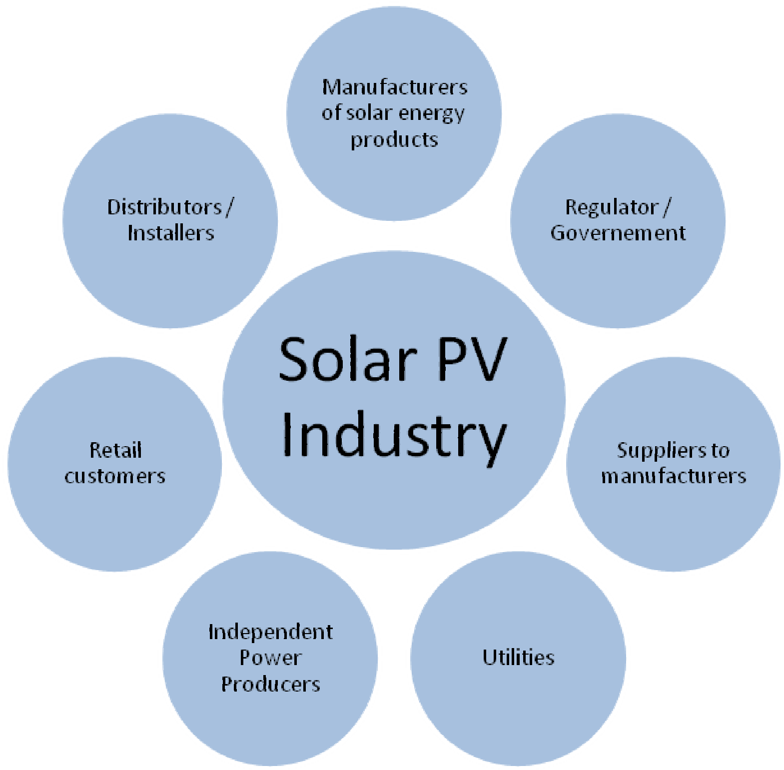
The primary goal of this scenario planning is to better understand the key issues that an incumbent player in the solar energy industry faces. The three key issues are:

- What will be the overall demand for solar PV in the future?
- Which technologies will be dominant?
- Which products and services will be required to serve future demand in the best possible way? What business models will be successful in the future?

6.2 Stakeholders

In this paper we take the view of an incumbent player, mainly active in c-Si technolgy, in the solar PV industry. However, there are a number of stakeholders that are affected by industry dynamics and who might shape the future of the industry to some extent. Below we discuss each stakeholder briefly.

Figure 15: Stakeholder of the solar PV industry



Manufacturers of solar energy products: They are obvious stakeholders. Their ability to sell products is highly dependent on the overall demand for solar PV products. They shape the future of the industry by developing and applying technologies. Moreover, solar PV manufactures have the most power to shape the value chain by integrating down or upstream. Future innovation is most likely to be done by these stakeholders.

Regulator / Government: Regulators have played an important role in the solar energy industry. Most of the current demand is generated by governmental incentives or mandates. The economics for most applications require some form of intervention by the regulator. Such interventions are motivated by political agendas to i) increase energy independence and security, ii) reduce greenhouse gas emissions, and iii) decrease the environmental impact of power generation in general. When the costs of solar PV are reduced the dependency on regulation will decrease. However, regulation might still play an important role with regards to permits for projects and grid connections as well as the approval and trade of products.

Suppliers to manufacturers (equipment and raw materials): Equipment suppliers can be simple suppliers of manufacturing equipment. However, they can also act as key technology provider. If they take this role they can potentially have a significant impact on technological advancement and the competitive landscape. In the thin film market, many of the production lines are 'turn-key', meaning that much of the knowledge and the technological development come from the equipment manufacturer (such as Applied Materials and Oerlikon).

Raw material suppliers can shape the industry especially in times of undersupply of materials, such as the undersupply of polysilicon. Their reaction and capacity ramp-up will have a major impact on the c-Si technology.

Utilities: Utilities are usually buyers of electricity generated by solar PV products or customers for solar PV products. Some utilities also build and operate their own solar PV devices. They could potentially be involved in equipment manufacturing as well. However, in the past utilities have rarely been involved in power equipment manufacturing as it is not seen as a core competence. Furthermore, utilities can play a role in permitting a grid connection and can impose regulation to protect grid stability.

Independent power producers (IPP): IPPs are buyers of solar PV products and services. They usually have a purely economic interest and are mainly driven by economic aspects.

Retail customers: Retail customers are buyers of solar PV products. They can view the application of solar energy either as investment or as an act of environmentalism potentially combined with prestige aspects.

Distributors/Installation: Distributors and installers are obviously concerned about the overall market size of solar PV. They might be less affected by technology changes as long as these changes do not shortcut them. With decreasing cost of solar PV products installation becomes an important cost factor of the end product. Installers should be concerned about this as it could mean additional cost pressure on their side.

6.3 Main Forces

We divide the main forces that impact the solar PV market into key trends and key uncertainties. Trends are changes where the direction is well understood. Uncertainties are changes where neither the direction nor the extent of the change is known.

6.3.1 Key Trends

Energy demand/prices: There are multiple indicators for a long-term trend of increasing energy prices such as increasing worldwide demand and increasing cost of exploitation of additional energy resources. The most significant energy price for solar PV is the price of electricity. In many markets the price of electricity is dependent on prices of natural gas, oil or coal. Hence, electricity prices will tend to increase as fossil fuel prices increase.

Energy politics: Energy politics increasingly favor clean and domestic energy production. At this point of time there are no indications that this trend will reverse any time soon. Therefore, increasing support for clean and domestic energy production is classified as a trend in the scenario planning.

Support by general public of alternative energies: In line with energy politics it appears that the trend of public support for alternative energies will continue. At this point there are no indications that speak against this being a trend.

Declining cost of solar PV: Advancement of technologies and manufacturing processes through increased knowledge, economies of scale and manufacturing process integration have lead to declining cost for solar PV (despite a temporary price increase during the last few years). We classify this as a trend because we see no reason for increasing costs for solar PV products. Furthermore, we think that over the next 4-5 years decreasing cost will be passed on to consumers in form of lower ASP[35].

Improving energy efficiency: The efficiency of solar products has constantly improved and is likely to improve further. Deutsche Bank[36] estimated that the impact of a 1%

---

[35] See Chapter 4
[36] Deutsche Bank, Solar PV industry update, October 2009

efficiency increase for c-Si cell will yield 5-6% lower total cost.[37] Figure 13 gives some indication about technological efficiency improvements achieved in labs – which will often also be achieved on a manufacturing scale later on in the process.

Vertical integration: Recent years have seen a trend of vertical integration Several major players have undergone vertical integration: REC Group (moving downstream organically), MEMC Semiconductor Materials (moving downstream through the acquisition of SunEdison), SunPower (moving downstream through the acquisition of several systems integrators), LDK (moving upstream by building polysilicon capacity), or FirstSolar (moving downstream by investing in Solar City and acquiring OptiSolar).

Relocation to low cost production countries: Production moves more and more to low cost countries such as China and Malaysia. In 2005, 80% of solar PV production capacity was located in Japan and Western Europe. By 2007 the share of China and Taiwan has increased to 38%[38]. From the general news flow we conclude that this share was even higher in 2009. Furthermore, newly announced plans for new manufacturing sites allow us to foresee a further increase in low cost country (LCC) production share.

