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Solar PV Technology Cost Dynamics and Challenges for US New Entrants

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Abstract Renewable energy generation is being used more than ever due to the increasing awareness of climate change. Solar energy has emerged as the fastest-growing energy technology alongside other renewable energy sources, such as wind energy. Although the United States developed photovoltaic solar cell technology and led the first wave of efficiency and cost improvements. In the following years, US companies could not dominate the market and lost their pioneering position. In this work, we reviewed some of the factors why some American companies found it difficult to survive in the solar PV market. It is necessary to review some of the factors that led to the demise of some of the American Solar PV companies, with the hope of identifying the significant issues that impacted these companies so that new entrant into the market will review their position and prepare adequately to counter these forces. This report uses minimum price concepts to assess the evolution of solar photovoltaic manufacturing costs and economic factors in recent years. This analysis shows three different periods of cost improvement corresponding to periods of oil price highs and lows. A model was developed to explain why some US companies find it challenging to compete and enter the market in the second period and used some of these companies as case studies. The model shows that rapidly declining costs are making technology and production equipment obsolete. US companies took long lead times to prove their technology, raise funding, obtain the necessary permits and set up production facilities.

Keywords: *PV modules, solar industry, solar manufacturing, US, united states, renewable energy market*

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1. Introduction

Humans have used the Sun to generate energy for thousands of years. According to the United States Department of Energy, magnifying glasses were used in the 7th century BC to focus the Sun's rays to create fire. In the second century BC, the Greek scientist Archimedes used the reflective properties of copper shields to focus sunlight and burn wooden ships. The Greeks and Romans used mirrors to reflect the Sun's rays [1], and in 1767 a scientist named Horace de Saussure built a glass box that acted as the world's first solar furnace [2]. Less than a century later, French scientist Edmond Becquerel discovered the photovoltaic effect in 1839 [3], and several decades later, French mathematician Auguste Mouchet designed a solar-powered steam engine in 1860s [4]. After this point in history, solar began to be utilized to generate electricity, and the technology has advanced significantly throughout the 20th and 21st centuries.

In 1884, an American inventor, Charles Fritz, developed the world's first working selenium cell and used it to build the first rooftop solar array. The electrical conversion efficiency of these selenium cells was about 1%. At the time, oil and coal were much more convenient and economically viable, so it made no sense to continue developing such expensive technology in the 1940s [5]. Photovoltaic technology was born in the United States in 1954, and in 1959 Hoffman Electronics achieved 10% efficiency of commercial photovoltaic cells. In 1964 NASA launched Nimbus 1 satellite powered by a 470-Watt photovoltaic array, and in the late 1970s, Elliott Berman, with help from Exxon, developed a much cheaper solar cell that cut costs by 80%. In 1980, Arco Solar became the first company to produce more than one megawatt of photovoltaic modules in a year [6]. Decades later, solar power is at the forefront of renewable energy generation.

The energy industry, especially renewable and sustainable energy, is highly competitive. There is a race to develop the cheapest and most efficient energy sources involving researchers, investors, and politicians. Solar power is one of the technologies benefiting from scientific and investment interest, making it the fastest-growing energy resource deployed annually in the United States [7]. Some of the interest in solar energy is borne by global awareness of decarbonizing the planet, and the use of solar panels for energy generation is one of the easiest and technically feasible options for the ordinary person to participate in the global decarbonization effort.

In addition to the need to save the planet, oil, and gas prices influence how governments approach developing renewable energy policies. Individual circumstances shape countries' renewable energy strategies: oil-producing countries and countries that rely on imported oil and gas for energy have different ways of developing renewable energy policies. As oil and gas prices rise, some oil-producing countries tend to shift their local energy generation from oil to renewable energy, generating renewable electricity locally to reduce oil consumption, and selling some of that oil on global markets to increase revenue. This strategy works well when oil prices are around $100 a barrel and at prices higher than or comparable to the price of renewable energy generation. Electricity tariffs are subsidized in most oil-producing countries, so that higher oil prices will increase subsidy costs. As oil and gas prices fall, interest in developing renewable projects in oil-producing countries declines as generating electricity from fossil fuels becomes cheaper than renewable energy sources. For example, sites with the lowest solar potential in Iraq receive up to 60% more solar energy from the Sun than the best sites in Germany. Still, the photovoltaic systems built in Germany provide 2.5 times the power capacity of all Iraq's oil, gas, and hydropower plants combined [8].

Saudi Arabia's recent interest in renewable energy is also driven by oil and gas prices. The country is one of the fastest growing and needs diversification in its economy. With the world's highest per capita energy consumption [9], rapid population growth, increasing urbanization, and rapid industrialization, power demand is likely to increase in the future. As of 2012, Saudi Arabia generates more than half of its electricity by burning expensive petroleum and diesel fuels due to a shortage of natural gas. Authorities have been forced to raise prices to encourage consumers to take efficiency measures and, most importantly, to reduce domestic demand for oil and gas that could otherwise be exported [10]. Therefore, there are good reasons to shift dependence on oil to solar, wind, and nuclear energy sources. For some of these reasons, Saudi Arabia’s solar industry aims to reach 24 GW of solar capacity by 2020 and 41 GW by 2032 [11]. The government plans to invest more than $108.9 billion into the solar industry and announced offers, including financial support of up to 50% for project costs and other generous tax breaks [11].

The United States is both a producer and an importer of oil. However, its historical position in the development of renewable energy is complicated. When oil prices peaked in 1978, the United States suspended its Energy Tax Act and its Solar Photovoltaic Research and Development Act policies [12]. Solar photovoltaic technology has been pioneered in the United States, and solar energy has become a vital energy mix in the country.

In 1954, three scientists at Bell Labs invented the silicon solar cell that became the model for converting sunlight into electricity today [13]. The components of a photovoltaic system depend on whether it is an independent or grid-tied photovoltaic system. Primary components include solar panels, batteries, controllers, and inverters. The most critical component is the solar panel, which is made up of crystalline silicon solar cells (CSSC). Silicon-based solar cells, also known as first-generation solar cells, are expensive and deliver the highest power conversion efficiency in the market, between 20% - 27% [14].

Since the discovery of photovoltaic solar generation, the US has been at the forefront of solar technology. However, in the 1980s and 1990s, American interest dwindled while interest in other parts of the world increased. Solar photovoltaic technology is considered a high-performance renewable technology with an average annual growth rate of more than 40% over the past decade. According to the National Renewable Energy Laboratory, the success of the photovoltaic industry is mainly due to the steady development of polycrystalline and monocrystalline silicon semiconductor wafer manufacturing technology [15]. This growth is underpinned by a strong combination of three key competitive advantages: (1) industry-leading solar conversion efficiency; (2) reliability of products from qualified suppliers per good product warranties; and (3) the consistent ability to offer modules at competitive prices, enabled by the ability to implement cost reductions throughout the silicon supply chain. Some of these manufacturing initiatives started in the United States when Elliot Berman, with the help of the Exxon Corporation, designed a much cheaper solar cell, thus reducing the price from $100 per watt to just under $20 [16].

