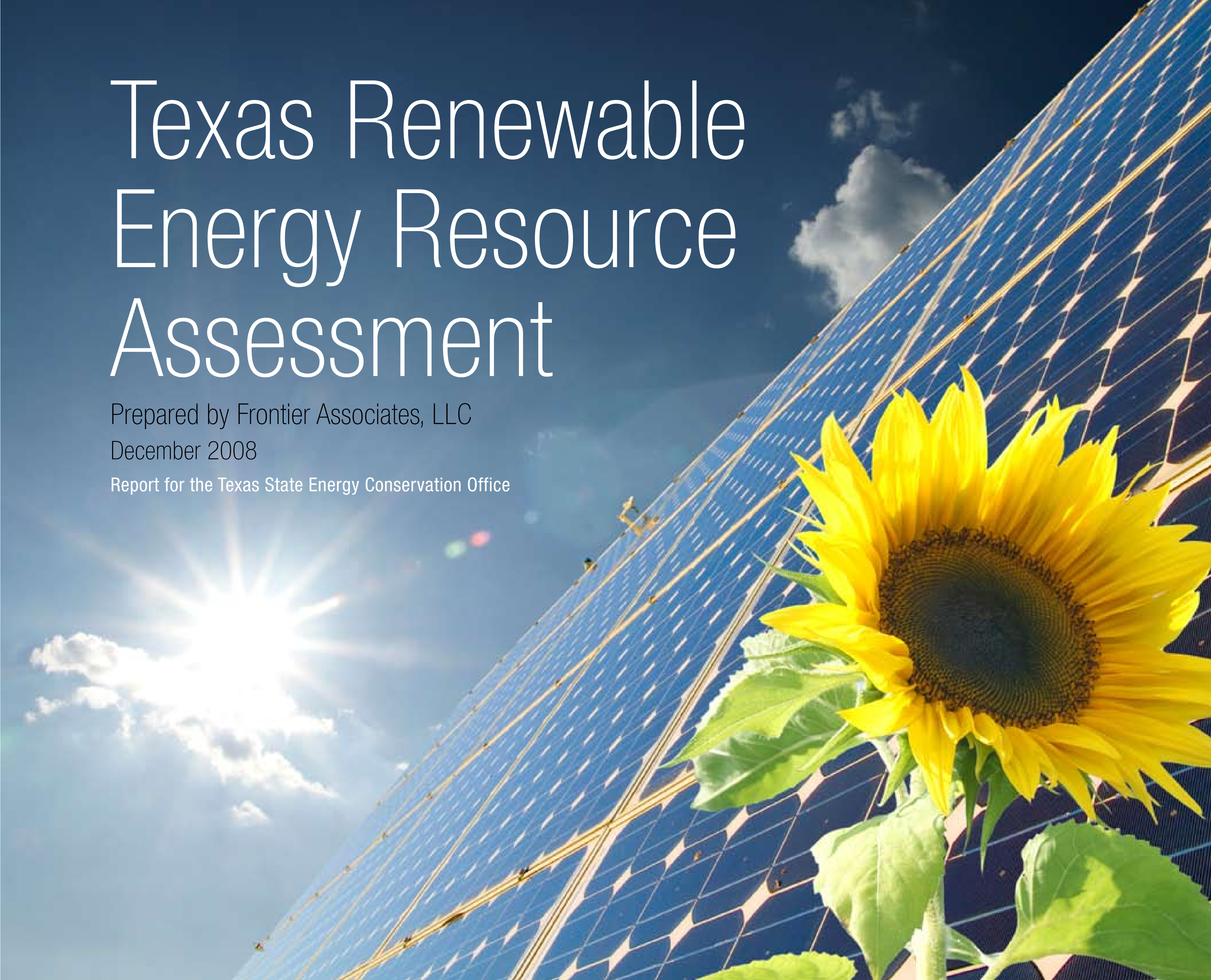
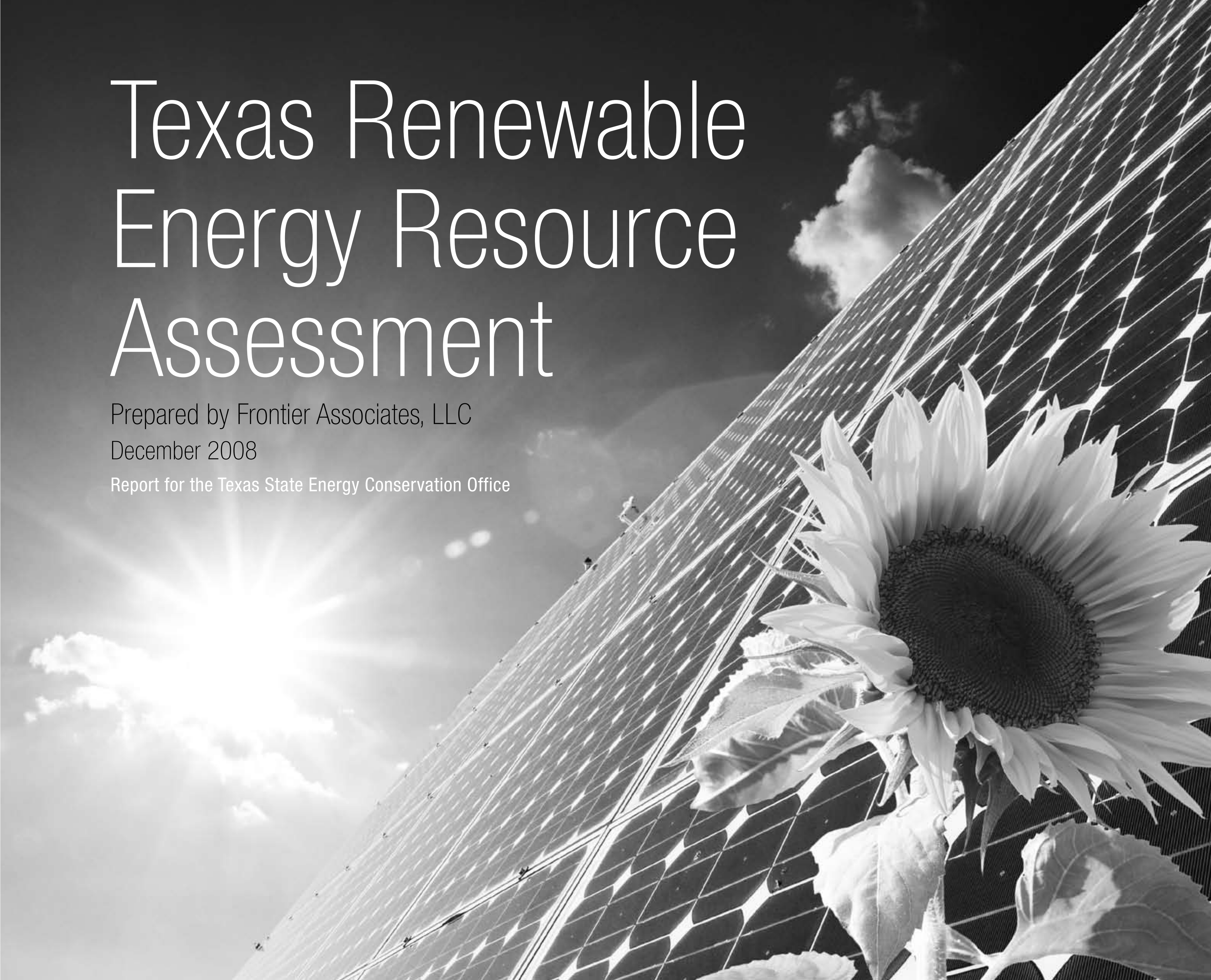
Texas Renewable Energy Resource Assessment

