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OPPORTUNITY ON THE HORIZON:
PHOTOVOLTAICS IN TEXAS

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Photovoltaic devices convert the light of the sun into electricity. Photovoltaics (PV) have been a long time in development from the discovery of the photovoltaic effect in 1839 to the manufacture of the first silicon-based PV in 1941 to the building-integrated PV systems that are beginning to emerge in the marketplace today. Due to rapidly declining costs and increasing consumer demand, PVs have achieved commercial viability and are becoming a leading source of renewable energy competitive with existing electricity sources.

The United States was once the undisputed leader in photovoltaic research, development, and commercialization, but today the nation is ceding this position to more aggressive competitors, including Japan, Germany, and China. Texas has the opportunity to leverage its natural solar endowment, semiconductor industry expertise, energy business talent, scientific leadership, and forward-thinking public policy to create a PV industry that will lead the U.S. and the world in creating the next generation of electricity production.

This position paper establishes the economic, public policy, and technological rationale for supporting the solar industry across Texas. Intended for a knowledgeable lay audience, is was prepared by researchers at the IC^2 Institute at The University of Texas at Austin to identify areas of future research and recommend actions for public, private, and academic sectors that will enhance Texas' PV industry.

Why Solar and Why Texas?

Texas has been a global energy leader for over 100 years. However, to remain a leader, Texas must effectively leverage its experience and natural resources to expand its portfolio of productive energy assets. Just as Texas in the past took advantage of its hydrocarbon resources to become an energy leader, the state needs to harvest its wind, sun, biomass, tidal, and geothermal resources to maintain its leadership position among the energy producers of tomorrow.

Maintaining this leadership position is not a given. Around 1900, Michigan managed to couple successfully its regional expertise in the buggy and carriage industry with the combustion engine to become the center of the automotive industry. However, Michigan lost its competitive edge when companies there failed to respond to changing consumer needs for more reliable and diverse product offerings and failed to respond to the threat posed by new market entrants. Similarly, Texas, which has been a global energy leader in oil and gas drilling, production, and refining, can use its knowledge base to develop the next generation of energy production in renewable energy. There is no reason that the state's leadership and expertise in energy research, innovation, and manufacturing – combined with huge natural solar resources – should not translate into a leadership position in renewable energy over the next thirty years.

The case for supporting the growth of the PV industry in Texas is strong:

- Texas has among the best untapped solar resources in the United States;
- Building on its wind energy experience, its high technology infrastructure, and its ability to leverage its demand, Texas can create a photovoltaic industry from "sand to demand";
- Photovoltaics could bolster Texas' weakening semiconductor and materials industries;
- Photovoltaics create high-quality technology and manufacturing jobs;
- Photovoltaics benefit Texas energy consumers—residential, commercial, and industrial as well as agricultural and urban areas;
- With solar and other renewables, Texas has a chance to become a net exporter of energy and energy products rather than a net importer;

- Texas has a narrow window of opportunity to enter into the increasingly competitive solar landscape;
- Texas can leverage its demand-creation ability to create a whole industry;
- Photovoltaic electricity generation provides a cost-effective alternative to other forms of peak energy generating technologies.

We elaborate on each of these important arguments and close with recommendations for steps to secure Texas' leadership in the photovoltaics industry.

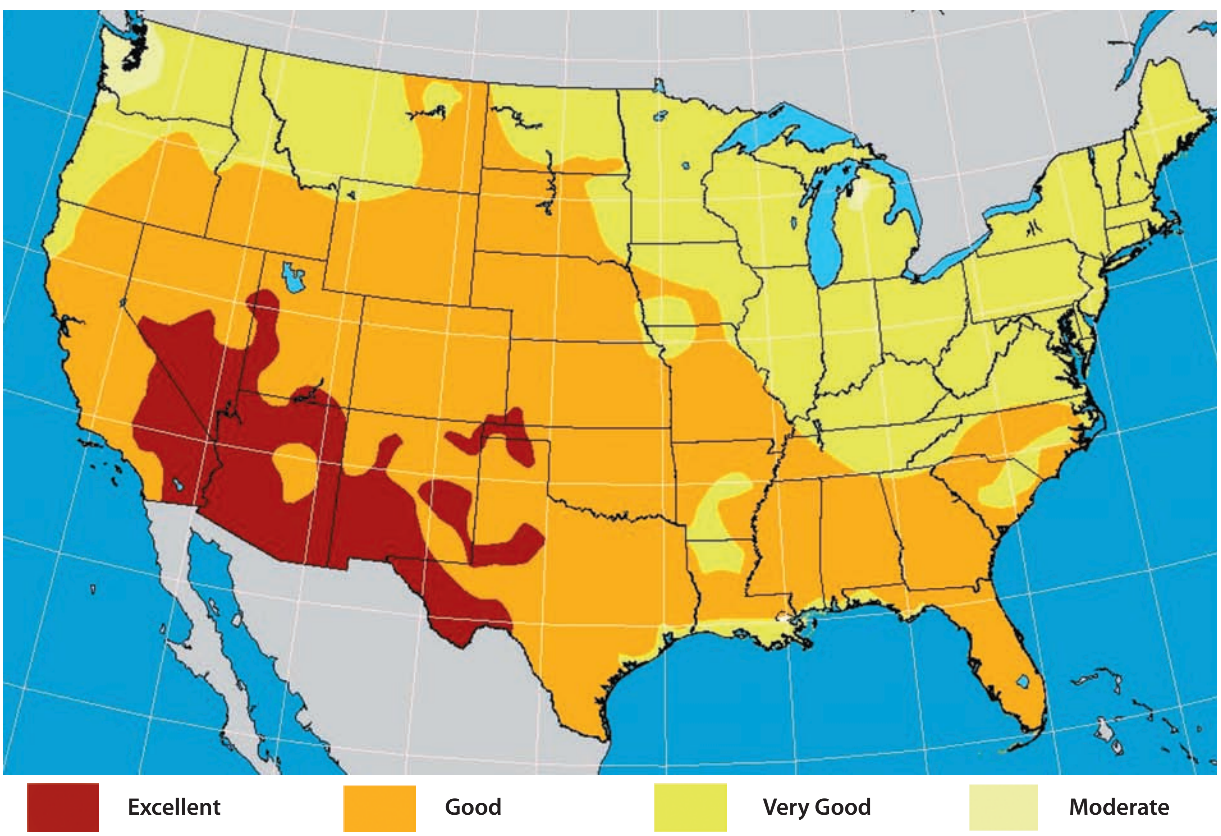
Texas' Natural Solar Endowment

Texas receives among the best solar radiance (called insolation) of any state in the country. A 2002 NREL study estimated that Texas could produce 127,000 megawatts of photovoltaic-generated electricity based on solar radiation quality, optimal installation conditions, and land availability. Such capacity would require approximately 638,000 acres or 0.04 percent of Texas' total land area.[1] In 2005 Texas had approximately 101,000 megawatts of electricity generation capacity from all sources, see Figure 1.[2]

Benefits for Texas' Energy Consumers

The historical benefits of photovoltaics to consumers was once limited. The un-rebated average retail price of solar power is $.21 per kilowatt hour,[3] somewhat higher than the Texas residential average $.1248 per kilowatt-hour.[4] However, many analysts, including those with Photon International, predict that the true price of photovoltaics will be $0.10 per kilowatt-hour by 2010, driven by new technologies and improved

Figure 1. Solar Photovoltaic (PV) Resource Potential



Desert regions of Far West Texas contain the sunniest areas in the state as well as some of the sunniest in the nation.

