Solar Energy: New Thin-Film Technology vs. Low Cost Chips for Traditional Technology

Management of Engineering and Technology
ETM 520/620
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Fall 2011

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Executive Summary

Our class term project focused on solar photovoltaic (PV) technology. The purpose of the project was to answer the question: Who wins the battle: New Thin-film Technology or Low Cost Chips for Traditional Technology?

During the project, a deep industry analysis was performed. Articles from journals such as Energy Policy, Progress In Photovoltaics: Research And Applications, and Science, for example, were analyzed. Information from reports, laws, and regulations was gathered and thoroughly studied from many sources including: National Renewable Energy Laboratory (NREL), International Energy Agency, and European Photovoltaic Industry Association.

Key project findings included the following:

1. Crystalline photovoltaics is a mature technology. This technology is the most prevalent technology used world-wide.
2. Thin-film photovoltaics is still a developing technology. As time passes, one or two of the thin-film technologies will emerge to dominant this subset of photovoltaics. Thin-film solar will continue to take market share away from traditional crystalline solar.

It can be concluded that although the current industry leader is the lower cost, more efficient and well-known crystalline PV, thin-film solar technology is gaining market share due to flexibility, less complex manufacturing process and a promising R&D perspective. As the world's demand for energy increases, renewable energy will play a key role in meeting those demands. There is room for both traditional crystalline and newer thin-film solar cells.

Introduction

With the limited amounts of fossil fuels left to consume and an increased awareness of the damage caused by the use of said fuels in producing energy, alternative energy proliferation has marked this era.

Solar energy in the form of photovoltaics (PV) has become an increasingly relied upon technology to produce "green" energy for consumption. Crystalline silicon (c-Si) has dominated the solar market due to being first on the market. Thin-film solar cell (TFSC) is a new technology and a "second mover" into the market. Both technologies have pros and cons.

The objective of the project is to study and forecast the future of the Solar Industry, specifically in regards to TFSC and crystalline silicon. This topic was selected because it demonstrates how differing technologies conflict, and drive innovation and risk-taking. As these technologies move from innovation to full commercialization, they become commod itized products, thus price competitiveness becomes a key focus of the technologies.

In order to be able to answer the questions raised in the project, we have analyzed the current state of solar market with regard to c-Si and TFSC. An industry analysis allows identifying the relevant environmental factors shaping an industry. Knowledge and understanding of industry's structure, competition conditions, forces that influence it help to predict its future and identify the progress direction.

The information was gathered from existing statistics, published reports, and defined laws and regulation. After analyzing these sources of information, we expect to learn where both of these technologies are at today and where each technology is trending.

The paper is structured as following:

1. Technology Description. A historical overview of the innovation of both technologies is given, as well as information about materials consumption, production process, advantages and disadvantages.

2. Market Trend for PV Solar Energy. Information is given about solar market recent trends, comparison of technologies in terms of adoption in different countries (USA, China, Euro zone) and describing of future goals.

3. Government Involvement. Summary of main energy policies of China, USA, France and EU are presented with emphasis on attitude toward silicon crystalline and thin-film photovoltaics.

4. Consumers. Major categories of solar panel consumers: consumer products, residential, government, utilities, and commercial/agricultural.

5. Discussion. Summarizes the main outcomes of the industry analysis and presents answers for the following questions: Why is c-Si PV is an industry leader? What are the steps for thin-film technology to gain market share? What predictions can be made?

6. Conclusion.

Technologies Description

The photovoltaic (PV) effect was discovered in 1839 by Becquerel while studying the effect of light on electrolytic cells. However, it took decades of development before solar cells of sufficiently high efficiency could be produced. Solar cells developed rapidly in the 1950s owing to space programs and used on satellites (c-Si solar cells with efficiency of 6–10%). The energy crisis of the 1970s greatly stimulated research and development (R&D) for PV. Solar cells based on compound semiconductors (III–V and II–VI) were first investigated in the 1960s. At the same time, polycrystalline Si (pc-Si) and thin-film solar cell technologies were developed.

