CHAPTER 3

SOLAR ENERGY

Introduction

The sun is nature's ultimate energy source. It is vast, environmentally benign and generally synchronous with both daily and seasonal energy demands in Texas. Meeting all future Texas energy demands with solar energy is technically possible, but further technology development and cost reductions are required before this immense resource will be able to provide a significant portion of Texas' energy needs reliably and at an acceptable cost.

During the early 1980s, the solar energy industry began developing in the U.S. as the federal government provided tax credits for solar water heaters. Solar industry growth slowed in the 1990s as fossil fuel costs remained low, but the U.S. and world solar market has experienced renewed growth since 2000. This new solar activity stems from the increasing costs and price volatility of fossil fuels, concerns about global climate change, decreasing costs and technology improvements in the solar industry itself, and the combined effect of new federal, state and local subsidies.

Humankind has more experience using solar energy than any other form of energy – the resource is well understood, and conversion technologies have long and positive operational track records. Still, three main barriers prevent widespread solar energy utilization. First, while the solar resource is vast, it is not highly concentrated and, therefore, requires significant surface area to collect an appreciable amount of energy. Second, the cost of producing energy in large-scale solar power plants is still high relative to other options. And third, the solar resource's intermittency and cyclical nature pose challenges for integrating solar at a large scale into the existing energy infrastructure. While the solar resource's dispersed nature cannot be changed, the cost of utilizing solar energy can be reduced through technological advances, improved manufacturing techniques, and increasing economies of scale. Intermittency barriers can be overcome with improved collection and storage technologies. It is generally concluded that when this occurs solar energy will become a major contributor to meeting future energy needs in Texas, the nation and the world.

Significance of Resource: Historical, Present and Future

The earliest humans to inhabit the earth recognized and utilized the light and heat energy provided by the sun. Shelters evolved to moderate the climate and provide interior lighting, and the sun was used to dry food and heat water.

A more sophisticated knowledge of the basic solar characteristics allows for the utilization of solar radiation in a broad assortment of thermal, electrical, photobiological and photochemical processes. Technologies in these areas, some under development and others available today, represent an opportunity to contribute to the future energy needs of Texas.

The most common applications of solar energy today are to provide heat, electricity and light. Today's solar industry supplies reliable products to provide heat and electricity for residential, commercial, and industrial applications using simple equipment such as flat-plate collectors. Natural sunlight is increasingly utilized in modern building design; day-lighting can be successfully incorporated into almost any structure, even underground buildings, such as the Texas State Capitol Annex.

Several utility-scale solar electric power plants have been built in the US and abroad that use concentrating optics to achieve sufficiently high temperatures to produce electricity using conventional steam turbines. Examples of such solar thermal electric technologies are parabolic troughs, central receivers and dish-Stirling systems. Current commercially-available photovoltaic (PV) solar cells are capable of converting sunlight directly into electricity at 15 to 20 percent efficiency, while cells in research and development environments have achieved greater than 40 percent efficiency.[1] Many solar applications are already cost-effective, while costs for others have been continually decreasing.

A key issue with the solar resource is its variability. To accommodate deep penetration of solar in the nation's power supply, integration of the resource with either adequate storage capability or other sources of energy to back it up is needed. While the market cost of some of the solar technologies is still relatively high, the desirable characteristics of solar technology - generally synchronous with demand, limited or no emissions and water requirements, and the vast solar resource in Texas—suggest great promise for the near future.

Exhibit 3-1 Classification of Solar Resource Quantities with Examples of Relevant Conversion Technologies

Resource Type			Relevant Conversion Technology		
Parameter		Description	Example	Product	Status*
Broadband	Direct Normal	Principal component of sunshine, directly from the sun	Solar thermal (parabolic trough, dish-Stirling, central receiver)	Electricity, Heat	A, B
			Concentrating PV	Electricity	A
	Diffuse Horizontal	Secondary component scattered by sky	Building climatology (daylighting)	Light	A
	Global Horizontal	Total (direct and diffuse on a hortizontal surface	Agriculture	Food, feed, fiber, energy	A
			Solar ponds, Passive solar heating	Heat, electricity	A, B
	Global Tilt	Total on tilted or tracking surfaces	Photovoltaic (PV)	Electricity	A
			Domestic water heating (DWH)	Hot water	A
Spectral		Wavelength band relevant to specific technology	Solar detoxification (photo chemical)	Toxic waste disposal	B

*A = Commercialized processes and products. B = Pilot level process demonstrations or infant industry.

The Characteristics of Solar Radiation

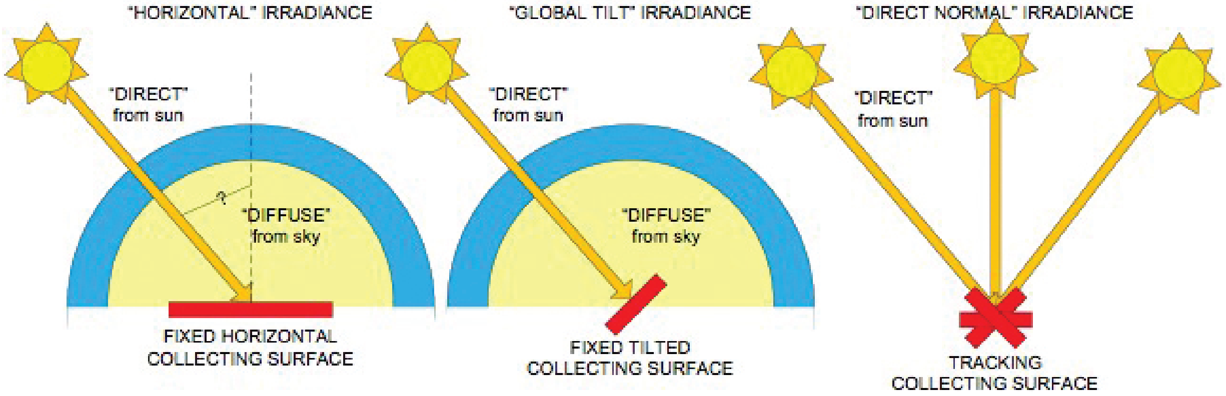
The various solar energy applications/technologies are influenced by the character of the resource, such as its directional nature (whether the sunlight is direct of diffuse—by clouds, for example—and it's angle of incidence on the collector surface), its spectral nature (what specific wavelengths of sunlight the collector technology responds to most effectively), and its variability. The variability characteristic can be in the span of a few minutes (how clouds will affect power production), seasonal (how climate patterns will affect the solar resource), interannual (how the resource will vary year to year), or even decadal (how climate change could affect the resource). **Exhibit 3-1** relates the various solar conversion technologies to the fundamental solar parameters on which they depend.

Directional Nature

Solar radiation, or "insolation," has directional character as illustrated in **Exhibit 3-2**. "Direct" or "beam" solar radiation is the radiation that comes directly from the sun, with minimal attenuation by the Earth's atmosphere or other obstacles. "Diffuse" solar radiation is that which is scattered, absorbed, and reflected within the atmosphere, mostly by clouds, but also by particulate matter and gas molecules. The result is that the sunlight reaching the Earth's surface is both direct and diffuse. On clear days the direct component is high and the diffuse is low, while on overcast days the total radiation is lower and most of it is diffuse. The direct and diffuse components together are referred to as the "total" or "global" radiation.

Exhibit 3-2 "Horizontal," "Global Tilt," and "Normal" Solar Insolation

$$\text{Global Horizontal (GHI)} = \text{Direct Normal (DNI)} \times \cos(\theta) + \text{Diffuse Horizontal (DHI)}$$



Surface Orientation

Surfaces that directly face the sun receive more solar radiation than others. Therefore solar panels which track the sun's path through the sky, or are stationary but tilted to the south, collect more energy than fixed panels mounted horizontally. Utility-scale PV and thermal solar installations often make use of tracking hardware to boost their energy output, though the addition of tracking hardware is usually not cost-effective on smaller installations, such as on the rooftops of residential or commercial buildings. Most subsidy programs encouraging installation of distributed solar specify minimum system design standards, which include standards pertaining to the tilt and orientation of the panels, to ensure that only systems with appropriate surface orientation are eligible to receive subsidy funding.

When discussing the solar resource, it is common to consider three orientations: "horizontal," "global tilt," and "normal." Horizontal insolation is that received by any flat, horizontal surface, such as a lake, hay field, swimming pool or warehouse roof. Global tilt insolation is that received by any flat surface tilted to the south at a tilt angle approximately equal to a site's latitude, like a sloped residential rooftop. Normal insolation is that received by a tracking surface that always faces the sun, such as a solar collector which tracks the sun's movement through the sky.

Solar radiation is usually measured with an instrument mounted horizontally, so that it sees the whole sky (direct plus diffuse), as indicted in the leftmost illustration in **Exhibit 3-2**, and such data is termed "global horizontal insolation" (GHI). If the instrument has a shade to block out the direct radiation then the result is "diffuse horizontal insolation" (DHI). "Direct normal insolation" (DNI) is measured using an instrument that tracks the sun and shades out the diffuse, so that it only records the direct component. These three solar quantities (GHI, DHI, and DNI) are related by the equation shown at the top of **Exhibit 3-2**.

Flat-plate photovoltaic devices, solar water heaters, and growing crops utilize both diffuse and direct radiation. For horizontal solar equipment and level fields or lakes the pertinent radiation is the global horizontal insolation (GHI). More commonly, solar equipment is tilted relative to horizontal (usually tilted toward the equator, e.g. south in the northern hemisphere, at an angle at or near the local latitude), such as on a sloped rooftop. In such cases, both direct normal (DNI) and global horizontal insolation (GHI) data can be used to estimate or model the solar radiation in the plane of interest, with the result referred to as global tilt insolation (GTI). Equipment using mirrors and other concentrating optics is only able to effectively focus the direct component, so "direct normal" solar radiation (DNI) is most relevant to these collectors.

Spectral Nature

Solar radiation is composed of a broad spectrum of wavelengths, from the ultraviolet, through the visible and into the infrared. This spectrum is modified by absorption within the atmosphere. The full spectrum is termed "broadband"

and implies the entire solar spectrum. Some solar processes operate on a limited spectral band, examples being photosynthesis and photovoltaic cells.

New research is aimed at producing solar conversion technologies that utilize greater portions of the available spectrum. Examples include "full spectrum" and "multi-junction" photovoltaic cells made of materials or layers designed to capture a broad range of wavelengths. These technologies enable more sunlight to be absorbed and converted into electric current, increasing overall efficiency. **Exhibit 3-3** illustrates the solar radiation spectrum and compares the spectral responsiveness of different PV cell technologies.

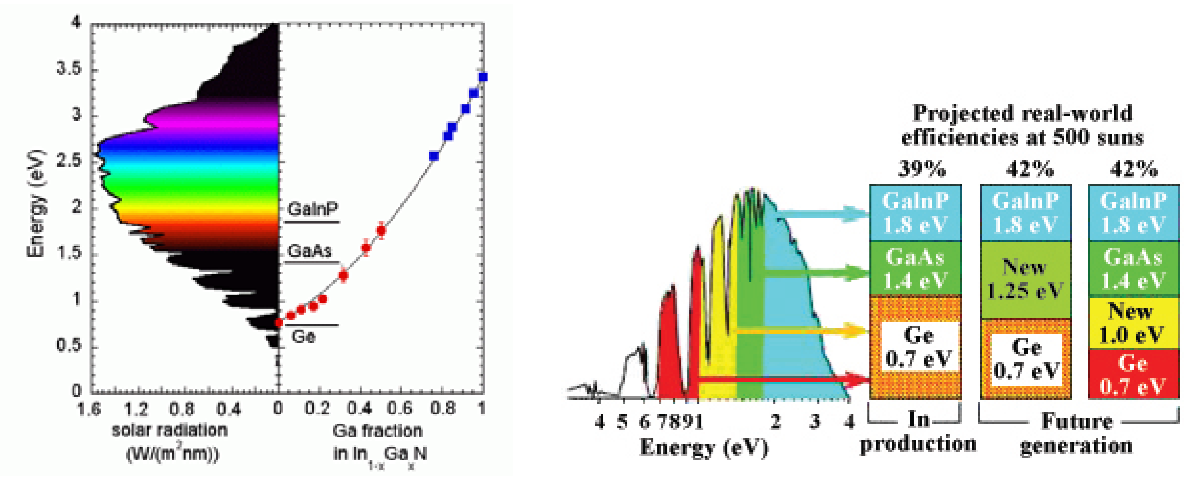
Variability

Solar radiation varies according to a combination of predictable annual and daily cycles, and irregular (though not entirely unpredictable) changes in weather. The annual and daily average variation is predictable within certain bounds; hourly variation over the course of a day is more difficult to predict. Certain events such as major forest fires and, even more significantly volcanic eruptions, can produce unexpected declines in solar irradiance for extended periods of time. Satellite-based forecasting models are currently being developed and are aimed at reliably providing hourly forecasts on a day-ahead basis.[2] Variability poses a challenge to large-scale integration of solar resources with the electric grid, but satellite-based forecasting models are currently being developed which can reliably provide hourly forecasts on a day-ahead basis.[3]

Development Issues: Considerations for Large Scale Use

In addition to the solar resource, major considerations for large-scale solar energy utilization are land use, water use, availability of adequate power transmission capacity, and the availability of feasible back-up power sources and/or storage technologies. Small-scale or distributed utilization of the solar resource often mitigates or eliminates the potential impact of some of these considerations by making better use of already-developed sites and by producing power at or very near the point of use.