Source: National Renewable Energy Laboratory (www.nrel.gov/gis/solar.html)

First Solar: A U.S. Success

Phoenix, AZ-based First Solar, Inc. (Nasdaq: FSLR) and its subsidiaries engage in the design, manufacture, and sale of solar electric power modules. The solar module is a thin-film structure that employs cadmium telluride semiconductor material to convert sunlight into electricity rather than utilizing polysilicon, meaning that the company is not as susceptible to silicon supply constraints as its competitors. The company sells its products to solar project developers and system integrators primarily in Germany. With plants in Germany and Malaysia, the company plans to compete aggressively on a non-subsidized basis with the price of retail electricity in key markets in the United States, Europe and Asia by 2010 .

Revenues: 2004: $13.5 million
2005: $48.1 million
2006: $135 million
Market Cap: $4.6 billion
MW : 175MW in 2007
275 MW planned in 2008

economies of scale with larger silicon PV and feedstock plants. While the price of solar continues to drop, the price of other forms of electricity generation likely will continue to rise, with global hydrocarbon competition and CO_2 emissions through global carbon cap-and-trade programs.

In addition, this retail prices does not reflect the substantial savings consumers can realize in terms of avoided generation capacity capital costs, avoided fuel costs, the value of avoided CO_2 emissions, the value of fossil fuel price hedging, and avoided distribution costs, to name only the largest savings categories. These savings in California were estimated to be $.078 to $.224 per kilowatt hour in 2005.[5] Texas already has higher than average residential, commercial, and industrial electricity prices.[6] Further research could more precisely estimate the range of potential savings for the citizens of Texas if PV generation were widely adopted.

Photovoltaics provide additional benefit to consumers by serving as a hedge against peak demand. The most expensive energy Texans use is peak energy, energy that is turned on only during the hottest part of the day on the hottest days of the year. Solar energy generation during the day is very closely correlated to peak demand and can cost-effectively offset the need to operate the least efficient power plants or build new generating capacity.

The addition of photovoltaics into the electricity generation mix would also meet Texan customers' demonstrated preference for – and willingness to pay for – clean, renewable energy source with zero emissions.

Moreover, utilities can build PV plants much more quickly than they can build conventional fossil or nuclear power plants because PV arrays are fairly easy to install and connect. Utilities can also build PV power plants where they are most needed in the grid since siting PV arrays is usually much easier than siting a conventional power plant. And, unlike conventional power plants, modular PV plants can be expanded incrementally as demand increases. Finally, PV power plants consume no fuel and produce no air or water pollution while they silently generate electricity. This makes photovoltaic power an attractive option for utilities that want or need to cut fuel costs while meeting local environmental regulations.[7]

PV Job Creation

Research has shown that renewable energy generates more jobs in its construction and manufacturing sectors, per megawatt of installed power capacity, than does fossil fuel generation.[8] Specifically for PV generation, far more jobs are produced constructing PV facilities than are produced by the construction and operation of coal and natural gas-fired plants. However, unlike fossil fuel operations, PVs require minimal maintenance. For Texas, with its large oil and gas extraction and refining industries, it is easy to conclude that any switch to a significant Renewable Portfolio Standard would mean the loss of jobs in these fossil fuel sectors. However, to date this potential job loss has not materialized, due largely to the overall high energy demand in the state.

Two studies have addressed potential job growth in Texas under differing renewable energy policy regimes. One study estimates that Texas, under a scenario of "climate protection strategies" of reforms in the transportation, electricity generation, and construction sectors, would gain 123,000 net jobs by 2020, second only to California's 141,000 net gain in jobs in the same time period.[9] This projected job growth is the result of the state's size, the amount of energy it already consumes, and its rapidly growing population. Another study analyzed the state-by-state impacts of achieving

Solar Energy Industries Association (SEIA) 2004 "PV Roadmap" and its goals for accelerating the nation's installed PV capacity from 340MW to 9600MW by 2015. It estimated that Texas will capture more than 13 percent of all new jobs created by instituting the aggressive plan, and more than 13 percent all new investment, with most of this growth coming in Texas-based manufacturing.[10] Additionally, since high-tech manufacturing employment in Texas has yet to return to pre-recession levels, the PV manufacturing industry creates an opportunity to generate employment for semiconductor and electric component workers statewide whose jobs have been outsourced offshore, Figure 2.

Other states, including Colorado, California, and Pennsylvania, have moved aggressively to capture this job growth potential in renewable energy by enacting incentive programs to encourage the type of demand-pull economic activity that such programs initiate.

The Texas PV Innovation Pipeline

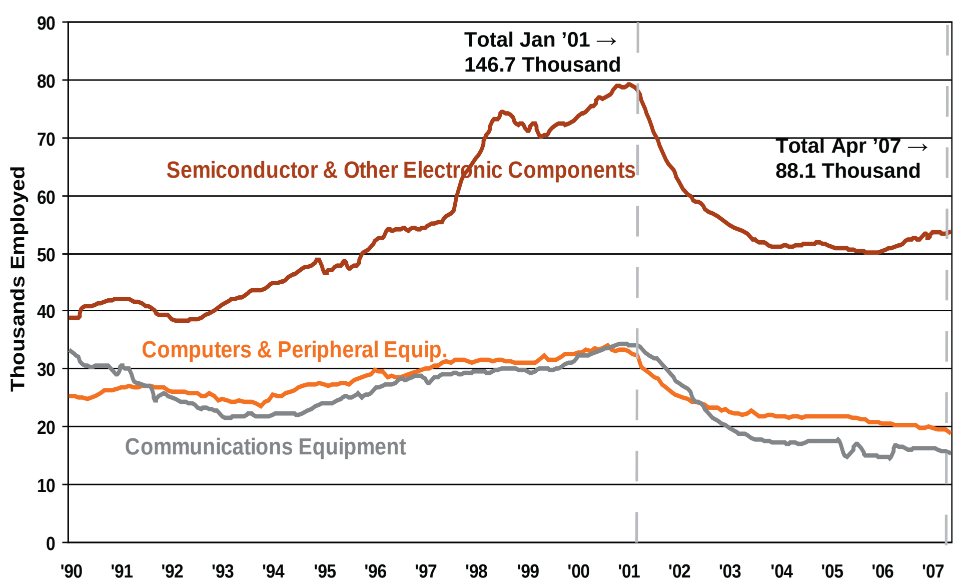
A 2005 IC² Institute study of the global photovoltaic industry showed that there are many competitors, nearly 1000 globally, that are actively attempting to achieve technological and market leadership within a relatively small number of photovoltaic-related technologies.[11] Not only are the competitors many and the technologies few, but the technologies appear to flow easily across organizations and across borders. For example, the study observed that one photovoltaic industry leader had established over fifty relationships with universities, research centers, and small companies in multiple countries to gain access to technologies needed to bring its business strategy to fruition.