Materials Consumption

crystalline
process

Figure . Monocrystalline solar cell

multicrystalline silicon

Figure . Multicrystalline solar cell

Ribbon silicon

Figure . Ribbon multicrystalline solar cell

solar cell
Many different photovoltaic materials are deposited with various deposition methods on a variety of substrates. Thin-film solar cells are usually categorized according to the photovoltaic material used:

Amorphous silicon
Cadmium Telluride
Copper indium gallium selenide
Dye-sensitized solar cell

Advantages and Disadvantages

Crystalline Silicone

Advantages

- Longevity: Monocrystalline solar panels are first generation solar technology and have been used for more than 60 years, providing evidence of their durability and longevity. The technology, installation, performance issues are all understood.
- Efficiency: Crystalline PV panels are able to convert higher amount of solar energy into electricity than the thin-film panel.

Figure . PV technologies efficiencies

- Installation Costs: lower than for the thin-film PV.

Disadvantages

- Nearing Maximum Efficiency: Single-junction c-Si and GaAs solar cells are approaching their upper limits in terms of the theoretical maximum efficiency.
- Initial Cost: Because PV panels made from single-cell silicon crystals the process of making them is one of

the most complex and costly ones around. Good silicon feedstock is expensive and the cost of making a single pure crystal is time-consuming and therefore costly. PV panels from single crystalline solar cells generally cost more per panel than competing PV technologies.

- Fragility.
- Wasted Raw Material: The manufacturing process for crystalline cells is wasteful.

Thin-films
Advantages:

- Versatility: Thin films can be disposed on a wide variety of surfaces such as glass or even paper. The technology allows tailoring different layers.
- Materials:
  - Thin-film materials can be deposited on flexible substrate materials. However, their flexibility is a characteristic of their construction and they are typically installed flat; and by the time they're installed, they become inflexible.
  - Low materials consumption/m2.
- Costs: Potential for lower module manufacturing costs due to processes standardization and using new equipment.
- Performance:
  - Thin-film modules offer higher so-called diffuse light efficiency than crystalline solar modules and are

thus better suited for indirect or diffuse lighting conditions.

- Good performance in high heat. Thin-film solar panels don't suffer a decrease in output when temperatures increase. High outdoor temperatures can lower efficiency of silicon based modules by 10% or more in some locations. Some thin-film modules may even have a slight increase in their outputs at higher temperature levels.

Disadvantages

- Efficiency: Thin-film solar panels have lower efficiency in comparison with crystalline panels.
- Raw Materials: Concerns about the scarcity of indium and tellurium and thus the limitation in production of thin-films panels.
- Toxicity Concerns: Both CdTe and CIGS use cadmium which is extremely toxic.
- Costs: High installation and operation and maintenance costs.

Market Trend for PV Solar Energy

Demand for energy is accelerating as more of the world becomes developed. Developing countries are anticipated to double the world's demand for energy in the next thirty years. The global solar power market has experienced tremendous growth during the last three years as a consequence of increasing government concerns about energy security and independence. In addition, other factors, such as rising energy prices, volatility of fuel costs, and government incentives for renewable energy, have contributed to the acceleration of market growth.

According to GreentechSolar's study published in July 2011, Germany is the country with the most solar installations, 28 times more installations than United States. On the other hand, the bankruptcies of three American solar power companies in summer 2011 have left China's industry with a dominant position in the manufacturing of solar panels in a world desperate for renewable sources of energy, according to the New York Times. In accordance with IEEE Spectrum Inside Technology magazine published in February 2011, the top countries for PV installations are: Germany, Italy, Japan, United States, France, and China.

The figure below shows the historical development of global cumulative PV power installed per region. Most of the market share belongs to Europe, Japan, and USA.