Exhibit 3-3 Spectrum Utilization by Full-Spectrum and Multi-Junction Photovoltaic Cells



Source: Left image is full-spectrum cell example, derived from emat-solar.lbl.gov/images/InGaN_Solar.gif, right image is multi-junction illustration gosunsolutions.com/home/content/view/17/2/

Land Use

Solar radiation has a low energy density relative to other conventional energy sources, and for all but the smallest power applications, therefore, requires a relatively large area to collect an appreciable amount of energy. Typical solar power plant designs, require about 5 acres per megawatt of generating capacity. For example, a 200 MW thermal trough plant in west Texas would require about 1,000 acres of land. Likewise, a 30 MW thin-film PV array in central Texas would require about 168 acres.[4]

While the construction of large solar power plants is technologically feasible, their size requires that land use issues be considered. However, these concerns may be mitigated to some extent since large solar power plants tend to be located in remote, unpopulated areas, and since small, distributed solar facilities are typically located on rooftops of existing buildings.

Water Use

The need for water depends on the solar technology. Solar thermal electric technologies, such as central receiver and parabolic trough designs require a considerable amount of water for cooling. While the quantity of water needed per acre of use is similar to or less than that needed for irrigated agriculture, dependability of the water supply is an important consideration in the sunny, dry areas of the state that are favored for large scale solar power plants.

Solar power plants based on photovoltaics and dish-Stirling engine designs, as well as small-scale photovoltaic and solar thermal installations, do not require water. These systems actually reduce water consumption by offsetting energy production from conventional generators which do consume water.

Availability of Transmission

The Texas solar resource generally improves toward the west, and large-scale solar energy power plants are typically located where the resource is best. To transport the power to urban load centers adequate transmission is required. Intermittent resources such as wind and solar can pose unique problems in transmission planning and in efficient utilization of transmission infrastructure, resulting in higher transmission costs, increased congestion, and even generation curtailments when adequate transmission capacity is not available. Due to potential transmission constraints, solar project developers will need to evaluate the economic tradeoff of locating where the resource is best versus locating nearer to loads where transmission constraints are less likely.

Because solar and wind generation in west Texas generally occur at different times (solar during the day, wind generation at night), combining solar power plants with wind farms has the potential to result in fuller utilization of transmission capacity and improved matching of generation to utility loading, including peak loading conditions.[5]

Availability of Backup Resources or Storage

Solar currently accounts for only a tiny fraction of Texas' total energy production. As that share grows, solar may present new grid integration challenges similar to those emerging with wind applications. Substantial penetration of intermittent energy resources into the Texas electric grid is likely to create additional costs to ensure that adequate operating reserves, demand-response, storage, or other technologies are online and available to respond to short-term fluctuations in energy production.[6] Widespread integration of solar resources may compound some of the grid integration challenges already posed by wind in Texas, but may alleviate others through resource diversification.

Aside from its potential to ease challenges associated with grid integration, storage is particularly useful to solar because it enables time-shifting of energy production to peak hours when the value of the energy produced is highest. While the solar resource is generally synchronous with demand, especially relative to other renewable resources, Texas electricity demand tends to peak during late afternoons in summer while the solar resource tends to peak in the early afternoon. This means medium-term storage technologies, enabling the delay of energy outflows from solar generators by just a few hours, could be quite valuable economically to solar generators.

The storage of grid-scale quantities of electricity as an extended supply is impractical, although progress is being made with high capacity batteries that might provide a bridge of a few minutes that could dampen most adverse effects of solar variability on the grid. Other methods, such as pumping water to a higher elevation (potential energy) for later electricity generation, are already in use. Some technologies, such as domestic hot water pre-heat systems, have effective storage built-in.

Distributed Generation

Another pathway for solar energy development is through distributed installations of small-scale systems for producing electricity or hot water, typically on residential, commercial, or industrial building rooftops. Distributed solar electric (photovoltaic) systems and solar thermal water heaters offer some important advantages. For example, they do not consume water and, to the extent that distributed generation facilities reduce the amount of energy required from traditional power plants, they can reduce the amount of water consumed in the production of electricity. In addition, small-scale solar systems can be sited on existing buildings, eliminating the need for dedicated land to produce energy and reducing, or at least not contributing to, the need for new transmission and distribution facilities.

The Texas Solar Resource

The Texas solar resource is vast and the recoverable energy is many times greater than the state's total energy demand. Texas has 250 "quads" of solar energy accessible per year.[7] Given that one quad is one quadrillion British thermal units (BTUs) of energy—enough to meet the annual needs of about 3 million people—Texas' solar energy potential is enormous.[8] High-quality data quantifying Texas' solar resource is essential for planning and siting new solar power plants, as well as for accurately predicting the output of solar in distributed applications, such as on homes and businesses.

Solar measurements in the United States date back to the mid-twentieth century when solar energy information began to be gathered along with meteorological data. Since the energy crises of the 1970s and 1980s, additional solar monitoring efforts have been undertaken to assist the evaluation of solar energy conversion devices. While the collection of solar data across the U.S. and Texas has been considerable, the number of stations which used high quality, well maintained instrumentation that was well maintained and collected data over many years is limited. To be useful for adequately assessing the solar resource in a specific location, it is necessary to have long-term and accurate data. For this reason, only reliable, long-term data is presented herein.

Data Sources for Solar Resource Analysis

Ground-Based Measurements

While a variety of instruments have been used to collect solar radiation data, the most common and reliable are broadband thermal-sensing pyranometers and pyrheliometers, typically having measurement uncertainties of less than 5 percent. The pyranometer measures the sum of direct and diffuse radiation, while the pyrheliometer measures only the direct normal component. Stations using these instruments are generally designated as Class 1.

Because of their relative robustness, better response and lower cost, simple photosensors are currently the most commonly used type of instrument. Such instruments use photovoltaic cells and thus operate over a limited portion of the solar spectrum (300-1120 nm), introducing some uncertainty for broadband applications. A rotating shadow band (RSB) instrument uses a photosensor with a motorized rotating band that periodically blocks direct sunlight from the sensor. This single instrument measures both global (beam plus diffuse) and diffuse radiation and from these two quantities direct normal can be computed. RSBs are becoming a standard instrument and data from them are generally designated as Class 2. Only data collected over several years from locations having Class 1 or Class 2 instruments were used as the basis for the latest National Solar Radiation Database described below.

Satellite-Derived Measurements

Imagery from satellites of cloud cover and ground conditions now permit the estimation of incoming direct and diffuse solar radiation reaching the Earth at any location. The satellite-based models have been improved and verified against ground-based measurements and may be used to provide solar radiation estimates at any ground location where suitable satellite imagery is available. One result of these efforts is a 10 km gridded hourly solar database for the entire U.S.[9] This gridded solar radiation data provides about 9 times better resolution than the approximately 90 km spacing provided by the 89 Texas ground-based stations included in the 2005 National Solar Radiation Database. Data are available for global horizontal, direct normal, and diffuse solar radiation on a temporal basis.

The other major attribute of satellite-derived data is that, being "recent" data, it has the potential to support forecasting local solar availability, an important consideration for a solar power generation facility feeding into the grid. Earth observation satellites circle the Earth on approximately 90 minute orbits so, with rapid processing of the data, information used in solar energy forecasting need be no older than about 1½ hours. Recently, extensive research has been done on improving solar energy forecasting and the results are very promising.[10]

National Solar Radiation Database

The National Renewable Energy Laboratory (NREL) and the National Climatic Data Center (NCDC) developed the first National Solar Radiation Data Base (NSRDB) based on ground-derived measurements for the years 1961 to 1990.[11] In 2007 the original NSRDB was updated using the latest ground- and satellite-derived irradiance data from 1991 to 2005.[12]

Exhibit 3-4 NSRDB2 Sites in Texas

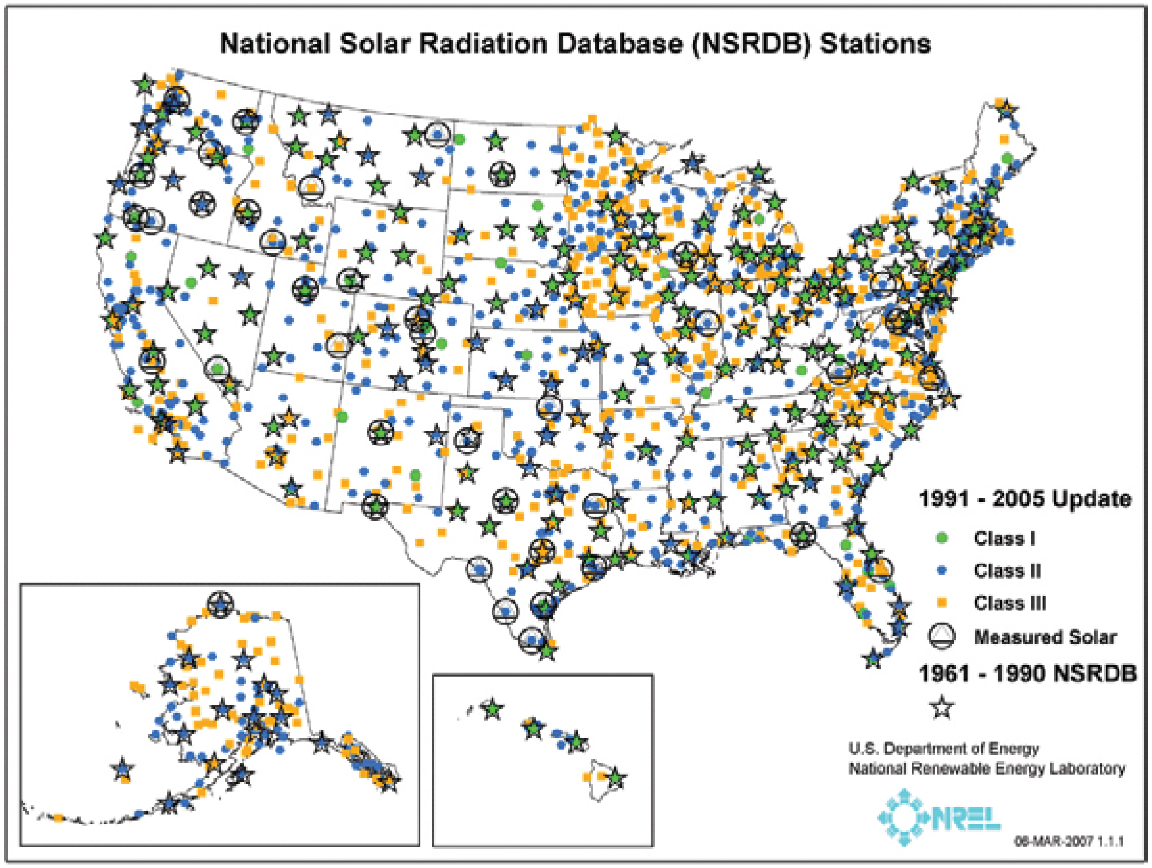
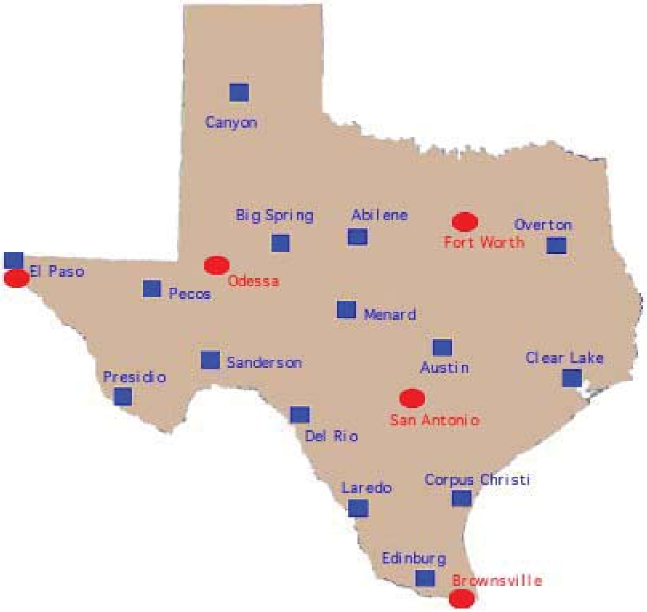


Exhibit 3-5 TSRDB Sites



Source: http://www.me.utexas.edu/~solarlab/tsrdb/tsrdb.html

The 1991–2005 NSRDB contains hourly solar radiation (including global, direct, and diffuse) and meteorological data for 1,454 ground stations across the nation. Ground stations are classified by data quality, with 221 Class I stations (the highest quality), 627 Class II stations, and 596 Class III stations. Within Texas, the 1991-2005 NSRDB has 89 stations, with 15 Class I, 38 Class II, and 36 Class III stations. In addition, it includes a satellite-derived gridded data set that contains hourly solar records for 8 years (1998–2005) for the United States (except Alaska above 60˚ latitude) at about 100,000 locations. The locations of the 89 NSRDB sites in Texas are shown in **Exhibit 3-4**.