The implication for Texas is that for the state to acquire and maintain a competitive advantage, it must create opportunities to align research, development, commercialization, and alliance-building strategies necessary to gain a substantial and sustainable foothold in the global marketplace. The Texas innovation pipeline describes the extant resources the state has to use as a foundation for future growth and how those resources stack up against other states and international competitors. The "Scorecard" in Table 1, page 7, provides an overview. The Scorecard components and the implications for building a Texas photovoltaic industry are discussed in more detail below.

The U.S. is Not Alone: Global Innovation

What the Scorecard does not reflect is the precariousness of U.S. leadership overall. The photovoltaic innovation landscape is shifting. Today the top ten countries produce 80 percent of the scientific litera-

Figure 2. Texas High-Tech Manufacturing Employment



Source: Federal Reserve Bank of Dallas, April 2007

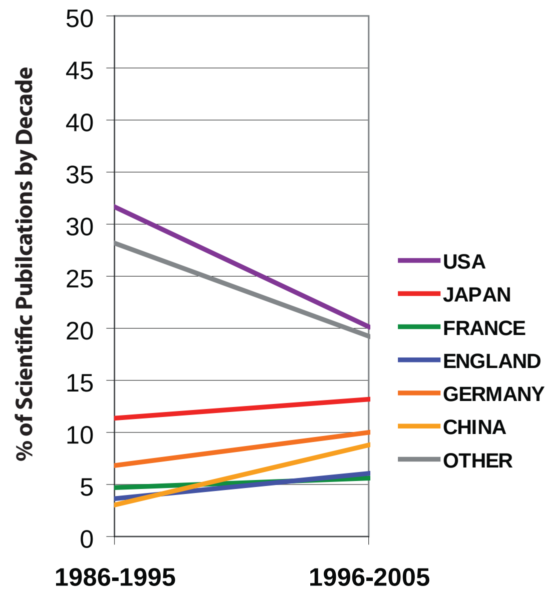
Table 1. Photovoltaic Innovation Scorecard

Rank of Texas PV efforts among U.S. Leaders	Federal Rsch Awards *	PV Patents 1**	Scientific Publications	Business Establishments
California	1	1	1	1
Colorado	2	5	2	3
Massachusetts	3	3	5	6
Texas	4	4	9	5
Florida	5	9	8	2
Ohio	6	7	3	11
New York	7	2	4	4
Michigan	8	6	11	8
New Mexico	8	10	6	7
Pennsylvania	8	7	7	9
Virginia	8	11	10	10

* 1993 - 2005 **1991 - 2005

Source: IC² Institute and Rand RadiUS, USPTO, ISI Web of Knowledge, Sourceguides.com

Figure 3. Global PV Scientific Production '85-86 v. '96-'05



Source: IC² Institute, ISI Web of Knowledge

ture related to photovoltaics. The last three decades can be characterized by the decline of U.S. dominance in the field, the ascendance of other strong players such as Japan and Germany, and the emergence of China. Figure 3 illustrates the point by comparing the last two decades in terms of leading countries' share of research articles related to photovoltaics. In both decades the United States is the clear scientific leader; however, the trend is troubling. In the first decade (1986 to 1995), the United States produced 32 percent of scientific literature on photovoltaics. In the second decade, 1996 to 2005, the U.S. share of scientific publication fell to 20 percent. In the same time period Japan and Germany built upon their earlier scientific leadership and China went from making relatively modest contributions to the field to producing nearly 10 percent of scientific work in the 1996-2005 timeframe. The UK and France maintained their relative positions. In the first decade, scientific publication was relatively dispersed, and researchers in countries outside of the top tier produced 28 percent of the research. By the second decade their contribution fell to 19 percent, indicating that scientific leadership is consolidating among the top tier of countries. A handful of countries is aggressively pursing photovoltaic research agendas, accumulating the intellectual capital on which to build new products and services.

U.S. Scientific Productivity: Research Awards & Scientific Publications

The leading eleven states reap 62 percent of all federally funded research awards related to photovoltaics, Table 2, page 8. There are three clear leaders: California, Colorado, and Massachusetts. California received 15 percent of the awards with more than half going to business and about one-third to educational institutions. Nearly half of Colorado's awards went to federal facilities, namely the National Renewable Energy Laboratory. About one-third went to business and only six awards went to educational institutions. In Massachusetts, industry captured approximately two-thirds of the research awards and about a quarter went to education institutions. Texas' awards were evenly split between industry and educational institutions.

Scientific productivity is even more concentrated among these top states in terms of publishing the results of scientific research. These states publish 87 percent of the U.S. scientific literature on photovoltaics. Texas

Table 2. Productivity in Photovoltaics

	# Federal Rsch Awards *	% of U.S. Total	# Scientific Publications **	% of U.S. Total	# Photovoltaic Patents **	# PV Businesses
California	62	15%	261	20%	289	310
Colorado	44	11%	255	19%	63	85
Massachusetts	35	8%	101	8%	73	34
Texas	18	4%	44	3%	68	65
Florida	17	4%	52	4%	30	94
Ohio	15	4%	125	10%	55	14
New York	14	3%	113	9%	83	76
Michigan	13	3%	40	3%	59	29
New Mexico	13	3%	53	4%	27	31
Pennsylvania	13	3%	53	4%	55	22
Virginia	13	3%	41	3%	13	19
% of U.S. Total		**62%**		**87%**		

* 1993 - 2005 **1991 - 2005

Source: IC² Institute and Rand RadiUS, ISI Web of Knowledge, USPTO, Sourceguides.com

is not strong among the leaders, producing only 3 percent of the published articles. This finding indicates that Texas is not particularly competitive in introducing new ideas that may later evolve into products or may attract existing photovoltaic businesses looking for research collaborations.

Turning Science into Products: U.S. Patents

In terms of converting research into exploitable ideas, the top states have an uneven record. Again, California is the clear leader in terms of holding, by far, the greatest number of photovoltaic-related patents. To be sure, patents are a crude measure of innovative capacity; however, there is a long-recognized link between patent activity, innovation capacity, and economic growth.[12, 13]

Business Establishments

There are few comprehensive resources for identifying photovoltaic firms by region. However, one directory, sourceguides.com, which focuses primarily on installers, integrators, and system design firms, and less on manufacturers, provides some perspective on the relative size of the solar industry in each state. The number of firms is a poor measure of competitiveness, but it is an indicator of the type of foundation on which the Texas photovoltaic industry can be built in terms of particular strengths within the photovoltaic value chain.

Texas does have some significant photovoltaic technologies and intellectual capital, but the current university, research organization, business, and state resources are not sufficient to develop a comprehensive, cohesive, and synergistic strategy to achieve sustained success in the global marketplace.