With the rise of the global solar market, America's leading edge has dwindled. Most American companies could not compete with US-based manufacturing costs, where companies ultimately outsourced operations or went out of business. Some of the significant players that did not survive in the intense solar technology space include Solyndra, Abound, Advent Solar, Applied Solar, and Optisolar, to name a few. Given these developments, it is necessary to explain why it was difficult for some US companies to compete and enter the market to manufacture solar photovoltaic panels.

2. Methodology

The minimum sustainable price (MSP) and manufacturing cost decline was used to model the historical solar PV module cost from 1970 to 2020 [17]. The MSP represents the lowest price amount financially supporting the manufacturer [18], and it is a function of time and location. The MSP and expected margin sum should converge to a sustainable price that yields an internal rate of return (IRR) equal to the manufacturer's weighted average cost of capital (WACC). The main cost categories for MSP analysis generally include manufacturing cost (COG), depreciation, overhead cost, and gross margin.

In the case of solar PV cells, manufacturing costs include materials, overhead, direct labor (skilled and unskilled), energy inputs, and ongoing operations and maintenance. Overhead costs include research and development, sales, general operations, and administrative expenses (SG&A). These associated costs and strategies were utilized to develop a model representing the US solar industry and its global competitiveness.

The main question we seek to answer is the rationale for cost dynamics and its impact on US businesses with a first-timer competitive advantage. We applied quantitative statistical analysis using data available in the scientific literature. The datasets used include:

1. Price of a solar photovoltaic model from 1970 to 2020,
2. Oil price in US$/barrel from 1975 to 202,
3. Market share of monocrystalline, polycrystalline, and thin film photovoltaic solar panels from 1980 to 2015 and,
4. Polycrystalline silicon material prices from 1957 to 2020.

This approach is a top-down method instead of a bottom-up one that requires surveying critical stakeholders in the PV production value chain to identify all the different cost centers and associated improvement opportunities. While a bottom-up approach looks to the future and forecasts price changes, our approach looks back to identify lessons we can learn from more than five decades of solar PV panels manufacturing experience. We have often used statistics to answer these causal relationships, and the data quality is reliable to support a valid conclusion in this study.

The model used cost decline rates per year, squared difference (SD), and the sum of least squares difference (SSD) between the calculated model price and actual market price to identify the main cost-driving elements of the MSP. The research focuses on manufacturing crystalline polysilicon modules, which are still the dominant technology for PV modules, with over 95% market share [19]. We also attempted to correlate the downward trend in solar costs with oil prices from 1975 to 2020 to identify any trends between the movement of oil prices and efforts to reduce solar photovoltaic solar cell costs. The model also compares the global market share of monocrystalline silicon (Mono-Si), polycrystalline silicon (multi-Si), and thin film PV technologies [20] and the average price of photovoltaic modules to see the relationship between technology adoption and cost reduction. To assess the impact of raw material costs, the average price of polysilicon [21,22], a key ingredient in producing solar cells, was correlated with the price of solar modules.

Lastly, a business timeline analysis was performed with the selected companies like Abound and Solyndra and their respective trend in costs to identify factors that could support or counteract the success of the selected failed companies.

3. Results and Analysis

As shown in Figure 1, the cost of solar PV modules has dropped by more than 90% since 1975, and this price reduction was observed in all the major brands. To understand the trend of the solar PV cost, the yearly decline of the cost to ascertain the magnitude of the cost reduction was calculated, where n represents the number of years.

$$\nabla Cost_n(\%) = \frac{(Cost_{n+1} - Cost_n)}{Cost_n} \quad (1)$$

In 1975, a solar cell was about \$106 per watt. Suppose this price is allocated to the cost elements based on the cost structure of US solar PV manufacturing companies in 1975 [18], as shown in Figure 2, one can see that the material cost accounts for more than 50% of the manufacturing cost.

In 2020 the average price of solar PV dropped to about \$0.2 per watt. With the price of solar PV in 1975 as a reference point, the impact of price reduction in each cost element was investigated. The impact of a 5% – 30% cost reduction per year in all the elements was investigated. Then, the square of the difference (SD) was calculated between our model price and the actual price each year. The sum of the square difference (SSD) was calculated at the end of 2020.

$$SD_n = (Model\ Price + Actual\ Price)^2 \quad (2)$$

$$SSD_n = \sum_{K=1975}^{2020} (Model\ Price + Actual\ Price)^2 \quad (3)$$

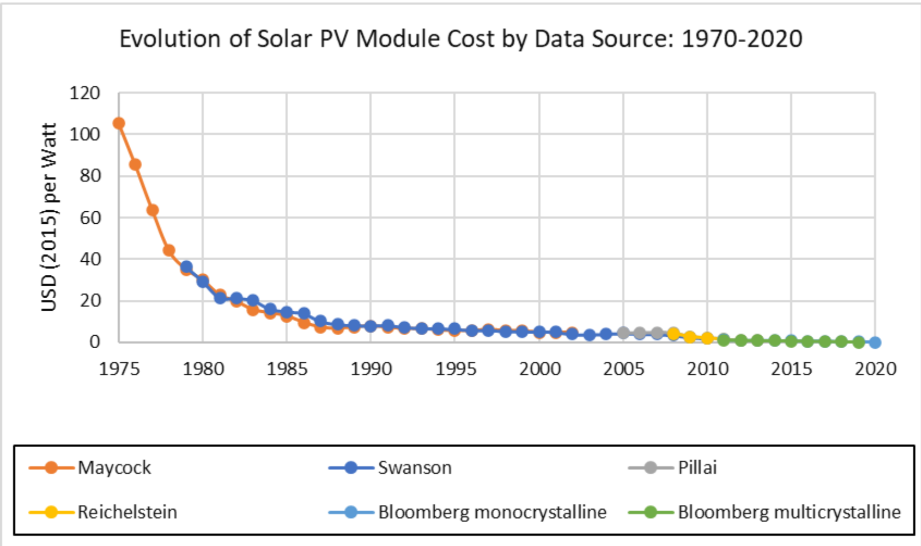

Figure 1. Evolution of solar PV module cost (1975-2020) data source [17]

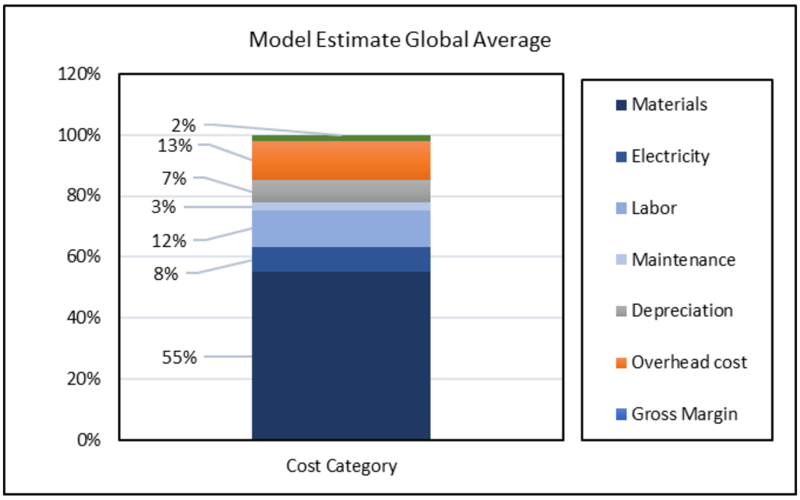

Figure 2. Estimated cost distribution [23]

4. Sensitivity Analysis

The price decline was modified for the main sensitivity parameter from 5% to 95% while maintaining the rest of the elements at a 5% price decline rate. The main cost components analyzed include material cost, labor cost, and overhead cost. These expenses account for over 80% of the overall solar PV cost.