Texas Solar Radiation Database

In a project supported by the Texas State Energy Conservation Office (SECO)[13] a Texas Solar Radiation Database (TSRDB) was developed using solar data obtained at 15 locations in Texas (Abilene, Austin, Big Spring, Canyon, Corpus Christi, Del Rio, Edinburg, El Paso, Clear Lake, Laredo, Menard, Overton, Pecos, Presidio, and Sanderson) between 1996 and 2002. Data from 10 of these locations were used in the development of the new 1991-2005 NSRDB. The TSRDB Internet site[14] provides global horizontal, direct normal and diffuse horizontal data for the 15 locations on hourly intervals from 1996 to 2002. **Exhibit 3-5** shows the locations of the 15 TSRDB locations.

Other Significant Measurement Networks

There are other measurement networks that emphasize other measurements, but may now or in the future also record solar radiation data, likely with a single photosensor. These include the Texas Commission on Environmental Quality air quality monitoring,[15] Texas Coastal Ocean Observing Network,[16] and the Texas Mesonet,[17] but the emphasis in each of these is on other meteorological data. In addition, many of the Texas A&M Agricultural Research Stations record solar radiation, as do some of the wind stations supported by West Texas A&M.

Typical Meteorological Year Data

Assessing the long-term performance of solar energy systems is simplified through the use of "typical meteorological year," or TMY, data sets, which are produced and updated periodically by NREL.[18] The TMY typifies the climate in an abbreviated one-year data set by attempting to match long-term distributions of solar radiation, temperature and wind, while retaining the natural variability of daily or monthly measurements. TMY data have been used very successfully for solar analyses for more than two decades.

The latest TMY data set was released in May 2007 and is referred to as TMY3. TMY3 is based on the 1991 to 2005 NSRDB update and consists of 1020 sites nationwide, including 61 sites in Texas. TMY3 consists of actual hourly data taken from selected months out of the NSRDB to represent a "typical year." Each data set is composed of twelve months of actual hourly data, with each month selected as representative of the typical (long-term average) solar-weather characteristics for that month. The advantage of TMY is that it includes the short-term variations such as partly cloudy conditions and thunderstorms, but is typical of what can be expected in the future and consists of only 'one year' of data. TMY data have been used very successfully for solar analyses for more than two decades.

Solar Resource Characterization

Average Annual Insolation

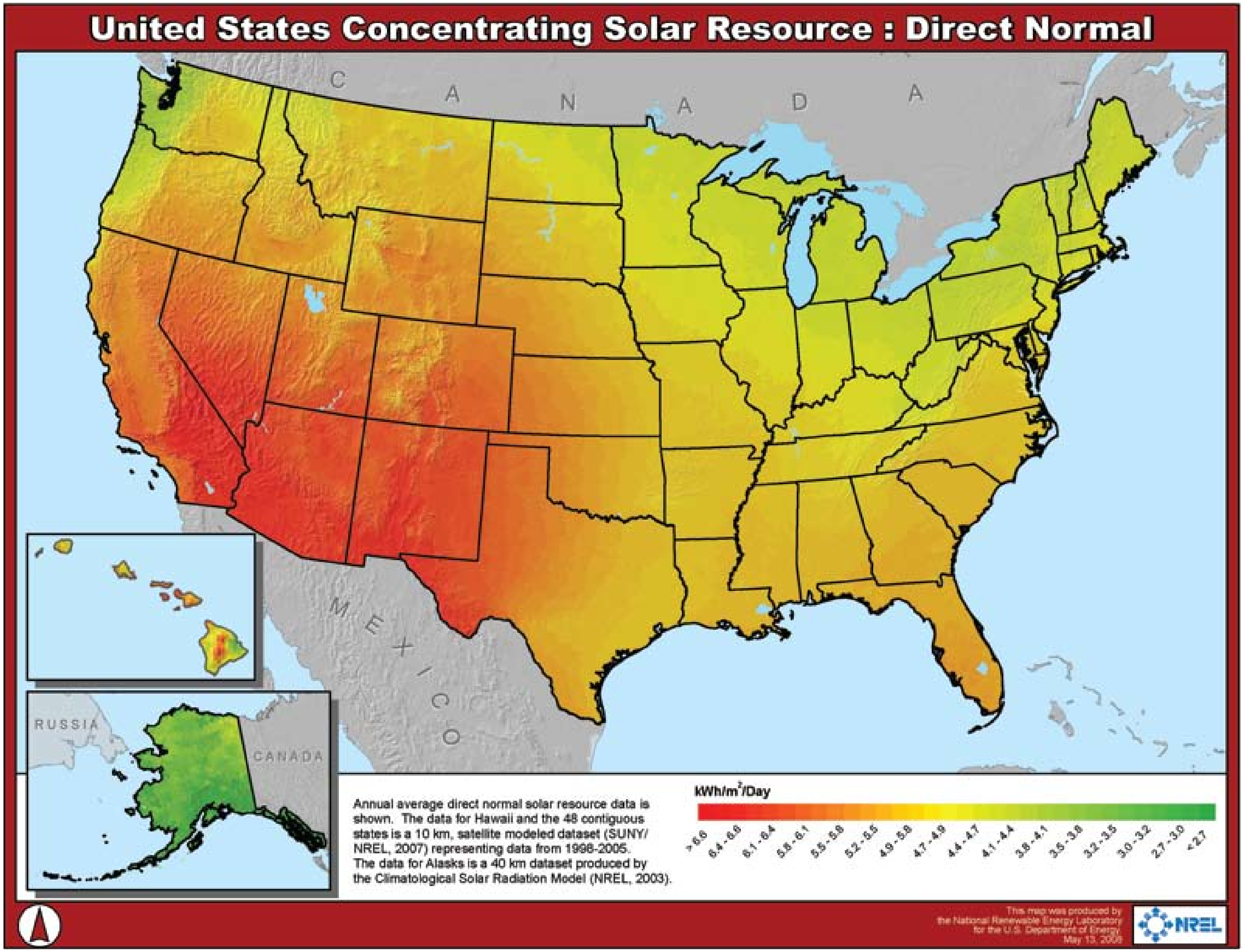
The average annual daily solar radiation (kWh/meter^2/day) at a specific location is of prime importance, as it is a good indicator of the long-term performance and economics of solar energy systems at that location. Since most common solar applications use either concentrating collectors (which collect direct normal insolation, DNI), or tilted flat collectors (which collect global tilt insolation, GTI), it is of interest to have these annual average data as a starting point for a more detailed analysis.

Exhibits 3-6 and **3-7** are contour maps for both the U.S. and Texas showing direct normal and global tilt insolation, respectively. The maps show that for Texas solar radiation increases from east to west. This is due to the generally higher humidity and cloud cover nearer the coast.

Direct normal insolation (DNI, that most relevant to concentrating solar plants) is more variable across Texas because cloud cover reduces the direct insolation. In contrast, diffuse insolation (which cannot effectively be used by concentrators, but which can be used by flat plat collectors) is present to some extent throughout markedly varying weather conditions. The desert Southwest experiences the highest levels of solar radiation in the United States and far west Texas receives insolation levels within 10-15% of the best in the nation.

Exhibits 3-8 and **3-9** show bar charts for the daily average direct normal solar radiation and direct plus diffuse solar radiation on horizontal surfaces, respectively, for 1991-2005 NSRDB Class I locations in Texas. The orange bar segments in each chart represent the direct (beam) radiation falling on the surface. The additional blue bars in **Exhibit 3-9** represent the diffuse radiation falling on the horizontal collecting surface; the sum of the two represents the total solar radiation striking the horizontal surface.

Exhibit 3-6 Direct Normal Solar Insolation (applicable to concentrating solar energy technologies, such as large-scale CSP power plants)

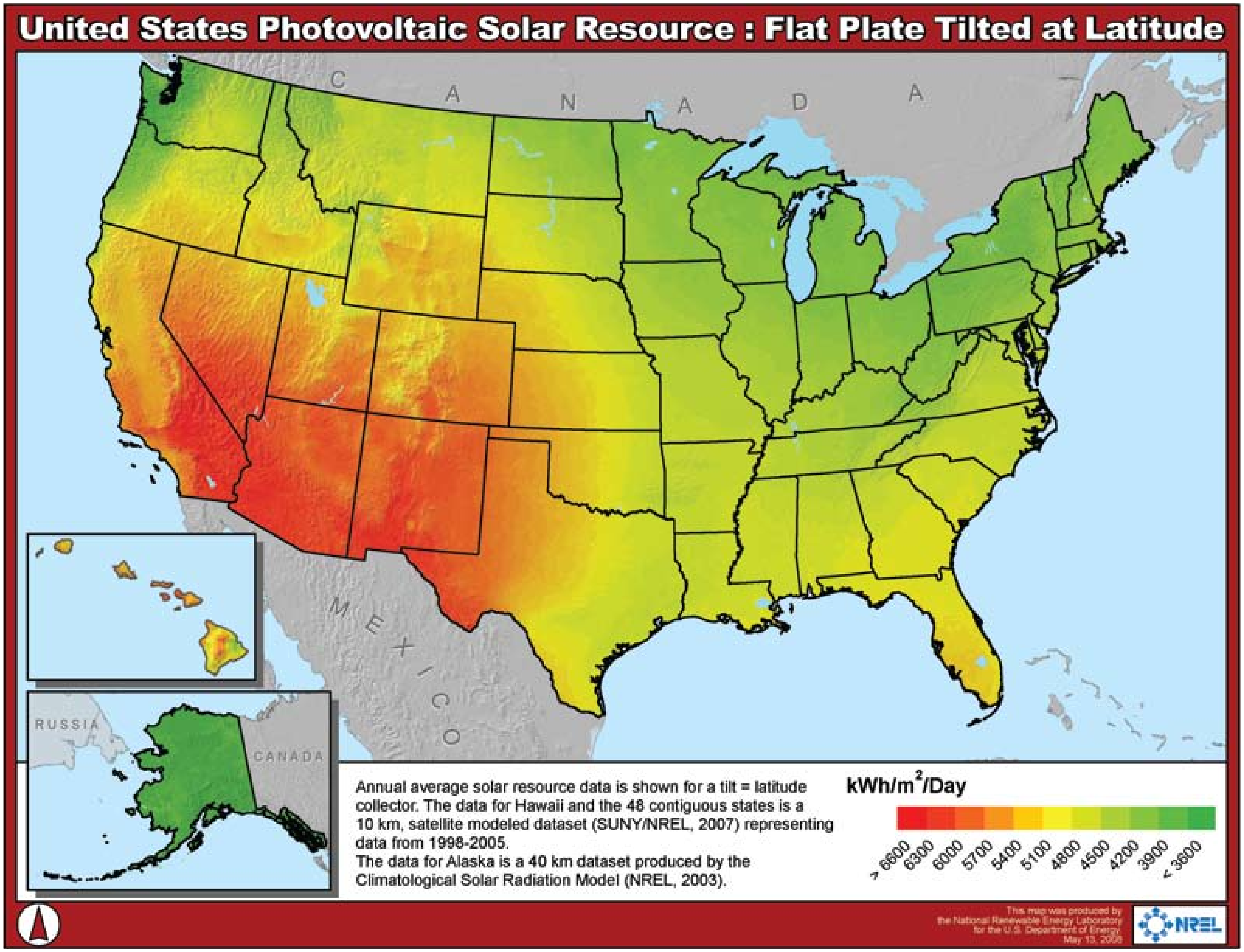


Annual average direct normal solar resource data is shown. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alasks is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by
the National Renewable Energy Laboratory
for the U.S. Department of Energy.
May 13, 2008

Source: Image can be found in file National_CSP_Letter.pdf.

Exhibit 3-7 Global Insolation on a Tilted Surface(applicable to flat-plate systems, such as most rooftop photovoltaic and solar water heating systems)



Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

Source: Image can be found in file National_PV_Letter.pdf.

