Texas Solar Primer

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for

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EXECUTIVE SUMMARY

Texas is very rich in Solar wind resource, and in some parts has a solar profile that is comparable to California (one of the richest solar resource states). Solar tends to track well with load profile, and has proven to be very suitable for residential and distributed applications. Texas is home to several key-players in the Solar industry, and plays host to 11.5% of the worlds silicon processing capacity. Several companies engaged in Solar PV equipment manufacture and research are resident in Texas. Despite the relatively high prevalence of resource and industry, solar PV is yet to reach the same level of commercialization as major success stories like California and New Jersey. At this time, Solar PV costs in Texas are not very competitive with the other existing alternatives.

Technology is not the only key to solving the cost equation in the favor of commercialization. Historical trends indicate that technological improvements have consistently driven reductions to the installation price. This is not enough to engender broad market capture. To bridge the inhibitive cost gap between Solar PV and other resources, Texas policy makers must create incentives that help defray some of the costs to potential customers. These incentives should be fashioned after incentives that have succeeded elsewhere but with the Texas context in mind. The following incentives will go a long way to improve the solar status-quo in Texas:

- Establish a **Feed-in-Tariff** that will guarantee purchase of Solar PV at fair buy-back rates
- Define specific Solar Carve-outs on **Renewable Portfolio Standard.** Employ market-based mechanisms like Solar Renewable Energy Credits (SRECs) to enforce compliance with standard.
- Simplify Interconnection Standards and institute favorable Net **Metering Policy**, to ensure that Solar PV owners get compensated for excess generation. Time-of-Use rate structures will favor solar since it tracks with peak load.
- Provide sustained funding for low-interest financing mechanisms like **Property Assessment Clean Energy (PACE)** financing that allows solar PV owners to avoid up-front cost responsibility.

However, Incentives cannot be offered indefinitely, and these will naturally decrease going into the long-term. In addition to incentives, sustainable financing business models that are responsive to several typical customer complaints are required. An example of one such model is the Third Party Solar Lease Model which shifts the ownership responsibility to a Solar Developer. This model has been very successful in California**.**

In the long-term Technology will be enough to sustain all the cost-reductions required to make solar competitive. However, short and medium term commercialization in Texas will need a combination of favorable policy initiatives and Financing Models.

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1 INTRODUCTION

Texas, like several states in the U.S is currently reliant on fossil fuels, particularly coal and natural gas, for it electricity supply. These energy sources, albeit being relatively cheap today, are finite in nature and prone to market volatility. The generators required for conventional sources are centralized, and will require expensive transmission in the inevitable event that expansion becomes necessary. Conventional energy sources also give out significant CO2 emissions, and are much less attractive in an era of heightened environmental awareness. The potential for the commercialization of electric vehicles has necessitated a smarter grid that is composed in significant part of clean energy sources. To tackle the aforementioned issues, states across the U.S are beginning to diversify their energy vista to include energy alternatives that enhance sustainability. California has established a niche for itself as a national bellwether in this regard. Texas must pursue this strategy of diversification to ensure that it has an energy supply that is sustainable, and in the best long-term interest of the state.

Wind is clearly abundant in Texas. If diversification is the goal, several proponents of wind energy are inclined to look askance at Solar Photovoltaic as an alternative to wind, which is already a runaway success in the state. Nonetheless, it must be stated that these two sources of energy are fundamentally different and cater to differing energy needs. Figure 1.1 shows profiles of wind and solar juxtaposed against a typical load profile. From this particular figure, it can be observed that whereas wind tends to track poorly with load profile, Solar offers very commendable tracking qualities.

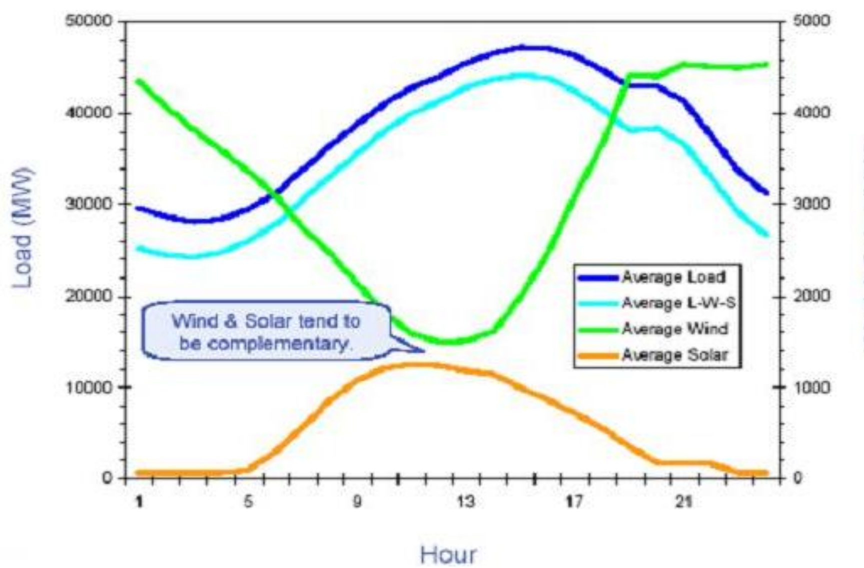

Figure 1.1: Profiles of Wind, Solar, and Peak Load [1]

Wind also scales better on the utility side, and has found more success in large-scale applications. Solar PV on the other hand has seen considerable global and local success on a much smaller scale. This means that Solar PV is more suited for residential and distributed generation applications. For this reason, Solar PV obviates the need for very expensive transmission networks as opposed to utility-scale wind. Wind turbines have constraints related to shadow, noise, and aesthetics that further hinder its commercial practicability in the residential sphere. Solar is bereft of any of these issues.

Having established the relevance of Solar as a potent energy source in the distributed and residential space, it is imperative that we spell out its specific relevance to Texas. Figure 1.2 shows the U.S Solar profile against two of the leading international players in Solar PV: Germany and Spain. Texas very noticeably has a better solar profile than both countries that have ha significant success stories in Solar PV. Texas also has a better solar profile than New Jersey, one of the leaders of Solar PV in the U.S. The State Conservation office touts the solar potential in

Texas, declaring that ―Solar panels lining an area thirty miles by thirty miles in West Texas could power the entire state". [2]

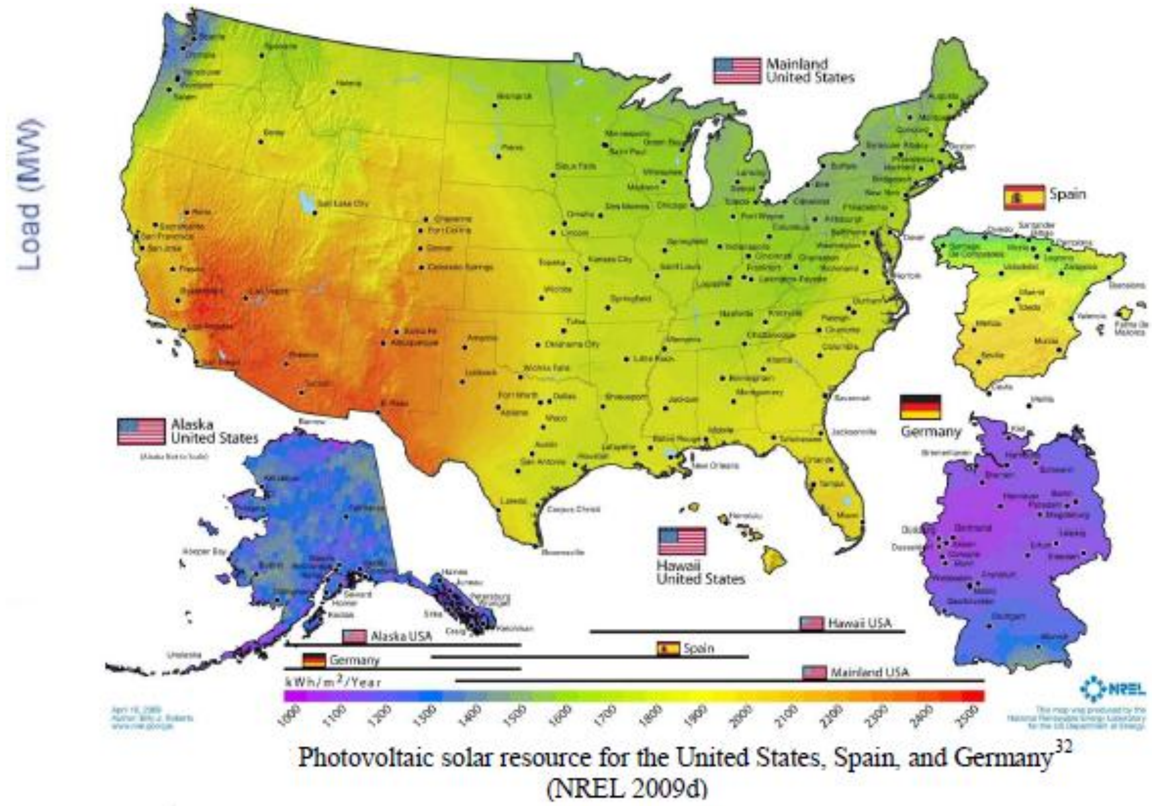

Fig 1.2: U.S Solar Profile Compared to Germany and Spain. [3]

Despite the clear abundance of cultivable solar resource, Texas has a long way to go in order to achieve wide-scale adoption of Solar PV. This report is intent on examining the various factors underpinning the growth of Solar PV in Texas. Section 2 provides an insight into the status of Solar PV technology on a global scale, with specific reference to industry presence in Texas. Section 3 includes a broad description of the policy barriers militating against solar PV in the state, and policy incentives to aid the growth of the Solar PV industry. Section 4 presents the economic picture as it pertains to viability of various initiatives for solar PV commercialization in Texas.