Figure . Historical development of global cumulative PV power

Crystalline Silicon and Thin-Film World-wide Market

Since the goal of this research is to compare crystalline silicon and thin-film solar panels, the following information is focused on these two technologies, their market shares today, and forecasts for the future. In the year 2000, it was predicted that TFSC technology would dominate the PV market. However crystalline silicon is still the largest solar energy technology and it is expected to dominate the market in the upcoming years. There are several reasons to explain this domination. First, high efficiency c-Si panels are available at low cost-per-watt. Additionally, crystalline silicon technology is known as an efficient product with at least a 20 year lifetime and low risk replacement with high expectation for return on investment. WinterGreen Research's new report indicates that the dynamic growth of silicon solar panels will continue, furthermore, its forecasts show an approximate increase of $90 billion in market share from 2010 to 2017.

Despite the fact that crystalline silicon is leading the solar energy technology market, TFSC cells are gradually gaining importance. Two key elements that can place TFSC in a market leadership position are feedstock and cost.

- Feedstock: One significant reason that could allow thin-film technology to gain market share is the global shortage of silicon. Until 1995, rejects of microelectronics industry were used in PV industry; they could obtain silicon feedstock at reduced prices. Today however, the availability of silicon feedstock is acknowledged as the critical issue in keeping up the high growth ratios of crystalline silicon market. The availability of silicon for PV industry depends on the needs of semiconductor industries as well. Semiconductor and photovoltaic industries both need silicon for their products and since semiconductor industry can pay more to feedstock manufacturers, silicon feedstock can affect PV industry more than before. However, analysis by some researchers demonstrates that the thin-film PV market will not suffer from the scarcity of silicon, and it may benefit from this situation . While crystalline silicon PV manufacturing process suffers from the silicon shortage in 2006 and 2007, the thin-film manufacturing process has the capacity to grow further. The figure below shows the production capacity from 2003 to 2010 in crystalline silicon and thin-film technologies.

Figure . Production capacity

- <u>Cost</u>: Cost can play an important role in increasing market share of TFSC. The cost of silicon accounts for about half of the production cost crystalline silicon solar cells . Sun Power Corporation has predicted that in the next 10 years, the solar module manufacturing costs will be approximately $1/W for both technologies, but it is anticipated that thin-film technology will take further cost reduction steps. Considering installation costs, the ultimate desired manufacturing costs should be $0.5/W at efficiency greater than 10% . Additionally, fossil fuel cost can directly change the overall market share of these two technologies; escalation of fossil fuel price will result in slower solar market development.

Both cost and raw materials issues are pushing the world-wide market toward TFSC cells. More than 100 companies have entered the thin-film solar industry between 2001 and 2009. For the decade ahead, the major thin-film producing countries (Japan, China, and United States) have expanded incentives for renewable energy installations and these countries have even changed some regulations for more support. WinterGreen Research has studied the thin-film marke t share, strategies and forecasts from 2010 to 2017. As a result, it has announced that thin-film technology, which already has $2.9 billion of the market share, will grow to $44 billion by 2017. Figure 7 shows the market share of both technologies in the past, present, and expectations for the future market.

Figure . Thin-film and Crystalline Silicon market share

The lower market penetration realized by thin-film technology is explained by its lower efficiency compared to c-Si, that in spite of TFSC cost-effectiveness. Due to the poor global economic situation, inventors and manufacturers are more willing to invest in mature and abundant crystalline silicon technology rather than thin-film technology. Reflecting the prediction of increased TFSC market share, figure 8 shows that global production capacity will continue to increase.

Figure . Production capacity of thin-film and c-Si

Thin-film Technology Adoption World-wide

In 2012, the thin-film market capacity is expected to be high in China and Taiwan. Europe and North America are so close to each other that can both be considered as the second ruling participants of thin-film industry. Estimates of 2012 thin-film capacity by both region and technology indicate that Asian countries (Japan, China, and Taiwan) have adopted amorphous silicon as their first choice in thin-film technology. At this time, these countries have not considered use of CdTe in thin-film industry. In Europe, amorphous silicon is the primary technology of in the thin-film market. Europe uses CdTe for thin-film solar, as well.