Exhibit 3-8 Normal Insolation on a Surface that Tracks the Sun Continuously (cities appear in order from west to east)

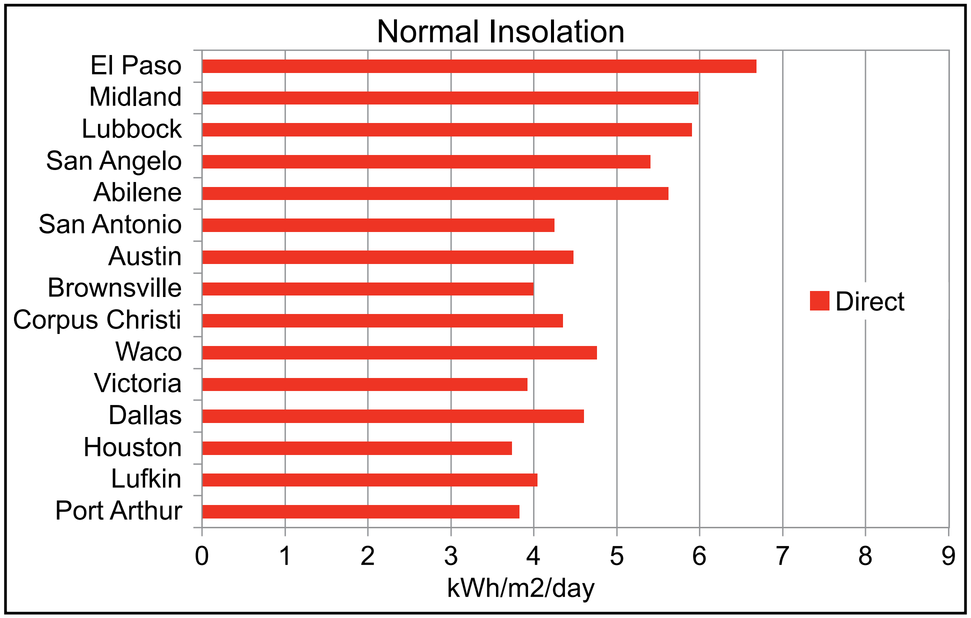


Exhibit 3-9 Horizontal Insolation (kWh/m2/day) (cities appear in order from west to east)

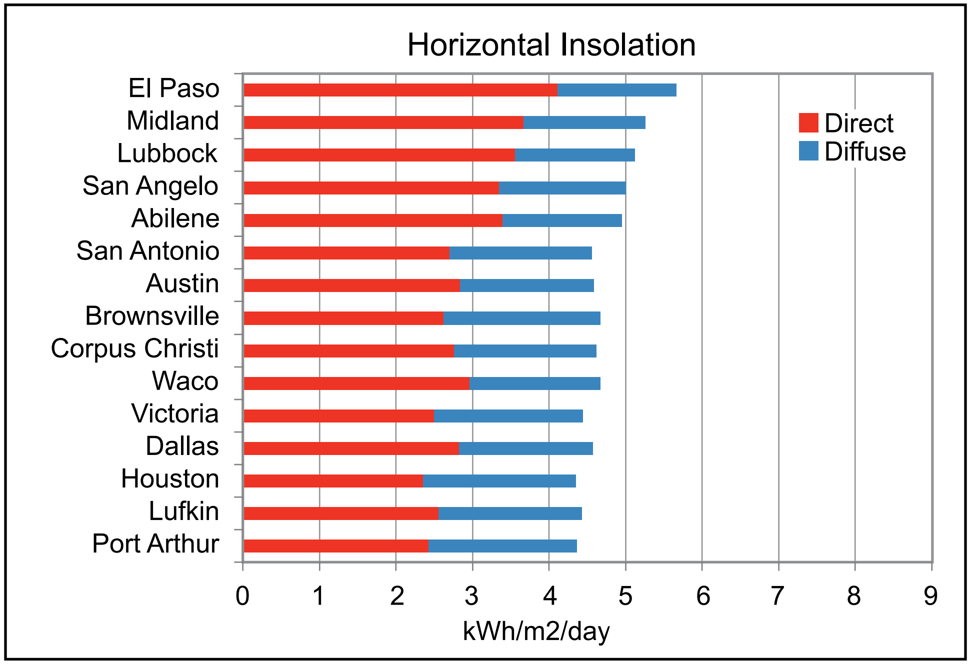
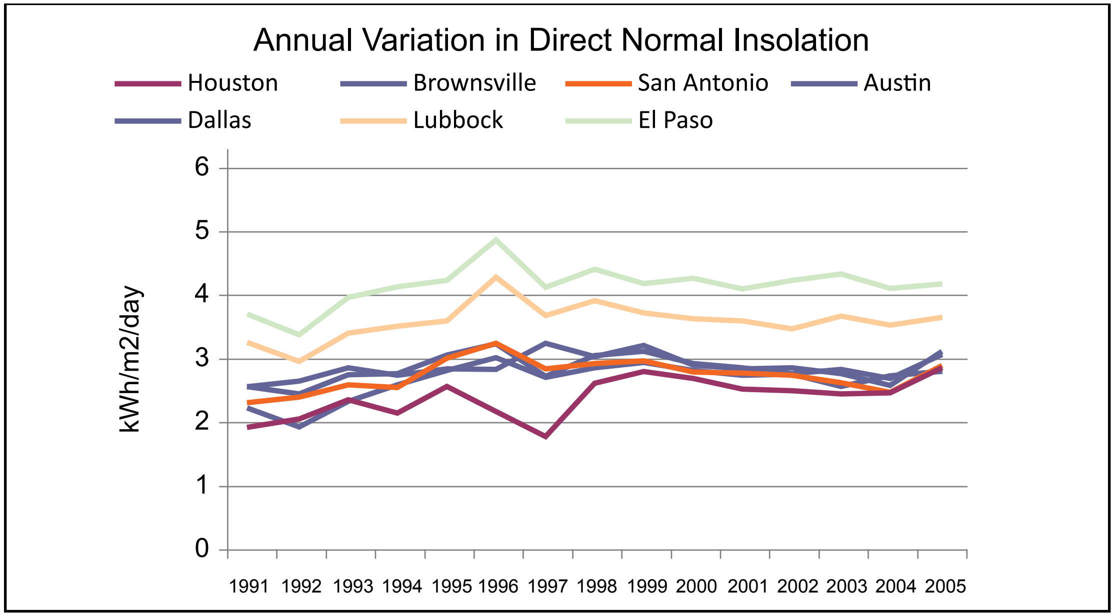
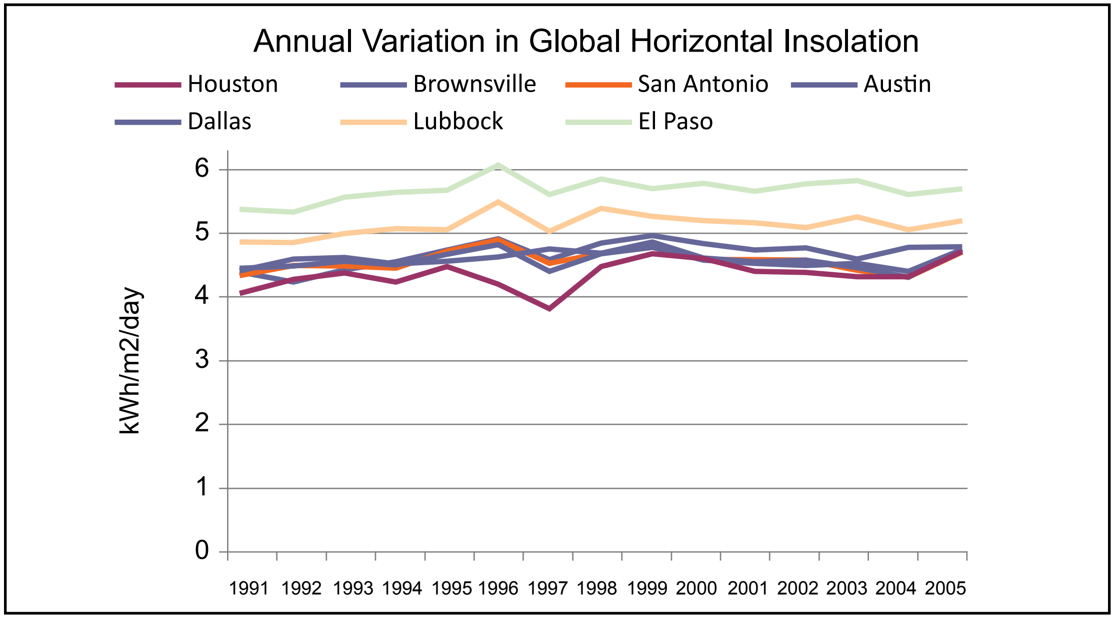


Exhibit 3-10 Annual Variability





Consistent with the contour maps (**Exhibits 3-6** and **3-8**), locations further to the west exhibit increasing total horizontal and direct normal insolation levels. In contrast, diffuse insolation decreases at locations further to the west. Direct normal insolation values also vary over a wider range than do horizontal insolation values. For example, direct normal insolation is about 80 percent higher in El Paso than Houston, but global horizontal insolation is only about 30 percent higher in El Paso than Houston This means that concentrating solar plants, whose performance is driven by normal insolation, have more to gain by locating in far west Texas. And conversely, it means that the performance of flat plat collectors, typically used in residential and commercial applications and whose performance is driven by direct plus diffuse insolation in the plane of they collector array, is less dependent on their specific location in the state.

A comparison of direct normal insolation with the total insolation on horizontal surfaces is of interest for low temperature applications. For west Texas locations with high total insolation (i.e. El Paso through Abilene), the direct normal insolation alone is greater than the total horizontal insolation. In contrast, in almost all other cities the direct normal insolation is lower than the total horizontal insolation. Thus, if a low temperature application such as solar water heating is considered, flat plate collectors which collect both the direct and diffuse radiation are not only less expensive, but will perform better in east Texas than concentrating collectors which operate on direct radiation only. Even for locations where the direct normal insolation is higher than total horizontal insolation, flat plate collectors may still be the better choice, especially for smaller-scale systems, because they tend to be less expensive and more reliable.

Of course, for applications involving high temperature collection (industrial process heat or solar-thermal power generation) concentrating collectors are superior in areas where direct normal insolation is highest. Higher levels of direct normal insolation are needed to produce the high temperatures required by these processes, and the scale of these applications is more likely to justify increased initial and ongoing costs of concentrating and tracking systems.

Variability

As with some other renewable energy resources, the intermittent nature of solar radiation may be a barrier to its widespread use. The solar resource does vary, but it can be predicted reasonably well over long time periods. The following exhibits depicting resource variability show both direct normal insolation, the most variable component of solar radiation, and global horizontal insolation. As a general rule, the variability of global horizontal insolation is less than that of direct normal insolation.

Annual

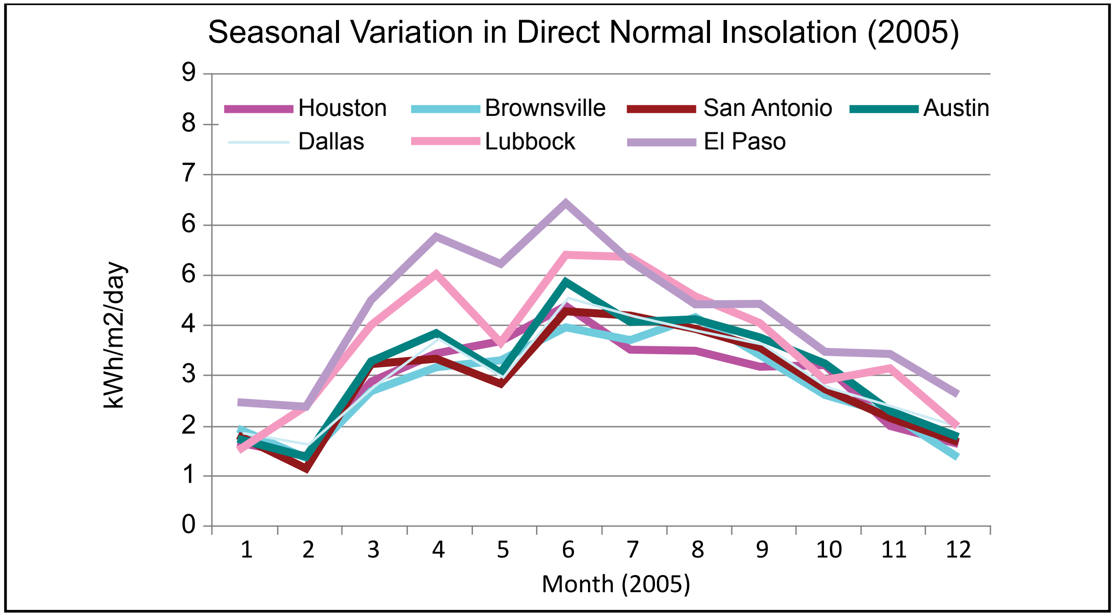
The annual variability in direct normal and global horizontal insolation by year from 1991 to 2005 is shown for several Texas locations in **Exhibit 3-10**. Variability in annual insolation from year to year is small, typically about 15%. Low and high insolation years typically occur simultaneously for all of Texas, the low years usually a result of persistent rain caused by El Niño events. This year-to-year variability poses little concern for solar power plants if proper care has been taken to consider the economics and operational effects of low and high solar resource years.

Seasonal/Monthly

The seasonal variability of direct normal and global horizontal insolation is shown in **Exhibit 3-11** for several locations across Texas. Generally the summer months exhibit the greatest monthly insolation, due to longer days, more direct exposure to the sun due to the tilt of the Earth's axis, and to generally clearer skies. In the winter months the days are shorter, cloud cover is greater, and the sun is lower in the sky, requiring sunlight to travel a longer path through the through the atmosphere and be scattered by clouds, dust, and pollution before reaching the Earth's surface.