2 TECHNOLOGY

2.1 PV Residential on Grid System

While the PV panel is the main component of the solar installation, it makes up only the capture element for solar-to-electricity conversion. The rest of the materials and installation is referred to as the balance of system (BOS). For PV installations, the BOS includes all the hardware and components besides the panel, as well as the design and labor needed to put the installation together. [4]

The various hardware BOS elements include:

- Mounting—frames, support elements, roof support structures
- Connecting wires and conduits
- The inverter
- Power interface—breakers, protective switches, etc.
- Meters

The other elements for the general BOS include:

- System design (including the feasibility study)
- System installation (including site preparation
- System permitting and commissioning
- Operations and maintenance.

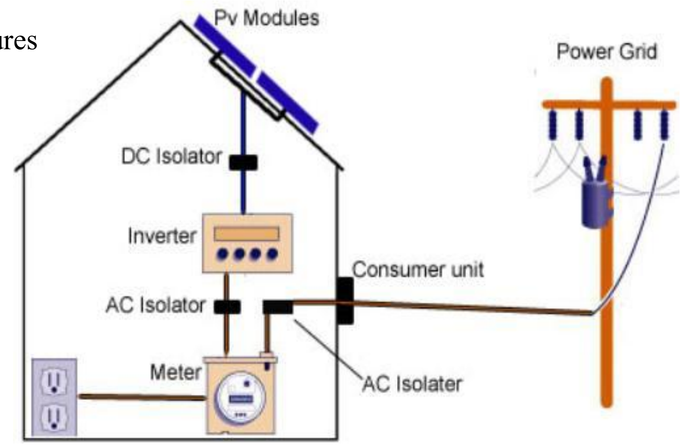

Figure 1: PV System

All these together form the PV system since they contribute significantly to the costs associated with it. The following figure gives the division of cost categories for the PV system. It can be seen that PV modules contribute only 45% of the total costs and rest 55% are for BOS components; mainly 10% for the inverter and 21% for installation charges. This cost categories do not take operation and maintenance into account. This represents just the upfront costs for a owner. It can be seen that there is a significant amount of cost reduction capability if improvements are made to BOS components. The current trend of research is geared towards decreasing these costs associated with PV to make it more viable.

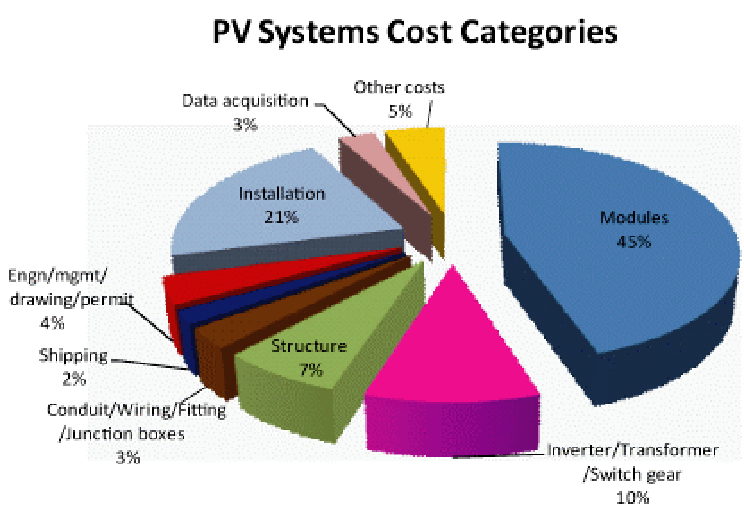

Figure 2: PV system cost categories [5]

2.2 Current Research Areas for PV System

Department of energy (DOE) of United States has identified area of technological improvements in a PV system, the specific changes that can be made to improve performance, increase reliability, or reduce cost of components and other elements of installed system cost and came up with the following table.

TIOS		METRICS			
TIER 1 TIOs	TIER 2 TIOs	Performance Efficiency	Cost	O&M	Reliability
Modules	Module	Red	Red	Grey	Yellow
	Absorber	Red	Red	Grey	Grey
	Cells and Contacts	Red	Red	Grey	Yellow
	Interconnections	Grey	Grey	Grey	Yellow
	Packaging	Grey	Yellow	Grey	Red
	Manufacturing	Yellow	Red	Grey	Yellow
Inverter & BOS	Inverter	Yellow	Yellow	Yellow	Red
	Inverter Software	Yellow	Grey	Yellow	Grey
	Inverter Components/Design	Grey	Yellow	Yellow	Red
	Inverter Packaging/Manufacturing	Grey	Grey	Yellow	Red
	Inverter Integration	Yellow	Grey	Grey	Yellow
	Other BOS	Yellow	Yellow	Yellow	Yellow
Systems Engineering & Integration	System Engineering & Integration	Grey	Red	Yellow	Yellow
	System Manufacturing/Assembly	Grey	Yellow	Yellow	Red
	Installation & Maintenance	Grey	Red	Red	Yellow

Note: Red Box = High Impact, Yellow Box = Moderate Impact and Grey Box = Little or No Impact [6]

The research focus for the PV modules is about increasing the module efficiency, reducing the costs associated with the manufacturing. But for the inverter it is focused more about improving the reliability and for systems engineering it is about decreasing the manufacturing costs and also operation and maintenance. DOE has awarded funding for various universities and companies working in these areas as part of Solar Energy Technologies program.

2.3 PV Module Technology

The basic building block of a PV system is the PV cell, which is a semiconductor device that converts solar energy into direct-current (DC) electricity. PV cells are interconnected to form a PV module, typically up to 50-200 Watts (W).PV modules technologies are divided into three generations.

2.3.1 First Generation

This generation uses Crystalline Silicon, both multi and single crystalline for PV modules. The first generation solar cells have the highest recorded efficiency when compared with the other two generation solar cells. On the other hand, the manufacturing cost for such solar cells is also the highest as these solar cells require extremely pure silicon. First generation refers to high quality and hence low defect single crystal photovoltaic devices these have high efficiencies and are approaching the limiting efficiencies for single band gap devices. These currently have the maximum market share. Key areas of research for crystalline silicon technologies are to:

- Improve the efficiencies of the cells to 25%
- Reduce the silicon consumption to < 2g/W
- Adopt technologies to reduce wastage of silicon.
- Adopt new silicon materials and processing methods
- Improving cell contacts, emitters and passivation.
- Improving the productivity and cost optimization in production by automation and process controls.

Key achievements in industry include:

- Ever green Solar: Novel Manufacturing processes (Si ribbon growth)
- Applied Materials: New wafer saw technology to reduce Si wastage
- Sun Power Corp: Novel back contacts
- Applied Materials: Thinner grid lines to improve efficiency
- 1366 Technologies: honeycomb-like texture to increase the internal reflection and increase efficiency.
- Passive optical elements are used to concentrate sunlight onto photovoltaic cells to improve the efficiency

2.3.2 Second Generation

This generation uses less or no Si for PV module and hence these solar cells when compared with those of first generation have lower cost and efficiency values. These are most frequently associated with thin film solar cells, designs that use minimal materials and cheap manufacturing processes. The most popular second generation solar cells are copper indium gallium selenide (CIGS) solar cells, cadmium telluride solar cells, amorphous silicon solar cells, and micromorphous silicon solar cells. This technology involves low cost and low energy intensity growth techniques such as vapor deposition and electroplating. Such processes can bring costs but because of the defects inherent in the lower quality processing methods, have much reduced efficiencies compared to First Generation. Key areas of research for thin film technologies are to:

- Develop novel large area deposition processes
- Improve substrates and transparent conductive oxides
- Improve cell structures and deposition techniques

Key industry achievements include:

- Global Solar: Flexible thin-film (CIGS) photovoltaic modules deposited on stainless steel
- First Solar: Thin CdTe modules of 1GW capacity
- SoloPower, which is making CIGS panels, uses electricity in a low-temperature process called electrodeposition.
- Signet Solar: A novel a-Si solar-manufacturing line

2.3.3 Third Generation

Third generation solar cells, which are still at research stage, came in to the picture so as to achieve the best of both generations. The primary reason was to make solar cells cheaper without having to compromise on its efficiency. Some of the third generation solar cells include polymer solar cells, dye-sensitized solar cells, and hybrid solar cells among others. Similarly some of the technologies associated with third generation solar cells are multi-junction PV cells, tandem cells, nanostructured solar cells, and so on. Research activities are taking place around the globe in reducing the manufacturing cost and to increase the efficiency of third generation solar cells. This generation uses non toxic and abundant elements.

With regard to third generation PV technology, key market needs include low cost, high efficiency, low weight, longer lifetime, and flexibility.

Key Industry achievements include:

Commercial applications of Dye Sensitized Solar Cell (DSSC) photovoltaic modules for consumer electronics and building integrated photovoltaics (BIPV) have been successfully demonstrated. Companies like G24 Innovations Inc., Dyesol, SolarPrint etc have been actively involved in manufacturing DSSCs that could be used to recharge lower end consumer durables.

Overall the PV modules technology is progressing towards improving efficiencies of the PV module, this is because, higher cell efficiency (higher power density) results in less needed PV module area which reduces the cost of labor for installation, module shipping and handling costs, structural support costs, and inter-module wiring costs.