Although North America was expected to have almost equal growth for all types of thin-film technology, a higher rate is seen in CIGS. This could be due to the growth of the few of the many TFSC manufacturers in United States.

Figure . Thin-film by technology and region

First Solar is predicted to remain the largest thin-film manufacturer in the world for the next three years; its production is spread across manufacturing sites in Germany, France, United States, and Malaysia. China and Taiwan show a large capacity, one thin-film company in China is considered in the top-ten dominant solar firms based on the study done by GTM Research group. This fact indicates that there might be many small and mid-sized firms in this region whose survival will be unlikely.

Amorphous thin-film is more successful in non-European market including the United States, Middle East, India, and

China; this type of thin-film operates better in hotter climate and that is why the regions stated are more suitable for TFSC technology. In the United States, due to its diverse climate, amorphous silicon thin-film technology works better in Sacramento and Phoenix than it does in Seattle.

China's Role in Future of the Thin-film and Crystalline Silicon PV Market

Having received funding and resources from Chinese government, solar companies in China have increased their rates of production by orders of magnitude in the past decade. The solar manufacturing sector is shifting from being governed by different countries around the world to one dominated by Chinese companies. Between 2003 and 2005 the performance of the PV market, especially that demonstrated by Germany, encouraged China to increase its PV production. Chinese manufacturers' significant improvements in conversion costs and silicon utilization, as well as normal silicon prices, will make the race between crystalline silicon and thin-film technology very close to each other.

Some negative and positive points regarding China's PV industry are indicated below.

Crystalline Silicon:

- Rapid Rate of Growth

- High dependence on imported feedstock: Lack of feedstock and international market will influence Chinese market. Ninety-five percent of the silicon feedstock must be imported from abroad.

- Production of mono-crystalline silicon: The CZ-silicon technique is mature and can be made domestically in China, which is inexpensive compared to imported polycrystalline silicon. Many Chinese manufacturers produce monocrystalline silicon technology which results in a significant investment for these PV firms. However, in rest of the world, mono-crystalline silicon is more expensive and therefore its use is half that of the polycrystalline silicon technology.

Thin-film:

- Production of amorphous silicon solar panels (thin-film): Dupont, which is known for its material that protect solar cells from moisture, is mass producing amorphous silicon solar panels in China.

Suntech, a leader in China's crystalline PV industry, sells its production domestically and exports c-Si to Europe, USA, Middle East, South East Asia, and Africa.

Future Technology Goals

Research and development (R&D) is one of the differentiating factors in success of current PV manufacturers all around the world. In the previous years, dominant countries have increased their investments in R&D. Future goals and R&D efforts for both thin-film and crystalline silicon technologies are discussed below.

- Crystalline Silicon

According to Energy Technology Perspectives crystalline silicon PV modules will remain a dominant technology in the market until 2020. Although their technologies are mature and their lifecycle is reliable, there are still some challenges in their use and production. The main challenge for c-Si modules is to improve cell efficiency and increase the effectiveness of resource consumption through materials reduction, improve cell concepts, and factory automation. Greater solar panel efficiency will translate to maintaining current market share.

Crystalline silicon PV	2010-2015	2015-2020	2020-2030
Efficiency Targets	• Single-crystalline: 21% • Multi-crystalline: 17%	• Single-crystalline: 23% • Multi-crystalline: 19%	• Single-crystalline: 25% • Multi-crystalline: 21%
Selected R& D areas	• New silicon materials and processing	• Improved device structures • Productivity and cost optimization in production	• New device structures with novel concepts.

Table . Technology goals and key Rand D issues for crystalline silicon

- Thin-Film

Thin-film technology had not yet become the leading technology in the solar industry. Its drawbacks include low efficiency, and with limited experiences, solar life-time is not known. Increasing the cell efficiency will result in increased market share.

