Solar Power Renaissance

Taejas P. Srinivasan[#1], Divakar Rajamani[*2]

[#1]*Thomas Jefferson High School for Science and Technology*
6530 Braddock Road, Alexandria, VA 22312, USA
12016tsriniva@tjhsst.edu
[*2]*Naveen Jindal School of Management, The University of Texas at Dallas*
800 West Campbell Rd, Richardson, TX 75080, USA
[2]*divakar@utdallas.edu*

***Abstract*—Over the past decade, the solar industry has flourished, resulting in more cost competitive power production. In this paper, we focus on the underlying factors for the solar panel manufacturing cost decrease from supply chain improvements, which have led to a more attractive profitability potential in the industry despite price pressure on revenue. However, we find no evidence that the supply chain cost gains can continue to dramatically lower the cost of production any further. Therefore, manufacturers need to find new ways to improve the manufacturing efficiencies subject to the theoretical limits on energy conversion efficiencies or move up the technology maturity curve to the next generation of solar technology.**

***Keywords*—** *Solar Panel Supply Chain, Declining Solar Power Cost, Solar Power Scale Advantage, Next Generation Solar Technology*

1. Introduction

Global solar power production has been accelerating over the last decade as both developing and developed countries are beginning to realize the potential behind various renewable sources, particularly, in the context of climate change as well as self-sufficiency in energy production. While wind energy has reached more maturity due to its inherent advantages, such as all-day production in wind rich areas along with geographical latitude independence, the solar energy production is slowly maturing and becoming more competitive. Various factors account for this acceleration, including tax subsidies, government mandates to utilities, impressive technological growth, price collapse in silicon production costs, and the geo-political uncertainty around fossil fuel production.

In this brief paper, we identify the drivers for lowering the cost of solar panel manufacturing. We discuss our methodology in Section 2 and the overall cost impact from supply chain and scale effect in Section 3. In Section 4, we devote our attention to the future technology drivers, which may contribute to additional cost decline. These include both the conventional ones in place today as well as disruptive technologies on the horizon that would make them more affordable. We conclude this paper in Section 5 with areas to explore as next steps.

2. Methodology

We have structured our research based on a few key hypotheses, observed in other markets and renewable energy. Like any other industry, renewable energy is subject to similar market dynamics. First, rapid cost decline occurs through supply chain optimization and manufacturing efficiencies. Subsequently, scale advantages accumulate as wide-scale adoption follows from competitive costs. Upon saturation, the industry reinvents through discovering new technologies to arrive at new orbits of cost decline. We have investigated the aforementioned trends: supply chain cost reduction, scale advantage, and advent of new technologies. Our analysis is based on publicly available market data through industry reports, company financial statements and annual reports, and our own modelling.

3. Cost Impact from Supply Chain Improvements and Scale Effect

The solar panel industry, like any other renewable energy field or energy industry in general, undergoes boom and bust cycles due to large capital needs. Being a relatively young market for widespread adoption, this effect is more pronounced. Every time the investors conclude that we have reached a beginning of the end of a market segment, a new technology or market externalities kicks in to revive the market rapidly.

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Because energy, as a consumable product, is a substitutable for the most part, investors chase the profitability in the segment when technology innovations do not meet the promised potential.

With an installed capacity to date around 60 Gigawatts (GW) around the world, growing at a Compound Annual Growth Rate (CAGR) of 6%, solar energy has enormous potential, comparable to the successful penetration of the wind energy into mainstream power production [1]. However, a few foundational challenges inherent to solar energy remain: 1) need to follow the sun for maximum harvesting, 2) geographic dependence on staying closer to equator, and 3) weather dependencies. Despite these challenges, even at the current required rate of 6-8 acres per Megawatt (MW) capacity [6], plenty of inexpensive real-estate is available around the equator belt, making it highly competitive.

In less than a decade, solar panels have become more affordable and have resulted in a pay-back period less than 8-10 years. This progress is attributable to four key drivers:

- Subsidies and tax breaks to spur demand
- Government mandates to utilities for solar farming
- Education on climate change, influencing public mind-set about renewables
- Technology growth resulting in much cheaper silicon production and price collapse in silicon wafers, efficiencies in manufacturing processes, and disruptive new approaches to pushing efficiencies

While the first three factors result in a higher scale economy, the last factor is what we would primarily focus on in this paper. It is worthwhile briefly to study the cost structure for a typical solar panel company. We recognize that the cost structure may change depending on the geography, underlying technology, and the target markets. Nevertheless, directly relevant conclusions can be derived as we look at the cost structure (see Figure 1) for a typical manufacturer, as reported by Goddard [3].