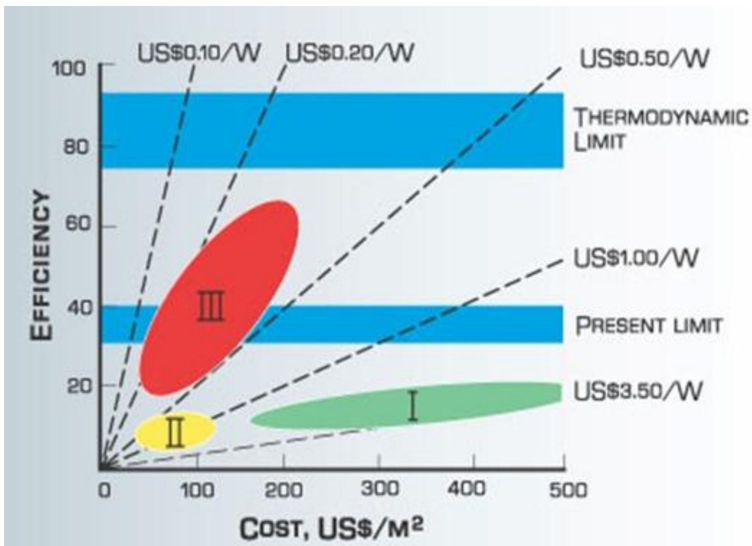

Figure 3 Comparison of various generations of PV modules [7]

2.4 PV Inverter

PV inverters convert DC power into AC power and may provide data monitoring. For a typical life time of 25 years for PV modules, at the current state of art technology, inverter needs to be replaced at least twice. So the current research focus is towards increasing the reliability of the inverter. The following are the innovative technological improvements in inverter technology now available in market.

- Multi string inverters: In many installations, strings of PV modules operate under different conditions, which require a separate inverter for each string. Multi-string technology allows multiple (usually two or three) strings to be connected to a single inverter. So-called multi-string inverters feature a separate Maximum Power Point Tracker (MPPT) for each string, ensuring maximum energy yield [8]
- Transformer less/ HF design: The transformer in conventional inverter designs is responsible for losses of around 2% in peak efficiency and accounts for the larger part of the inverter‘s weight. Designs that do away with the transformer are cheaper, more efficient, and lighter. High frequency (HF) transformers are a compromise between the conventional low frequency (LF) transformers and transformer less designs. HF transformers are small, lightweight, and provide electrical isolation.[8]
- Micro inverters: Micro inverters convert DC to AC at each module and thus have following advantages.
    - Having micro inverters for each module with each individual maximum power point tracker will increase energy harvest by mitigating the shading effects.
    - Micro inverter technology increases reliability due to the change in architecture to a distributed inverter system where each unit is only converting a small portion of the power of the array.

Micro inverters typically have a small thermal footprint and low nominal operating voltages, both of which reduce stress on components, thereby increasing reliability.

- Micro inverter systems can incorporate AC BOS equipment rather than DC junction boxes, DC combiner boxes, connectors, and fuses. Generic AC equipment is much cheaper than specialized DC BOS, and so total installation expenditures can be reduced significantly.
- Also DC equipment will need specially trained labor for installation thus increasing the labor costs associated.

Ongoing Research topics for PV inverters include

- Since capacitor is the element which reduces the reliability of an inverter research is focused on developing innovative topologies to reduce capacitor requirement and increase the reliability. [8]
- To simplify, standardize, and improve inverter connectors since connectors are the weakest link in the inverter circuit
- Circuit integration and Better thermal management
- Use of replaceable capacitors in inverter circuit so that only the failed capacitors are replaced in the inverter instead of the whole unit.
- SiC based switches in Inverters They can tolerate higher temperatures, can handle very high voltages, they have low resistance, and can operate at high frequency –which translates into inverter improvements in weight, size, cost, reliability, and efficiency.

Figure 4 Micro inverters

2.5 PV Mounting Systems

Frameless modules: Today most PV modules are sold with a frame to provide means for mounting the module. This frame is one of the largest single contributors to module cost. In large systems, the support provided by the system structure is adequate, making the module frame redundant. Eliminating this frame significantly reduces the module selling price.

Structural Adhesives: As an alternative to mechanical fasteners, structural adhesives offer the benefits of reduced stress points, leaks and corrosion, resistance to extreme environmental conditions, and enhanced sealant properties. The adhesive had excellent durability with no failures after more than 20 years of operation. Further, since installers offer panel warranties to their customers, usually from 5-20 years, for the installation, they require the consumer to purchase an agreement plan. Under the plan, the installer returns to the installation every 30-90 days to tighten the mechanical fasteners -- and that could be hundreds of fasteners. The mechanical fasteners, used to secure the photovoltaic arrays to the supporting racks and tracking systems, loosen over time due to wind-induced and/or structural vibration. Structural adhesives not only eliminate the problem of loosening fasteners, but also eliminate the need to visit an installation site for maintenance follow-ups. Structural adhesives eliminate the weight of mechanical fasteners and improve stress distribution, while providing a clean, streamlined appearance.[9]

Multipurpose PV: Several approaches are beginning to emerge where PV could be used in a manner that provides an offset of its cost by serving a multipurpose role . These functions include:

- PV roofing panels that also serve as insulating panels:
- PV awnings that provide a shading benefit
- PV roofing shingles

2.6 PV System Integration

PV system is moving towards integrating the PV modules and BOS components into one single system to reduce the installation and labor costs but this dream will take very long time to be realized with the current state of art technology.

It can be said that today, technology is progressing towards reducing the overall system costs.

2.7 Texas Solar Technology Capability

With technological advancements going on elsewhere Texas is right in the middle of it. Texas has all the technological potential it takes make solar more viable.

Texas is already home to 11.5% of the world‘s processing capacity for silicon Texas is also home to pioneering companies producing solar PV technology like Heliovolt,1 Soltech, Quad energy, Solarbridge, Cipher . These firms show the potential for economic growth in Texas from solar power investment.

Texas State has Emerging Technology Fund (ETF) to recognize and fund the state of art technologies that make difference in the common man‘s life. ETF were awarded to the following recipients in solar technologies [10]

- Solarbridge Technologies for their micro-inverters
- 21-Century Silicon Inc, for their proprietary furnace design that achieves solar-grade polysilicon manufacturing at ½ the cost of conventional methods.
- Solarno Inc, for novel solar cells that access the power of the full solar spectrum
- Heliovolt and NREL invented a hybrid manufacturing process for CIGS PV technology

University level research in Texas:

Solar Energy Technologies Program awarded funds for these universities[11]:

- Texas Engineering and Experimentation Station, for novel Poly Si Fabrication technology
- University of Houston, for novel deposition technology for Thin films
- University of Texas, Arlington, for novel transparent conducting oxides for thin films

University of Texas Austin had solar laboratory which works on collecting data for solar radiation across Texas and number of community level colleges like ACC offer certificate courses like Advanced Solar Photovoltaic Installer.

Technology is progressing towards reducing the costs down and making solar viable but this would take some time before it is realized, in the mean time to jumpstart the technology, incentives must be given.

3 BARRIERS

3.1 Background

Solar achieving grid parity is the key to the growth of PV installations in Texas as well as anywhere else in the world. Advancements have been made in the form of optimizing, reducing the cost, and increasing the reliability of the technology. Today research is ongoing to continue to decrease the cost of a PV system; however the cost of the system is still much too great to compete with grid electricity costs. This type of barrier to reaching grid parity is one that will take an extensive time. Thus the focus of the barriers section will lean towards a barrier that can be modified through legislation to offer a ‗jump start‘ increase in solar installations. This type of barrier involves a variety of federal, state, utility, and local incentives that currently are either available (maybe lacking mass awareness) or not available currently in Texas.

Financial incentives for photovoltaics (PV) are incentives offered to electricity consumers to install and operate solar-electric generating systems. A government may offer incentives in order to encourage the PV industry to achieve the economies of scale needed to compete where the cost of PV-generated electricity is above the cost from the existing grid. Such policies are implemented to promote national energy independence, job creation and reduction of carbon dioxide emissions to address the global warming. When, in a given country, the cost of solar electricity falls to meet the rising cost of grid electricity, then 'grid parity' is reached, and in principle incentives are no longer needed.

Incentives are the driving factors behind solar installation growth. Investigating the growth charts and incentives offered in different areas, the most effective incentives can be inferred from this data and can be applied to Texas with the aspiration to achieve such growth in the solar industry.

3.2 Incentives

Currently, Texas has no state wide policies that are required by all the utilities to be followed to promote Solar in particular but permits the utilities to have their own incentives to be given out for promotion of renewable energy generation. The state Renewable energy portfolio standard requires 500MW generation from renewable energy sources other than Wind but does not have a mandated share to be achieved for Solar. This section looks into the current Texas state policies and incentives as well as successful incentives offered in high solar capacity states and countries.

3.2.1 Renewable Portfolio Standard (RPS)

In recent years, Texas has enacted laws to encourage the development and use of renewable energy sources in general. In 2005, Texas expanded the RPS goals to require an additional 5,000 megawatts, incrementally, beyond the then-required 880 megawatts of renewable capacity [12]. It set a target of 10,000 megawatts by 2025. The 2015 goal of 5,880 megawatts was surpassed in 2008 by all renewable sources, seven years early, with more than 6,000 megawatts just from wind power [12]. In an effort to diversify the state‘s renewable energy sources, when the renewable portfolio standard was expanded in 2005 state lawmakers required the Public Utility Commission (PUC) to set a target of at least 500 megawatts of capacity from a renewable energy technology other than one using wind energy. However no solar specific carve out exists.