Thin-Film PV	2010-2015	2015-2020	2020-2030
Efficiency Targets	• Thin-film Si:10% • CIGS: 14% • CdTe: 12%	• Thin-film Si:12% • CIGS: 15% • CdTe: 14%	• Thin-film Si:15% • CIGS: 18% • CdTe: 15%

Selected R& D areas	• Large area deposition process • Improved subtracted and transparent conducive oxides	• Improved cell strictures • Improved deposition techniques	• Advanced materials and concepts

Table . Technology goals and key Rand D issues for thin-film

In general, these criteria will ensure both of these technologies will dominate the solar market:

- Operational Characteristics
- System cost variables
- The price and availability of substitutes, for example cost and availability of crystalline silicon PV can

significantly affect thin-film PV market.

- Market Characteristics such as incentive structures in different countries, market application type, and

environmental conditions in each area.

- Potential Supply which depends on manufacturing capacity.
- Qualitative Factors

To sustain a growth rate in PV market either of these scenarios should be implemented:

- Drastic increase of solar grade silicon production capacities.
- Accelerated reduction of material consumption per silicon solar cell, higher efficiencies, thinner wafers, less waf

ering losses.

- Accelerated introduction of thin-film solar cell technology into the market and capacity growth rates above the

normal trend.

Governmental Involvement

Various governments have implemented policies that have influenced the manufacture and usage of solar technology. Policies from the United States, China, and European Union were reviewed. While none of the policies specifically favor solar technology (e.g. thin-film, c-Si), these policies are worth mentioning because of the influence government involvement has in the progress of solar technology innovation and adoption.

United States Energy Policy Development

Five key goals can be seen as components of the United States energy strategy:

- Diversify energy supply by promoting alternative and renewable sources of energy, encouraging the expansion of nuclear energy in a safe and secure manner, increasing domestic production of conventional fuels, and investing in science and technology.
- Increase energy efficiency and conservation in homes and businesses
- Improve the energy efficiency of cars and trucks
- Modernize the electrical power infrastructure
- Expand the Strategic Petroleum Reserve

The application of PV technology can help the United States meets these goals. As of 2010, the solar power industry in the United States generated approximately 2.9 GW (this figure includes both solar PV and solar thermal capacity). The

Department of Energy (DOE) estimates that approximately 16 GW could be available by 2020.

In the United States, at the federal government level, several key pieces of legislation have been passed over the decades. The National Energy Act of 1978 encourages public utilities to generate electricity from renewable sources. The Energy Independence and Security Act of 2007 grant funds for solar technology research and development . State governments also pass legislation to bolster the solar industry. California has several laws that impact the solar industry; this research focuses on two. First, the Homebuyer Solar Option and Solar Offset Program passed in 2006. It requires that home builders offer solar power solutions to home owners. There is also an opt-out clause; however the home builders are required to install solar power units elsewhere. Secondly in California, there exists a specific Solar Contractor License called C-46 . This license requires the contractor have four years of experience and be versed in business and trade rules. The state of New Jersey has a similar residential solar requirement to California. In this example, the developer must install a solar power system on all residential buildings with more than 25 units .

There are a number of government projects that support R&D in the solar PV area. One of the premier examples of such incentive is the National Renewable Energy Lab (NREL) Thin Film Photovoltaic (PV) Partnership Project, which was conducted from 1994 to 2009. The aim of this project was to support interactions and communication between solar com panies (e.g., First Solar, Global Solar) and universities/government laboratories with the intention of improving the thin-film PV technologies. The following lessons come from the project and can be used in future:

- Create industry-government partnership to facilitate innovation adoption process in large companies.
- Account the size of the companies that take part in the project in order to share responsibilities and cost burden accordingly.

- Encourage engagement of universities by partial or full funding of the project.
- Include national laboratories.
- Emphasize the importance of team work as it helps universities to learn industry needs and companies to know want researchers can do for them.