Global horizontal insolation shows similar seasonal variation to that of direct normal insolation. Local weather conditions have a significant effect on seasonal and short-term solar radiation. An example is the sharp drop in insolation during late summer in El Paso, when the rainy season occurs in the Desert Southwest. In contrast, the eastern half of Texas

Exhibit 3-11 Seasonal Variability


Seasonal Variation in Direct Normal Insolation (2005)

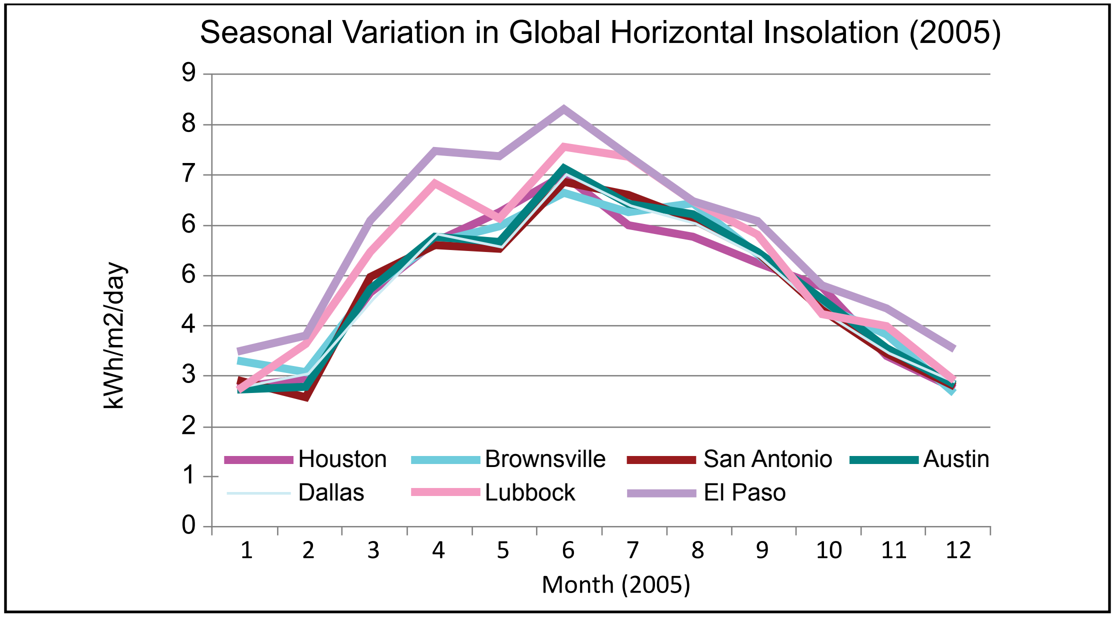
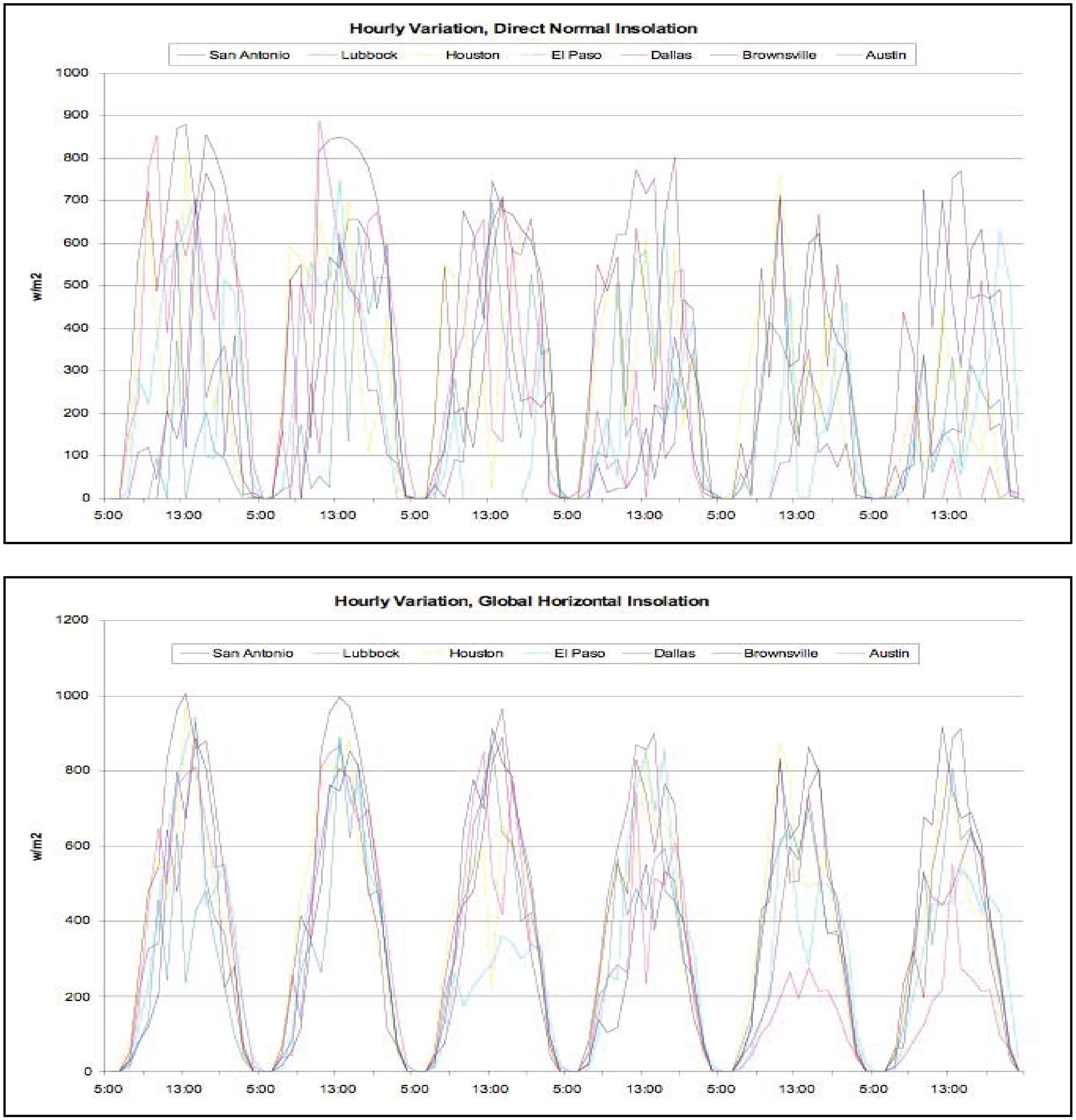

Seasonal Variation in Global Horizontal Insolation (2005)

Exhibit 3-12 Daily and Short Term Variability[19]



experiences relatively high insolation during mid- to late-summer. Even though these are the sunniest months along the Texas Gulf Coast, the level of direct normal insolation throughout the coastal region is still about 25 percent lower than that experienced in west Texas. The summer period is bracketed by May and September, two of the heaviest rainfall months for much of Texas. **Exhibit 3-11** indicates that, for most of Texas, these two months have relatively low insolation for most of Texas.

The seasonal variation in solar radiation tends to be synchronous with energy demand in Texas because high levels of solar radiation in the summer are a major contributor to heat gain in buildings, increased air conditioning loads, and thus peak electrical demand. Seasonal variation may pose some concern for solar power plants in Texas if solar becomes a significant portion of the state's energy resource mix, unless technologies for seasonal energy storage to compensate for these seasonal variations become feasible.

Daily (Diurnal) and Short-Term

Daily and intermittent variations in direct normal radiation are a result of the diurnal (day/night) effect and changing atmospheric conditions, mainly cloud cover. These may exhibit some differences from season to season but they exhibit similar character, clear days mixed with cloudy/overcast days. **Exhibit 3-12** shows a five-day period in the summer for several locations across the state, a span which includes clear periods and periods with intermittent sunshine. The nighttime periods (9 pm to 5 am) have been omitted.

Clear days exhibit hourly variations in direct normal radiation that are somewhat ‘square’ and non-clear days exhibit extreme short-term variations, from high levels to near zero. Note that for this particular week there are significant differences depending on location, and these are due mainly to prevailing weather fronts and patterns. Note that for any clear day the global horizontal insolation exhibits a more ‘parabolic’ pattern over the day than does the direct normal, and the variations during cloudy days are not as extreme.

These diurnal and short-term variations in solar energy pose the greatest problem for utilization of the solar resource. However, unlike the impracticality of long-term storage to ameliorate seasonal variations, storage for diurnal and short-term variations is more likely to be feasible. Most large solar thermal power plants, for example, are now designed to accommodate several hours of thermal energy storage. Research is ongoing to determine the effects of passing clouds on the generation characteristics of large-scale photovoltaic plants.

Utilization

Overview

Much of the energy use in our society is electrical, which currently is generated at large central power stations. But another significant energy demand is for thermal energy, including heating water and living spaces, moderate to higher temperature industrial heating applications, as well as drying of grain crops and wood products.

Solar energy can be used for both central and distributed electrical generation and also for decentralized thermal loads, such as water and space heating. The distributed generation capability of solar is a major advantage, because energy production at the point of demand reduces the need for transmission and distribution infrastructure. Furthermore, solar energy by its nature is suitable for local generation, producing no air, water, or noise pollution.

Conversion Technologies

One can consider the potential solar energy contribution to our energy demands in three general categories: 1) central electrical power generation using solar-thermal or direct photovoltaic conversion, 2) distributed thermal or photovoltaic energy production, and 3) small stand-alone electrical applications.

Central Power Generation Systems

While electrical generation plants are ideally located relatively near load centers, central solar thermal power plants would typically be sited at locations where insolation is best, particularly direct normal insolation. For central solar power generation the systems may be either solar thermal or photovoltaic.

Thermal Technologies

A variety of solar thermal conversion systems have been developed, but the most common in use over the last two decades uses parabolic trough concentrators. This design uses linear parabolic reflectors (concentrators) to reflect direct solar radiation to a tube carrying a fluid along the focal line. The radiation’s energy is absorbed in the fluid which flows to a steam generator and turbine which drive an electric generator.

The most recent example of a linear concentrator is the Nevada Solar One project which went online in June 2007 (**Exhibit 3-13**). It has a capacity of 64 MW and is projected to produce approximately 130 million kWh per year. The total project site is approximately 400 acres (0.6 mi² / 1.6 km²), while the solar collectors cover 300 acres (1.2 km²). The plant was constructed by Spain’s Acciona Energy. It is the third largest solar power plant in the world, and the largest built in the past 17 years.[20] The world’s largest, known as the Solar Energy Generating Systems (or “SEGS”), consists of nine parabolic concentrator facilities operating commercially since 1984 in California’s Mojave Desert by Southern California Edison with a combined generating capacity of 354 MW.

Several other solar thermal power system designs have been tested and operated, though not as extensively as the parabolic trough design. One is the ‘central receiver’ or ‘power tower’ concept in which a large number of heliostats (mirrors on two-axis trackers) reflect solar radiation onto a central receiver located on a tall central tower. There, the solar energy heats a fluid, which flows to a steam turbine, which in turn drives an electric generator.

A 10 MW central receiver system was constructed at Kramer Junction in the California desert in the early 1980s and operated as a demonstration project for several years in two design versions, the first being steam generation in the central receiver itself and later with molten salt used as the transfer fluid for a separate steam generator. This project was decommissioned in 1999 (**Exhibit 3-14**).

Exhibit 3-13 Nevada Solar One
(parabolic trough linear concentrator design)

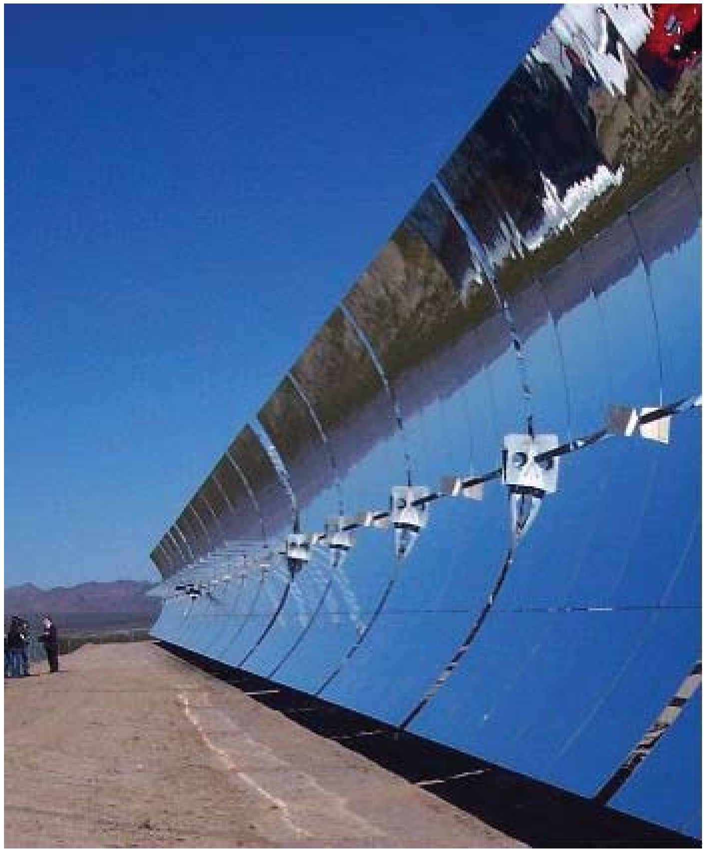


Exhibit 3-14 Solar Two (central receiver design)

Exhibit 3-15
Dish concentrator
(dish Stirling design)

Source: Photo from http://www.stirlingenergy.com/news-media/images-video.asp

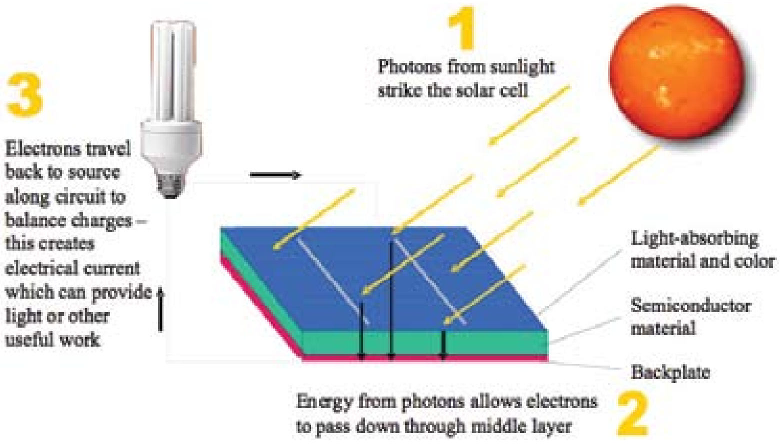
The use of ‘dish concentrators’ is a third promising design. The heart of the design is a parabolic dish reflector, which tracks the sun and concentrates the direct solar radiation to its focal point. Depending on the design, the radiation either: 1) heats a fluid, which drives a steam turbine-generator; 2) drives a Stirling engine located at the focus to produce electrical power, or 3) uses photovoltaic cells in the focal region to produce electricity directly. **Exhibit 15** shows an example of a ‘dish concentrator’ system.