Photovoltaic Industry Maturity

Photovoltaic Technology

According to the Texas State Energy Conservation Office (SECO), photovoltaic technology is best understood in the following way:

> *Electricity can be produced from sunlight through the process of Photovoltaics (PV). Photo refers to light, and voltaic refers to voltage. Photovoltaic cells convert sunlight directly into electricity. When sunlight strikes PV cells, electrons are released and then gathered to create an electrical current. A thin silicon cell, four inches across, can produce about one watt of direct current electrical power in full sunlight. Solar electric systems can be connected to local utility grids in urban areas to reduce costs, and many states offer consumers credit for excess power produced by the system.*[14]

Today, just a few years after the SECO paper was first written, the major growth in solar photovoltaics is in grid-tied applications, which include utility-scale solar electric power plants, commercial buildings, as well as entire residential sub-divisions.

Crystalline Silicon (c-Si)

Crystalline silicon (c-Si) photovoltaics dominate the industry, accounting for about 93 percent of all installed PV modules. They are what could be considered "conventional" solar cells and are similar to semiconductors in structure and manufacturing process. A purified silicon ingot is "doped" with phosphorous and boron and formed into solar cells.

When photons from sunlight are absorbed by these semiconducting materials, the energy of the photons is transferred to the material's electrons, which frees them from their atoms, causing them to flow as an electric current. Thus, electricity is generated. Efficiency rates of crystalline silicon range from 11-16 percent, meaning that 11-16 percent of the solar energy that strikes a c-Si cell is converted into electricity. Crystalline silicon PV systems are long-lasting and typically have a warranty of 25 years.

Thin Film PV

Thin film PV products have become an increasingly intriguing substitute for traditional crystalline silicon PV given the ability to mass produce cells in a lower cost roll-to-roll manufacturing environment. Thin film is also promising in the number of different applications that it can address. In addition to rooftop modules, thin film can be used for building integrated photovoltaics (BIPV) and other conformable and portable applications. There are primarily three types of thin film technologies that are the current focus of the solar industry: Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium Gallium Selenide (CIGS/CIS).

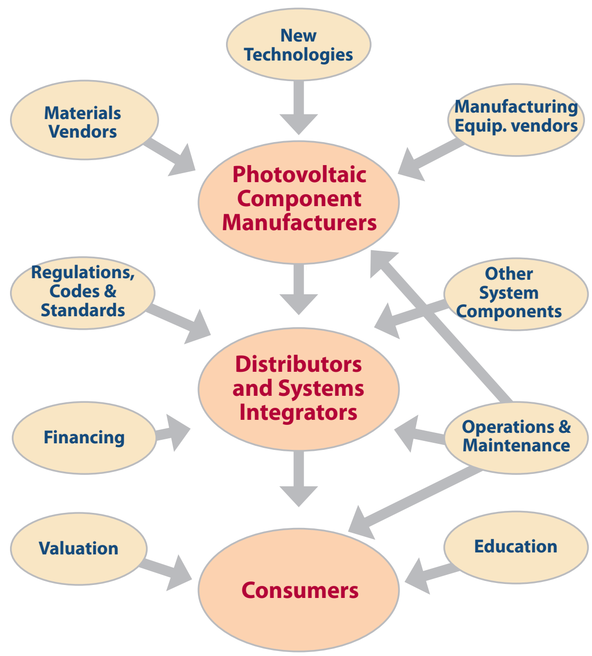
The most developed thin film technology is a-Si, which is simply the non-crystalline form of silicon. Efficiency rates for amorphous silicon are estimated in the 5-8 percent range. Handheld calculators have used amorphous silicon technology for over twenty years. It potentially can be made much more cheaply using "roll-to-roll" processing techniques and it had the largest share of the thin film market (64 percent) as of the end of 2005.

The next-generation thin films PV are Cadmium Telluride and Copper Indium Gallium Selenide. Cadmium Telluride had 26 percent share of the thin film market, and Copper Indium Gallium Selenide, which is predicated on "nano" technology, had a 10 percent share of the thin film market in 2005.

Advantages of these next-generation thin film technologies over conventional c-Si include:

- Lower cost of production than conventional silicon processes.
- Lower manufacturing facility cost per watt – Capital expenditure.
- Uses much less material than the amount used in standard c-Si cells.
- Lower energy payback -- Amount of time until the product produces more energy than was utilized in its manufacture.
- Ability to be attractively integrated into buildings -- Building Integrated Photovoltaics (BIPV).

Figure 4. The PV Industry Value Chain



Source: U.S. Photovoltaic Industry Roadmap

Photovoltaic Business

The conventional crystalline silicon photovoltaic industry is based on a number of basic steps (Figure 4) that refine sand (silicon dioxide) into installed photovoltaic systems:

- Raw silicon – silicon dioxide is refined into metallurgical silicon
- Silicon Ingots/ Wafers – metallurgical silicon in the form of ingots is sliced into wafers
- Cells – silicon wafers are etched, textured, doped, coated, and connected electrically
- Modules – are formed from the assembly of individual wafers, interconnected, and encapsulated
- Systems – modules are installed onto rooftops or commercial arrays and include cabling, connectors, inverters, power controls and conditioning, and sometimes energy storage
- Solar equipment – the manufacturing equipment necessary to manufacture the above.

The worldwide solar industry is growing fast: global PV cell shipments amounted to 1,800MW in 2005 but are expected to rise to 5,093MW in 2010, which means the value of annual sales will reach $11 billion by 2010.[15]

According to researchers Paul Maycock and Travis Bradford, the world's top fifteen manufacturers of PV cells produced 1488 megawatts of solar capacity (MW) in 2006, 85 percent of global production, Table 3. No U.S.-based company was in the top ten. Japan, Europe, and China now dominate the market.[16]

Texas' Deregulation & Renewable Portfolio Standard Outcomes

In 1999 the Texas Legislature adopted a bill that introduced retail competition in the sale of electricity and renewable portfolio standards (RPS). Beginning on January 1, 2002, consumers in deregulated markets were no longer obligated to buy power from their designated utility but could choose to purchase power from a number of different retailers. Although deregulation has not been without challenges or skeptics, according to a study by The Perryman Group in April 2006, the deregulation of the electricity market in Texas has resulted in electricity prices that are lower than they would have been in a regulated market.[17]

The legislation also included a Renewable Portfolio Standard (RPS) that requires the state's electricity providers to collectively develop 2000 megawatts (MW) of new renewable energy capacity by 2009. At the time of the bill's passage, Texas had 880 MW of electricity generated by renewables, mostly in the form of hydroelectric power.[18] The RPS mandated that each electric retailer serving a competitive market must service a fraction of its load with renewable energy.