The sensitivity analysis results, as shown in Figure 3, show that the overall price is not sensitive to labor and overhead costs. Most US companies are reportedly unable to compete because Chinese companies use cheap labor and have less overhead [24]. Some say it is a short-sighted move against rising polysilicon prices. In contrast, others blame Chinese manufacturing, cheap capital, accessible permits, and established supply chains for a severe market oversupply (i.e., sell below the actual cost to enter the market and crowd out other suppliers). Other reports stated that investors either put too much money into too many companies or needed more venture capital to pull them out [25]. This analysis shows that even if US companies cut overhead and labor costs, they will still need help to compete with global prices. As shown in Figure 4, Figure 5, Figure 6, and Figure 7, historically, US companies would have to reduce costs by at least 10 - 15% yearly to compete in the global solar PV market.

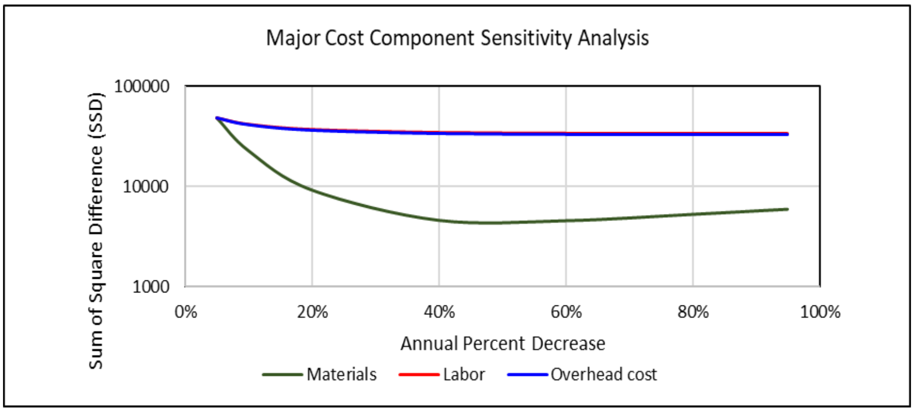

Figure 3. Estimated cost distribution.

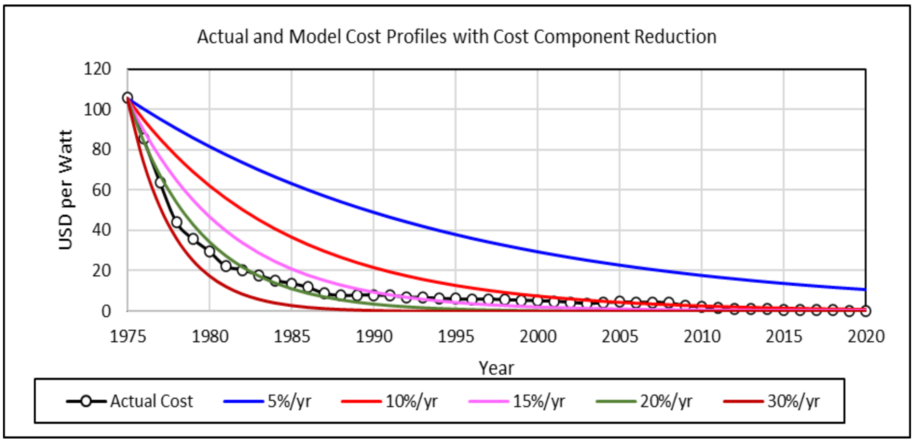

Figure 4. Estimated cost distribution [18]

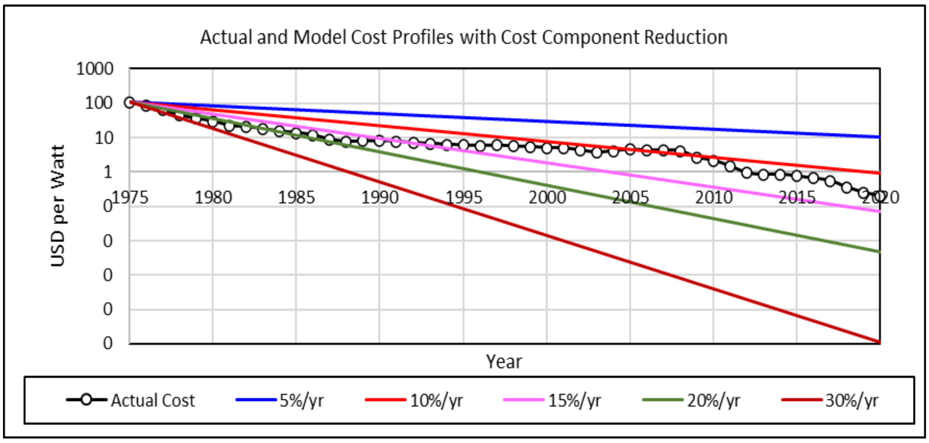

Figure 5. Log plot of actual and model cost profiles with cost component reduction