Several other solar thermal concentrating system designs have been proposed and/or are being developed, including the Compact Linear Fresnel Reflector (CLFR) concept of Ausra (an Australian firm), and the natural draft tower-turbine generator being built in Spain. Another is the salt-gradient pond, which permits solar radiation to be captured in nearly saturated brine at the bottom of a pond, which then can be recovered to drive a Rankine cycle engine-generator.

Photovoltaic Technologies

Central power can be generated directly using photovoltaic (PV) cells. This may be accomplished using flat PV panels that are either stationary or tracked to follow the sun, or by using concentrating optics to focus the radiation on a much smaller area, thus reducing the amount and cost of expensive cells. The tracking and concentrating methods parallel those described in the previous section on solar thermal technologies, and are not addressed here.

Exhibit 3-16 How Photovoltaic Cells Work



Source: Image courtesy of Clean Energy Associates

PV cells convert sunlight directly into electricity by taking advantage of the photoelectric effect. Cells are constructed from semiconductor materials coated with light-absorbing materials. When photons in sunlight strike the top layer of a PV cell, they provide sufficient energy to knock electrons through the semiconductor to the bottom layer, causing a separation of electric charges on the top and bottom of the solar cell. Connecting the bottom layer to the top with a conductor completes an electrical circuit and allows the electrons to flow back to the top, creating an electric current and enabling the cycle to repeat with more sunlight. **Exhibit 3-16** illustrates how photovoltaic cells work.

Individual PV cells are typically only a few inches in diameter, but multiple cells can be connected to one another in modules, modules can be connected in arrays, and arrays can be connected in very large systems. This enables PV cells to be combined in scale to produce large, multi-MW central station power generation facilities.

PV cells and modules take advantage of different materials and manufacturing processes. The most common technology in commercial production historically and today uses highly-refined crystalline silicon for its semiconductor layer. While crystalline solar cells have decades of solid field performance history, they involve high energy and labor inputs which prevent significant progress in reducing production costs, and are limited in theoretical efficiency.[21] More recent PV technologies attempt to reduce materials and manufacturing costs, and achieve higher actual and theoretical efficiency, by depositing non-crystalline (or “amorphous”) semiconductor materials, onto low cost substrates. Examples of these “thin film” technology types include cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon. The latest designs in research and development attempt to achieve even higher efficiency with thin films by using combinations of materials (“multi-junction” cells) or single materials (“full spectrum” cells) that respond to wider ranges of available spectrum, thereby producing even more energy.

The largest PV power plant in the U.S. was commissioned in 2007 at Nellis Air Force Base in Nevada. It consists of about 70,000 tracking solar panels distributed over 140 acres, is rated at 15 MW (18 MW-DC), and produces about 25 million kWh annually. SunPower Corporation’s PowerLight subsidiary designed and installed the system (see **Exhibit 3-17**). A dozen or so other PV plants one MW or greater are currently operational in the U.S., in states as diverse as Arizona, California, Colorado, New Jersey, and Pennsylvania. Larger PV power plants up to 100 MW are under development.

Exhibit 3-17 15 MW Tracking PV Array at Nellis Air Force Base, Nevada

Source: Photo from http://www.sunpowercorp.com/For-Power-Plants.aspx

Distributed Solar Power Generation

Distributed solar generating systems are sited at the point of use, typically on or near residential or commercial buildings, and serve some or all of the energy needs of the building. Distributed systems may utilize solar thermal or photovoltaic technologies. When used to produce electricity, utility interconnection and net metering policies greatly influence a customer's ability to install systems and lower their energy bills, respectively.

Distributed Thermal Applications

There are many energy applications for which the load is purely thermal, such as water heating, space heating, swimming pool heating, cooking, industrial process heating and drying, and many of these energy needs can be supplied by solar energy. The most difficult thermal applications to achieve are cooking and high-temperature industrial heat applications. Since it is generally not cost-effective to transport thermal energy over long distances (more than a mile), these applications are invariably distributed, with energy being collected near the point of demand. Any of these applications could be met by electricity, so if they are met by solar thermal they may be considered "distributed,", since electricity does not need to be transported and distributed to meet them. A common example is water heating, which is normally accomplished with electricity or gas, but can also be readily accomplished by solar.

Solar thermal collectors may be of either flat plate or concentrating design. Flat plate thermal collectors consist of a dark absorber panel with incorporated fluid passages housed in an insulated box with a transparent glazing on the front. The heat-absorbing energy transfer medium may be either a liquid or air. For a low temperature application like swimming pool heating, the only thing that is necessary is an absorber panel with integrated fluid passages; however, glazing and insulation are needed to achieve higher temperatures for domestic water heating. Evacuated tube collectors, which house the absorber in an evacuated glass tube, permit even higher temperature collection with flat plate collectors.

The highest temperatures are achieved with concentrating collectors. These come in a number of designs, but in general consist of either a reflector or lens which concentrates solar radiation onto a smaller absorber surface including passages for the transfer fluid. There is a wide variety of industrial heat applications requiring temperatures up to and more than 1,000 degrees Fahrenheit and for most of these applications concentrating solar thermal collectors are required.

In addition to heating, cooling can be achieved by a number of solar thermal means, one being absorption cooling. Solar absorption chillers use a heat source, such as natural gas or hot water from solar collectors, to evaporate pressurized refrigerant from an absorbent/refrigerant mixture. Condensation of vapors provides the same cooling effect as that provided by mechanical cooling systems. Although absorption chillers require electricity for pumping the refrigerant, the amount is very small compared to that consumed by a compressor in a conventional electric air conditioner or refrigerator. Solar absorption cooling systems are typically sized to carry the full air conditioning load during sunny periods. Because absorption cooling equipment requires input temperatures of approximately 200 to 250 degrees Fahrenheit or greater, concentrating or possibly evacuated tube collectors are needed. While technically feasible, these technologies are not currently cost effective.

Exhibit 3-18 Domestic Solar Thermal Water Heater

Note: This system is part of the Historic Gardens Phase II project, by the San Antonio Development Agency (SADA). Several different floor plans have had solar water heaters installed by Sun Trapper through grant funding by City Public Service.

Source: Downloaded from www.solarsanantonio.org/localrenewable.html.

Exhibit 3-19. Residential-scale PV System

Source: Photo courtesy of Meridian Energy

Exhibit 3-20 Commercial-scale PV Systems

Source: Photos courtesy of Meridian Energy

Distributed Photovoltaic Applications

Distributed PV systems, typically of 1 to 5 kW capacity for residences and from 5 kW to several thousand kW capacity for businesses and institutions, are becoming common. For residential applications the panels are usually fixed on a tilted roof facing south (see **Exhibit 3-19**), while for commercial applications the panels are typically located on flat roofs or mounted on special structures outside the building (see **Exhibit 3-20**).

In most cases these systems are grid-connected, interconnected with the customer's AC power supply, such that when insufficient power comes from the PV system to meet the building's load, additional AC power is drawn from the utility distribution system. Conversely, when excess power is produced by the PV system, the excess flows out of the customer's property and into the utility distribution system.

In some cases the customer may have storage (typically batteries) to provide emergency backup for a few hours. As with solar thermal technologies, solar cooling may be achieved by driving conventional air conditioning systems with PV-generated electricity.

Net Metering

Under traditional "net metering" policies offered to utility customers in at least 68 different jurisdictions in the U.S., excess energy provided to the distribution system is netted against a customer's metered consumption and credited back to the customer on monthly electric bills at the retail rate. Such a policy was in place for Texas customers of vertically integrated utilities until the introduction of competition to the state, at which time net metering was no longer available to customers in the ERCOT competitive area.

New legislation passed in 2007 is scheduled to be fully implemented for customers in the ERCOT competitive area and for regulated utilities outside ERCOT in 2009. It replaces traditional net metering with a voluntary program in which utilities or retail electric providers (REPs) do not net a customer's production against consumption, but instead have the option to buy back excess production at a rate negotiated with customers. At this point it is not clear how many REPs or utilities will offer a buy back option, how many customers will be served by a REP offering a buy back option, or what the value of buy back offers will be.

Some of the state's municipal utilities and rural electric cooperatives, including several of the largest municipal utilities, have voluntarily adopted traditional net metering policies for their customers, though these programs are neither required nor consistently designed.

Stand-Alone Applications

There are numerous small demand applications for which PV systems are designed to stand alone, without any connection to the electrical distribution system. Some examples include rural water pumps, traffic signals, emergency call phones, metering and communication equipment in oil-field applications or other remote applications where it would be expensive or impractical to extend a utility distribution line (**Exhibit 3-21**).

To meet varying load requirements with the variable power from sunlight, stand-alone systems require some type of storage, typically batteries. The battery capacity is typically designed to provide five to ten days of autonomy so that the systems very rarely fail to meet the load. Inclusion of battery capacity to meet the load during inclement weather period is often more economical than extending a distribution line and incorporating a step-down transformer, or providing fuel and a back-up generator. In the case of rural water pumps, storage is provided not by batteries by a water storage tank or reservoir, ensuring that water is pumped when sunlight is present but available even when it is not.

Exhibit 3-21 School Zone Warning Light.
An Example of a Stand-Alone Solar Application

Economics

Costs

The current cost, and cost-effectiveness, of different solar technologies and applications varies widely. In general, some solar thermal applications, especially passive applications like daylighting, and active applications like solar water heating, have been cost-effective for many years.

Others, such as central solar thermal and thin-film photovoltaic power generation, are rapidly becoming cost-effective at utility scale as their costs decline, efficiencies improve, and the cost of fossil-based electricity continue to increase. Texas is beginning to see serious interest in development of these projects already, and it is likely that one or more large-scale solar projects will be developed in the state over the next several years.

Finally, other solar applications such as distributed photovoltaics are expected to be cost-effective within 10 years, but in the meantime can be made cost-effective for customers today through a combination of federal, state, and utility subsidies and policies. A number of other states and countries have adopted such policies and fostered large domestic markets, industry experience and skilled workforces which they plan to capitalize on when large-scale markets emerge elsewhere.

Electricity Costs in Texas

The cost to produce energy using solar technologies is not meaningful without reference to the cost to produce energy by other means. This section focuses on Texas electricity costs, and reports recent retail and wholesale costs of electricity in order to enable meaningful comparison of solar technologies to market costs.

Texas retail electricity prices averaged 11.99 cents per kWh for residential, 10.27 cents per kWh for commercial, and 8.27 cents per kWh for industrial customers in March 2008, according to the U.S. Department of Energy, using a methodology that includes all utilities and customers in the state.[22] For the ERCOT competitive market area, the Public Utility Commission of Texas reported that during the same month, published annual retail electric service offers for residential service ranged from a low of 9.9 cents per kWh to a high of 17.1 cents per kWh, with most offers in the range of 13 to 16 cents per kWh.[23]

Wholesale electricity costs are significantly lower, averaging 5.5 cents per kWh but ranging from an average monthly low of about 4.5 cents per kWh in October to an average high of about 7.5 cents per kWh in August 2006.[24] The wholesale price of electricity during peak hours, however, can sometimes rise to over 80 cents per kWh [the article you cite actually references wholesale price of up to $4.40 per kWh] in ERCOT,[25] helping to make solar thermal and PV applications more competitive during peak periods. Solar energy systems usually generate more electricity during the hottest time of the day, and thus can help to offset the need to add expensive electric generating capacity to satisfy peak demand. Solar thermal generators incorporating some degree of storage are even better able to capture high wholesale prices during periods of peak demand.

Solar Thermal

Cost of Central Solar Thermal Power Generation

The levelized cost of energy from new central solar power stations using solar thermal technologies currently ranges from about 12 to 18 cents per kWh. Large-scale solar thermal technologies achieved dramatic cost reductions in the 1980s relative to other renewable technologies due to increased efficiencies in parabolic trough, power tower, parabolic dish, and fresnel reflector designs. During the 1990s solar thermal research and development funding levels were lower and cost reductions came largely from improvements in operation and maintenance. Future cost reductions are projected to result from improved reflectors and lower-cost heliostat designs, improved solar thermal receivers, heat exchangers and fluid handling technologies, and turbines and generators, as well as from volume manufacturing.[26] **Exhibit 3-22** shows historical and projected costs of centralized solar thermal power.