Renewable generation projects that are eligible under the Texas RPS include power production from solar, wind, geothermal, hydro, wave, tidal, biomass, biomass-based waste products, and landfill gas. Renewable energy sources that offset electricity (e.g., solar hot water, geothermal heat pumps), and off-grid projects such as solar photovoltaics are also eligible. Wind energy has been the biggest winner under the RPS due to its competitive pricing, available federal tax incentives, a huge amount of wind resources in the

Table 3. Top PV Cell/Module Producers (MW)

Company	2000	2001	2002	2003	2004	2005	Rank
Sharp	50	75	123	198	324	428	1
Q-Cells	-	-	-	28	75	166	2
Kyocera	42	54	60	72	105	142	3
Sanyo	17	19	35	35	65	125	4
Mitsubishi	12	14	24	40	75	100	5
Schott Solar	14	23	30	42	63	95	6
BP Solar	42	54	74	70	85	88	7
Suntech	-	-	-	-	28	82	8
Motech	-	-	-	-	35	60	9
Shell Solar	28	39	58	73	72	59	10
Isofotón	10	18	27	35	53	53	11
Deutsche Cell	-	-	-	17	28	38	12
E-ton	-	-	-	-	-	28	13
Photowatt	14	14	17	20	22	24	14
Sunpower	-	-	-	-	-	23	15
Total	**229**	**310**	**447**	**630**	**1030**	**1488**	
World Total	**288**	**399**	**560**	**759**	**1195**	**1759**	

Source: PV News, Vol. 25, No. 3, March 2006 state, and the scalability of large wind projects.

Not only was the policy change a boon to consumers, but it spawned a new industry. By rapidly developing wind-generated clean energy in response to renewable portfolio standards, Texas companies have already demonstrated they can respond to well-designed policy and market incentives. In 2005, the Texas Legislature passed Senate Bill 20, which greatly increased the state's RPS goal to 5,000 MW by 2015. The legislation also set a goal of reaching 5,880 MW in renewable energy capacity by 2025. The Texas wind rush shows no signs of slowing, with more than 1,000 additional MW either under construction or in the planning phases.[19]

Despite the positive lessons learned from deregulation and the support for renewable electricity production in general, the RPS has yet to lead to an icrease in solar energy production.

Lesson #1: RPS works

Strong political commitment, an effective enforcement mechanism, limited wind-power siting constraints, and built-in flexibility in the tradable "renewable energy credits" (RECs) system allow the RPS to achieve the desired results. The RPS was so successful that its 10-year goal was met in just over six years as Texas overtook California as the state with the highest installed wind generation capacity in the country.

Lesson #2: Regulatory certainty is an important element in investment decisions

Although deregulation increased the liquidity and pricing transparency of the electricity market, a boom-and-bust cycle of installed wind capacity in Texas has been caused by the short-term characteristics of the Federal Production Tax Credit (PTC). The PTC historically has been implemented as a one- or two-year provision, adding a degree of uncertainty to the predicted future returns on investment in renewable energy projects. For example, when the PTC expired in 2002, nationwide installation of new wind farms dropped from about 1700 MW in 2001 to under 500 MW. The PTC was renewed in 2003, sparking another 1700 MW of new farms, only to fall back down when it again expired in 2004.

Lesson #3: Done correctly, deregulation facilitates consumer-driven demand for green power

The Texas Electric Restructuring Act of 1999 included provisions requiring electricity retailers to disclose their fuel mix and type and amount of emissions. Utility customers can receive information about whether their electricity is produced from wind, solar, coal, natural gas or nuclear and the amount of CO_2, NOx, SOx, and particulate matter that the associated plants produce. This transparency has created a new market for innovative product offerings from electricity providers. Customers can choose to support the development of renewable energy by switching to providers that maintain higher percentages of electricity generated by renewables in their portfolio than their competitors.

Lesson #4: Additional incentives are needed to spur non-wind renewables

The Texas RPS created a surge of new wind capacity because of wind's cost advantage over other renewables. Many states have implemented policies that aim to diversify the supply of renewable energy from many different sources. Inland wind farms typically produce the majority of their electricity at night when load demands are the lowest. Complementing that supply with solar generation or other forms of daytime-producing renewables would provide more consistent electricity supplies to retailers and would reduce the risk of supply shortages. Senate Bill 20 included a requirement that Texas electricity providers must meet 500 MW of the 2025 RPS target with non-wind renewable generation. Compared to the 5,880 MW overall requirement, non-wind generation will continue to be a very small percentage without further incentives.

The Competition: What Other Regions Are Doing to Build Their PV industries ***Now***

Germany

Germany employs a feed-in tariff model to regulate its renewable energy industry rather than utilizing a quota system. Feed-in tariff models require energy supply companies to give priority to electricity generated using renewable energy sources, feed it into the grid, and pay producers a fixed price, whereas under a quota system, the regulatory authority specifies that a fixed proportion of electricity on the market must be produced by renewable energy sources.

On August 1, 2004, Germany amended the German Renewable Energy Sources Act (EEG), which regulates the input and payment of electricity from renewable resources by the utilities. The feed-in tariffs were adjusted according to changes in supporting market introduction programs. The rates are guaranteed for a period of 20 years with a built-in annual decrease of 5% percent annually for basic installed systems and a decrease of 6.5% percent for field installations.[20]

Table 4. Total Installed PV Power by the End of 2005

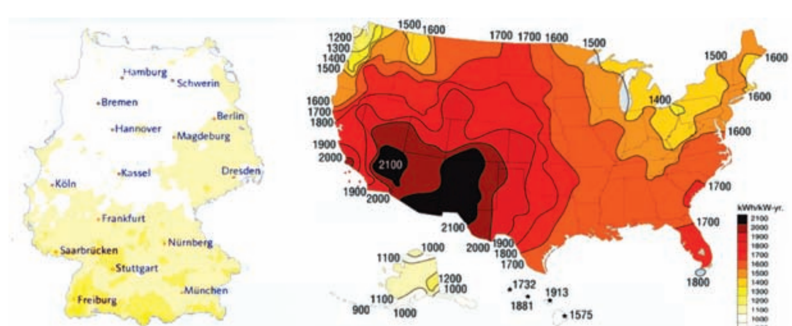
Country	Cumulative PV Capacity			PV power installed in 2005		Total installed per capita
	Off-Grid PV [kW]	Grid-Connected [kW]	Total [kW]	Total [kW]	Grid-Tied [kW]	[kW/Capita]
DEU	1,400,000	29,000	**1,429,000**	635,000	632,000	17.32
JPN	1,420,760	1,148	**1,421,908**	289,917	287,105	11.13
USA	379,000	100,000	**479,000**	103,000	70,000	1.62
ESP	41,600	15,800	**57,400**	20,400	18,600	1.32
NLD	45,857	4,919	**50,776**	1,697	1,547	3.12
AUS	41,813	8,768	**50,581**	8,280	1,980	2.97
FRA	19,199	13,844	**33,043**	7,020	5,900	0.54
ITA	22,200	5,300	**27,500**	6,800	6,500	0.64
CHE	24,120	2,930	**27,050**	3,950	3,800	3.66
AUT	21,126	2,895	**24,021**	2,961	2,711	2.93
MEX	4,218	14,476	**18,694**	513	30	0.17
CAN	10,843	5,903	**16,746**	2,862	612	0.52
KOR	14,168	853	**15,021**	6,487	6,183	0.31
GBR	10,650	227	**10,877**	2,732	2,567	0.18
NOR	452	6,800	**7,252**	362	0	1.58
SWE	887	3,350	**4,237**	371	0	0.47
DNK	2,580	70	**2,650**	360	320	0.49
ISR	235	809	**1,044**	158	2	0.15
Estimated Total	**3,494,524**	**202,276**	**3,696,800**	**1,092,851**	**1,039,917**	

Source: International Energy Agency, www.iea-pvps.org

Clearly, the feed-in tariff has accelerated the development of the photovoltaic (PV) market in Germany. Although the International Energy Agency (IEA) states that Germany only generates 1% percent of its power from PV, the industry exhibits the highest growth rate of all renewable energies. In 2005, Germany led the world in both total PV installed and cumulative PV capacity, edging slightly ahead of Japan, Table 4.