The two largest components of the cost structure for a typical solar panel manufacturer are a) labor costs and b) supply chain costs. The predominance of the labor costs, despite most of the volume of solar panels being produced in cheaper labor cost countries, such as China and Malaysia, is not surprising, considering the complexity in assembling the solar panels together in a high quality fashion to reduce warranty costs from defects. There are typically six layers in a panel: a top surface to conduct the charge without shadowing the cells, a second layer as an anti-reflector coating, three layers for the n-type cell junction and the p-type parts of the semi-conductor, and the back layer for the metal contact to harvest the charge [6]. Yield rates are often challenging. Automation technology should evolve in reducing the labor costs.

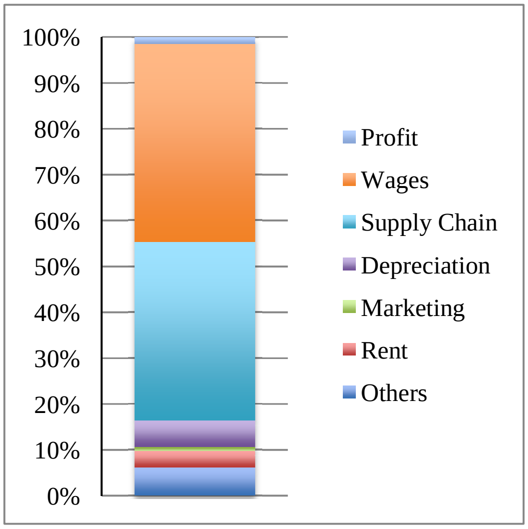

Figure 1. Typical Industry Cost Structure

Meanwhile, the supply chain cost of 39% is an area where the industry witnessed a significant opportunity [2]. One of the most important supply chain components for solar panel manufacturers is silicon. Solar panel makers have benefited a great deal from the competition with silicon manufacturers.

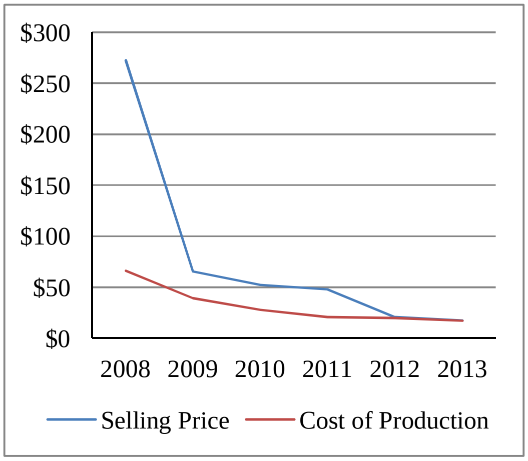

Figure 2. Market Price and Cost of Silicon

Silicon prices have come down dramatically from $275 per kg to $17 per kg in recent years (see Figure 2) due to both more competition as well as technology improvements to lower the cost of production by about 75% (from $75 to $17), as reported by Lepont [6]. While initially the silicon manufacturers held on to the margins, competition forced them to pass on the margins to the solar panel manufacturers, leading to the price collapse by about 90% from $275 to $17. Like any other commodity price collapse, this hyper competition has negative consequences as well. With most of the manufacturers located in China and Japan, the low prices triggered high unemployment in this sector as well as consolidation of the industry, resulting in bigger players buying the smaller ones for distress deals [2].

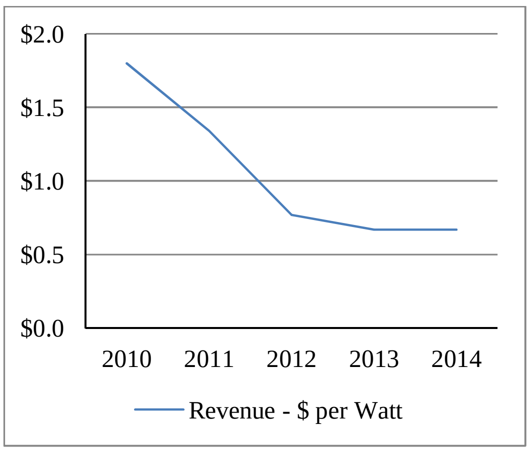

Figure 3. Revenue for Solar Panel Makers

The collapse of silicon prices has forced the solar panel manufacturers to lower their price to pass on the savings to the consumers, increasing the installed capacity from 10GW in 2009 to about 40GW in 2013. Revenues for them declined from $1.8 per watt to $0.67 per watt (see Figure 3).