Cost of Distributed Solar Thermal Applications

Solar swimming pool heating, while often considered a luxury, is very economical compared to the alternative of heating with electricity or natural gas. Solar water heating (residential, commercial and institutional) is generally cost effective in Texas in comparison to heating with electricity (10 to 15 year payback) but somewhat less cost effective compared to heating with natural gas (15 to 20 year payback). Active solar heating of living space in Texas (except possibly far north Texas), is not generally considered cost effective, because of Texas' short heating season. Solar driven air-conditioning, while it may seem ideal in the sunny and hot Texas climate, is not currently considered economical.

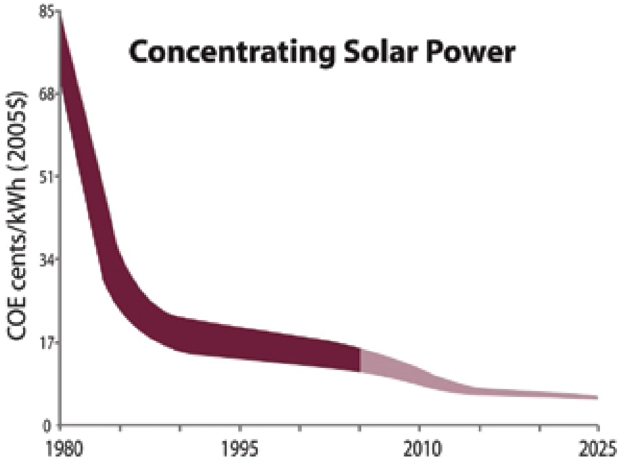
Photovoltaics

The levelized cost of energy from photovoltaics currently ranges from about 20 to 35 cents per kWh. This cost is mostly a function of the cost of solar photovoltaic modules, though as module costs decrease other factors are likely to become more prominent. Module costs were $10-20 per watt in the 1980s and fell to $5-10 per watt in the 1990s. Currently, solar photovoltaic modules retail at around $4.80 per watt in the U.S., with some thin-film products retailing as low as $3.70 per watt. Retail module prices in the U.S. were as low as $4.30 per watt in 2002-2004,[27] but increased worldwide demand for silicon stocks has driven prices higher since then.

It is expected that installed system prices will approach $4.00 per watt by 2010 from their current level of $6.00 per watt as thin film production volumes increase and new silicon refiners come on line.[28]

Photovoltaic cost projections are based on increasing penetration of thin-film technology into the building sector. Likely technology improvements include higher efficiencies, increased reliability (which can reduce module prices), improved manufacturing processes, and lower balance of system costs through technology improvements and volume sales.[29] **Exhibit 3-23** shows the historical and projected levelized costs of energy from photovoltaic power.

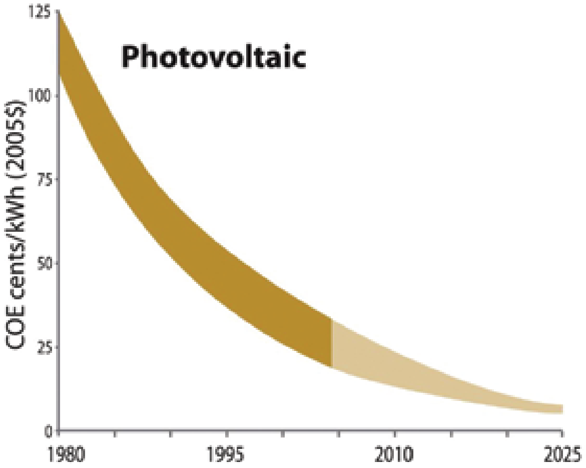
Exhibit 3-22 Levelized Cost of Concentrating Solar Power, Historical (1980-2005) and Projected (2006-2025)



Note: Projected costs for 2005-2025 are from the U.S. Department of Energy's 2005 Multi-Year Program Plan for Solar and based on parabolic rough technologies and a detailed due-diligence study completed in 2002.

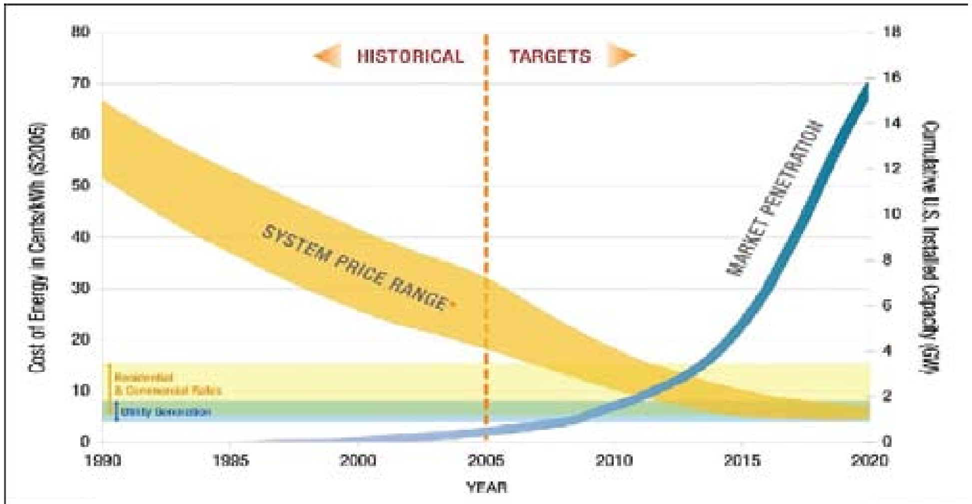
Source: Renewable Energy Cost Trends, Levelized cost of energy in constant 2005, NREL Energy Analysis Office

Exhibit 3-23 Levelized Cost of Photovoltaic Power, Historical (1980-2005) and Projected (2006-2025)



Source: Renewable Energy Cost Trends, Levelized cost of energy in constant 2005, NREL Energy Analysis Office

Exhibit 3-24 U.S. Solar Market Trajectory



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7

Source: Solar Energy Industry Forecast: Perspectives on U.S. Solar Market Trajectory, U.S. DOE Solar Energy Technologies Program May 30, 2008

Other Solar Technologies

In passive architectural design (homes and other buildings) the use of solar energy, i.e. day-lighting, window designs, and thermal mass in buildings is very cost-effective.

U.S. Solar Market Trajectory

Because of solar's huge resource availability worldwide and the potential for cost reduction through research and development achievements and economies of scale, the U.S. Department of Energy projects that solar market penetration will increase dramatically in the next 5 to 10 years, once falling prices for solar achieve parity with the costs of conventional generation (see **Exhibit 3-24**).

Benefits

The major benefits in making use of solar energy are that the source is renewable, inexhaustible, and generally non-polluting. Additionally, solar energy tends to be synchronous with energy demands, and when deployed as distributed generation can reduce loads and congestion on utility distribution and transmission systems.

The generation of energy from sunlight generally does not contribute to noise, air, or effluent pollution, and does not result in the release of carbon dioxide into the atmosphere. Producing energy from solar offsets energy produced from other, typically fossil, resources, and therefore reduces emissions that would otherwise be produced from those resources. Of course, the manufacturing of solar equipment, like equipment for any power system, requires energy inputs and results in some effluent waste. At the other end of the equipment's lifespan, improper disposal of certain photovoltaic technology types which make use of heavy metals, such as cadmium, could result in environmental harm. Many companies utilizing such technologies are currently implementing or developing manufacturer-sponsored recycling programs and improved reprocessing techniques which could greatly ameliorate these concerns.[30]

Another benefit of solar energy is that it tends to be synchronous with energy demands, particularly in Texas. In most areas of the state, demand is at its maximum in the summer due to air conditioning when the solar resource is greatest. Furthermore, peak demand for electricity typically occurs in the later afternoon when available solar energy is still high. Some applications, such as water heating, are particularly well matched to solar energy and have a positive effect on a utility's load factor. Water heating systems typically have their own storage vessel and one of their characteristics is that late in the day in the hottest summer months, when the utility experiences its highest demand, solar water heaters are fully charged during the day and require little if no energy during the late-afternoon peak demand period.

A final benefit of solar is that it can be utilized as a distributed energy source, either electrical or thermal. By producing energy at the point of consumption, distributed generation reduces the need for the transmission and distribution infrastructure and make for a more robust system, with less susceptibility to central systems failures.

Incentives and Subsidies

The solar energy industry, and in particular the photovoltaics industry, has grown in direct response to federal, state and local tax policies and subsidies. At the federal level, an important subsidy is a 30 percent federal tax credit (ITC) for solar energy equipment. (A tax credit is a dollar for-dollar reduction of an individual's or business' tax liability.) The tax credit applied to business investments in equipment that uses solar energy to generate electricity, or in solar heating or cooling systems. Homeowners could qualify for an income tax credit up to a maximum of $2,000. The credit originally was set to expire at the end of 2007, but Congress extended it for another year, through December 31, 2008. Then, in October 2008, Congress extended the credit for an additional 8 years and eliminated the $2,000 cap for residential systems.

Industry analysts agree that the federal income tax credit for solar energy has expanded markets for solar products, but note that the limited time period for the credit has created uncertainty in solar industry markets.[31] The longer-term extension in 2008 should help provide a more stable environment for solar project development.

State and local initiatives — tax policies, rebate programs, standardized interconnection and net metering rules and renewable portfolio standards — also have encouraged the solar industry's growth in some locations. In Texas, the state provides businesses with both a franchise tax deduction and a franchise tax exemption for solar energy devices. In addition, Texas has a property tax exemption for the appraised value of a solar or wind-powered energy device for on-site energy production and distribution. Thus far, however, these state policies have not resulted in significant growth in Texas' solar market.

Texas' Renewable Portfolio Standard, or RPS, has promoted the growth of renewable energy in Texas, but while it has created a market for wind, it has not proven to be an effective driver for the solar market, where higher costs (relative to wind and biomass) outweigh the higher revenues afforded by the ability to create and sell renewable energy credits (RECs).[32] A 2007 study of the PV industry conducted by the University of Texas' IC^2 Institute concluded that "additional incentives are needed to spur non-wind renewables" in the state.[33]

To encourage diversity of renewable resources in the State, in 2005 the Texas Legislature established a target of 500 MW of non-wind renewable generation while increasing the state's original RPS goal from 2,000 to 5,000 MW.[34] In 2007, the Legislature authorized the Public Utility Commission to establish a separate alternative compliance payment for meeting the 500 MW non-wind goal,[35] but the voluntary implementation mechanism established has not yet created sufficient additional value to significantly increase non-wind renewable generating capacity. Since 2005, just 9 MW of non-wind renewable generating capacity, in the form of a single landfill gas plant,[36] along with several MW of customer-sited solar generation spurred by municipal subsidy programs, has been completed. In August 2007 the PUC reopened a project concerning the 500 MW implementation mechanism to determine whether additional measures should be taken to advance the state toward the 500 MW non-wind goal.[37]

Interconnection policies and practices are also inconsistent throughout the state.[38] Texas has standardized interconnection policies and procedures developed by the Texas Public Utility Commission that apply to investor-owned utilities, but not to electric cooperatives or municipal utilities.[39] These procedures, moreover, are silent on some issues critical to distributed generators, such as definitions of what types of equipment (such as solar panels, wind turbines and inverters, which convert solar-generated electricity into household current) are eligible for interconnection. Texas' net metering policies and practices are similarly inconsistent and depend upon the particular retail electric provider, municipal utility or rural electric cooperative to which the distributed generator is interconnected.

Throughout the U.S. and within Texas, state- or utility-sponsored solar rebate or subsidy programs have been the primary driver stimulating demand for solar energy. In Texas, these programs are exclusively offered by municipal utilities on a voluntary basis. Austin Energy currently offers solar rebates ranging up to $4.50 per watt. The cost of installing a 1 kW (1,000 watt) solar system in Austin, for instance, ranges from $6,000 to $10,000, and the Austin Energy rebate pays up to $4,500 toward its purchase and installation.[40] San Antonio's CPS Energy, also a municipal utility, offers rebates of $3 per watt for PV panels and installation, capped at $10,000 for residential customers and $50,000 for commercial and industrial customers.[41] Bryan Texas Utilities offers a rebate of $4.00 per watt.[42]

Key Issues

Texas' solar resource is vast, accessible, and generally synchronous with energy demand. While the resource level improves from east to west across the state, it is not highly localized like other renewable energy resources. This means solar is useful in central solar power stations in west Texas or in distributed generation applications which reduce the need for transmission from resource-rich areas to load centers.

The main factor limiting utilization of the state's solar resource at a large scale today is its cost. However, solar costs are declining with the introduction of new technology types and improvements in manufacturing processes. As costs decline, larger projects may leverage economies of scale and become cost-effective within the next few years. In fact, two of the state's utilities have solicited proposals for central station solar power facilities within the past 18 months.[43]

Expanding the use of renewable energy in Texas can have a significant positive impact on employment. Research has shown that renewable energy generates more jobs in the construction and manufacturing sectors, per megawatt of installed power capacity, than does fossil fuel generation.[44] This conclusion is reflective of the relationship between labor and fuel costs as inputs to energy generation. An Austin Energy study[45] considered the economic development impacts of investing in 100 MW of solar energy by 2020, and found that the Austin economy would receive the benefits of 293 net new jobs, a $952 million net increase in Gross Regional Product, $283 million in increased earnings, $8.8 million in net sales tax revenue, and $0.6 million in net property tax revenue. Those new jobs require a skilled workforce which must be developed and trained over time.