European Union Energy Policy Development

The EU lacks a cohesive energy policy, as demonstrated by the US material above. Most energy policy legislation is generated by EU member states. Germany is an example of a member state that provides legislation and financial incentive to drive the adoption of solar technology in its country. A major incentive in Germany is the use of feed-in tarif fs. These tariffs are effectively a subsidy from the German government to entities that generate solar power (e.g. home owners). The German Renewal Energy Act defines the subsidy on the cost of generating the solar power, it disallows utilities from participating in the program and program participants receive the feed-in tariff subsidy for 20 years. Additio nally, Germany instituted a program, ending 2004, called the 100,000 Solar Roof Initiative. Participants of this program received low interest loans to install solar power systems. The goal of the program was to drive down the cost of PV technology in Germany. The program successfully realized the installation of all 100,000 solar installations on roofs .

China Energy Policy Development

China is more like the United States than Europe, in that there are energy policy goals and key pieces of legislation to meet those goals. Author Ming Yang, et.al, identifies four issues for China: Low energy efficiency, artificially low electricity tariffs, gap in supply-demand curves, under productive state-owned business . All four of these issues have driven China to adopt new laws with regard to solar power. The Law for Prevention and Control of Air Pollution of 2000 is an example law that encourages the use of solar technology.

Consumers

With governments world-wide supporting solar technology, a wide consumer based has grown. Consumers of thin-film and crystalline solar technology include Consumer Products, Residential, Government, Utilities, and Commercial/Agricultural. Consumer Products include items such as solar powered chargers and toys. The Residential category includes roof- and ground-based solar panel arrays. Governments use solar technology in various ways, from solar arrays on federal buildings to solar powered vehicles for space exploration. The Commercial/agricultural category is similar to the residential category, but arrays implemented here are much larger. The Utilities category also implements large solar panel arrays, but main purpose of these solar farms is to produce power which then sold to electricity customers (as opposed to being consumed upon generation).

Consumer Products

There are many solar-powered consumer products available. Solar-powered consumer products cover a wide variety types. Examples include solar-powered chargers, toys, garden lighting, attic fans, calculators, wireless computer keyboards and mice include just a few of the consumer products that utilize solar technology. Because thin-film is less expensive and is a flexible technology, it is the most popular solar technology used in the consumer products market. But there are examples of crystalline PV used in consumer products. One such example is Brunton's portable solar array .

Figure . Logitech solar powered thin-film keyboard

Figure . Brunton poly-crystaline solar charger

Residential

Both thin-film and crystalline technologies comprise the residential use solar technologies. Roof-based solar panel arrays are most popular, but ground-based arrays also exist. In addition to traditional solar arrays, home owners could also build a roof from thin-film solar tiles.

Figure . Solar Slates, a solar panel alternative

There are many factors influencing home owners' decisions to install a solar panel array on one's property.

- Technology: Thin-film or crystalline. Home owners must balance the lower cost of thin-film panels with the higher efficiencies realized with crystalline technology.
- Restrictions: North facing roofs, heritage properties.
- Funding: Homeowners much secure funding in order to install solar arrays on one's home. There are instances of local credit unions offering special financing for solar installations. Feed-in tariffs is an alternative financial model for home-owners. Here, the government pays the homeowner for the solar energy produced by the array. Leasing is also an option.
- Aesthetics: Solar arrays are considered unattractive by some. There are attempts by panel makers to produce thinner solar panels, to have a lower profile on rooftops. Additionally, black solar panels are now available, which are considered more attractive than older style panels. Lastly, as pictured in Figure 11, solar tiles mimic the look of a roof.

Government/Military

- US Military – From solar backpacks and chargers to solar arrays installations, the United States military is using solar technology.