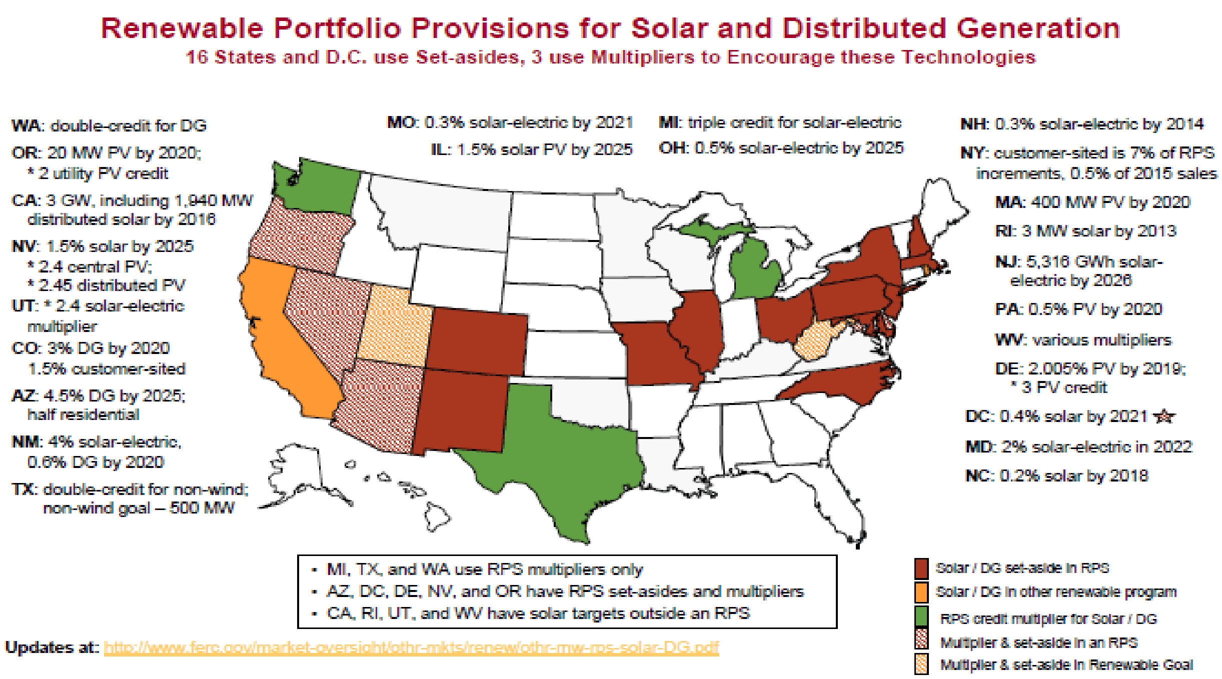

Figure 3.1: Map of Solar & DG Provisions in RPS policies (August 2010) [13]

Several states offer solar carve outs in their RPS polices as observable in fig. 3.1. The top two US solar capacity states (California and New Jersey) offer specific case studies for RPS solar carve out success in increasing solar installations. Specifically, California has an RPS requirement of 20% by 2010 and 33% by 2020. The RPS requirement has and will continue to lead to more utility-sector solar installations in future years [14]. In New Jersey, a generous (albeit inconsistent) state rebate program and an RPS with a solar requirement have helped build a strong PV market. The solar requirement is 306 GWh in 2011 increasing to 5,316 GWh in 2026. Now, for larger installations, the capacity-based rebate program has been converted into a performance-based incentive that involves payments based on the actual energy production of a PV system. This performance based program created a market for solar renewable energy credits (SRECs), which New Jersey utilities use to comply with the RPS. In 2009, new installations with a combined capacity of 34 MWDC were selling SRECs, representing 60% of new installations in New Jersey. Smaller PV installations, typically residential, will continue to receive rebate payments [14].

California remains the solar capacity capital of the country at 1,102 megawatts which is nearly 10 times that of New Jersey (70 megawatts) [15]. Interestingly, New Jersey‘s incentives tend to be higher than California‘s but do to the variation in these programs; it remains a distant second [16]. Larry Sherwood, a consultant to the interstate council said, ―The thing about California is that they have a consistent program that has 10 years of funding [16].” Thus it is essential to not only have numerous large incentives but to keep the incentives consistent to achieve constant growth as found in California.

3.2.2 Financial Incentives

Texas currently offers various tax deductions and exemptions to encourage use of renewable energy sources, including solar energy. Few are statewide like corporate deduction and solar energy business franchise tax exemption and others like rebate programs are utility specific.

When the investment tax credit (ITC) was renewed at the end of 2008, the $2,000.00 cap was revoked for residential installations by the Obama administration. This particular incentive created a delay in sales as many homeowners decided to wait for the larger 2009 credits to kick in [14]. This also caused the panel manufacturers to slash prices by more than 40% in 2009 to sell their PV modules, leading to a 10% decline in the cost of PV arrays [15]. Several states benefited from this modification to the ITC in 2008, particularly 10 states, led by Colorado, Hawaii, Connecticut, Oregon, Arizona, North Carolina, Pennsylvania and Massachusetts, that more than doubled their rooftop solar capacity in 2008 [16]. Observing fig. 3.2 will provide insight into the substantial growth of PV over the last two years in particular.

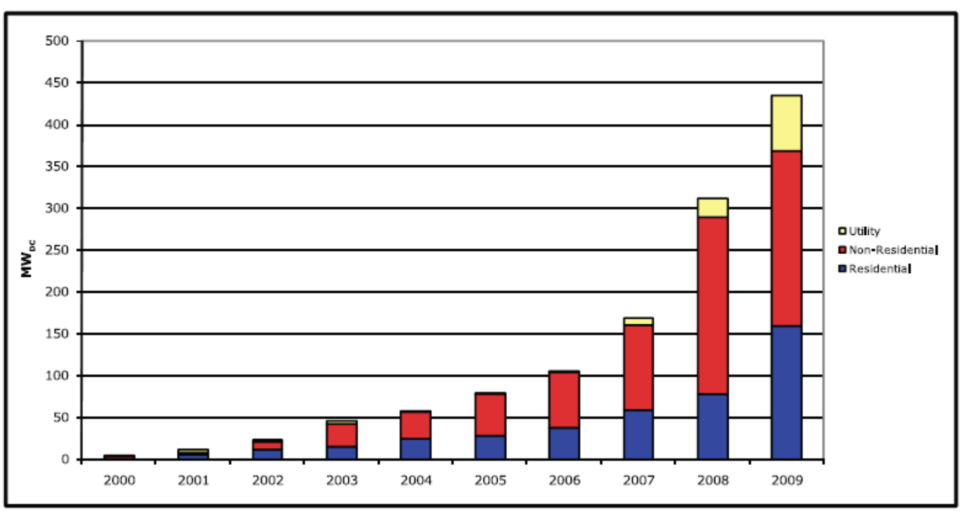

Fig. 3.2: Annual Installed Grid-Connected PV Capacity by Sector (200-2009) [14]

Prospects for growth in solar installations are a guarantee. Early indicators point to accelerating market growth in 2010 due to the long-term extension of the federal solar investment tax credit (ITC), recent federal legislation that allows utilities to take advantage of the ITC, and a deadline to start construction in 2010 to participate in the federal cash grant program. Companies have announced plans for many large solar electric projects, including both PV and CSP projects. Some of these projects will begin construction in 2010, and a few will be completed in 2010. Many more CSP plants will begin construction and come on-line in 2011 and beyond. Financing and transmission issues will determine when, and if, these projects can be constructed [14].

In Texas people need to be made aware of these federal tax credits to take greater advantage of them and add to the number solar installations (increased solar capacity).

3.2.3 Property-Assessed Clean Energy (PACE) Financing

Property-assessed clean energy (PACE) financing allows homeowners and business owners to finance on-site renewable energy systems, such as rooftop solar panels, and energy efficiency projects by way of a special multi-year assessment on their property [2].
PACE financing addresses the major issue of high upfront costs and the fact that people may sell their homes before the payback period of the improvements is reached for retrofitting a home. PACE would allow homeowners to pay only a pro-rated share of the costs for the period they own the house.

3.2.4 Third-Party Ownership of PV Systems

Another financing alternative for on-site renewable energy systems, such as rooftop solar panels, would be allowing a third party to own the systems. For example, in North Texas, SolarCity, a business entity, has teamed with TXU to lease panels to homeowners. SolarCity builds, owns, operates, and maintains the system, and the homeowner signs a 15-year lease for it, eliminating the upfront costs. The deal is exclusively between SolarCity and the homeowner [2].

3.2.5 Solar-Ready Homes

The Legislature also may consider establishing goals and creating incentives for making new buildings ―solar ready" by integrating solar energy systems into buildings at the time of construction or preparing buildings to make solar improvements easy to install [2].

3.2.6 Net Metering

Net metering policies require utilities to compensate consumers for the excess solar power they supply to the grid. Unfortunately, Texas has poor net metering policies. Under new rules recently passed by the Public Utility Commission of Texas, integrated investor-owned utilities (IOU) will be required to provide specific net-metering options for customers that produce excess electricity from solar installations. However, as a result of deregulation, less than 25% of Texas is currently served by integrated IOUs, so the policy has limited applicability [2].

Furthermore, owners of solar panels may need to pay for separate meters that measure the outflow of any power they send to the grid. The new rule also fails to exempt solar panel owners from paying distribution charges to their local utility in months when they feed more electricity into the grid than they receive. Texas' net metering policies create heavy burdens on customers wanting to install solar panels but provides no guarantee that customers who generate surplus electricity will ever get paid. The U.S is the main leader in this area, with the rest of the world lagging far behind [17]. Given that net metering makes use of a complex smart meter and that it might be economically complex to administer, it is understandable that countries in the developing world favor other simpler alternatives.

Ultimately, it can be stated that the health of Texas' solar energy industry depends upon there being a sizable demand for its products and services and upon reduction of the costs associated with meeting that demand. Meager state incentives present significant barriers to all types of solar energy development in Texas, including distributed solar power. Leading into the next section on feed-in tariffs, it's important to point out that quite often net-metering is combined with a feed-in-tariff, in which case the tariff only applies to excess electricity.

3.2.7 Feed-in Tariff

Feed-in tariff incentives generate electricity for the utility sector and represent a small, but growing, segment of the U.S. PV market. Feed-in tariff involves the utility purchasing all the output of the PV system at a set price that is typically higher than retail electricity prices. Over 34,000 grid-connected PV installations were completed in 2009, with 92% of these at residential locations (see Figure 5). By contrast, residential systems accounted for only 36% of the PV capacity installed in 2009, as discussed previously. At the end of 2009, 104,000 PV installations were connected to the U.S. grid, including over 93,000 residential installations. The average size of non-residential systems is more than ten times the average size of residential systems [14]. Fig. 3.3 demonstrates the rate of PV installations over the past 9 years.