Off-grid systems attractive/decentralization in certain regions of world: Off-grid systems based on solar PV combined with batteries or other storage devices can be an economically attractive alternative to conventional power generation (mostly diesel generators). In places where no grid connection is available (such as some areas in rural India) solar power is already cost competitive and its application is expected to increase[39].

Steady improvement of competing technology: Energy technologies that are competing with solar PV undergo steady improvement as well. Fossil fuel power plants increase their efficiency and become cleaner. Nuclear power plants have advanced their security systems and their waste management. Other renewable energy technologies such as wind, solar thermal, geothermal, hydropower and biopower are steadily making improvements in efficiency, cost effectiveness and applicability.

[37] HSBC estimates 1% increase yielding 12% lower cost
[38] Arnulf Jäger-Waldau, "PV Status Report 2008", Joint Research Center of the European Commission, 2008
[39] Alliance for rural electrification, www.ruralelec.org

More demand for building integrated PV (BIPV): Building integrated solar PV increasingly gets more support versus green field installations. Germany has paid a higher tariff for building integrated solar PV from the very beginning of its incentive program. In the last revision of the legislation it decided to degrade the feed-in-tariff for green field installations faster than for building integrated[40]. Spain and Italy adopted similar incentives recently. The United States removed the cap on investment tax credit (ITC) for rooftop systems.[41] This supports a trend towards more building integrated solar PV.

6.3.2 Uncertainties

Technological advancement (relative): While technological advancement has been identified as a trend, technological advancement of c-Si relative to other solar technologies is an uncertainty. Currently the pace at which alternative technologies (such as thin film-based technologies) advance in terms of cost and efficiency is higher than the pace of advancement of c-Si[42]. If this relative pace is maintained c-Si can be potentially overtaken as a leading technology in the mid-term. However, whether this will ever happen is uncertain.[43]

Legislation/Incentive programs for solar energy: An increasing number of legislations give incentives to renewable energy and solar PV specifically. In most markets solar energy is currently only competitive with an incentive scheme in place. Before grid parity is reached such incentives are crucial for the commercial success of solar PV. It is uncertain if and for how long solar PV will receive specifically targeted incentives. If such incentives fall away too early solar PV will in the short run not be competitive in most markets.

Key Innovators: In the past, key technologies were typically developed by the manufacturers of solar products. However, recently equipment suppliers have been driving

[40] Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich, Bundesanzeigerverlag, October 2008
[41] Energy Improvement and Extension Act of 2008, The Library of Congress, 2008
[42] Based on information in investor presentations and product specifications of First Solar and Sunpower
[43] Analyst reports offer a good example of the level of uncertainty. While some see thin film clearly cheaper, others favor c-Si by 2020.

innovation. It is unclear whether the industry will go in a direction where the equipment suppliers will do almost all innovation and sell technology with their equipment or if innovation will stay with manufacturers. A scenario where both happens at the same time might be possible as well (especially for different technologies). In case key innovations will be with equipment manufacturers, it is likely that this would accelerate the trend to relocate production to low cost countries. Manufacturers that follow a best-of-breed strategy might leap-frog on the performance side and / or the cost side in such a scenario.

Grid parity (timing and location): It is key for the solar PV industry to achieve grid parity[44] before incentives for solar PV become obsolete. It is uncertain when grid parity can be achieved. The uncertainty is especially high in places where sun radiation is less abundant.[45]

Acceptance: So far solar faces few NIMBY[46] problems since people are often neutral or in favor of the appearance of solar PV installations. However, there is a potential that these problems will arise once the penetration of solar PV increases further, as has happened with wind turbines. This could potentially hinder new projects and slow down the growth of demand for solar PV. Large-scale solar farms might be especially subject to this uncertainty.

Greenhouse gas legislation: While it seems to be a trend that an increasing number of legislations implement some mechanism to reduce greenhouse gas emissions it is unclear if and to what extent solar PV would benefit from such legislation. Only schemes that increase the production cost of conventionally generated electricity will improve the competitiveness of solar PV. It is uncertain if such schemes will be implemented in the future.

Market protectionism: So far there is little or no market protectionism seen in the solar PV industry. However, the shift of production to low cost countries might cause political

---

[44] See Chapter 4 for a definition of grid parity
[45] See Figure 1 in Chapter 4 for the uncertainty in grid parity predictions
[46] NIMBY: Not in my backyard – Opposition against installations by local residents because of appearance, environmental or emissions (such as noise, electromagnetic, hazardous materials etc.) issues

pressure to impose protectionist measures in favor of local manufacturers. China and Quebec have shown signs of wind industry protectionism[47]. Also several analysts[48] discuss market protectionism in the context of the potential Chinese subsidies program.

Advancement of emerging technologies: While the uncertainty of the relative advancement of emerging technologies is covered in the uncertainty "**Technological advancement (relative)",** the extent to which emerging technologies advance in absolute terms is an uncertainty as well. We view advancement in general as a trend. Whether emerging technologies reach a stage in which they can capture some market share or disappear completely is an additional uncertainty.

Distribution structures: We discussed vertical integration as a trend in the industry. However, distribution channels have not yet been impacted by this integration. We view the future market structure of these distribution channels as an uncertainty. One potential outcome is that solar modules will be distributed as do-it-yourself installations[49] through retailers. Another potential outcome is the emergence of large distributors (which are already active in energy related matters such as heating, etc) which concentrate a lot of power.

Economic Health: The health of the economy affects the solar PV industry. Raising capital to finance growth and research & development for instance is much easier to do in a healthy economic environment than in a downturn. Furthermore, this uncertainty influences the likelihood that costly incentive programs for solar PV will be introduced or maintained, as an unhealthy economy might push solar PV down in its list of priorities. In addition, the cyclicality of capital markets affects the ability to raise funds for expansions in the solar industry.

---

[47] Both Quebec and China require a minimal local value creation for turbines installed under its incentive schemes.
[48] Jefferies Research, Clean Technology Primer, September 2009
[49] An recent article in BusinessWeek points out that US retailer Best Buy has begun trials for selling these DIY solar cells ("Why Tech bows to Best Buy", Business Week, Dec 10 2009)

6.4 Scenario Building

As described in Chapter 5, four potential scenarios are developed along the two main uncertainties. We identified two uncertainties as key in their impact on the industry until 2020:

- **Technological advancement (relative to other solar technologies)**
- **Legislation / Incentive programs for solar energy**

They are highly relevant for shaping the future and are not highly correlated. There is a weak correlation in that subsidies may stimulate competing technologies and also once new technologies emerge that achieve grid parity, subsidies will likely reduce. We use these meta-uncertainties to develop four scenarios which aim to cover 95% of all possible outcomes (see matrix below). The scenarios are built from the view of an incumbent manufacturer of solar PV cells based on c-Si technology (e.g. Q-Cells). The scenarios describe a future in 2020.

Figure 16: Scenario Analysis Overview

		Technology advancement (relative to other solar technologies)	
		Low	**High**
Legislation / Incentive programs for solar energy	**Low**	**Scenario "Wallflower"**	**Scenario "Survival of the fittest"**
	High	**Scenario "Delayed technology shock"**	**Scenario "Golden age"**

The following blueprint maps all other uncertainties and associated outcomes for each of the four scenarios in an internally consistent way within each scenario column. This blueprint helped our scenario-building process by checking the viability of various combinations of possible outcomes.