Figure . Solar array in Afghanistan

- NASA – Mars Rovers use gallium arsenide/germanium thin-film solar cells.
- Federal buildings – In 1979, the White House, under the presidency of Jimmy Carter, installed a solar array

on the roof of the building.

Figure . Opportunity's solar panels (dust free!)

Commercial/Agricultural

Solar arrays used in Commercial/Agriculture are similar to residential solar arrays, but are on a much larger scale. The power produced is used on-site to augment or replace traditional power sources of power.

Figure . 83 kW commercial array, poly-crystalline solar modules

Utility

Utility companies install massive solar arrays for the purpose of selling power to consumers.

Thin Film Solar Power Plants

- First Solar & NRG Energy: 66 megawatt (AC) Alpine solar project in Lancaster, California (thin-film). This power plant serves 25,000 homes annually.

- Blythe PV Power Plant: Located east of Los Angeles. The entire power plant will be 500 MW. First Solar thin-film panels make up this power plant. There are about 350,000 panels covering approximately 70 acres. Power is purchased by Southern CA Edison in a 20 year agreement. This plant went commercially operational in 2009.

Figure . First Solar power plant in Blythe, CA. Power purchased by Edison.

Crystalline Solar Power Plants

- Los Angeles Department of Water and Power, Adelanto, CA (under construction): 12 MW. Power to serve 2500 homes daily.

- SMUD Rancho Seco: began in 1984 with a 1 MW array. Today: 6 PV systems, latest array installed in 2004, totaling 3.2 MW, enough to power about 3000 homes.

Discussion

The currently distribution of market share between crystalline silicon and thin-film is 90% and 10%, respectively . The main reasons of larger market share of silicon crystalline are:

- High efficiency.
- Proven decades of solar panel performance.
- The largest producers of crystalline silicon panels are Chinese companies. These companies have become the industry leaders by achieving cost advantages due to low-cost manufacturing processes and equipment, huge manufacturing capacities and high economy of scale, local and government support.
- Less expensive installation because of a smaller quantity of these high-efficient panels are needed for the same electricity output.
- Absence of government support for installation of thin-film PV.

Movements and actions that are changing the industry and moving it toward greater innovation:

- Incremental innovation and improving energy conversion efficiency, approaching and eventually exceeding traditional crystalline PV enhance their efficiencies.
- Developing economically viable manufacturing processes.
- Providing among consumers better understanding of the unique and wide range of structural and chemical characteristics of thin-film materials, and effective usage of these properties for applications on varieties of

surfaces and in different environment conditions.

- Government policies support R&D of thin-film technology as well as incentives for companies to install thin-film s olar panels.
- Programs and projects to support communication between industry and academia.
- Incremental innovation of crystalline silicon photovoltaic technology in terms of effectiveness, manufacturing process optimization, material usage reduction.

Future predictions:

- Both technologies will present in the market for years to come.
- Silicon crystalline PV will reach the technology limit and only companies that produce low-cost and high module efficiency PV will survive (most likely they will be Chinese companies).
- R&D will be directed toward increasing the efficiency of thin-film PV devices and developing cost-effective manufacturing technologies.
- Traditional crystalline installations will continue, particular in small solar installations. Thin-film installations will also realize heavy adoption, especially in residential installations and large-scale installations.

Conclusion

The purpose of the project was to answer the questions: What is the future for Solar Energy? Who win the battle: New Thin-film Technology or Low Cost Chips for Traditional Technology?

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Key project findings included the following:

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2. Thin-film photovoltacis is still a developing techology. As time passes, one or two of the thin-film technologies will emerge to dominant this subset of photovoltaics. Thin-film solar will continue to take market share away from traditional crystaline solar.

It can be concluded that although the current industry leader is lower cost, more efficient and well-known crystalline PV, thin-film solar panels are gaining market share due to flexibility, less complex manufacturing process and a promising R&D perspective. As the world's demand for energy increases, renewable energy will play a key role in meeting those demands. There is room for both traditional crystalline and newer thin-film solar cells.