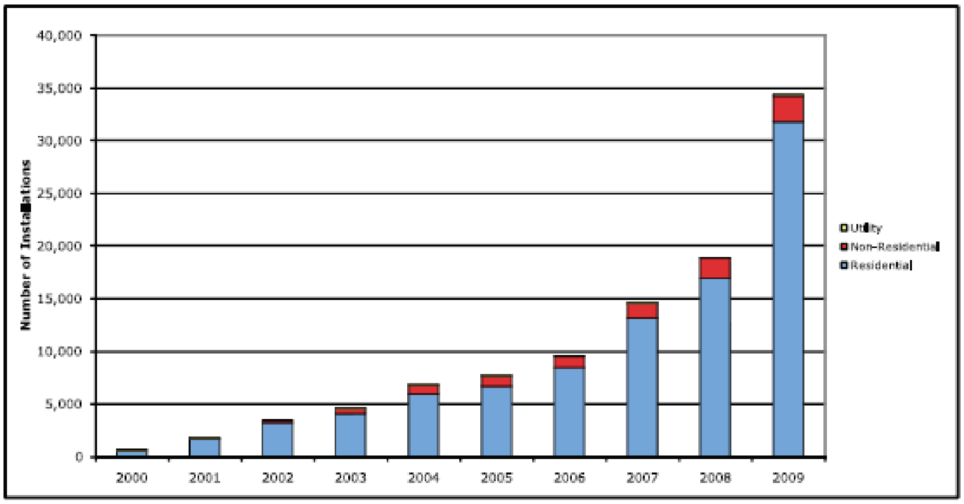

Figure 3.3: Number of Annual U.S. Grid-Connected PV Installations (2000-2009)[14]

Grid-connected PV systems installed in 2009 were concentrated in California, New Jersey, Florida, Arizona and Colorado, as shown in Table 3.1. Most amazingly, these 5 states make up eighty percent of grid-connected PV capacity installed in 2009 and 92% from the top ten states. For the first time the market share for annual installations in California slipped below 50%. Yet markets in California continue to grow much faster in other states. Of these states California in acted a FIT policy in 2008, Florida in 2009, and Hawaii as well in 2009 [18].

Table 3.1: Top Ten States Ranked by Grid-Connected PV Capacity Installed in 2009[14]

2009 Rank by State	2009 (MW_{DC})	2008 (MW_{DC})	08-09 % change	2009 Market Share	2008 Rank
1. California	212.1	197.6	7%	49%	1
2. New Jersey	57.3	22.5	155%	13%	2
3. Florida	35.7	0.9	3668%	8%	16
4. Colorado	23.4	21.7	8%	5%	4
5. Arizona	21.1	6.2	243%	5%	8
6. Hawaii	12.7	8.6	48%	3%	5
7. New York	12.1	7.0	72%	3%	7
8. Massachusetts	9.5	3.5	174%	2%	11
9. Connecticut	8.7	7.5	16%	2%	6
10. North Carolina	7.8	4.0	96%	2%	10
All Other States	34.2	24.6	41%	7%	--
Total	**434.6**	**311.3**	**40%**	**--**	**--**

2008 and 2009 columns include installations completed in those years.
"2009 Market Share" means share of 2009 installations. "2008 Rank" is the state ranking for installations completed in 2008.

Outside the US, Feed-in Tariff (FIT) is by far the most commonly used incentive on a global scale. FITs imply payment of a fixed tariff to Solar PV producers for every kwh produced. A feed-in tariff usually involves the following components

- Guarantee by government sanctioned electricity purchasing authority
- Intent is to create some kind of reasonable profit for the investor (typically in the vicinity of 5 – 10%)
- Limit to the size of installation (< 5MW)
- Long-term guarantee of fixed tariff (usually about 20 years)
- Tariff based on cost-of-generation plus profit for the investor
- Tariff is reviewed yearly to adjust for inflation and reduction in the cost of components.
- Usually a National plan

Feed-in tariffs are used widely in several countries in Europe. Spain and Germany are very strong examples. FITs have been consistently proven to drive significant PV development in the countries where it is used. Japan is a very instructive story of FITs, as PV growth reached a plateau in Japan when the government back-pedaled on its FIT strategy in 2006 [19]. However, growth increased significantly with the reintroduction of FITs in 2008 [20], observable in fig. 3.4. Canada Ontario Power Authority has also recently introduced an FIT that is already showing telling signs of success [21] (April 2010 [22]). Germany, Spain, Japan, Italy, France, and South Korea (countries with strong national FITs) command about 85% of the market *[3]*.

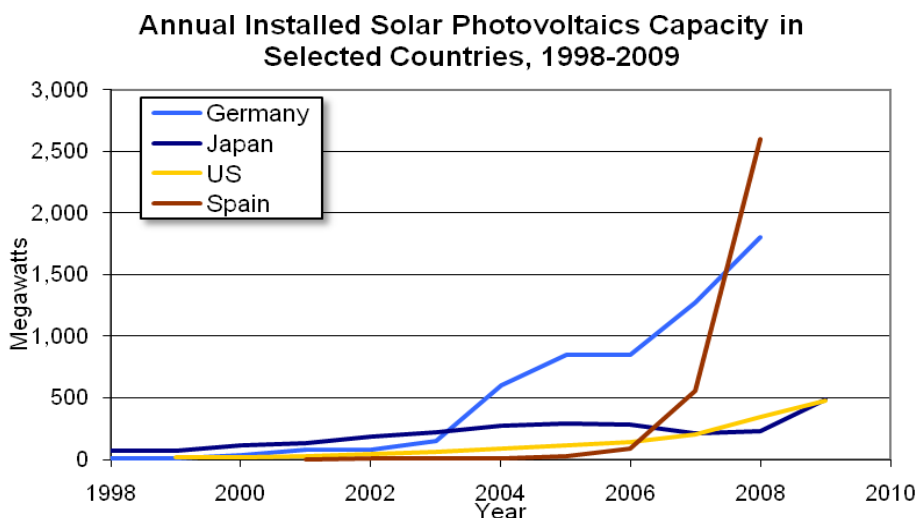

Figure 3.3: Number of Annual U.S. Grid-Connected PV Installations (2000-2009)[23, 24]

Notice that countries with the most aggressive programs (Germany and Spain) have the steepest slopes in added PV. Spanish growth begins to surge in 2007 with the introduction of the Spanish feed-in law (661/2007). German PV growth also experienced a steep increase with the promulgation of the German Energy Sources Act (EEG law) in 2004 [18]. Reductions to the tariff in Germany between 2005 and 2006 caused growth to flat-line temporarily. Countries like U.S that do not have a national FIT program have relatively flat slopes in terms of annual growth. The decrease in slope for Japan between 2006 and 2008 was because Japan eradicated its FIT program.

3.3 Recommendations

On the average, most PV financial incentives cause a slight increase in the price of electricity, since PV is in real terms more expensive than the other conventional forms of energy. The impact varies in the different countries, as the alternative to PV varies in the respective countries. The high prices for fossil fuels in Europe will imply that Grid Parity (point at which solar PV matches other conventional sources) will be reached faster that a country like the U.S (where PV has to compete with an abundance of conventional sources like coal). Nevertheless it must be observed that increasing the demand of PV through financial incentives like FIT will continue to drive its cost down via economies of scale. Once this is done grid parity will be accomplished sooner than later.

The PV industry continues to grow significantly on a global scale. Last year PV grew by about 50%. PV growth is driven primarily by decline in cost of components and favorable financial incentives. The most successful countries have been in Western Europe (Germany and Spain). Growth in America has proceeded at a slower pace, which is in part attributable to the lack of the best combination of financial incentives. The different states in America have embraced various types of initiatives, but only California and New Jersey have witnessed appreciable success in PV. Texas currently lags behind and must endeavor to emulate the policies that have worked elsewhere. It will also be in the best interest of the nation's PV industry if the U.S government adopts favorable nation-wide initiatives like a Feed-in Tariff. A move in this direction will signify political will, and actuate investors and residential consumers to pursue more PV projects.

4 ECONOMICS

4.1 Current Economic Status

One of the main barriers facing PV in the general sense is its prohibitive cost relative to other energy alternatives. In order to commercialize residential PV on a large scale, system, policy, and business planners must adopt strategies that reduce the cost of PV. The installed prices of solar PV have steadily shown a trend of decrease as seen in Fig. 4.1a. This decrease is indicative of the economies of scale that have been derived as Solar PV installed capacity has increased significantly in the last 10 years (Fig. 4.1b). Various technological improvements, notably in module efficiency, have also contributed significantly to this cost reduction.

Fig. 4.1b is illustrative of the global production trends for solar PV. Global volume is currently around 12GW, and continues to grow exponentially. From Fig 4.1a, it is easy to see that PV installation costs for residential installations are quite higher than their counterparts in commercial or utility scale projects. This is largely due to the economies of scale that accrue to commercial projects, as well as the higher tax incentives that commercial projects can utilize. Fig 4.1b also serves to illustrate that the vast majority of projects that have been installed are on-grid. Both figures (4.1a and 4.1b) bode well for the commercialization of solar PV, and present the message that we are on the right path.