Figure 17: Scenario Analysis Blueprint

Uncertainties:	Scenario 1 "Wallflower"	Scenario 2 "Survival of the fittest"	Scenario 3 "Delayed technology shock"	Scenario 4 "Golden Age"
Technology advancement (relative)	Low	High	Low	High
Legislation / Incentive programs	Low	Low	High	High
Key Innovators	Manufacturers	Manufacturers and equipment suppliers	Equipment suppliers (production outsourcing)	Status quo: manufacturers and equipment suppliers
Grid parity	Late	Early	Medium	Early / Medium
Acceptance	High	Medium	High	High
Greenhouse gas legislation	No global legislation	No global legislation	Yes	Yes
Market protectionism	None	None	Increasing	Moderately increasing
Advancement of emerging technologies	Low	Low	High	Medium
Distribution structures	Unchanged	Aggressive downstream integration and more direct distribution	Slow trend towards downstream integration	Direct distribution to large accounts, residential via wholesalers
Economic health	Medium	Medium	High	High

6.5 Scenario Description

The following part describes each of the scenarios in more detail. Also, we recommend a business strategy which allows an incumbent player to create the most value possible for its shareholders in the specific scenario.

6.5.1 Scenario "Wallflower"

Scenario Description

By 2020, the solar PV industry is only a "wallflower" compared to other energy industries (renewable and traditional).

In this scenario *incentive programs decline fast and the number of new incentive programs worldwide is small.* Big programs expected as of today, such as that of China, have never materialized. While the industry grows fast until 2012, the industry does not grow further thereafter and starts to shrink back to today's levels. Demand only materializes for large-scale projects in markets where sun radiation is strong and that have achieved grid parity before 2012 (California, Italy, Northern Africa, the Middle East). Off-grid application in rural areas adds some growth but is not material for the industry as a whole.

Relative technological advancement of c-Si is slower than for thin film. The absolute development of c-Si is too slow to reach grid parity before incentive programs end by the end of the decade (for the major non-sunny market). Emerging technologies, such as thin films, also do not advance sufficiently to replace c-Si technologies and become cost competitive without subsidies. Both technologies are competing in the market by 2020 as they are still based on cost/benefits. There is a market edge for thin film, but only at large-scale production. But the lack of incentive programs makes it very hard for small thin film players to achieve this necessary scale.

Due to the lack of growth prospects equipment suppliers invest little in R&D leaving most innovation to manufacturers. Overcapacity is a major issue for all players, driving out especially small players and emerging technologies without sufficient scale in manufacturing. Most players face heavy losses starting in the middle of the new decade and eventually merge with larger players or disappear. With only 3-4 surviving players, there is a strong focus on efficient production that will be downstream integrated in order to secure business. Most of the production is in Asia.

Financially, the industry will go through a dire time. By 2020, the surviving players are at least able to earn the cost of capital[50], yet growth remains elusive. Compared to 2010, much of the industry value has been destroyed.

To conclude, the "wallflower" scenario describes a likely outcome in which solar PV will not live up to its expectations and play only a minor role for certain niche markets (regional and products). Financially investors will lose money until the end-game in 2020 allows surviving players to generate decent returns.

Winning Business Strategies

Players that want to survive in this scenario must shift their strategy compared to the strategies that we observe today.

Surviving players identified *market access to niche markets* (mainly sunny markets in California, Italy, The Middle East) as the only way to survive in this scenario. Without this market access a company can experience a major drop in their top-line as soon as existing incentive programs run out and the demand in these markets dries up. A successful business model for a c-Si player secures market access through downstream integration. Business in regions such as Northern Africa and Middle East might also require government contacts.

Based on the low relative and absolute advancement in c-Si (and thin film) technology, *production efficiency becomes the key capability for wining in this scenario*. Surviving players are in either one of the technologies, but with a clear focus[51]. Successful players must achieve large economies of scales and improve production processes. Innovation focuses on manufacturing, which is located in Low Cost Countries (such as China). Marketing aspects are minor when selling the PV modules as business customers are

[50] I.e. return on invested capital (ROIC) in line with cost of capital. Decent ROIC's due to the low competition as entry barriers are significant (investment in plants of more than $1bn USD).
[51] As said before, thin film might have an edge if scale can be achieved (which we doubt in this scenario).

highly professional. Differentiation through services is an added value offering, i.e. operating and servicing the large-scale projects.

All incumbent players with sizable market share in 2010 and a solid balance sheet are potential survivors in this scenario. We expect oversupply based on the announced capacity ramp-up. A company that wants to survive in this scenario must be able to live through these times (either with the help of an investor who believes in the company or by having the necessary financial depth)[52].

To sum up, we see the following strategic imperatives in this scenario:

- Market access to sunny regions must be built in 2010/2011
- Single technology approach with strategic focus on production efficiency (with economies of scale a must)

The following figure provides an overview of the recommended business model:

Figure 18: Overview of Recommended Business Model for "Wallflower" Scenario

	Scenario 1 "Wallflower"
Strategy/Business Model	
Core capability to survive	Market access in sunny regions
Core capability to win	Production efficiency
Technology	Single technology focus (C-Si, or Thin-Film)
Market focus (regional)	California, Middle East, North Africa
Major Customers	Utilities
Distribution	Direct - large scale projects for utilities
Production	Outsourced or in LCC (China, etc)
Level of Integration	Downward integration a must
Market	
Market size (2020)	At 2010 level or lower
Market growth (2020)	None - very low

[52] This generates a catch 22, as the company needs scale to survive and hence builds up capacity, but the industry overall will suffer depending on the capacity built up over time.

6.5.2 Scenario “Survival of the Fittest”

Scenario Description

By 2020, only the fittest c-Si players survive and are able to enjoy attractive but less-than-expected growth of the solar PV industry.

Similar to the “Wallflower” scenario *incentive programs decline fast and the number of new incentive programs worldwide is small.* Big new programs never materialized (China, India). The industry experiences strong growth until 2012/2013. Afterwards growth slows considerably. As c-Si technological advancement is high, cost/Wp drops faster than expected. Demand in markets with high radiation remained strong and grid parity is achieved before 2013 in these markets (California, Italy, Northern Africa, Middle East). As most government incentives run out by 2015, further market growth is based on the competitiveness of the cost per Wp relative to other energy sources. Unlike in the “wallflower” scenario, faster (absolute) technological advancement allows the solar PV industry to grow in areas with less radiation, however at a much lower pace than forecasted by many analysts.

Relative technological advancement of c-Si is faster than thin film. The absolute development of c-Si is fast and hence c-Si reaches grid parity in high radiation regions before incentive programs end. The lack of incentive programs causes prices to fall more quickly from 2013 onwards as solar PV has to pass on cost savings to become more competitive in the absence of subsidies. Still, in this scenario, grid parity in many regions (such as Western Europe, Northern US, and China) can only be achieved by 2020. Emerging technologies, such as thin films, do not advance sufficiently to replace c-Si technologies. Hence, c-Si keeps its market share of >90% by 2020 in this scenario.

Growth prospects for the total solar PV market are medium overall. High growth is seen in the first phase until 2015 (when the last incentive programs ended). Thereafter, the industry does not grow until grid parity is reached in some of the large markets (by 2020). Overcapacity caused by high investment in the boom phase increases the financial pressure in the time from 2015-2020. This overcapacity causes major consolidation in the market.

The relatively weak development of other technologies such as thin film technologies in that scenario are caused by three factors: (i) low technological advancement (ii) less improvement in the manufacturing process and (iii) higher system installment cost as % of total cost due to little improvement in system installation. By 2015-2017, overcapacity and related price pressure meant the end to most of the thin film players.