Interestingly, the outlook for silicon prices going down any further in a dramatic way as it did in the last five years is not promising. This means that manufacturers have to identify new opportunities to bring down the cost of manufacturing through new technology, new materials, and new approaches. It is very clear that the learning curve advantage remains to be exploited. One of the best parallels to this scenario is wind turbine manufacturing. Not too long ago, the wind turbine blade technology, manufacturing, delivery, installation, and maintenance costs were prohibitively high, making wind energy a niche segment for off-grid usage. The combination of scale advantage resulting from regulatory mandates, composite materials for the turbines, and innovation in in-situ maintenance, have increased the adoption levels to wind power generation, becoming almost a mainstream power production segment. We expect solar energy to go through a similar maturation process, and we already see some evidence of this.

We identify below key technology drivers that may potentially lift the solar panel industry to the next orbit of profitability [8]. Our goal for this study is to understand the cost curves for each of these groups of products individually and attempt to forecast where the respective markets will be in the next decade.

4. Technology Growth as the Next Source of Cost Savings

We can divide the solar panel market broadly into four categories depending on technology maturity: 1) mono-crystalline and multi-crystalline silicon, 2) thin-film, 3) on the horizon technologies such as quantum dots and organic photo-voltaic, and 4) concentrated photo-voltaic. While, the focus of the first three segments is mostly the innovation in improving the solar panels, the last one focuses on introducing innovation on driving more solar energy for a better harvest into the panel assembly, thus creating another downstream market segment.

4.1 Mono Crystalline and Poly-Crystalline Technology

Crystalline silicon solar technology has been in use for over two decades. Being the simplest of its kind and mass commercialized today, solar panels based on this technology are relatively cheaper at less than $1 per Watt with an efficiency yield of 15-20% [6]. While the single crystalline structure is slightly harder to manufacture, it is much easier to fabricate the remaining layers in the panel with single crystalline cells. The multi-crystalline structure makes it slightly cheaper to manufacture but at the cost of slightly lower efficiency. There are many manufacturers, including Trina Solar, Canadian Solar, Jinko Solar, and Yingli Solar that make single and multi-crystalline panels. According to Lepont [6], the cost per watt for these manufacturers is widely varying, as shown in the Figure 4.

A natural question arises: how do we explain the differences in the manufacturing cost per watt for the different manufacturer? How is it that Jinko

Solar produces at 25% cheaper than ReneSola, considering that all the manufacturers have their operations based in China. Could scale economy help explain the difference?

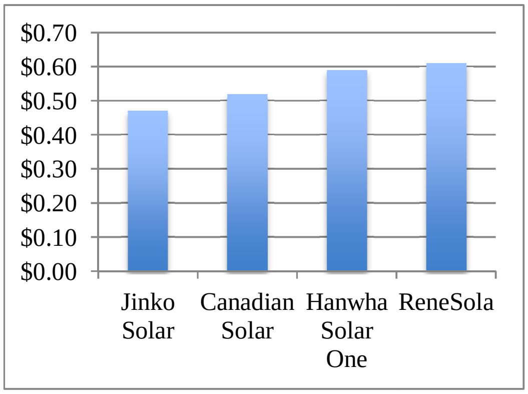

Figure 4. Manufacturing Cost per Watt

Exhibit 5 shows the installed capacity sold by the different companies. To a certain extent, the scale economy does explain the difference between the manufacturers' cost performance. Canadian Solar and Jinko Solar have a higher installed capacity than Hanwha Solar by 30-40%. However, ReneSola has an installed capacity closer to Canadian Solar and Jinko Solar, and yet its cost per Watt is 15-20% higher than Canadian Solar and Jinko Solar.