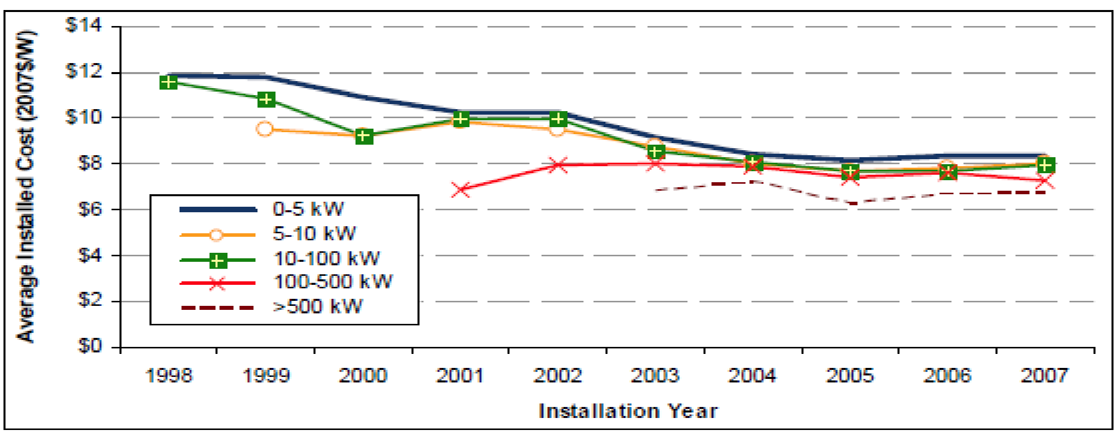

Figure 4.1a: 10-year average Installation Cost [25]

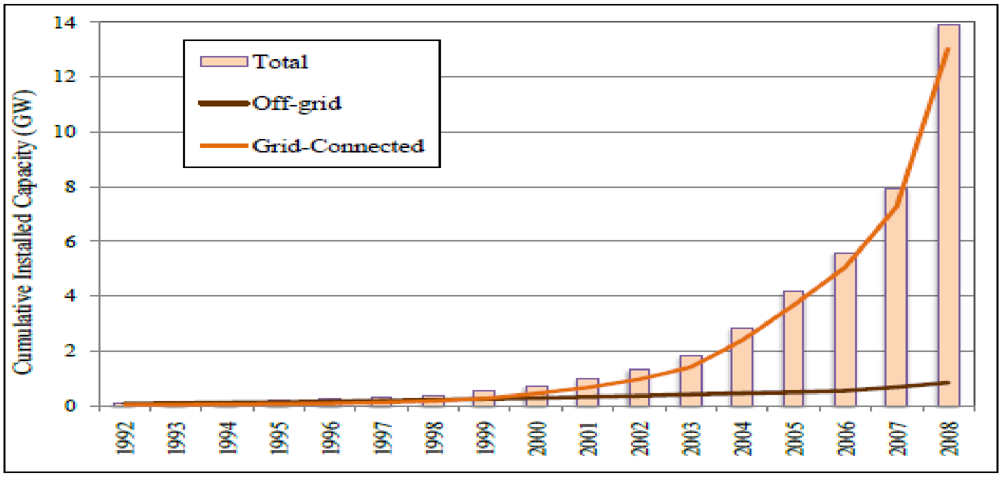

Figure 4.1b: Cumulative installation capacity [3]

The values from Fig 4.1a are currently outdated (circa 2007). Current estimates from Solar-buzz indicate a module price average of about 3.50/Wdc[26]. Operating under the standard assumption that module costs are about 50%, we can estimate current residential estimates to be about 7.00 $/Wdc. This value represents the installation cost before any sort of incentives. Pre-incentive costs are known to vary significantly across different states and cities largely because of supply constraints and non-material costs (permitting, installation, etc). An average value of $7.00/Wdc still represents a significant expense to a potential residential customer. A 4kw system – a typical residential installation – will cost about $28,000; almost the same as the cost of a low-end luxury car. Solar PV costs will have to reduce appreciably in order to sustain market commercialization. The succeeding paragraphs present a description of the various cost drivers, and the metrics for measuring PV cost.

PV costs are largely driven by the module price which accounts for 40-50% of total costs. The inverter also takes a significant chunk of the costs (10%). Balance of System (BOS), installation, and indirect costs (permitting, business, administrative) make up the cost remainder at the time of installation. Fig. 4.2a[5] and Fig. 4.2b [27] serve to illustrate the different cost components and their respective percentage shares of the total cost.

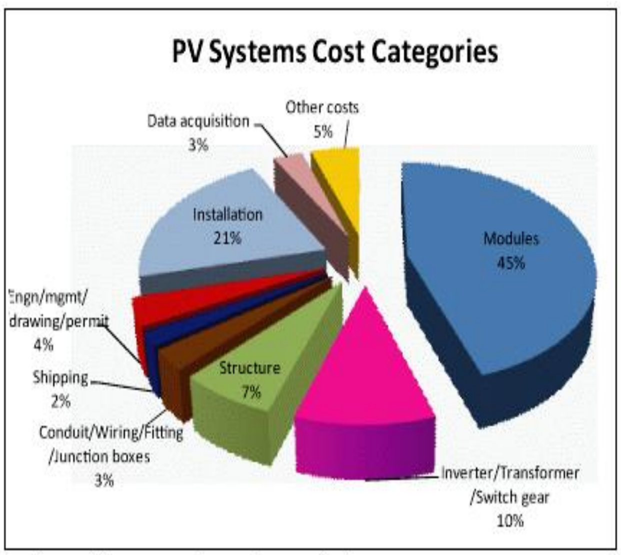

Fig 4.2(a) - Cost Drivers for Installation Cost

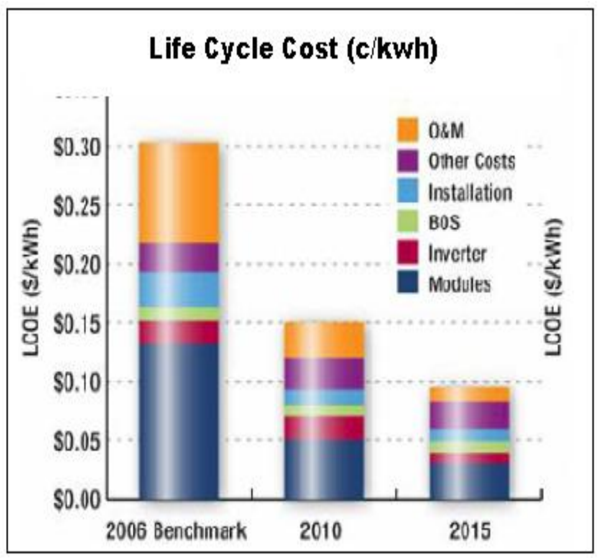

Fig 4.2(b) - Levellized Cost of Energy (Phoenix, Residential)

From fig. 4.2(a), it is clear that a good amount of the cost of PV systems goes into the PV module, hence a lot of the previous research has being focused on reducing the module cost. However, industry efforts to achieve cost gains in the other components (inverter, BOS, installation etc) are being intensified. Fig. 2.2(b) presents an interesting perspective that is not easily revealed by metrics that consider only the installation cost ($/W). We observe that the Operations & Maintenance (O&M) costs could constitute a significant chunk of the total PV cost over the entire product life cycle. O&M costs typically include inverter maintenance, panel cleaning, site monitoring, insurance, financing, parts replacement and repairs.

Given the potential significance of post-installation costs, it is important for PV industry players to use a standardized cost language (metric) that considers PV life-cycle when comparing various cost reduction initiatives. The installation cost index in $/W provides no information about post-installation costs, and does not intrinsically reward projects that maximize energy harvest. The Levellized Cost of Energy (LCOE) approach addresses most of these concerns by encompassing the entire product life cycle, and yields a result that is a function of the energy generated over the product life-cycle.

4.2 Standardized Cost Metric

4.2.1 Levellized Cost of Energy (LCOE)

The Department of Energy (DOE) is beginning to use the LCOE as the standard cost metric for defining various cost reduction targets for PV. The LCOE is more representative of true cost, as it looks at the entire life cycle of a PV project. Grid parity analysis is another important consideration that is accommodated by the LCOE metric. Grid parity is essentially the point at which the cost of solar becomes comparable to retail electricity rates. The LCOE is in c/kwh, and can be compared directly against local electricity rates. It is fair to assume that once PV costs become competitive against current electricity rates, commercialization stands a better chance of actualization.

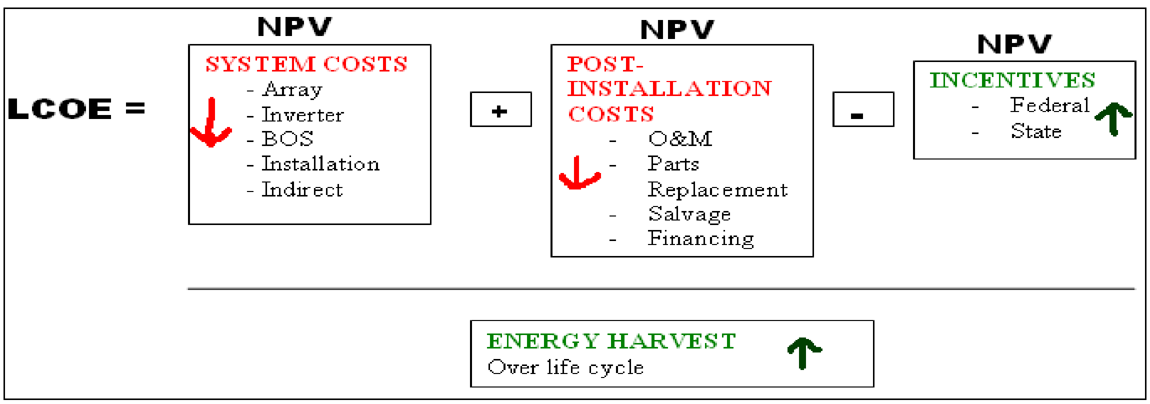

Figure 4.3: Levellized Cost of Energy (LCOE) Components.

From Fig. 4.3, we can clearly see the various components of the LCOE. Cost initiatives must be designed to reduce both system and post installation costs, as well as maximize energy harvest. Policy planners in Texas should endeavor to reduce life cycle costs by providing incentives that reduce the life cycle cost and in turn the LCOE. This standardized language and approach will go a long way to ensure that all industry players are working concertedly in the right direction.