The large players in the market have to focus on R&D as well as operating efficiency. We imagine that players take different routes here in order to achieve the lowest cost per Wp for the c-Si modules.

Recommended Business Strategy

Similar to the "Wallflower" scenario, incumbent c-Si players must shift their strategies to win in the "Survival of the Fittest" scenario.

Again, *market access to niche markets* (mainly sunny markets in California, Italy and the Middle East) is a major capability to survive in the "Survival of the Fittest" scenario. Without this market access in California and potentially the Middle East, a company will face large top-line risk when demand dries up (2015 onwards) driven by decreasing incentives. To complicate things, market access must be gained (or kept) in markets that reach grid parity by 2020 (Southern and Western Europe, parts of China and India). A successful long-term strategy will build presence there much sooner than when grid parity is reached.

In this scenario, incumbent c-Si players should have a single technology focus on c-Si technology. A key capability to win in this scenario is to offer the lowest cost/Wp. This will be achieved by two strategies: a) Focus on technology improvement such as efficiency or material usage or b) Manufacturing efficiency leveraging high economies of scale. The latter, strategy b, will most likely coincide with the emergence of large-scale solar fabs[53] (similar to the semiconductor industry) in Asia.

[53] Which will offer manufacturing services to other solar PV players

The distribution channel depends on the regional market. For markets that reach grid parity before 2015, demand will increase for large-scale projects. Residential application (higher fixed cost of installation) might not reach grid parity, hence consumer marketing and brand building is not key.

To sum up, we see the following strategic imperatives in this scenario:

- Focus on R&D excellence and technological advancement
- Clear production strategy (in-house vs. outsourced to foundries) allowing to capture efficiency gains in scale
- Access to sunny markets is key in order to gain necessary scale. Downstream integration in these markets is a given to secure projects.

The following figure provides an overview of the recommended business model:

Figure 19:– Overview of Recommended Business Model for "Survival of the Fittest" Scenario

	Scenario 2 "Survival of the fittest"
Strategy/Business Model	
Core capability to survive	Market access in sunny regions & scale
Core capability to win	Technological advancement & operational efficieny
Technology	C-Si
Market focus (regional)	California, South Europe, Middle East, North Africa
Major Customers	Distibutors (for residential) and Utilities
Distribution	As today (no large distributors)
Production	Signifcant share of production in Asia (60-80%)
Level of Integration	Downward integration
Market	
Market size (2020)	1-3x today's level
Market growth (2020)	Low

6.5.3 Scenario "Delayed Technology Shock"

Scenario Description

By 2020, the delayed technology shock leaves very few - if any - incumbent c-Si players that play a significant role in the solar PV market.

Unlike the "Wallflower" and "Survival of the Fittest" scenario, the number of *incentive programs increases and creates a solar PV boom with very strong growth prospects*. New large programs (China, India and USA) were started by 2012/2013. Existing programs continued until 2020. Hence, the Solar PV industry experienced strong growth until 2016/17. While growth slowed down due to a few new incentive programs, the PV market still grew considerably until 2020 because of the grid-parity-driven demand.

The downside of the incentive programs is that little pressure and incentive exist for companies to decrease prices/cost for consumers. Therefore, prime facie, the scenario suggests that solar PV is as competitive as other energy sources. At the same time, strong demand allows companies to capture higher economies of scale, ultimately decreasing the cost of production significantly. This results in high margins until 2015.

Grid parity is achieved before 2013 in markets with high radiation and high power prices (California, Italy). Grid parity for most other markets (e.g. Western Europe) is achieved later (2017/2018), when competitive forces (e.g., overcapacity) compel companies to start decreasing prices at a much faster rate.

Upcoming new incentive schemes might contain at least some level of market protectionism. Potentially, this hinders companies in accessing some of the new growth generated.

In the "delayed technology shock" scenario, relative technological advancement of c-Si to other technologies is low. The absolute development of solar PV technologies is fast (due to more money in R&D and higher economies of scale). The demand driven by incentive programs allows the c-Si technology to stay competitive until 2015 as adding new production capacity for the superior PV technologies takes time. *Hence, the technology* *shock for c-Si is delayed until the second part of the decade (2015-2017).* As incentive programs decrease, pure cost considerations became more important. Players in thin film technologies have significantly lower costs than c-Si players (cost per MW). The results are lower prices for consumers and stronger margins for thin film players. By 2020, the current market share of c-Si vs. other emerging technologies (90% vs. 10%) is flipped. In 2020, c-Si is only used in certain niche markets.

Large incumbent c-Si players in the market have to focus on R&D in several promising thin film technologies. Equipment manufacturers play an important role in the R&D process. However, successful firms do not rely solely on the equipment manufacturer for successful R&D. Downward integration is low compared to the other scenarios as the market growth is big enough to allow most companies to grow without secure direct access to the large-scale projects. Other potential applications are "install-yourself" solar PV modules which are sold directly to end consumers. We see operating efficiency of lower importance as improvements in technology play a more important role until 2020 (as the emerging technologies offer many areas for technological improvement).

Recommended Business Strategy

Successful business strategy for an incumbent c-Si player focuses on R&D diversification into new technologies in the first phase (2010-2015) and best in class R&D in the second phase 2015-2020.

While this scenario offers excellent market conditions, the scenario is a major threat to any incumbent c-Si player. The scenario allows c-Si players to post great margins and returns until 2014/2015 when incentive programs start to add little new growth, cost/Wp becomes the key metric in the market and thin film has added enough new capacity to serve the market[54]. Based on experience from other industries, many incumbent players fail to adapt their business models in such a market environment as the change needs to be achieved in a time of their own great success. Late adaption means the end to many players (or the

[54] And reaps the cost benefits in production from the large economies of scale

undertaking of long-shot acquisitions to stay in business - most likely at cost of the shareholders).

A new business model mainly differs in the much broader R&D focus on several emerging technologies. New technologies must be explored and learning must be achieved in the most promising field. Similarly, the company must be flexible in manufacturing so that it is able to upgrade the production once a new technology achieves a tipping point. The rising of special solar PV production “fabs” might be another possible outcome in this scenario.

Market access is less important than in the two previous scenarios, yet a successful business model must incorporate possible market protectionism especially in new emerging markets and access to distribution channels in the largest markets (China, US, Western Europe). However, market access provides a barrier of entry to some emerging thin film players, especially in the distributor/residential market. This allows a c-Si player to buy some time to react. Similarly, branding the actual solar PV cell generates significant benefits in pricing and customer demand for a specific company. A positive example from a related industry is Intel’s “Intel Inside” campaign which has been a huge success related to end consumer market in a formerly business to business market.

To sum up, we see the following strategic imperatives in this scenario:

- Build R&D portfolio in several promising technologies, identify the most promising technologies and focus on time to market
- Flexible production strategy allowing to upgrade to new technology fast while still capturing economies of scale
- Market access to distribution channels which focus on high growth regions such as China and USA
- Branding of PV solar products to end consumers for high end market

Figure 20: Overview of Recommended Business Model for "Delayed Technology Shock" Scenario

	Scenario 3 "Delayed technology shock"
Strategy/Business Model	
Core capability to survive	Broad R&D focus and flexible production system
Core capability to win	Be active in winning technology with lowest cost
Technology	Thin-Film
Market focus (regional)	NA
Major Customers	Distributors and large scale project operators
Distribution	Distributors and B2B direct distribution
Production	No specific focus - importance of R&D centers and cluster
Level of Integration	Slow downward integration
Market	
Market size (2020)	Multiple of today
Market growth (2020)	Medium

6.5.4 Scenario "Golden Age"

Scenario Description

By 2020, c-Si is the dominant PV solar technology in a market that offers excellent prospects to successful solar PV players (hence, scenario of "Golden Age").