Additionally, Germany has invested in national research & development (R&D) programs, with the most recent (5th) Energy Research Program 2006-2008. Nationally sponsored PV R&D programs are designed to support the German PV industry to reach, maintain, and extend its industry leadership by funding projects in silicon wafer technology, thin-film development, and system technologies.

Figure 5. Solar Resources in Germany vs. the United States



Source: Solar Energy Industries Association

The favorable feed-in tariff program, as well as national R&D support, has sparked innovation and development within Germany's PV industry, despite the fact that Germany's natural available solar resources are far below those found in the United States, Figure 5. As a result of these initiatives, Germans invested nearly $5 billion in new solar photovoltaic systems in 2006 and in doing so employed nearly 35,000 workers in the solar industry.

United States

According to the U.S. Department of Energy, 20 states and the District of Columbia have adopted Renewable Portfolio Standards (RPS). Since the RPS is a market standard, it relies almost entirely on the private market for its implementation, resulting in competition, efficiency, and innovation throughout the value chain of the renewable energy industry. Additionally, Illinois and Vermont have issued non-binding state goals for renewable energy adoption rather than a RPS. Table 5 details the current renewable portfolio standards in participating states and their administrating agencies.

Several states have gone beyond the RPS to establish initiatives to encourage solar industry promotion and adoption within the state economy. If appropriate

Table 5. Summary of State Renewable Portfolio Standards

State	Amount	Year	Organization Administering RPS
Arizona	15%	2025	Arizona Corporation Commission
California	20%	2017	California Energy Commission
Colorado	10%	2015	Colorado Public Utilities Commission
Connecticut	10%	2010	Department of Public Utility Control
District of Columbia	11%	2022	DC Public Service Commission
Delaware	10%	2019	Delaware Energy Office
Hawaii	20%	2020	Hawaii Strategic Industries Division
Iowa	105 MW		Iowa Utilities Board
Illinois*	25%	2017	Illinois* Department of Commerce
Massachusetts	4%	2009	Massachusetts Division of Energy Resources
Maryland	7.5%	2019	Maryland Public Service Commission
Maine	10%	2017	Maine Public Utilities Commission
Minnesota	25%	2025	Minnesota Department of Commerce
Montana	15%	2015	Montana Public Service Commission
New Jersey	22.5%	2021	New Jersey Board of Public Utilities
New Mexico	20%	2020	New Mexico Public Regulation Commission
Nevada	20%	2015	Public Utilities Commission of Nevada
New York	24%	2013	New York Public Service Commission
Pennsylvania	18%	2020	Pennsylvania Public Utility Commission
Rhode Island	15%	2020	Rhode Island Public Utilities Commission
Texas	5,880 MW	2015	Public Utility Commission of Texas
Vermont *	10%	2013	Vermont Department of Public Service
Washington	15%	2020	Washington Secretary of State
Wisconsin	2.2%	2011	Public Service Commission of Wisconsin

* Two states, Illinois and Vermont, have set voluntaryoals for adopting renewable energy instead of portfolio standards with binding targets.

Source: U.S. Department of Energy, Energy Efficiency and Energy Renewal, www.eere.energy.gov long-term incentives are enacted, the solar energy industry in the United States will contribute billions of dollars of investment and income. According to the Solar Energy Industries Association (SEIA), as many as 22,000 additional jobs could be created in manufacturing and distribution, as well as in trade jobs for electricians, plumbers, roofers, designers, and engineers as the PV industry develops over the next decade.[21]

California

California stands out among the states in promoting renewable energy. It leads the nation in setting energy standards and in both venture and public capital investment in "cleantech." California currently leads the nation's solar energy production, and if it were a separate nation, it would rank third in the world, behind Germany and Japan.

In 2006, California specifically acted to attract the solar industry to its state through two specific mechanisms: the approval of the California Solar Initiative by the California Public Utilities Commission (PUC), and the signing into law of SB 1, more commonly known as the Million Solar Roofs Bill.

On January 12, 2006, the California Public Utilities Commission (PUC) approved the California Solar Initiative, which authorized the state to invest $3.3 billion for consumer rebates in small-scale solar electric power systems over 11 years and established a statewide goal of building a million solar electric roofs, or 3,000 megawatts (MW) of solar electric power. The investment was funded from a small surcharge on electric and gas customers within the utilities regulated by the PUC.[22]

Eight months later, on August 21, 2006, Gov. Arnold Schwarzenegger signed SB 1 into law, establishing policies that complement the California Solar Initiative and that the PUC did not have authority to establish on its own. SB 1 expands the Million Solar Roofs plan to customers of municipal-owned utilities over which the PUC does not have jurisdiction, increases the state's net metering cap to 2.5 percent, allows approximately 500,000 new solar systems into the program, and requires developers of more than 50 new single family homes to offer the option of a solar energy system to all customers beginning January 1, 2011. Figure 6 illustrates company growth in relation to these policy changes.[23]

New Jersey

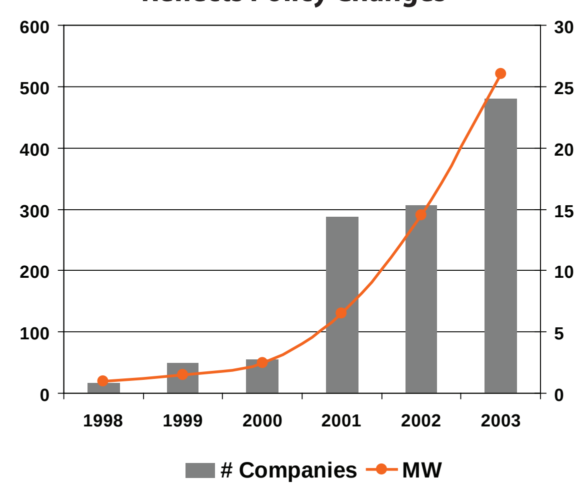
In April 2006, New Jersey took steps to ensure the future growth potential of the PV industry. The New Jersey Board of Public Utilities (BPU) issued additional regulations that require the state to produce 22.5 percent of its energy through renewable resources by 2021, including 2.12 percent from solar.[24] The solar electric set-aside percentage is an interesting policy

Suntech Power Holdings Co., Ltd: Foreign Power

Suntech Power Holdings Co., Ltd. (NYSE: STP) is a solar energy company based in China that designs, develops, manufactures and markets a variety of PV cells and modules. Suntech's products are used in a variety of residential, commercial, industrial and public utility applications in various markets for both on-grid electricity generation and off-grid use such as standalone lighting for street lamps, garden lamps, telecommunications relay stations, and mobile phone networks. Less than 5 years old, Suntech sells its modules and cells into global markets and is already the world's eighth largest PV manufacturer. The company's objective is to become the "lowest cost per watt" provider of PV solutions to customers in the world.