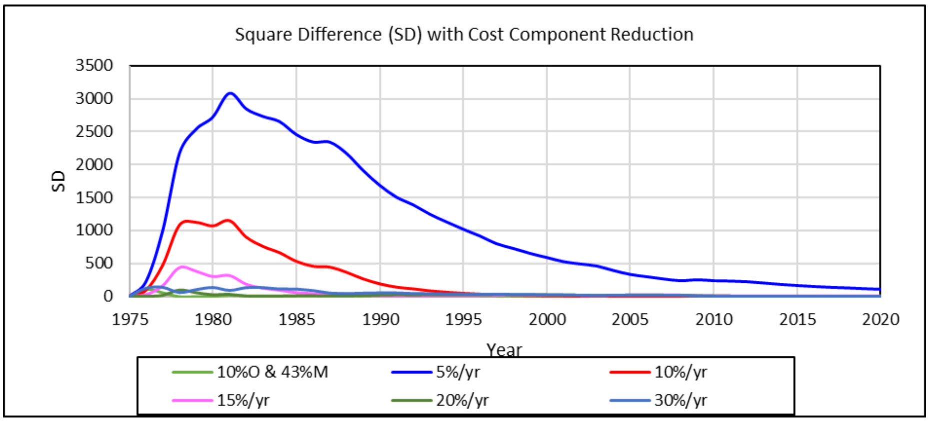

Figure 6. Square Difference (SD) with all Cost Component Reduction

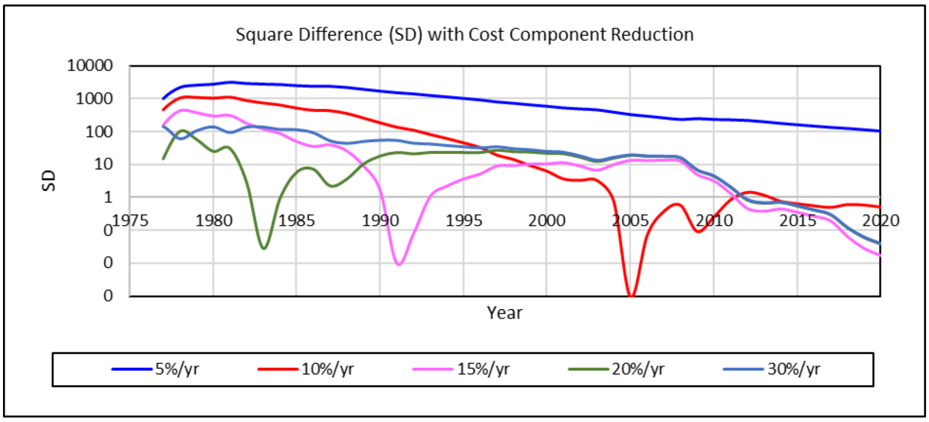

Figure 7. Log plot Square Difference (SD) with all Cost Component Reduction

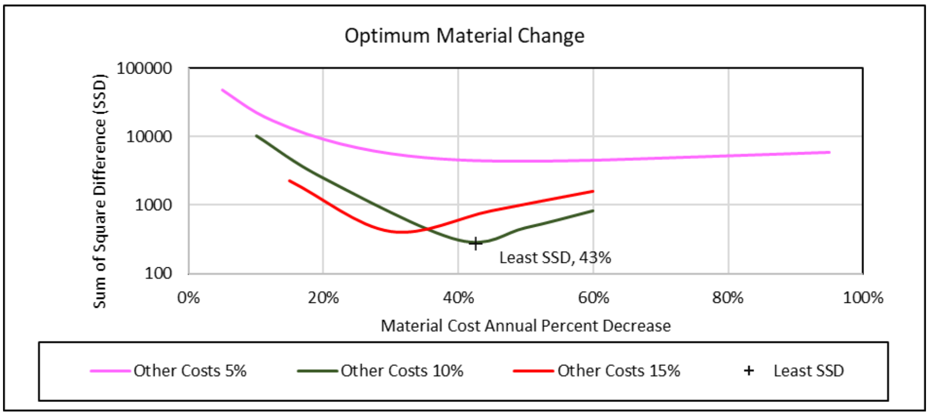

Figure 8. Combination of material cost and another cost element that contributed to overall cost reduction.

A more practical cost reduction combination would be 43% of material cost year over year and 10% for the remaining cost elements yearly. This combination produced the lowest square difference, as shown in Figure 6, Figure 7, and Figure 8.

The annual historical cost changes were plotted with time, as shown in Figure 9. The plot shows three periods of cost changes. Period 1, which is between 1975 -1988, has an average year-over-year cost decline of about 18%, while Period 2, between 1989 – 2008, has an average cost decline of about 3%, and Period 3 was between 2009 – 2020, with the highest average decline of about 23% per year. Figure 9 presents the historical oil price from 1975 – 2020 [26], showing that Periods 1 and 3, with high-cost declines, coincide with high oil prices. Period 2, with a low-cost decline and some cost increase, coincides with the relatively low oil price period.

As shown in Figure 10, we attempted to correlate solar cost declines with oil prices and found a weak indirect correlation between oil prices and PV cost decline rate. As oil prices rise, the cost of solar power falls somewhat because of government interest and funding of renewable energy to replace traditional fossil fuel sources. However, when oil prices fall, interest in finding alternative energy sources wanes, reducing funding for renewable energy.