4.2.2 Customer Perspective on Cost Metric

Life-cycle costing is already widely practiced within the business community in areas beyond solar PV, and has also gained significant traction in the solar PV industry. Nonetheless, the typical residential customer will not engage in a detailed cost analysis employing sophisticated metrics like the LCOE. A customer buying a luxury vehicle does not usually attempt to gauge its life cycle cost, and is even less likely to have the orientation or resources to compute a ‗true" LCOE cost for solar PV. Residential consumers respond to a different cost language that has two main by-words: up-front costs and payback-time. Up-front cost basically refers to the cost of PV at the time of installation. Pay-back time gives an indication of how long it will take for the customer to break-even on his investment in solar PV. In contriving commercialization strategies, it is imperative that industry players and policy makers take the customer‗s perspective into account. Opportunities for cost-reduction exist in both the technical (technology) and non-technical (policy/financing) categories. The subsequent report sections will present a few of the salient opportunities using the LCOE metric and ―customer-centric" cost language.

4.3 Commercialization Strategies– Technology

Several alternatives exist for cost reduction in the technical space. These opportunities are myriad and include module efficiency, inverter reliability, micro-inverters, systems integration, supply chain optimization, BOS improvements, stream-lining business processes, building-integrated PV, tracking systems, concentrating PV, etc. Section 2 of this report addresses the technological aspects of PV and goes into more detail on each of these. This particular section will focus on Micro-inverters and Inverter Reliability, and use these as an illustrative example of how technological changes could impact cost. Additionally, a macro-scale approach - using DOE cost reduction targets - is also employed to estimate the effect of an aggregate of several technological changes on the Texas PV market.

4.3.1 Micro-Scale - Micro-inverters and Inverter Reliability

The typical residential installation makes use of a single inverter connected to all the string-connected modules in the PV array. The micro-inverter approach involves the connection of each individual module to a small inverter. On the face of it, the centralized approach will appear to be less complex and plausibly more cost effective. However, closer scrutiny shows that the micro-inverters might be a better bargain over the entire product life-cycle using the LCOE metric.

Micro-inverters have several advantages over regular inverters. They do not require specialized DC wiring since they make use of conventional AC wiring. This entails significant savings in the installation cost. The installation cost savings are estimated by Enecsys (micro-inverter manufacturer) to be about 25% [28]. Micro-inverters also show significant advantages over centralized inverters when it comes to power Harvesting. DC wiring, module mismatch, and poorer reliability (centralized inverter is a single point of failure) all make the micro-inverter about 4% better on energy harvest [28]. Maintenance cost is reduced by about 9% with micro-inverters because of easier maintenance and longer life-cycle (25 years for some micro-inverters) [28].

Presently, centralized inverters have a typical lifetime of about 10 to 15 years. The typical PV module has a life-time of about 25 years. This implies that during the life-time of such a PV system, the centralized inverter will need to be replaced at least once. Solar-buzz indicates that the current inverter cost to be about $0.715/W [29]. For a 4kw residential system this total system replacement cost (10 years from now) for a system purchased today has a present day value of $3661. Some micro-inverters have 25 yr life cycles, and will not need replacement during this period.

To do an LCOE analysis, we will use a single centralized inverter rated at 4kw from SMA (Sunny Boy) with a unit cost of $2,470 [30]. A micro-inverter from Enphase with a unit cost of $200 and a rating of 210w is used [30]. We assume installation costs for DC wiring to be 21% of the $7/W (1.47 $/W). The AC wiring is adjusted to be 25% less. The LCOE computation results for both scenarios follow below in table 4.1

. Table 4.1: Micro-inverter/ Inverter Reliability

	Single Inverter	Micro-Inverter
Inverter Cost	2470	4000
Installation Cost	5880	4410
Non-inverter/installation Cost	19600	19600
Total Upfront Cost	27950	28010
Energy Yield (kwh)	**4518**	**4698.72**
Replacement Cost ($)	**3661.041796**	**0**
System Life	25	25
Lifetime Energy Output	112950	117468
LCOE	**27.98675679**	**23.84479177**

It can be seen that a reliable micro-inverter (25-yr life-cycle) can potentially offer up to 15% in LCOE savings, even though in this particular case the up-front cost is higher.

4.3.2 Macro-Scale - Department of Energy(DOE) Road-Map

In view of the variety of technological options, it is important to note that there is no ―silver bullet” for accomplishing commercialization. It is quite beneficial to aggregate various technological advancements and give a composite cost reduction figure to the upfront and O&M costs. The Department of Energy (DOE) does this by setting composite cost reduction targets for specific years (2011, 2020) [27]. This section uses these composite cost reduction targets to illustrate the influence of such changes on the Texas PV market. The DOE projections are contained in Appendix A. The DOE reduction target essentially postulates that by 2011, technology-driven reductions in PV cost will drive system installations costs to $5/Wdc. Furthermore, by 2020 changes in technology will drive costs to $3.30/W. Using the solar advisory model (SAM) – a DOE tool for estimating solar PV cost – payback time and LCOE values where obtained for 4 cities in Texas (El paso, Austin, Dallas, and Houston). Assumptions are contained in the Appendix A.

The intent is to index grid parity (solar PV competitiveness against other alternatives) using (LCOE), and simultaneously measure customer appeal (payback time). An arbitrary ―sweet- spot” of 13 c/kwh and 10 years is chosen. 13c/kwh is close to the Texas retail average of about 11.95 c/kwh[31]. We postulate that PV will be in a position to be highly commercialized if the LCOE and payback values calculated for a 4kw test-system are lower than the values at the ―sweet-spot”, essentially within the ―sweet zone” labeled green in fig. 4.4. Four scenarios were tested:

- Case1: DOE 2011 Cost Reduction Projection ($5.00/W) without any additional Incentives
- Case 2: DOE 2020 Cost Reduction Projection ($3.30/W) without any additional Incentives.
- Case 3: DOE 2011 Cost Reduction Projection ($5.00/W) with additional Incentives ($5000)
- Case 4: DOE 2020 Cost Reduction Projection ($3.30/W) with additional Incentives ($5000)

All cases include the Federal ITC, which has been extended to accommodate residential PV projects. The additional incentive of $5000, is meant to simulate the effect of policy incentives of that magnitude ($5000 is not an unusual sum for incentives for example utility subsidies/rebates driven by SRECs). Case1 (Fig. 4. 4a) shows that with the 2011 projection and no additional incentive, none of the states are competitive. Case 2 highlights the fact that technology will make Texas cities more competitive (El Paso achieves Grid parity and the other cities are reasonably close to the ―sweet-zone”). However, this particular case does not give PV a clear edge over prevailing electricity rates, and payback times are still high across the Texas cities studied.

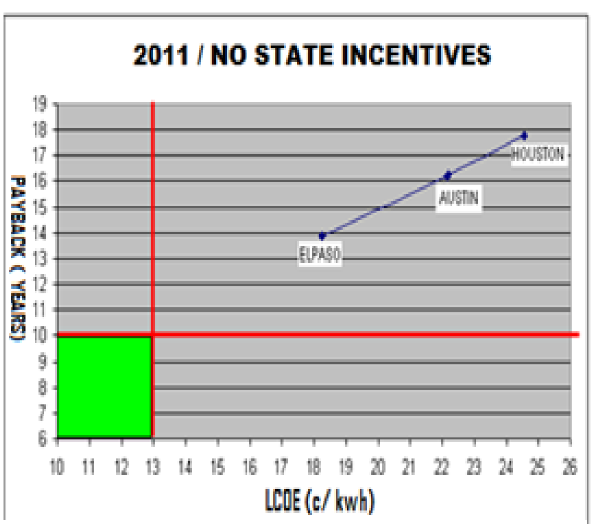

Fig 4.4(a) - Case 1

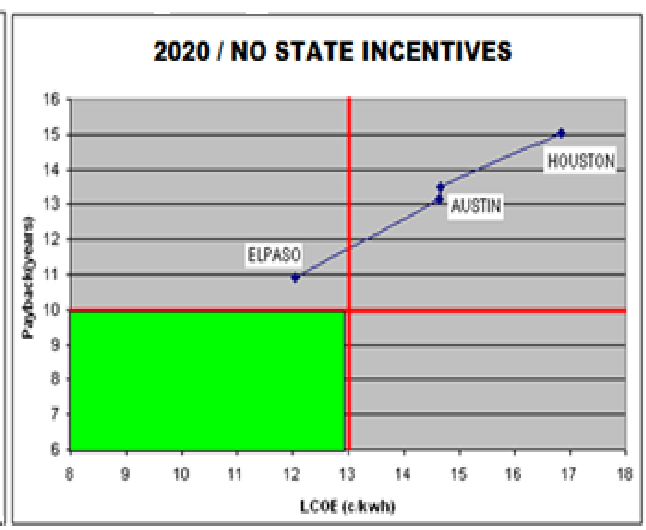

Fig 4.4(b) - Case 2

Case 3 (Fig. 4.4c) shows that adding incentives to the 2011 projection will actually make solar PV more competitive than waiting for 10 years of technological innovation. Case 4 (Fig. 4.4d) represents a perfect scenario **but serves to show that technological improvements plus sustained incentives will make PV very highly competitive as practically all the cities will fall into the sweet zone**. The amount of incentives need not be as high as $5000 to foster appreciable growth in the PV industry.