Similar to the "Delayed Technology Shock" scenario the market for solar PV is driven by a number of new, large *incentive programs* (China, India and USA) starting by 2012/2013. Existing programs are continued until 2020. The Solar PV industry experiences strong growth until 2017. Grid parity (achieved in 2012 in the sunny regions and by 2017 in most regions) and the world's hunger for clean energy allows solar to continue growing after 2020.

In the "Golden Age" scenario, *relative technological advancement of c-Si is higher than that of other technologies.* The absolute development of solar PV technologies is high (due to more investment in R&D and higher economies of scale due to the higher demand). By 2013/2014, c-Si is regarded as the superior technology in this scenario. Results show that most investment will focus on c-Si, driving down total production cost and increasing production capacity. As a result, prices decline faster than in the "Delayed Technology" Scenario and margins to c-Si player decrease as well[55]. However, operating margins achieved by 2015 are sustainable for successful market players (unlike in the "Delayed Technology Shock" scenario). Also, by 2020 c-Si captures most of the solar PV market. Thin film applications might be very interesting to building integrated solar PV applications.

We see most of the production by 2020 in Asia. R&D will be centered in few solar PV clusters. Equipment manufacturers are of importance, but solar PV players are eager to protect their know-how and sustain their competitive advantage (lowest cost per MW). The importance of economies of scale might generate an M&A wave with only few companies sharing the PV solar market. Another potential outcome is the upcoming of global

[55] And hence be lower than in the delayed technology scenario

production foundries in Asia with some c-Si players only focusing on R&D and market access.

(Building) corporate brands plays a significant role in this scenario as end customer (residential market) rely not only on the specific promises of cost/Wp but also on the brand as key purchasing factor when buying solar PV applications.

Recommended Business Strategy

The recommended business strategy for an incumbent c-Si player is similar to what many players already follow today. The company must focus on technological improvement through R&D and reap all benefits from economies of scale related to production efficiency.

The "Golden Age" will only be golden for a few large players. Depending on today's position, a company must either focus on R&D or on production improvement. In the end, both need to converge in order to be successful[56]. Market access is key, especially for distributors in the residential market as they are more prone to assume a long term relationship with a manufacturer (a small increase in efficiency is not the most important to them in terms of serving their end-customers).

To sum up, we see the following strategic imperatives in this scenario:

- Be one of the top 3 market players in terms of volume and capacity by 2013/2014
- Focus R&D on c-Si technology and achieve incremental increase in technology efficiency
- Production strategy must capture maximum of economies of scale (large fabs[57] in Asia or outsourcing)

[56] This could mean that the most successful business model is two have two companies. One with focus on R&D and the other one a global foundry focusing on production (similar to many companies in the RAM market today).

[57] With production capacity of at least 1- 2 GW

- Market access to distribution channels is key to serving the residential market
- Build brand in order to differentiate from cheaper, lesser quality products from Low Cost Countries (important for residential markets)

Figure 21: Overview of Recommended Business Model for "Delayed Technology Shock" Scenario

	Scenario 4 "Golden Age"
Strategy/Business Model	
Core capability to survive	Focus on R&D in c-Si & market access in new markets
Core capability to win	Economies of scale
Technology	C-Si focus
Market focus (regional)	Western Europe, California, China and India
Major Customers	Large distributors and project operators
Distribution	Distributors and B2B direct distribution
Production	LCC production (China, etc) & foundries
Level of Integration	Slow downward integration
Market	
Market size (2020)	Multiple of today
Market growth (2020)	Medium

7. Strategic Option Analysis

Based on the scenario analysis in the previous chapter a strategic option analysis is conducted. To be as specific as possible we do analyze the example of Q-Cells, a manufacturer of solar PV cells. The framework described in section 5 is used for this analysis. In the following we will demonstrate the management of strategic options. We start by introducing the strategic option that Q-Cells owns (Part 7.2) and by discussing the process of strategic assessment of these options (Part 7.3 and 7.4). Also, we perform a quantitative assessment of the actual strategic option portfolio and the current strategic gap that Q-Cells faces. Performing a quantitative valuation and selection of strategic options is not in the scope of this paper.

Company overview

Q-Cells' core business is the production and marketing of photovoltaic cells based on crystalline silicon (c-Si). The firm was established in 1999 in Thalheim, Germany and quickly grew to be the largest producer of solar cells with a market share of 8% in 2008.[58] Q-Cells reported revenues of € 1.2 billion and a net income of € 191 million for the full year 2008. As of November, Q-Cells trades at € 11 per share, equivalent to a market capitalization of € 1.2 billion. However, before the financial crisis, the stock had been trading at over € 95 per share.

Q-Cells business segments are:

- **'Solar Cells'** - Q-Cells core segment manufactures c-Si PV cells. This segment generates 92% of sales and 98% of gross profit.[59]
- **'Q-Cells International'** develops large-scale solar PV projects. This segment contributes 7% to the group's revenue and 0.3% of gross profit.
- **'New Technologies'** focuses on investing and developing new technologies.

---

[58] Jefferies Research, Clean Technology Primer, September 2009
[59] Q-Cells Annual Report 2008

7.1 Options Generation

Q-Cells names the following two major sources of strategic options:

- **Expert Pool:** A pool of internal and external experts informs and advises about technology developments and market trends.

- **Collaborations with Universities:** Q-Cells maintains close ties with leading universities in solar power technologies. This relationship is another source of potential initiatives that generate strategic options for Q-Cells.

Another potential source of options are Q-Cells' investors with backgrounds in renewable energies. As these investors screen alternative technologies and business ideas, they can provide a good source of knowledge to Q-Cells and could potentially accommodate collaborations with Q-Cells where a meaningful option can be generated.

For the purpose of this analysis we use strategic options that Q-Cells has generated and publicly announced. Q-Cells initiatives are grouped in line with the key strategic focuses that we proposed in the section "Scenario Analysis":

- Emerging solar PV technologies

- Market access

- Production in low cost countries

Emerging technologies:

Q-Cells takes stakes in companies that own or develop emerging technologies. The table below lists the currently active investments.

Figure 22: Q-Cells Technology Initiatives

Investment (ownership)	Technology	Description / Status
Solibro (100%)	CIGS	In 2009, Solibro's production capacity is 70 MW and is expanded to 90 MW in 2010.[60]
Calyxo (93%)	CdTe	Calyxo owns an exclusive global license for the commercialization of a thin film technology based on CdTe. A test production with a capacity of 25 MW was in operation during three quarters in 2008. It is planned to ramp up the production to 60 MW starting in the first half of 2010.
Sunfilm (50%)	a-Si/ µ-Si	Sunfilm uses a technology owned by Applied Materials to manufacture solar PV modules based on a-Si / µ-Si. Sunfilm's production capacity is 85 MW which is planned to be expanded by 60 MW.
Flexcell (58%)	a-Si on flexible substrate	Flexcell was established to develop and commercialize a flexible solar PV cell based on a-Si technology. The product is targeted for the building and product integrated applications. Flexcell is currently ramping up its production to 25 MW.
Sovello (33%)	String Ribbon	Sovello is a Joint Venture with Evergreen Solar and REC. Sovello uses the string ribbon process to produce wafers, cells and modules. Its production capacity is 100 MW and is currently up-scaled to 180 MW.
Solaria (32%)	Low concentration c-Si	Solaria develops an alternative cell design based on c-Si. Small mirrors concentrate sunlight to a conventional cell. Thereby material efficiency of the module is improved.