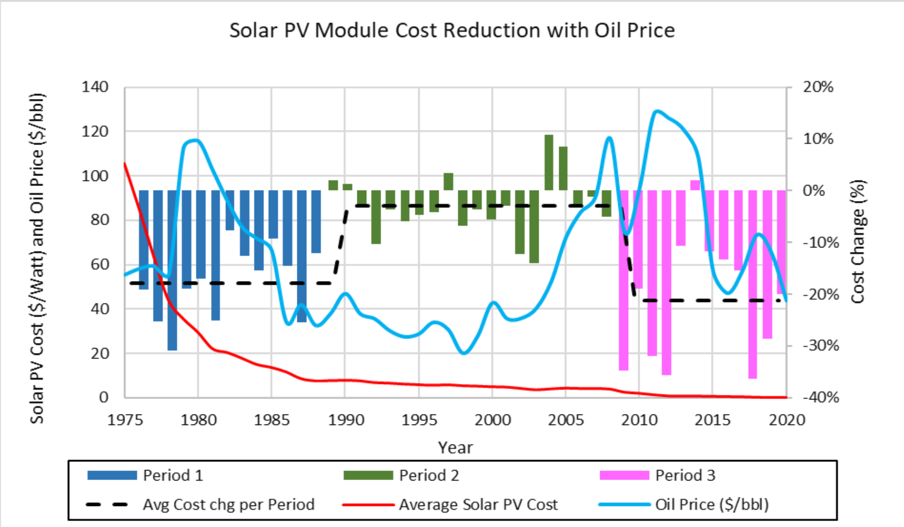

Figure 9. Historical Solar PV module cost reduction and oil prices

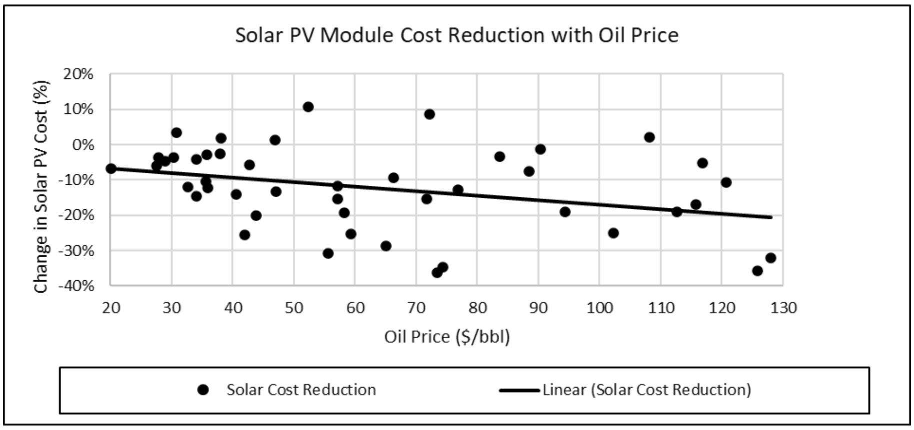

Figure 10. Solar PV module cost reduction with oil prices

Table 1. Activities and Economic Force During Each Period

Description	Period 1	Period 2	Period 3
Energy driver	Oil price shock. US imports and produces oil locally. US responded with some solar investment but reduced funding after oil prices dropped	Low oil price. Germany and Japan import most of their oil. Investment in solar as alternative energy by German and Japan Governments.	Rising oil prices. China's increasing energy consumption and oil import China's investment in solar as alternative energy.
Major Players	American Companies	Most American companies closed and sold operations. German and Japanese companies entered the industry to satisfy local demand	German and Japanese companies. Chinese companies Few American companies
Strategy	Product differentiation	Cost focus for the local market	Cost leadership with mass production
Market	A niche market, satellite, and equipment	Domestic and public consumption need to expand in the Chinese market	Huge Chinese local demand and global market
Financing	Government subsidies and special projects.	German government, private banks with 20 years price guaranteed contract.	Chinese government subsidies started in 2009 American venture capital Some US Government renewable subsidies.

The oil embargo that lasted from October 1973 to March 1974 was the catalyst that started the solar PV industry. The long gas queues it caused highlighted the United States' dependence on foreign oil at that time. The US Congress responded by enacting the Solar Research, Development, and Demonstration Act of 1974 [27]. The act stated that it was henceforth the federal government's policy to "pursue a vigorous and viable program of research and resource assessment of solar energy as a major source of energy for our national needs." The act's scope embraced all energy sources renewable by the Sun—including solar thermal energy, photovoltaic energy, and energy derived from wind, geothermal, and photosynthesis. The act established two programs to achieve its goals: the Solar Energy Coordination and Management Project and the Solar Energy Research Institute. Over the decade following the act's passage in 1974, the United States government spent $4 billion on research in solar and other renewable energy technologies. Over the decade following the act's passage in 1974, the United States government spent $4 billion on research in solar and other renewable energy technologies. During the same period, the government spent an additional $2 billion on tax incentives to promote these alternatives [28]. Despite the promise of solar energy in the 1970s and the fear of reliance on foreign petroleum, the United States' spending on renewable energy sources declined dramatically during the 1980s [29]. Over the past decade, several factors have conspired to undermine the federal government's commitment to solar energy. These include the availability of cheap oil, skeptics of government-sponsored initiatives, and concerns about government spending [30]. As a result, some solar manufacturing technologies developed because of the 1980 oil price shock were not maintained.

Before the oil crisis that sparked interest in solar energy in California and the United States (see Table 1), the solar industry in California had nearly 20 years of PV experience in niche markets such as remote-controlled navigation buoys and radio beacons and satellites.

California benefits from solid sunshine in major population centers, vital for distributed residential and commercial solar installations. It is also one of the world's leading regions for sizeable solar energy production. The Mojave Desert is less than 100 miles from Los Angeles, which has the second-largest population density in the country. In addition to the climate, the state boasts world-class technical universities, business infrastructure, and (since 1974) the country's most aggressive renewable energy policy. As such, California is a natural hotspot for both the use and production of solar technology [20]. Nevertheless, it was demanding displacing conventional fossil-based electricity consumers.

From 1975 to 1986, the Energy Research and Development Administration (and later the Department of Energy) spent $235 million to fund low-cost silicon solar [31], but the solar PV market remained small. The focus of power generation from solar shifted to projects that used solar thermal energy to heat the fluid and power the turbine. In the 1980s, Luz and Arco Solar, both California companies, created the world's most extensive grid-connected solar system. These companies were the largest suppliers of photovoltaic technology in the United States during the 20th century. However, declining fossil fuel prices have ended US government support; some California companies returned their focus to niche markets.

Overall, the US market has begun to lag other countries in terms of intervention policies, and efforts to develop solar power as an alternative to conventional energy have been discouraged by low oil prices, environmental awareness, and government policies. Other countries, such as Japan and Germany, have pushed renewable energy expansion, running counter to the US response.

Political economists have attempted to determine why countries responded differently to the 1979 oil shock [32,33]. A typical starting point is that transitions result from differences in national energy policies [34]. Others also pose this question: What do countries want to achieve with their energy policies? One of the most important goals of energy policy [35] was to balance demand and the security of supply. Germany and Japan have advanced market economies and needed a secure energy supply; from the 1960s - the 1980s, Germany and Japan pursued energy policies of competitive and accelerated adjustment [36]. This author described how Germany and Japan are trying to reduce their dependence on oil imports. With its large coal reserves, Germany thought little of importing fuel for power generation. More recently, the governments of both countries have used projections of demand growth and energy self-sufficiency targets when formulating their energy strategies. Germany expanded wind and solar power and phased out nuclear power in the 1990s. In 1990, German Siemens bought California-based Arco Solar PV.

In Period 2, large Japanese companies diversified into photovoltaic cell manufacturing, and Germany created its policy on renewables, the feed-in tariff system. This guaranteed a constant long-term price for electricity from renewable sources. This virtually eliminated the investment risk to finance purchases and led to the explosive growth of the German wind and solar PV market [37]. Faced with the need to develop alternative energy sources to reduce its reliance on energy imports from abroad, the Chinese government introduced renewable energy subsidies in 2009, sparking substantial local demand for solar power. This started in period 3 when the cost of manufacturing solar power was reduced by 23% year over year from 2009 to 2020 (see Figure 9).

Achieving the level of cost savings equivalent to 43% of material cost year over year and 10% for the remaining cost elements yearly comes not only from manufacturing process improvements but also from manufacturing process innovations. An analysis of the PV technology market share profile shown in Figure 11 shows that after the initial period (Period 1), the market share of thin-film PV modules started to decrease. In contrast, the market share of monocrystalline and polycrystalline began to increase. This means that German and Japanese companies, the key players in the second period, primarily adopted monocrystalline and polycrystalline technologies. After 1995, the market share of monocrystalline PV modules started to decline, and the market share of polycrystalline PV modules increased.

According to some authors, one of the reasons for the failure of some US companies is that they have invested in the wrong technology, namely low-cost thin-film photovoltaic systems without silicon [24]. As shown in

Figure 11, this analysis tends to support this assertion, as the market has stabilized for silicon-based solar panels with the growing shares of mono-silicon and polysilicon-based solar cells. According to MIT Technology Review, Solyndra failed due to global industry changes that few could have foreseen. Solyndra aims to produce silicon-free solar panels. However, the technology, spurred by industrial policies abroad, led to the ensuing boom in global silicon production, driving down the cost of panels made by Solyndra's competitors [38].

Monocrystalline silicon cells are more efficient due to the quality of the crystals, but they are more expensive to manufacture, require more cutting and shaping, and waste material. Polycrystalline silicon cells are less expensive to manufacture, and the rectangular shape of the ingots means less cutting is required and less material is wasted. Eliminating some of these cutting processes and reducing material waste may be why polycrystalline silicon cell technology has dominated the market.