Revenues: 2004: $85.3 million
2005: $226 million
2006: $599 million
Market Cap: $5.78 billion
MW: 420 MW planned for 2007

Figure 6. California PV Industry Growth Reflects Policy Changes



Source: California Energy Commission

that will result in about 1,500 megawatts (MW) of solar-electric power.

As a result of the state's continued commitment to promoting solar initiatives since its Clean Energy Program was first enacted in 2001, New Jersey has become one of the nation's largest PV markets in terms of installations, second only to California, which has four times the population and energy usage. Four factors have led to robust market development within the state:

- a solar electric set aside within the RPS legislation that has helped create demand and investor confidence in the market;
- reliable interconnection and net metering standards that have made it much easier for systems to connect to the distribution system and be compensated for their contribution;
- a Solar Rebate Program that has helped finance over 50 percent of the cost of installation;
- a Solar Renewable Energy Certificate Trading Program that provides energy credits and additional long term financing for PV installation.

Solar Renewable Energy Certificates (SRECs) represent the renewable attributes of solar generation, bundled in minimum denominations of one megawatt hour of electricity production.[25] New Jersey's SREC program provides a channel for solar certificates to be created, verified, tracked, sold to and eventually retired by electric suppliers to meet their solar RPS requirement. New Jersey's online marketplace for trading SRECs was launched on June 25, 2004 and is recognized to be the first of its kind in the world.

MEMC: The Sand King

MEMC Electronic Materials, Inc. (NYSE: WFR) is engaged in the design, manufacture and sale of silicon wafers. Headquartered in Missouri, this international company has manufacturing plants in Sherman and Pasadena, Texas, as well as Japan, Taiwan, Malaysia, South Korea and Italy. The company provides wafers in three catagories: prime polished, epitaxial and test/monitor, and in sizes ranging from 100 millimeters (four inch) to 300 millimeters (12 inch). Its wafers are used as a starting material for the manufacture of various types of semiconductor devices, including microprocessors, memory, and logic and power devices. MEMC is one of four wafer suppliers having more than a 10% share of the overall market. The company also sells intermediate products, such as polysilicon, silane gas, partial ingots and scrap wafers. MEMC is a major supplier of polysilicon, the raw material required for developing solar panels. In fact, The silicon wafer industry grew at a CAGR of 9% from 1,118 million square inches in 1985 to 7,975 million square inches in 2006, according to SIA/SEMI.

Revenues: 2004: $1.02 billion
2005: $1.1 billion
2006: $1.54 billion
Market Cap: $15 billion

Pennsylvania

The Pennsylvania Alternative Energy Portfolio Standard (AEPS) was enacted in November 2004 and calls for 18 percent of the state's electricity to come from qualifying renewable sources by 2021. The Pennsylvania regulations establish two tiers of renewable obligations, as well as a solar PV set-aside of 0.5 percent by April 2021.[26] This set-aside will result in the development of approximately 860 MW of solar PV over the next 15 years, which equates to enough PV capacity to power 300,000 homes within the state.

The state has also established guidelines for Sustainable Energy Funds, which are designed to promote the development of sustainable and renewable energy programs and clean-air technologies throughout Pennsylvania. The funds have provided more than $20 million in loans and $1.8 million in grants to over 100 projects since their inception in 1999.[27]

Pennsylvania is enjoying a convergence of factors that are encouraging the growth of the PV industry within the state. It is estimated that the Mid-Atlantic region will add 5,710 local jobs in installation, operation, and maintenance and 8,080 manufacturing jobs in the PV industry as a function of the favorable legislative atmosphere.[28] Additionally, the *Philadelphia Business Journal* reported in March 2007 that venture-backed companies based in Pennsylvania added more jobs from 2003 through 2005 than their counterparts in other states. The state managed to increase employment by 167,000 jobs, topping both Texas and California companies, which added 139,400 and 111,400 jobs, respectively.[29]

Recommendations

This paper has outlined photovoltaic developments and initiatives in other states and in Germany and has tried to identify opportunities to pursue in developing a solar strategy for Texas. What follows is a set of initiatives, reforms, proposals, and recommendations that flow from material presented here.

Stimulate demand: Modest public investment in the form of rebate initiatives, system benefits charges, or other public finance programs have demonstrated an ability to stimulate commercial and residential demand for PV installations in other states and foreign countries, which in turn generates new company formation, job creation, and all the ancillary benefits of renewable energy production.

Create research pipeline: More public and private R&D spending, and more targeted spending, will leverage Texas research and educational assets already in place. Investments in intellectual capital will create new technologies, stimulate technology transfer, and present commercialization opportunities for entrepreneurs to launch PV-related businesses.

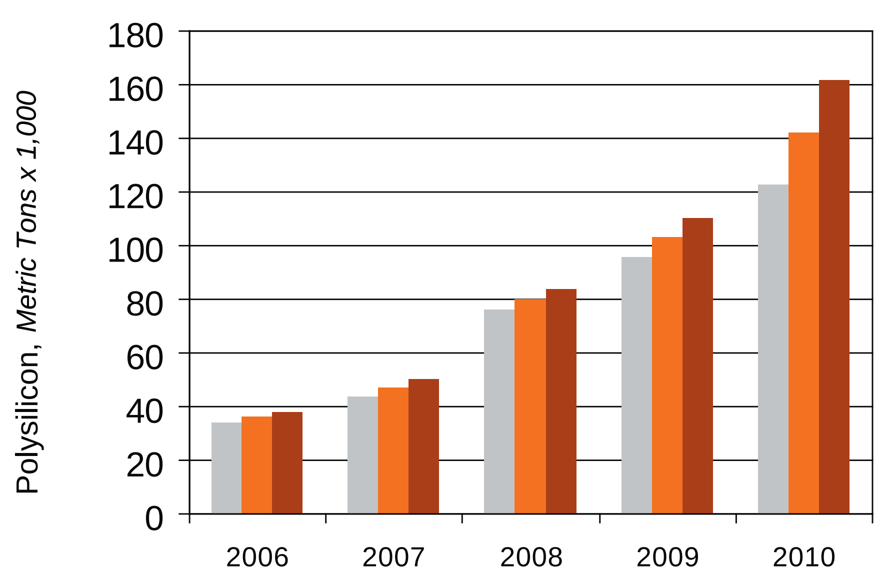
Create economic incentives: Building PV companies in, and attracting firms to, Texas should be a priority in the state's economic development strategy. The Emerging Technology Fund and the Enterprise Fund should give priority to clean energy, and specifically PV, companies.