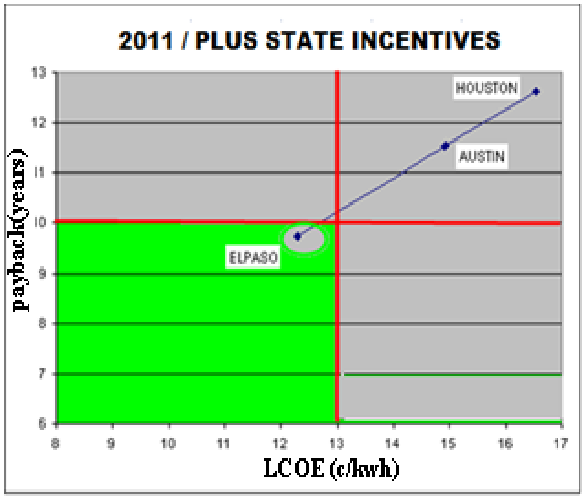

Fig 4.4(c) - Case 3

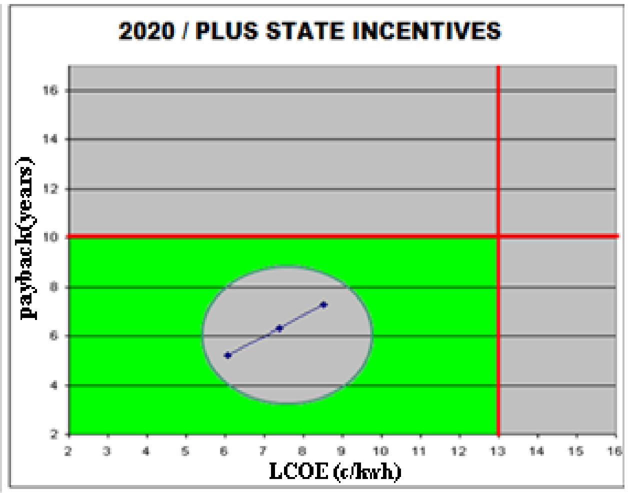

Fig 4.4(d) - Case 4

4.4 Commercialization Strategies: Financing

4.4.1 Traditional PV financing

The foregoing section makes a strong case for using policy-based incentives as a supplement to technological innovation in order accelerate the deployment of solar PV in Texas. However, incentives cannot be utilized indefinitely and will have to be replaced or supplemented by sustainable business models that achieve a similar effect. The main problem from the customer standpoint is the financial responsibility occasioned by the high up-front cost. Traditional financing models, which include home equity loans and refinanced mortgage loans have all adopted the philosophy of treating solar like a conventional home improvement project [32].

These models have being insufficient in dealing with several typical customer concerns. Chief among these concerns is the long payback period of a typical solar project. People tend to change homes often and are worried that they will have to give-up their PV installation before it actually breaks-even. Another pressing worry is the burden of O&M responsibility. Several potential owners are clueless about PV and have understandable misgivings about the associated O&M. There is also the hassle of choosing the right installer and installation, which could be time and resource demanding. On the other hand, there is no compelling imperative that ―forces" Texas customers to jump on the PV band-wagon. Utility bills are relatively low, and the potential savings do not constitute a definitive case for PV. Financing models that address these issues are required to give PV the much needed face-lift. Two relatively new models that are directly relevant to the state of Texas are viable possibilities: Property Accessed Clean Energy (PACE) financing (covered in section 3), and Third Party Ownership.

4.4.2 Third Party Financing – Solar Lease

Third-Party financing usually involves a developer and/or investor who leverages scale and commercial tax benefits. Third party arrangements have several variations but this report focuses on the solar lease arrangement. In the solar lease arrangement, ownership of the system shifts from the residential customer to the solar aggregator/ developer. The customer pays a monthly lease that is typically less than the utility bill savings from installing the solar system. The Solar developer pays in full for the upfront costs of installing the system. Solar lease conditions tend to vary but in most cases the O&M is fully the responsibility of the developer. Solar city is an example of a developer that assumes O&M responsibility.

4.4.3 Solar City

Solar City is currently the leading player in the solar lease industry in Texas. Originally based in California, Solar City has expanded its operations to include a presence in Texas, particularly Austin. In Austin, Solar City Partners with TXU - the utility that provides rebates based on the system capacity [12]. These rebates help the utilities satisfy their RPS requirements (Renewable Portfolio Standards). Solar City installs, maintains, monitors, and owns the installations. Solar City currently has over 300 contracts in Austin, and has reached the entitlement on its lease quotas [12].

The leases offer several benefits to the consumer. The first benefit is the reduction of upfront costs. Lease plans are flexible, and customers can choose to go with a zero-down payment option. Ostensibly, paying a little up-front reduces the lease amount. Another significant benefit to customers is that in most cases the savings to the customer begin from the very onset, which essentially reduces the pay-back time to zero. Fig. 4.4 illustrates this. It is also noteworthy that benefits increase with time as utility rates will typically grow faster than the lease rates. The customer is also absolved from the ownership hassle of O/M.

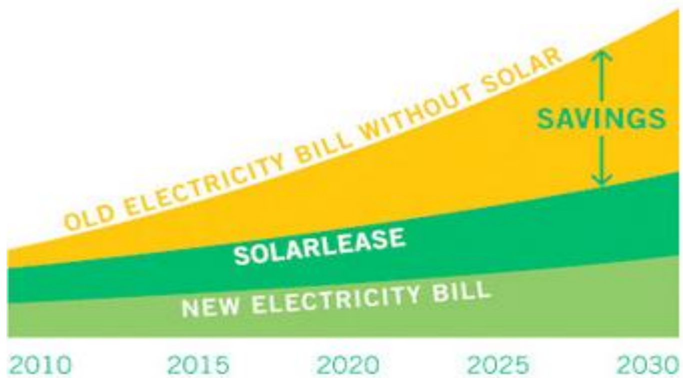

Figure. 4.4: Solar City Residential Customer Benefit Curve [33]

Solar City benefits from the arrangement by leveraging scale from its vast variety of projects. In some instances an Investor provides a loan facility, and both Solar City and the investor could benefit from the various tax incentives and MACRS depreciation that are only available for commercial scale projects. Solar City owns the PV and as such the renewable energy credits that stem from it. In the right market environment, companies like Solar City stand to gain from the sale of SRECs to utilities.

5 CONCLUSIONS

Texas' solar profile offers one of the best solar energy potential of any state. Currently meeting grid parity by decreasing technology cost alone is far off and enticing home owners to invest into a PV system at such a high cost is not typical. Therefore continuing technological advancements to reduce the cost and increase the reliability of the system are a necessity to meeting grid parity in the long haul. In the near future the key ingredients for Texas to achieve a substantial solar capacity increase can be taken from commanding solar capacity states and countries, particularly in the form of incentives. Texas should incorporate a solar specific carve out into its RPS program as well look into adding a feed-in tariff. These two incentives seem to pull the most weight in accelerating PV grid tied system growth. Outside of incentives, creating third party solar system owners who act as a go between for the home owner and utility company have been observed to increase solar sales. Home owners tend to be more comfortable when the high dollar upfront costs and maintenance of the system land in the hands of another. The simpler solar becomes for the home owner, the more solar system installations will be seen in Texas. These incorporation of these three areas, technology development, incentives, and third party ownership provide the best opportunity for solar growth in Texas.

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7 APPENDIX A

4.3.1 – Inverter Reliability

Assumptions [28]:

- 4kw Test system is used
- System degradation is ignored
- O&M costs are ignored
- Financing Model is up-front cash payment
- Inflation rate is assumed to be 2.5%
- System Life is assumed to be 25 years
- Annual Energy yield is obtained from SAM for Houston, TX.
- The number of required micro-inverters is 20.
- Inverter costs are all obtained from the affordable solar website.
- Module is assumed to be 50% of the costs.
- BOS is assumed to be 20% of the cost
- upfront cost = Module cost + inverter cost + BOS + installation cost
- Installation Cost for Micro-inverters = 0.75*Installation cost for centralized inverters
- Energy Yield for Micro Inverters = 1.04*Energy Yield for centralized inverters

$$LCOE = \frac{NPV(upfront \text{ cost} + \text{inverter replacement cost})}{[\text{annual energy yield} * 25]}$$

$$\text{Present Value} = \frac{A_n}{(1+i)^n}$$

$$\text{Present Value} = \frac{A_0}{(1+i)^n}$$

A_n = value at year n

A_0 = Present day value.

i = inflation rate

4.3.3 - Macro-scale (SAM)

Solar Advisory Model is used for Analysis.

Information on software: https://www.nrel.gov/analysis/sam/cost_data.html

System Degradation = 1%

Inflation = 2.5%

Discount rate = 5.5%

Utility rate escalation outside inflation = 2.5%

DC – AC Derating = 0.77

System life is 25 years

O&M costs - $60 per annum in initial year.

All cases studied include federal Investment Tax Credit (ITC) of 30%

Table A.1: DOE Cost Reduction Targets **[27]**

2005 Benchmarked Parameters, 2011 and 2020 Projections for Modeling of 4-kW Residential Reference System

System Element	Units	2005	2011	2020
System Location		Phoenix		
System Size	kW	4	4.56	5.92
Module Price	$/Wdc	4.00	2.20	1.25
Conversion efficiency	%	13.5	16	20
Module size	Wpdc	100	118.5	148
Inverter Price	$/Wac	0.90	0.69	0.30
Inverter size	kW	4	4.74	5.92
DC-AC conversion efficiency	%	90	96	97
Inverter life/replacement	Years	5	10	20
Other BOS	$/Wdc	0.61	0.40	0.33
Installation	$/Wdc	1.66	0.57	0.42
Other/Indirect*	$/Wdc	1.30	1.14	1.00
INSTALLED SYSTEM PRICE	$/Wdc	8.47	5.00	3.30
Lifetime	Years	30	35	35
Degradation	%/Yr	1	1	1
System derate	%	5	5	5
O&M Cost (not including inverter replacement)	% installed price	0.5	0.3	0.2
LEVELIZED COST OF ENERGY (LCOE)	$/kWhac	0.32	0.15	0.09

*For this and other tables presented below, the "Other/Indirect" category includes design, engineering, site-related costs, permitting, and profit.