The historical prices of polycrystalline, a key ingredient in photovoltaic manufacturing, are analyzed. As shown in Figure 12, a short supply cycle leading to price spikes was observed, followed by an oversupply leading to price declines. The initial cost efficiency in 1975 created some demand for solar PV modules. Though the market size was limited in the US and other places worldwide, the awareness of power generation using solar panels created some global demand. As shown in the simplified polysilicon supply and demand curve in Figure 13, the awareness of solar PV power generation and cost reductions of photovoltaics have led to an initial demand point (1) at which polysilicon material demand begins to exceed polysilicon supply capacity. We found that this would lead to a shortage of silicon material, shifting the demand curve to the right and establishing a supply-demand equilibrium at higher prices. At point (2), demand needed to be met by supply, and the price peaked. Rising prices prompted other polysilicon suppliers to enter the market and incumbents to raise additional capital to expand and modify their manufacturing systems to meet new demand and monetize the rising prices. This influx of suppliers and expansion of the manufacturing base created an oversupply, shifting the supply curve to the right and establishing a new supply-demand equilibrium at lower prices at point (3). Falling prices will trigger a recession and pose new risks for polysilicon manufacturers. This has caused some suppliers to withdraw, freeze or halt future factory expansions, tighten polysilicon supplies, and raise prices to point (4). Then the cycle of shortage and oversupply repeated.

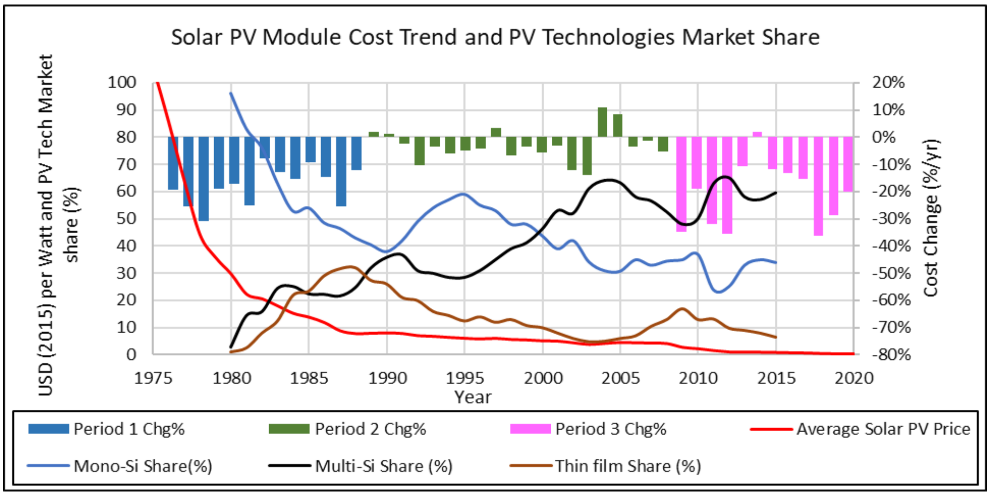

Figure 11. Solar PV module cost trend and PV Technologies market share [39]

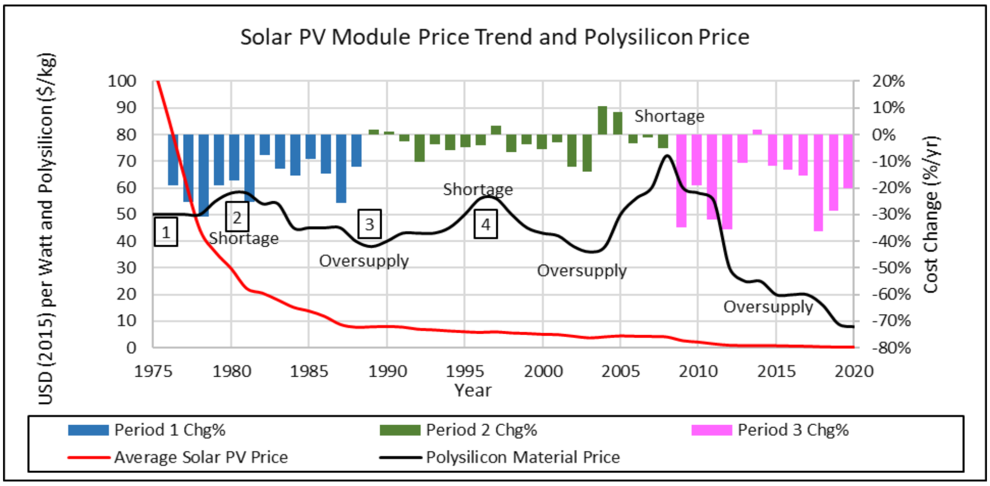

Figure 12. Solar PV module price trend and polysilicon material price [4,21]