[60] The Q-Cells Factbook, 2009

Market access:

During the last few years Q-Cells has made efforts to generate options that improve Q-Cells's access to the end market of its cell products (mainly via project development). The company also diversifies its regional market footprint[61]. The table below shows three current initiatives.

Figure 23: Q-Cells Market Access initiatives

Investment (ownership)	Type	Description / Status
Q-Cells International (100%)	Project development	Development solar parks. The current project pipeline is 200 MW (in Italy, Germany, USA, France and Eastern Europe)
JV LDK	Project development	Development of solar PV projects in China and Europe.
JV MEMC	Project development	Development of large-scale solar parks that are sold to financial investors after completion (currently only Germany)

Production in Low Cost Countries:

So far there is one initiative that generates a strategic option of manufacturing in low cost countries. In fact this option must be considered as exercised since the plant in Malaysia will make up for 38% of Q-Cells' production in 2010, however we see potential capacity increases as a strategic option.

Figure 18 – Q-Cells Low Cost Countries Production initiatives

Investment	Type	Description / Status
Malaysia plant	c-Si production	c-Si cell production in Malaysia with a capacity of 300 MW by end 2009

[61] Currently, the company generates 30% of its revenues in Germany, 45% in the Rest of Europe and 14% in Asia and the rest in the Americas and Africa.

Other potential strategic options:

According to the scenario analysis there are three other categories of strategic options that have significant value in at least one scenario:

- **Vertical integration:** While Q-Cells has created strategic options in project development, there are no publicly announced initiatives that would target any vertical integration merely adjacent to Q-Cells core business solar cells. Such strategic options could target upstream integration to wafer manufacturing and downstream integration into modules and systems. That being said, Q-Cells has entered long-term supply contracts with wafer suppliers and module manufacturers instead of pursuing integration of these activities.

- **Brand building in residential market:** We see little strategic options in Q-Cells's current portfolio, which focuses on brand-building for the residential market (similar to Intel's 'Intel Inside' approach).

- **Other technologies:** Q-Cells has generated a wide portfolio of strategic options in different technologies. There are still emerging PV technologies that are currently not covered by the current portfolio.[62]

7.2 Assessment

In the next step, the strategic options undergo an assessment to build the basis for the selection process.

Gap Assessment - Effectiveness, Efficiency, Robustness

One of the goals of possessing strategic options is to position the firm to succeed no matter which scenario happens. Strategic options do potentially close a gap that the firm currently has or might have in one or several scenarios. To demonstrate this step we use Q-Cells investment in Flexcell.

[62] Mainly GaAs, organic and CSG (Q-Cells Factbook, August 2009)

In this case the dimension that is addressed is low cost, flexible, ultra light, solar PV products for building and product integrated use. Product integrated usage of solar PV often demands that modules are flexible and light in weight. Q-Cells core product "solar cells" are used in modules that are rather heavy and not flexible. Should a significant market develop for product and building integrated products, Q-Cells could not fully participate in this market without the strategic option "Flexcell". The Table below shows an illustrative assessment of "Flexcell".

Figure 24: Assessment of Flexcell (illustrative)

Gap	Product targeted at product and building integrated solar PV markets		
Measure	**Effectiveness**	**Efficiency**	**Robustness**
Weight	50%	30%	20%
Description	How well is the gap closed	Investment level, speed of execution, use of resources	Effectiveness across scenarios
Assessment	The assessment allocates points from 1-5 for each criteria.		

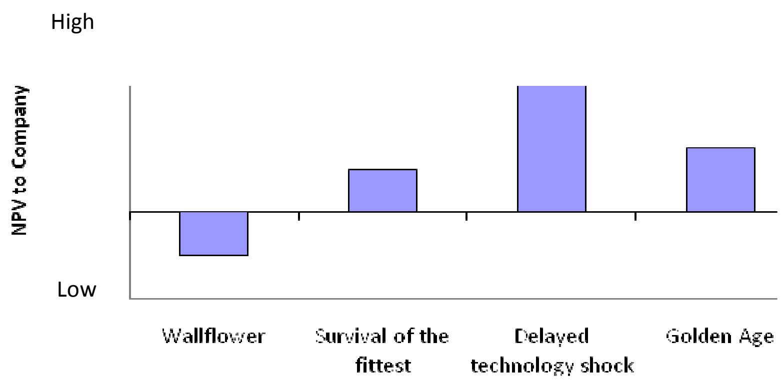
Valuation

An additional assessment is the valuation of the strategic option in all scenarios. The following assessment and the figure below demonstrate the valuation of Flexcell in different scenarios. This assessment is illustrative only and is not based on actual data.

In the "Wallflower" scenario, the Flexcell's technology did not advance enough to be commercially successful without subsidies. Hence, the investment must be liquidated at some point in time. In the "survival of the fittest" scenario, the technology advanced to some degree but the product will not be attractive enough to target a large consumer basis.

In the "Delayed technology shock" scenario, the technological advancement is sound in absolute terms but also relative to c-Si technology. In this scenario, Flexcell benefits from governmental incentives for an extended period of time and is highly competitive once incentive schemes phase out. In the "Golden Age" scenario, technological advancement of Flexcell is moderate in absolute terms but also relative to c-Si. While governmental incentives are still in place, the product is reasonably attractive. After governmental incentives phase out, Flexcell will find niche markets to place its product.

Figure 25: NPV Assessment of Flexcell (illustrative)

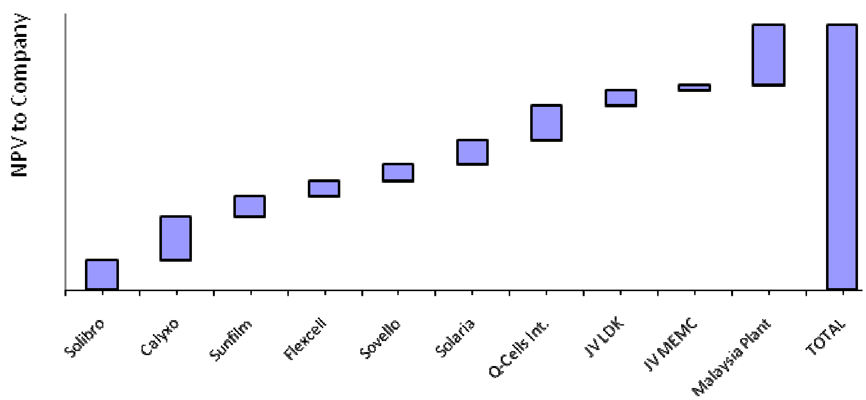


A more detailed assessment based on real options theory can be conducted using decision trees and might have great value in more complex cases. In cases where investment decisions are staggered in multi-period decision model, real options valuation is especially necessary. An option view will lead to very different assessments of investment opportunities, favoring investments that enable a company to ramp up the stakes over time. Hence, in environments with large uncertainty about the future, investments with large capital layouts will be valued less than the same investment allowing staggered investments over time. Also, immediate profitability is valued much more highly in a traditional DCF approach compared to an option approach.

Portfolio Assessment

In step 3, portfolios of strategic options are built and assessed by scenario. A potential result of this analysis of one scenario is illustrated below.