Leverage excess semiconductor capacity: PV cells and semiconductors use silicon wafers as the basis of their products. Human capital and industry expertise developed in the state's extremely advanced semiconductor manufacturing sector should be harnessed. Texas Instruments and other major semiconductor firms are transferring R&D operations from Texas to foreign countries. Other semiconductor firms already have solar initiatives. Applied Materials, a leading developer of semiconductor manufacturing equipment, has made a significant commitment to the solar industry, developing solar manufacturing tools as well as acquiring Applied Films.

Expand silicon processing: Texas has a number of PV assets already in place, including Hemlock and a manufacturing plant for MEMC, two of the world's largest silicon processors. Worldwide silicon processing capacity is expected to expand from an average of 47,000 metric tons in 2007 to 80,000 metric tons in 2008, representing a 70% increase, Figure 7. Texas is presently home to approximately 11.5% of the world's silicon processing capacity. Given worldwide distribution of silicon processing growth, Texas is forecasted to only own 4.9% of the market by 2010. Texas should specifically encourage the expansion of this industry niche in its longterm solar industry goals.

Institute retail net metering: Net metering, which allows customers to receive a retail credit on their

Figure 7. Polysilicon Capacity Forecast 2006e - 2010e



Source: Prometheus Institute, PHOTON Int'l, company reports, Signal Hill Estimates electric bill for the excess power they deliver to the grid, will make solar generation even more valuable and help reduce peak demand pressure on traditional utilities, which are forced to turn on inefficient plants to cover only peak demand.

Develop a strategy for high-surface-area electronics industry in Texas: The next stage in design and engineering of PV cells and semiconductors will be in high-surface-area manufacturing. The PV industry would be an ideal entry point for a major economic development initiative to take advantage of the next wave of technological innovation in wafer design.

Further Research

A number of issues need to be better understood to help policymakers, analysts, and industry stakeholders make informed decisions. To facilitate a more coordinated expansion of the PV industry by the state's political, academic, educational, and commercial leadership, we propose a number of research projects to assist stakeholders in understanding the needs, opportunities, and challenges of the photovoltaic industry.

Investigate the viability of PV understructure for disaster preparedness. Solar PV can have a significant value related to avoiding and mitigating economic costs of disasters and speeding disaster recovery. The value can be economically significant, i.e., in excess of $1,000/kW, in cases where solar is deployed in conjunction with appropriate amounts of energy storage. Overall, a disaster recovery benefit could increase the value of PV energy generation assets by as much as 50 percent.[30] Investigate the disaster recovery benefit and assess how distributed PV with distributed energy storage could be incorporated with disaster recovery services at the city and county levels for several Texas regions.

Explore the viability of neighborhood solar security clusters. As an extension of a disaster preparedness study and the role PV assets could play in disaster recovery, investigate how neighborhood solar security clusters could be formed. These would constitute shared solar PV generating assets and energy storage among several households for powering critical loads during grid outages. Specifically, investigate the engineering design, the impact on local utility service areas, and the community collaboration issue.

Conduct PV economic impact studies unique to Texas (by city, by region). Start with the C. Herig's "Value of Solar" study that was done for the City of Austin. Verify the 41 cents per kWh result for the Travis County Gross Regional Product. Investigate the Gross Regional Product results possible for other Texas locations.[31]

Investigate the viability of forming a next-generation thin film PV eco-system in Texas. There will be a significant technology substitution of thin film PV, like CIGS for c-Si PV, in the future. The United States still has a leadership position in these next-generation thin film PV technologies, but no regional cluster has been created as of yet to catalyze the growth of these emerging PV technologies in collaboration with enabling and complementary technologies.

Verify and identify leverage points with the semiconductor industry. This paper has assumed that a significant portion of manufacturing photovoltaics value chain can productively leverage state expertise and capacity in semiconductors, including silicon-pro-

APPLIED MATERIALS: From Semiconductors to Solar

Applied Materials (Nasdaq: AMAT) has long been regarded as a leader in the semiconductor industry and now also offers production solutions for wafer based, flexible and thin film silicon solar cells. The company acquired Applied Films for $484 million in May 2006 to grow its PV business. Less than one year later in March 2007, AMAT was awarded a contract to provide T-Solar Global S.A. of Spain with Europe's first thin film solar module production line using ultra-large 5.7m2 (2.2m x 2.6m) glass panels.

The company also announced plans in June 2007 to install an array of solar panels adjacent to its manufacturing plant on Highway 290 in Austin that will be capable of generating 24.6 kW of power at a cost of $200,000. The array will generate more than 33.8 megawatt-hours annually, which AMAT estimates will eliminate 58,370 pounds of carbon dioxide emissions. However, the company plans to build a larger 1.9 MW solar array at its headquarters in Santa Clara, CA primarily because the State of California offers much larger incentives for such projects.

Revenues:	2004: $8,013.05 million
	2005: $6,991.82 million
	2006: $9,167.01 million
Market Cap:	$27.4 billion

SUNPOWER CORPORATION: One that Got Away

SunPower, a majority-owned subsidiary of Cypress Semiconductor, used to be a Texas company. A prime example of the synergies between semiconductor manufacturing and PV, Cypress bought SunPower in 2002 and moved SunPower's solar cell manufacturing operation to its Round Rock, TX, plant. Without much state support for the industry, Cypress moved SunPower's manufacturing operation to the Phillipines and its R&D back to corporate headquarters in California. Today SunPower and its own subsidiary, PowerLight, designs, develops, manufactures, markets and sells solar electric power products, systems and services primarily in the United States, Germany, and Asia to system integrators and original equipment manufacturers.

2005: $78.6 million
2006: $236.5 million
Market Cap: $4.3 billion
MW: 108 MW in 2006
207 MW planned for 2007

duction, semiconductor fabrication, semiconductor equipment, advanced manufacturing, power equipment, and services industries. However, this complex issue warrants a much clearer and precise understanding to better identify and exploit leverage points and prepare a more effective defensive strategy for maintaining PV human, intellectual, and physical capital in the state.

Conclusion

In a recent survey, Texas registered voters were asked, "Do you think the Texas Legislature should encourage investment in solar power in Texas?" Fully 84 percent responded "Yes." To the question, "Would you support having the Texas Legislature encourage solar power investment in Texas if it would cost you less than one dollar per month on your electric bill," 81 percent said they would support such an increase. Texans are ready for clean energy development in the state.[32]

Texas would absolutely benefit from the expansion of solar power generation. By stimulating demand, Texas, with its enormous consumer market, can drive down the costs of manufacturing and installation. By investing in the intellectual capital in its research centers and universities where PV research is underway and could be expanded, the state can capitalize on existing assets in R&D. Texas companies will become globally competitive, creating wealth, luring out-of state firms to Texas, expanding jobs, and providing clean energy to millions of Texans. Employment in solar module construction consists of high-wage, advanced manufacturing jobs using nanotechnology and robotics, exactly the type of position for which the state's workforce development boards are training the next generation of workers. The state's residents will have real choices in choosing electricity providers and may even elect to produce their own power. Finally, solar power's distributed generation means that solar benefits all types of communities, from urban to rural, from big cities to the most remote parts of the state.

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