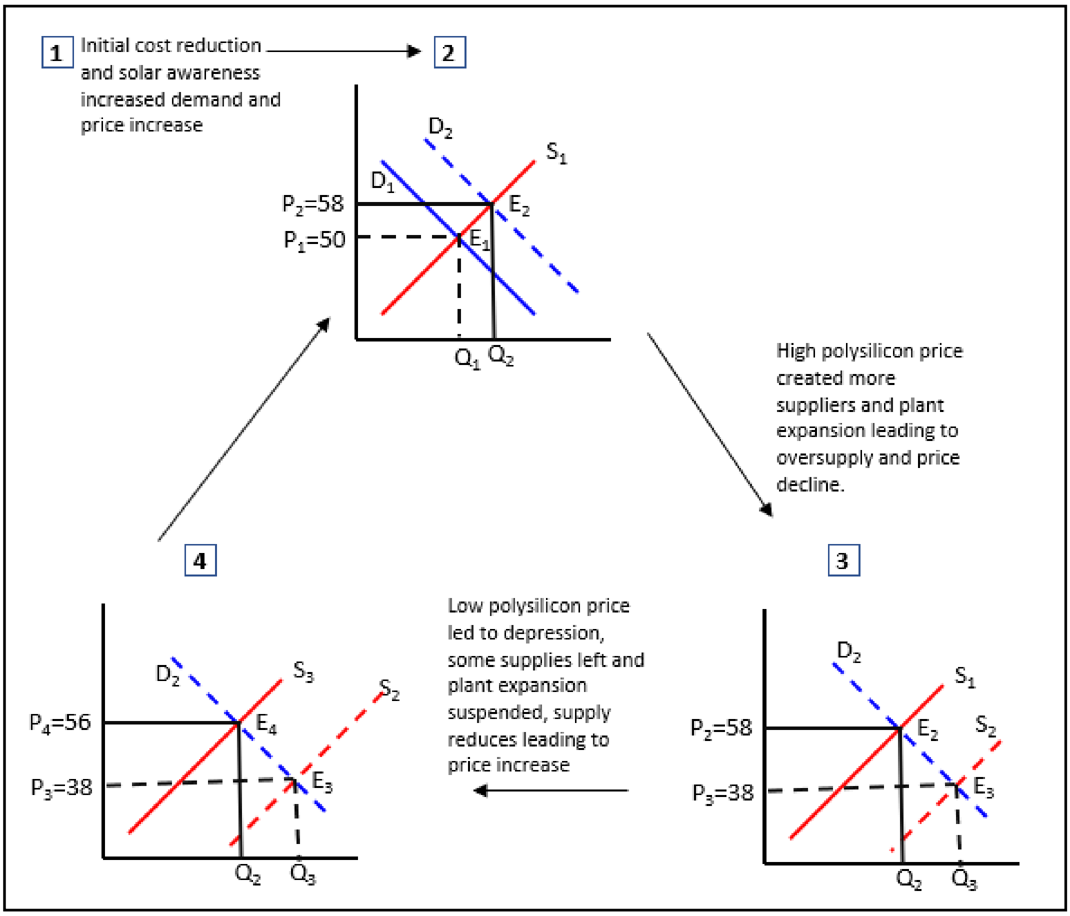

Figure 13. Simplistic polysilicon supply-demand curves showing shortage-oversupply cycle

5. Case Studies

5.1. First Solar

Contrary to the popular demand for silicon-based PV cells, the most successful American solar PV manufacturing company uses CdTe thin film technology. The company started in 1984 and was rebranded as First Solar and focused on cost reduction. It became the first solar panel manufacturing company to lower its cost to $1 per watt [40]. In 2009, First Solar became the first company in the world to ship one gigawatt, but in 2011 its output fell to second only to Suntech in China [37]. As of 2010, First Solar was considered the second-largest maker of PV modules worldwide [23]. First Solar's strategy focuses on reducing solar costs to sustainable levels through technology development, operational excellence, and scale. It uses affordable and adaptive business models and overseas partnerships to expand the market. In addition, it possesses and develops the technologies necessary to become a low-cost solar power supplier for a sustainable competitive advantage [41].

5.2. Solyndra

Solyndra was founded in 2005 and used thin-film PV technology; it planned its IPO for 2009, four years after its start-up. Solyndra used the copper indium gallium selenide (CIGS) thin film solar cells technology instead of CdTe. Despite $1.1 billion in private equity and $535 million in federal guarantees, the company filed for bankruptcy in August 2011. According to [42], Solyndra could not compete with conventional solar panel manufacturers of crystalline silicon. As shown in Figure 11, in 1995, the market shifted towards crystalline silicon-based solar cells, and recently, the technology accounts for more than 80% of the global supply.

In 2005 when Solyndra developed its business concepts, solar cost price was about $4.1 per watt; at the intended point of IPO in 2009, the cost of PV dropped to $2.63, and in 2011 the cost of PV was about $1.45 per watt. When Solyndra filed for bankruptcy, Chinese solar producers were already active, and the industry felt the declining impact on global silicon solar panel prices. The dynamic nature of the photovoltaic market does not favor long planning and commissioning times. Shelf IP and manufacturing equipment may be obsolete by the time they are completed.

Excluding the planning stages and assuming permitting process goes smoothly, the construction of a manufacturing facility in America will take an average of two to three years. Add another year or two to get the product approved, which could be four to five years from start-up to operation of the new facility [43]. As seen in historical data and our MSP model, a 20% reduction in the annual cost of photovoltaic manufacturing reduces industry costs by 67%. This means that the planned MSP entry point for the new manufacturing facility needs to be updated and is about 205% more expensive than the industry’s current costs. Changing manufacturing equipment to achieve production efficiencies that match industry averages is extremely difficult once the factory is completed. This is the case of Solyndra and Abound solar companies.

5.3. Abound Solar

Abound Solar was founded by a group of scientists and researchers to improve an inefficient solar technology utilizing Cadmium Telluride to support renewable energy growth and knowledge base [44]. The company developed its proprietary technology around 1998, and the average price of solar PV was about $5.55 per watt. However, as of 2010, when the company received funding and was ready to enter the market, the unit price of solar PV dropped to $2.13 per watt (see Figure 11). This price reduction is equivalent to about 38% of the price as of 1998. Based on our MSP analysis, material cost was about 55% of the total cost; Abound's plan entry material cost in 1998 was about $3.05 per watt. The material cost was higher than the solar PV price of $2.13 per watt. To compete, Abound would have to change its IP and manufacturing process to enter the market.

It is important to note that Abound developed its technology in period 2 (see Figure 11). This is the low oil price regime in the US. Interest in renewable energy funding from the US government and venture capitalists has been low compared to interest in Germany and Japan. It was not until 2010, 12 years after its technology development, that Abound Solar secured significant funding.

Advances and the introduction of the second-generation thin film solar cell (TFSC) helped in pushing the cost curve downward, but at a lower power conversion efficiency of about 12% – 23% (see Figure 13 and Figure 14). There are a variety of products that uses this technology, Cadmium Telluride, Copper Indium Gallium Selenide, Amorphous Silicon, and Micro Amorphous Silicon. There are also many third-generation emerging PV technologies, such as multi-junction cells and perovskite; these products occupy the high-cost and high-efficiency quadrant of the solar cost-efficiency matrix. The emerging solar cells also present cheap and low-efficiency technologies like dye-sensitized cells. As shown in Figure 14, the cost and efficiency curves have shifted positively with the new sets of PV cell technologies.

The cell efficiency of CdTe has improved remarkably from about 9% in 1980 to about 16% in 2009. Abound Solar, in March 2009, rebranded the company to capture the value of providing a moderately efficient solar cell at a less expensive cost. Similar or modified thin film solar cell technology abound in competition, including Solyndra, First Solar, and Silevo.

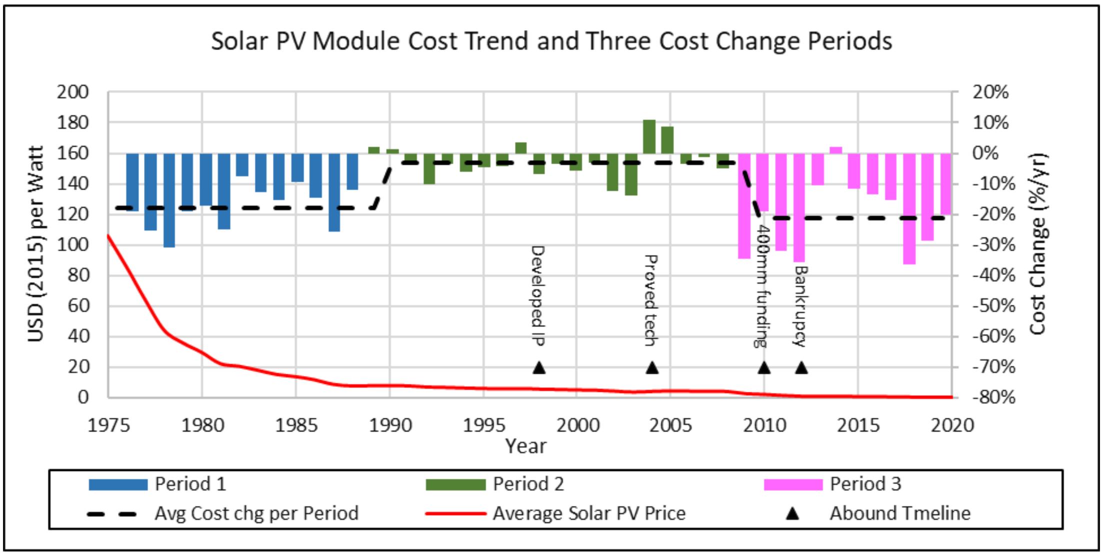

Figure 14. Abound Solar History and Evolution of Solar PV Cell Prices [17]