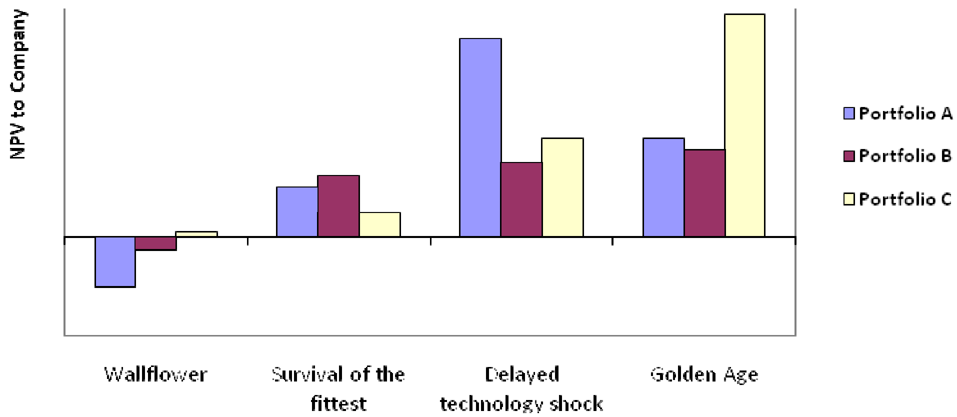
Figure 26: Portfolio assessment in Scenario X (illustrative)



7.3 Selection

Based on the assessments above, a portfolio of strategic options is selected. Selection criteria should reflect preferences of the stakeholders. Typical criteria are targeted to optimize the risk/return profile of the entire firm while considering constraints such as financial and non-financial resources and existing core competences. The figure below illustrates a potential set of information that could be used as a basis for portfolio selection.

Figure 27: Basis for portfolio selection (illustrative)

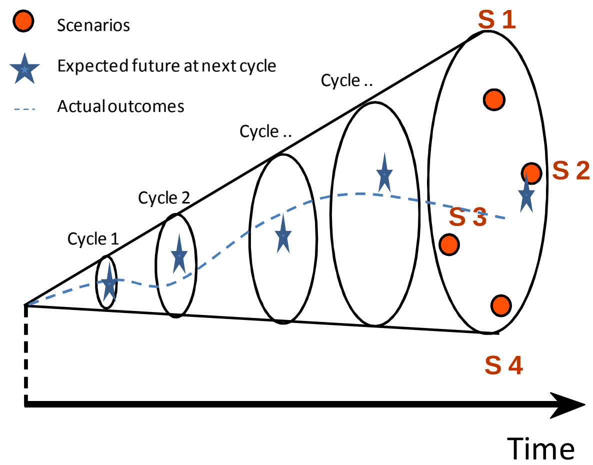


	Portfolio A	Portfolio B	Portfolio C
Investment sum			
Gap assessment score			
Expected return			
Volatility of returns			

7.4 Monitoring

Monitoring will track the path of the key forces defined during the scenario analysis. The actual state of the key forces is compared to the scenarios and a short term forecast for the next cycle is made. The scenarios are reassessed regarding their likelihood to become reality. As with financial options, real options must be monitored in relation to the strike price. However valuation is more complex for real options. Therefore a complex set of monitors, ideally linked back to the scenarios is required for monitoring.

Figure 28: Monitoring the key forces



As result of these changes the existing portfolio of strategic options as well as the option generation process is reassessed. Typically a dashboard is useful for such a monitoring process. A dashboard would compile relevant information about the key forces and expert advice and visualize the current present and the consequences thereof to the core business and strategic options. Finally decisions are made whether to execute or discontinue strategic option.

7.5 Assessment of Q-Cells strategic options portfolio

In this section we described the strategic options of Q-Cells (which are publicly known) and the theoretical assessment of each option (i.e. Flexcell example) and the overall allocation of budget to build option portfolios.

We conducted an overall assessment of the before described strategic option portfolio. Our assessment is based on the effectiveness and efficiency of each option for each scenario to meet the strategic imperatives (identified in Chapter 6). Overall goal of our assessment is to identify the missing strategic options which will hinder the company to strive in any of these scenarios.

Figure 29 summaries our findings about the effectiveness to meet the strategic imperative posed in each scenario.

- **Wallflower scenario**: In this scenario, most of the new technology options will have little value as c-Si stays the dominant technology. However, Flexcell might add considerable value to Q-Cells given that this technology allows Q-Cells to be active in a new market niche. The market access options do not meet the strategic imperative in this scenario as they focus on Europe and less on high radiation regions (California, Middle East, etc). Strategic options related to production are less important in this scenario.

- **Survival of Fittest scenario**: As c-Si technology is the single most dominant technology, the new technology options do not have any value. However, the market access through downstream integration will add significant value to Q-Cells (with the same caveat of the missing access to high radiation regions). The production option of increasing capacity in Malaysia adds significant value as it allows Q-Cells to generate significant economies of scale in a low cost country (with little operational risk).

- **Delayed Technology Shock scenario:** In this scenario, all new technology options will have major value to the company given the uncertainty which technology will be the most effective for generating solar PV. Similarly, options for downstream integration will allow Q-Cells to secure demand for its cells until mid of the decade. The production plant capacity increase has no value in this scenario as a new technology will require a complete remodeling of manufacturing.

- **Golden Age scenario**: Low concentration c-Si (lower dependency on suppliers of polysilicon) and the Flexcell (new niche market) will add significant value even in this scenario. Market access options are less important in this scenario. However, the potential increase in capacity in Malaysia adds significant value to Q-Cells. The option will allow Q-Cells to expand with little operational risk and secure its top rank in the market.

Overall, we infer that Q-Cells current portfolio matches very well the requirements of meeting the strategic imperatives across the scenarios. It provides a lot of value in the "delayed technology shock" scenario, which is of great importance to Q-Cells given the current assets of Q-Cells do not allow the company to compete effectively in this scenario. On the other hand, the portfolio of strategic options provides some value in the scenario "Golden Age" and "Wallflower". Q-Cells' current assets will allow the company to compete very well in both of these scenarios.[63]

Figure 29: Assessment of Q-Cells current strategic option portfolio

Assessment of current portfolio:	Scenario 1 "Wallflower"	Scenario 2 "Survival of the fittest"	Scenario 3 "Delayed technology shock"	Scenario 4 "Golden Age"
Technology				
Solibro - CIGS	◔	○	●	○
Calyxo - CdTe	◑	○	●	○
Sunfilm -a-Si	◔	○	●	○
Felxcell - a-Si (flexible)	◕	◑	◑	◕
Sovello - String Ribbon	◔	○	●	○
Solaria - Low Conc. c-Si	◔	○	●	◑
Market Access				
Q-Cells International (mainly Europe)	◔	◕	◑	◑
JV LDK (PV project in China, Europe)	◕	◕	◑	◑
JV MEMC (large scale projects, Germany)	○	◑	◔	◑
Production				
Malaysia Plant	◔	◕	○	●
Overall	◑	◕	●	◑

Legend: ○ = Ueneffective
● = Effective/meets strategic imperative

With the overall portfolio balanced and effective, we identified two major gaps in order to allow Q-Cells to compete efficiently across the scenarios[64]:

- **Lack of strategic options for market access in high radiation regions (e.g. California, Middle East).** This option would add tremendous value to the "Survival of Fittest" and the "Wallflower" scenario. Even for the two other

[63] With the Wallflower scenario being financially unattractive because of the market size of solar PV.
[64] Based on our research, we assume that Q-Cells posses many strategic options related to best–in class c-Si R&D.

scenarios, such an option will add many growth opportunities. Building or acquiring such an option will be of highest priority.