Finally, expanding use of solar energy requires new thinking about the role of customer-sited generation in the electricity marketplace. The concept of customer choice must be expanded to include not just choice among utilities or retail electric providers, but also the choice to generate or offset some or all of one's own energy through solar or other on-site renewable distributed generation. Clear and consistent interconnection and net metering policies and processes statewide would further enable solar industry development and foster a cleaner, more diverse energy supply for all Texans.

Information Resources

The Internet offers instant access to a rapidly growing list of solar resource information. A few relevant online resources are described below.

1. **National Renewable Energy Laboratories (NREL).** NREL makes available a "Solar Resource Information" site (http://www.nrel.gov/rredc/solar_resource.html) that is housed within their more general Renewable Resource Data Center (RReDC) to provide online access to a range of solar resource products. Of particular utility are:

   a. The National Solar Radiation Database (NSRDB, http://rredc.nrel.gov/solar/old_data/nsrdb/) provides hourly solar radiation and meteorological data for sites throughout the United States for 1961–1990 (http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/) and 1991–2005 (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/).

   b. The Typical Meteorological Year Data Sets provide hourly values of solar radiation and meteorological elements for U.S. sites and territories for a composite 1-year period (http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/tmy2/).

   c. National 10 Km Gridded Hourly Solar Database. This site provides satellite derived solar radiation on a 10 km resolution. Go to ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar. These data are on a resolution about 9 times finer than obtained for the 89 Texas sites in the 1991-2005 NSRDB.

   d. PVWatts is a performance calculator for PV systems which estimates the electrical energy produced by grid-connected photovoltaic systems available at http://www.nrel.gov/rredc/pvwatts/.

   e. Solar Radiation Data Manual for Buildings

   f. Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors

2. **The Texas Solar Radiation Database (TSRDB).** The University of Texas hosts the Texas Solar Radiation Database online at http://www.me.utexas.edu/~solarlab/tsrdb/tsrdb.html. The TSRDB is based on solar radiation measurements taken at 15 locations in Texas (Abilene, Austin, Big Spring, Canyon, Corpus Christi, Del Rio, Edinburg, El Paso, Clear Lake, Laredo, Menard, Overton, Pecos, Presidio, and Sanderson) over a approximately a six year period. Global-horizontal, direct-normal and diffuse-horizontal data area presented. Much of these data are included in the new NSRDB.

3. **The Texas Commission on Enviornmental Quality (TCEQ).** The Texas Commission on Environmental Quality monitors air quality at numerous sites across the state, emphasizing urban and high concentration agricultural areas. At selected locations global solar radiation is measured with a single horizontal photosensor. The data is accessible at http://www.tceq.state.tx.us/cgi-bin/compliance/monops/site_info.pl.

4. **The Texas Coastal Ocean Observation Network (TCOON).** The Texas Coastal Ocean Observation Network records weather and water data along the Texas Gulf Coast and at some of these locations simple solar radiation measurements are made. Go to http://www.lighthouse.tamucc.edu/TCOON/homepage to access the TCOON data.

5. **The Texas Mesonet.** The Texas Mesonet is a network of meteorological monitoring stations, broadly dispersed across the State, and reporting to a common point for display of the meteorological data in near-real-time at http://mesonet.tamu.edu/ . The goal of this site is to provide data for the emergency planners and managers, the public utilities, forecasters, the academic community, and others.

References

[1] National Renewable Energy Laboratories, “NREL Solar Cell Sets World Efficiency Record at 40.8 Percent,” NREL Newsroom, August 13, 2008, http://www.nrel.gov/news/press/2008/625.html (accessed 9/10/2008).

[2] Perez, R.; Moore, K.; Wilcox, S.; Renne, D.; Zelenka, A. (2007). Forecasting Solar Radiation—Preliminary Evaluation of an Approach Based upon the National Forecast Database. Solar Energy. Vol. 81(6), 2007; pp. 809-812; NREL Report No. JA-581-41774.

[3] Perez, R.; Moore, K.; Wilcox, S.; Renne, D.; Zelenka, A. (2007). Forecasting Solar Radiation—Preliminary Evaluation of an Approach Based upon the National Forecast Database. Solar Energy. Vol. 81(6), 2007; pp. 809-812; NREL Report No. JA-581-41774.

[4] Interview with Mark Kapner, Austin Energy, July 31, 2008.

[5] Vick, B., and Clark, N., Large Scale Deployment of Renewable Energy by Combining Wind Farms with Solar Thermal Power Plants, Proceedings of the SOLAR 2006 Conference, American Solar Energy Society, 2006.

[6] 2008 Texas State Energy Plan, Governor’s Competitiveness Council, July 2008, pg. 28.

[7] Virtus Energy Research Associates, Texas Renewable Energy Resource Assessment, Survey, Overview and Recommendations, July 1995.

[8] State Energy Conservation Office, “Texas Solar Energy,” http://www.seco.cpa.state.tx.us/re_solar. htm. (Last visited April 21, 2008).

[9] George, R.; Wilcox, S.; Anderberg, M.; Perez, R. (2007). National Solar Radiation Database (NSRDB)—10 Km Gridded Hourly Solar Database. Campbell-Howe, R., ed. Proceedings of the Solar 2007 Conference, 8-12 July 2007, Cleveland, Ohio (CD-ROM). Including Proceedings of 36th ASES Annual Conference, Proceedings of 32st National Passive Solar Conference, and Proceedings of the 2nd Renewable Energy Policy and Marketing Conference. Boulder, CO: American Solar Energy Society (ASES) 8 pp.; NREL Report No. CP-581-41599.

[10] Perez, R.; Moore, K.; Wilcox, S.; Renne, D.; Zelenka, A. (2007). Forecasting Solar Radiation—Preliminary Evaluation of an Approach Based upon the National Forecast Database. Solar Energy. Vol. 81(6), 2007; pp. 809-812; NREL Report No. JA-581-41774.

[11] National Solar Radiation Data Base (1961-1990) User’s Manual. National Renewable Energy Laboratory, Golden, CO: U.S. Department of Energy, 1992.

[12] Wilcox, S., National Solar Radiation Database 1991-2005 Update: Users Manual, Technical Report, NREL/TP-581-41364, April, 2007.

[13] Vliet, G.C. (2004). Texas Solar Radiation DataBase (TSRDB), ASME, Jr. Solar Energy Engineering, v. 126, n. 1, p. 575, Feb. 2004.

[14] See http://www.me.utexas.edu/~solarlab/tsrdb/tsrdb.html.

[15] The Texas Commission on Environmental Quality monitors air quality at numerous sites across the state, emphasizing urban and high concentration agricultural areas. At selected locations global solar radiation is measured with a single horizontal photosensor. See http://www.tceq.state.tx.us/cgi-bin/compliance/monops/site_info.pl.

[16] The Texas Coastal Ocean Observation Network records weather and water data along the Texas Gulf Coast and at some of these locations simple solar radiation measurements are made. See http://www.lighthouse.tamucc.edu/TCOON/homepage.

[17] The Texas Mesonet is a network of meteorological monitoring stations, broadly dispersed across the State, and reporting to a common point for display of the meteorological data in near-real-time. The goal of this site is to provide data for the emergency planners and managers, the public utilities, forecasters, the academic community, and others. See http://mesonet.tamu.edu/.

[18] See http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

[19] Hourly data is from August 10 through August 15, 2005 and derived from the 1991-2005 NSRDB. Note that El Paso data has been adjusted from its local Mountain time zone to coincide temporally with the Central time zone.

[20] Acciona Energy website, http://www.acciona-energia.es/default.asp?x=0002020401&lang=En, accessed 8/18/2008.

[21] Green, Martin A (April 2002), "Third generation photovoltaics: solar cells for 2020 and beyond", Physica E: Low-dimensional Systems and Nanostructures 14(1-2): 65–70.

[22] U.S. Department of Energy, Energy Information Administration, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, released August 5, 2008, http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html (accessed 8/19/2008).

[23] Public Utility Commission of Texas, Competitive Markets Division, Retail Electric Service Rate Comparisons, July 2008 Bill Comparison, http://www.puc.state.tx.us/electric/rates/RESrate/rate08/Mar08Rates.pdf (accessed 8/19/2008). Average rates are shown for customers using 1,000 kWh per month.

[24] 2006 State of the Market Report for the ERCOT Wholesale Electricity Markets, Potomac Economics, ERCOT Independent Market Monitor, August 2007, http://www.puc.state.tx.us/wmo/documents/annual_reports/2006annualreport.pdf (accessed 8/19/2008).

[25] "SHOCKED: Unprecedented energy prices jolt Rio Grande Valley business owners," The Monitor, August 2, 2008, http://www.themonitor.com/articles/electricity_15466_article.html/texas_prices.html (accessed 8/19/2008).

[26] Renewable Energy Cost Trends, Levelized cost of energy in constant 2005$, NREL Energy Analysis Office.

[27] Solar Module Retail Price Index, 125 Watts and Higher, and Price Survey, August 2008, Solarbuzz, http://www.solarbuzz.com/ (accessed 8/19/2008).

[28] Projection of PV System Prices: Australia, Europe, Japan, USA 2004-2030; The European PV Technology Platform, PV Platform Working Group 2, SubGroup 2, Objective 1; http://www.eupvplatform.org/fileadmin/Documents/WG2_061124_Rudek_03_PVSystemsPrice.pdf (accessed 8/21/2008).

[29] Renewable Energy Cost Trends, Levelized cost of energy in constant 2005$, NREL Energy Analysis Office.

[30] See, for example, First Solar (http://www.firstsolar.com/recycling.php), SolarWorld USA (http://www.earthtoys.com/news.php?section=view&id=1897), both accessed 9/9/2008.

[31] Solar Energy Industries Association, SEIA Guide to Federal Tax Incentives for Solar Energy (Washington, D. C., May 26, 2006), Letter, http://www.seia.org/SEIAManualversion1point2.pdf. (Last visited April 21, 2008.)

[32] Electricity Reliability Council of Texas, "Existing/REC New Capacity Report," http://www.texasrenewables.com/publicReports/rpt5.asp. (Last visited April 21, 2008.)

[33] Opportunity on the Horizon: Photovoltaics in Texas. By Bruce Kellison, Eliza Evans, Katharine Houlihan, Michael Hoffman, Michael Kuhn, Joel Ser face, Tuan Pham. University of Texas, IC2 Institute, June 2007.

[34] Senate Bill 20, Relating to this state's goal for renewable energy. Legislative session 79(1), 2005, http://www.capitol.state.tx.us/tlodocs/791/billtext/html/SB00020F.HTM (accessed 8/26/2008).

[35] Texas Legislature, H.B. No. 1090,

[36] Public Utility Commission of Texas, New Electric Generating Plants in Texas Since 1995, http://www.puc.state.tx.us/electric/maps/gentable.pdf (accessed 8/21/2008).

[37] Public Utility Commission of Texas, Project No. 35792, Rulemaking Relating to Goal for Renewable Energy.

[38] The Energy Report 2008, Texas Comptroller of Public Accounts, http://www.window.state.tx.us/specialrpt/energy/ (accessed 8/26/2008).

[39] The Texas Million Solar Roofs Partnership, and CSGServices, Interconnection and Net Metering of Small Renewable Generators in Texas: Final Report of the Texas RE-Connect Project (Austin, Texas, June 2005), p. A-6, http://files.harc.edu/Sites/GulfcoastCHP/Publications/InterconnectionGeneratorsTexas.pdf. (Last visited April 21, 2008.) and Texas Public Utility Commission, Distributed Generation Interconnection Manual, by Distributed Utilities Associates and Endecon Engineering (Livermore, California, May 1, 2002), http://www.puc.state.tx.us/electric/business/dg/dgmanual.pdf. (Last visited April 21, 2008.)

[40] Austin Energy, "Solar Rebate Program," http://www.austinenergy.com/Energy%20Efficiency/Programs/Rebates/Solar%20Rebates/index.htm. (Last visited April 21, 2008.)

[41] CPS Energy, "CPS Energy to Commit $96 Million to New Energy Source," San Antonio, Texas, June 25, 2007, http://www.cpsenergy.com/files/press_room/EEStrategicPlanNR6_25_07.pdf. (Last visited April 21, 2008.)

[42] Bryan Texas Utilities, "BTU's Green Plus Solar Photovoltaics," http://www.btutilities.com/New_Ventures/Rebates/Solar/Default.aspx (accessed 9/9/2008).

[43] "CPS Energy Seeking Bids from Solar Energy Developers," San Antonio Business Journal, August 13, 2008. And Interview with Mark Kapner, senior strategy engineer, Strategic Planning & Enterprise Development, Austin Energy, Austin, Texas, November 1, 2007.

[44] Daniel M. Kammen, Kamal Kapadia, and Matthias Fripp (2004) Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate? RAEL Report, University of California, Berkeley.

[45] City of Austin, Austin Energy, Tool for Analysis of Economic Development Benefits For Solar Manufacturing & Installation, Final Report, May 11, 2006, Principal Investigator Christy Herig, Segue Energy Consulting, LLC.