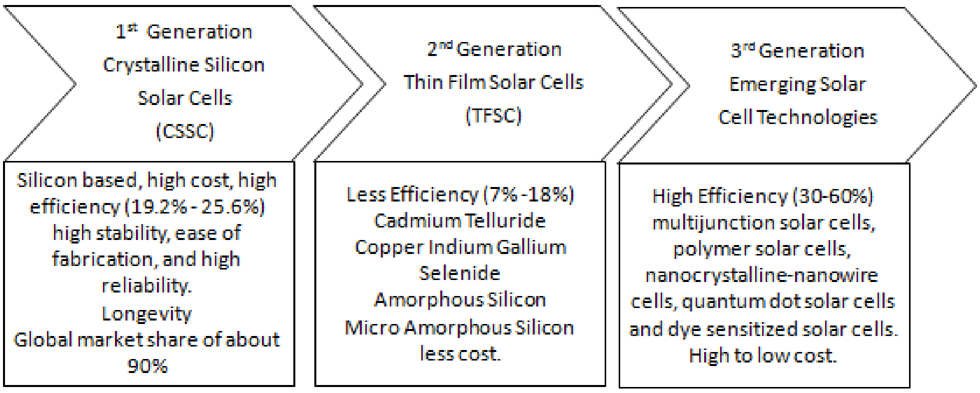

Figure 15. Evolution of Solar Cell Technologies

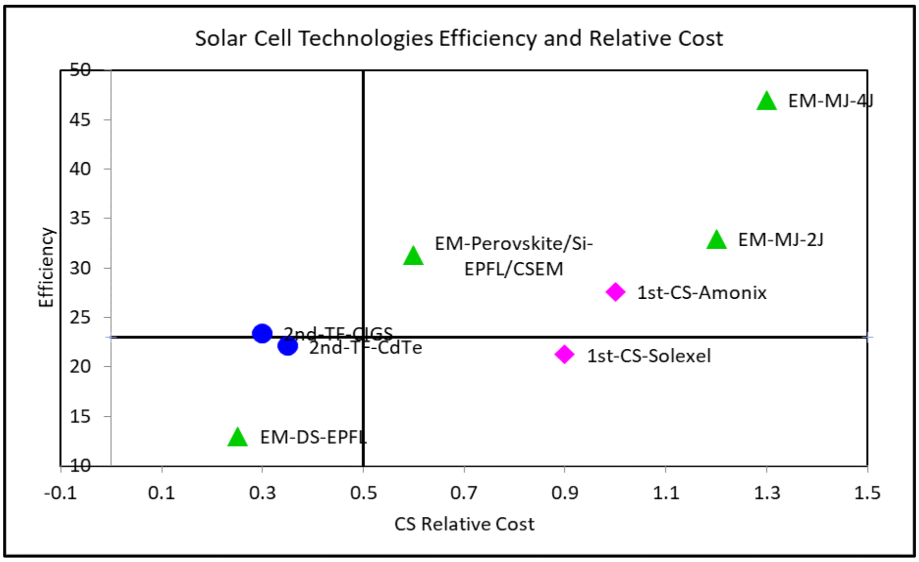

Figure 16. Solar cell technologies efficiency and relative cost [45]

6. Discussion and Conclusion

Global demand for PV solar cells continues to grow, and prices remain stable. The price volatility and uncertainty that caused some US companies to fail no longer exist. Nevertheless, the market is dominated by prominent local and international players with extensive manufacturing and distribution capabilities and market shares. Here are some factors to consider when entering the photovoltaic manufacturing market.

Market forces are very dynamic and like physical laws; businesses that ignore market forces do so at their own peril. An agile business model will remain competitive as much as its value proposition remains relevant and well-calibrated with changes in the marketplace. An introduction of a substitute product that is less expensive or an entrant of a new cost leader with a better cost structure and manufacturing capabilities could shift the dynamics in the marketplace.

The PV solar panel manufacturing companies review shows that the surviving companies have changed with time and have become bigger through integration and acquisition to reduce cost and stay competitive in the PV marketplace. The PV market is still multiplying. The market growth rate from 2010 to 2021 is 32% in cumulative PV installations. Although the global PV market is vital [19], US companies may need help to enter the market. First, we need to check our intellectual property to ensure it is current and can provide the required efficiency and cost parity. Emerging PV cell technologies offer higher-efficiency cells at a lower cost [46]. Some of these technologies include multi-junction solar cells with perovskite and silicon tandem design have produced efficiencies of about 47%. However, these designs are complex and expensive to manufacture; research is ongoing to find ways to reduce the cost of these multi-junction solar cells. As of 2014, multi-junction cells were expensive to produce [47], but as the technology of manufacturing solar cells improves, the cost of production is expected to decrease. Such a breakthrough would make a significant impact on the PV solar market.

Second, assuming the company can develop a viable technology, the next challenge is to raise the initial capital to start manufacturing. This would be a tall order, given America's passive financing of renewable energy. When oil prices were high, it was easier to raise such funds than when they were low. With so many projects competing for funding, a solar project's value proposition must be compelling to attract all forms of capital investment.

Third, if the company can raise the initial capital, it must prove that it cannot only manufacture at a low cost but must also prove that it can sustain downward price changes. Existing players in the market have created strategies that are difficult to duplicate or beat by only low-cost manufacturing. For example, Tesla Energy has a complete value chain from manufacturing to product distribution and services. Tesla is also sharing its cost with other products that the company is manufacturing. First Solar has plants in various markets, including suppliers and customer relationships, that any new entrant will need help to duplicate.

Fourth, assuming the new entrant has overcome challenges 1-3 above, the critical challenge is maintaining a competitive advantage and avoiding the events that caused previous solar companies to fail.

The PV solar industry is very dynamic, requiring short turnarounds for good results. The period from product to production facility construction must be short; five years or more is too long, and such construction and processes may become obsolete. Immediate feedback from stakeholders is necessary to fine-tune the analysis and design to meet relevant requirements in the market. With an adaptive approach to technology development, process-oriented companies such as photovoltaic companies rely on innovation and continuous improvement and must be willing to change to stay competitive.

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