- **Lack of strategic options for marketing and brand building for residential market.** Both scenarios with high incentives – "Delayed Technology Shock" and "Golden Age" – offer the possibility to differentiate the products by brand building. Currently, there is no information that Q-Cells has any strategic real option to build such a brand. Such a strategic option could be generated via branding campaign (staggered over time) with or without the support of partners in the supply chain (e.g. distributors).

Figure 30: Assessment of Q-Cells strategic option portfolio (incl. new strategic options to close gap)

Assessment of portfolio with add. strategic options:	Scenario 1 "Wallflower"	Scenario 2 "Survival of the fittest"	Scenario 3 "Delayed technology shock"	Scenario 4 "Golden Age"
Technology	◔	○	●	○
Market Access (existing	◔	◕	◑	◑
Production	◔	◕	○	●
Market Access (sunny regions)	◕	●	◑	◑
Marketing/brand building (residential)	○	◔	●	●
Overall	◕	◕	●	◕

Legend: ○ = Ueneffective
● = Effective/meets strategic imperative
New strategic options

We conclude that the addition of proposed strategic options – market access to sunny regions and marketing/brand building for the residential market – will allow Q-Cells to close the strategic gap and compete effectively across all four scenarios.

8. Conclusion

8.1 Strategic Insights from the Process of Scenario Planning and Strategic Options

When facing high uncertainty from emerging technologies, scenario planning can add much insight into the process of formulating corporate strategy. First, the process of formulating stakeholders, trends and uncertainties allows managers to understand the importance of each driver and the connections between these. Second, building the scenarios that cover 95% of the future uncertainty gives managers a better understanding of the driving force behind uncertainty. Furthermore, describing the scenarios allows managers to understand how each scenario unfolds. This in turn gives important indication about the monitoring process.

The next step in scenario planning is to formulate strategy based on the insight from the scenario building. A first important conclusion is that the strategy must be effective in all different scenarios and not only be focused on one possible outcome of the future. We introduced the concept of strategic real-option thinking. Compared to traditional budgeting, this approach values opportunities based on the possibilities to take on positive NPV projects later on in the future. Especially in environments with high uncertainty, such real options have a very high value to the company. In order to build the most effective strategy, managers should assess all options based on the effectiveness, efficiency and robustness across the scenarios. In the next step, the strategic options should be combined to efficient portfolios. Complementary to strategic options, a thorough review should incorporate companies' current strategic assets when recommending a certain portfolio.

8.2 Strategic Insights for Solar PV Companies from the Scenarios

When building the future scenarios for 2020, we identified incentive programs and technological development for c-Si vs. other solar PV technologies as key uncertainty. While this is not a surprise to industry experts, some of the strategic implications of the scenarios might are.

The "Wallflower" scenario (very little new incentives and low technological advancement) will result in a pure niche market position for solar PV industry, with little opportunity to create value for any of the players. To maximize a company's value, players need to have market access to these niche markets (regional – to sunny areas; or by products – e.g. building integrated PV).

The "Survival of the Fittest" assumes little new incentive programs but the fast technological advancement of c-Si (absolute and relative). Again, in this case a successful player must have access to high radiation regions (California, Southern Europe, etc). Furthermore, operational excellence in production and R&D is a key element.

The "Delayed Technology Shock" is based on many new incentive programs and slow development of c-Si compared to other technologies. We expect that by 2020, thin film technology will take over majority of the solar PV market. Hence, it is a strategic imperative for c-Si players to diversify their technology base into thin film. Flexible production is necessary as the winning technology might not be known before 2015. Major threat to c-Si player is not the rise of emerging technologies but rather to recognize in time that c-Si does not have a bright future in this scenario. This will be particularly hard as c-Si players will be very successful amid the boom generated by new incentive programs. Furthermore, the existence of residential application allows companies to differentiate themselves via brand building and services.

The "Golden Age" (many new incentives, fast technological development of c-Si) offers many possibilities to incumbent players. However, while seemingly positive, the scenario poses some challenges on any c-Si player. We expect the market to consolidate fast, allowing only the top three players to compete. Economies of scale and operational efficiency will be key to a successful strategy in this scenario. This means that prices might decrease faster than in any other scenario given this "race for size". Again, marketing, brand building and services offer differentiation potential.

All of the described scenarios will challenge management as incentive program will generate high growth in the next years. This will drive incumbent players to increase their capacity significantly to be among the top players. However, in three of the scenarios (Wallflower, Survival of the Fittest, and Delayed Technology Shock), the c-Si market will experience a significant decrease/no growth in the second part of the decade. Hence, a successful c-Si player needs to trade off the need for economies of scale and cost efficiency with the flexibility to adapt the cost structure (production, R&D) to the actual outcome of the future.

Overall, we conclude that the ability to adapt to a scenario, market access to sunny regions, production efficiency and marketing/brand building are key strategic imperatives across the scenarios.

8.3 Insights about Q-Cells Strategic Options Portfolio

Using a strategic option approach, we analyzed Q-Cells strategy based on the (publicly announced) strategic options. We analyzed the options in the categories new technologies, market access and production in low cost countries based on their robustness, effectiveness and efficiency across the scenarios. We conclude that Q-Cells has built a strong real option portfolio especially with regards to the strategic imperatives posed in the "Delayed Technology Shock" scenario. Also, the option portfolio has at least some effectiveness in all three other scenarios. Based on the current strategic options, we identified two main strategic gaps: first, the lack of market access to sunny regions such as Southwest of the US, and second, the lack of strategic options for brand building for the residential market. We recommend building options in this space to close the strategic gap and make the portfolio effective across all four scenarios.

9. Bibliography

Arnulf Jäger-Waldau, “PV Status Report 2008”, Joint Research Center of the European Commission, 2008

Ben Isaacson, “Alternative and Renewable Energy”, Scotia Capital, August 2008

Bosch Solar, “Module a-Si plus specification”, October 2009

Bosch Solar, “Module μ-Si plus specification”, October 2009

BusinessWeek, “Why Tech bows to Best Buy”, Business Week, December 10 2009

Deutsche Bank, “Solar PV industry update”, October 2009

Energy Improvement and Extension Act of 2008, The Library of Congress, 2008

First Solar, “FS Series 2 PV Modules Specification”, January 2009

First Solar, “SEC filing 10Q”, October 2009

Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich, Bundesanzeigerverlag, October 2008

HSBC, “Global Solar Power”, September 2009

Jefferies Research, “Clean Technology Primer”, September 2009

Paul J.H. Schoemaker and V. Michael Mavaddat, “Scenario Planning for Disruptive Technologies” in “Wharton on Managing Technologies”, G. S. Day and P. J. H. Schoemaker, Wiley, New York, 2000

Paul J.H. Schoemaker, "The Future of Bioscience", The Wharton School, Philadelphia, 2008

Q-Cells, "Annual Report 2008", 2008

Q-Cells, "The Q-Cells Factbook", 2009

Renewable Energy World, "Thin film's Share of Solar Panel Market", November 13 2009

Photon Magazine, "Market Share of Solar PV technologies", April 2007

Stefan Hirschberg et al., "Renewable Energies and Nuclear Energy", Paul Scherrer Institute, Villigen, 2005

Würth Solar Gene, "CIS Photovoltaic Modules specification", June 2008