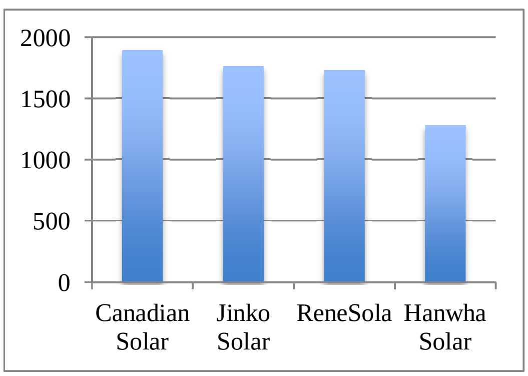

Figure 5. Installed Capacity in the Market

Our hypothesis is that Canadian Solar and Jinko Solar have gained additional potential manufacturing efficiencies. Canadian Solar, for instance, has lowered the overall cost of production at a CAGR of 48%, while the cost of silicon only went down by a CAGR of 28%. This clearly implies that market leaders such as Canadian Solar benefited significantly from scale as well as from manufacturing efficiencies.

4.2 Thin Film Technology

Thin film solar technology uses non-silicon semi-conductors such as Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS), which have a slightly lower efficiency level than the silicon crystalline cells, but are light weight and easy to produce. Before the crystalline silicon prices came down drastically, thin film technology appeared to offer a cheaper alternative for crystalline silicon. There are, however, certain advantages with thin film technology. They can withstand a higher temperature and can convert light into current even at lower lighting conditions. They are only about a tenth of the weight of silicon, making it attractive in certain applications such as solar powered vehicles, consumer electronics, and roof top solar panels.

The future of thin film solar market is unclear. On one hand, if the production of CdTe or CIGS, as a key supply chain component, becomes considerably cheaper as it did in the case of crystalline silicon, the thin film market can have a renaissance as the crystalline silicon market did. On the other hand, if such a break through does not come through, then the growth of this segment may be limited to the niche segments at about the 5GW level, focusing on select light weight solar panel applications such as consumer electronics.

4.3 Solar Technologies on the Horizon

Most solar technologies on the horizon are not yet commercialized [5]. We will highlight a few of the promising ones. The first one is the dye-sensitized solar cell, which is a multi-layer structure involving titanium dioxide coated with trihalide perovskite. The nano-porous particles absorb light to release an electron into the titanium dioxide, which can be collected through one of the electrodes. The efficiency levels exceed 18%, higher than the crystalline silicon and thin films [6]. What is promising about this technology is its simplicity, but it is not clear if commercial production can yield a cheaper and durable product that can be quickly adopted in the market.

Another close relative of dye-sensitized solar cells is the quantum dot technology incubated at MIT. Quantum dots substitute for the dye light absorbers, and have a very high absorption rate, and this can potentially decrease the form factor for the solar panel. They are also capable of producing current at very low light levels [8]. Although the demonstrated efficiency has only reached a peak of 8%, this technology holds enormous potential for improving the efficiency and commercialization.

Organic photovoltaic technology is another promising one, which seeks to considerably lower cost using polymers [5]. Though the efficiency levels are reported to be around 12%, given that they are based on organic molecules, they hold a promising future to lower the cost of solar panels. The first commercialization of this technology was launched in 2015.

4.4 Concentrated Photovoltaic Cell System

One of the fundamental challenges with the conventional solar technology is low efficiency, which results of the sub-optimal incident angle for the sunlight as it enters the array. A simple solution to this challenge is to build a series of lenses to re-focus the light, while tracking with the sun. The efficiency improvement from doing this incident angle adjustment is enormous. Even commercially installed systems have shown efficiencies in the range of 45%. However, this improvement in efficiency does not come without a trade-off. The concentration in light results in heating problems, which requires forced air or liquid cooling, which in turn increases the space requirement to mount the system. Since the cooling problem is more of a field-engineering problem, this technology shows good promise.

5. Summary

In this paper, we provided a brief treatise on various solar technologies in terms of the opportunities we foresee in lowering the cost of production for solar panels, which in turn makes solar power an attractive mainstream source of renewable energy. The opportunities identified can be broadly grouped into three efficiency levers: 1) supply chain cost reduction, 2) scale and learning curve advantage from manufacturing innovation, and 3) disruptive new technologies resulting in the next generation solar panels. While the first two types of efficiencies apply to the crystalline and thin-film devices, the third type of efficiency pull can catapult the solar panel market into a completely different level of market adoption. As next steps, we need to estimate the cost efficiency upper limits from the first two levers and relate it to the achievable efficiency with the third lever from a total cost of ownership perspective.

Acknowledgments

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