Prepared by Frontier Associates, LLC

December 2008

Report for the Texas State Energy Conservation Office





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ACKNOWLEDGEMENTS

The Texas Renewable Energy Resource Assessment was first produced by the Sustainable Energy Development Council in 1995. House Bill 1, Article 1, Comptroller Fiscal Programs, Rider 15, 80th Legislature, 2007, directed the State Energy Conservation Office to update the report.

SECO through the Innovative Energy Demonstration Program promotes the use of renewable energy and sustainable building practices through technology demonstration, hands-on instruction and renewable energy education.

Renewable energy can have significant economic development, security and reliability benefits and opportunities for Texas communities and individuals in the development of these resources.

Special thanks is giving to the Comptroller's State Energy Conservation Office and Research staff for their knowledge and expertise.

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EXECUTIVE SUMMARY

Overview

Texas leads the nation in non-hydropower renewable energy potential, being rich in wind, solar, biomass and geothermal resources. Wind resource areas in the Texas Panhandle, along the Gulf Coast, and in the mountain passes and ridge tops of the Trans-Pecos offer Texas some of the greatest wind power potential in the United States. Texas, in fact, leads the nation in wind-powered generation capacity, having surpassed California as the country's largest wind energy producer in 2006. Solar power potential is also among the highest in the country, with high levels of solar radiation suitable for distributed generation applications throughout the state, and direct sunshine capable of fueling large-scale solar power plants concentrated in west Texas. Due to its large agricultural and forestry sectors, Texas has an abundance of biomass energy resources. Texas' unused oil and gas wells provide access to a major geothermal resource. These renewable energy resources are available throughout the state and can be utilized in a variety of ways, from producing electricity through small, distributed systems or at large-scale central power plants, to providing liquid fuels for transportation.

Due to its large population and energy-intensive economy, Texas leads the nation in energy consumption, at 11.556 quadrillion Btu (2005),[1] up from about 10 quads in 1995, accounting for 11.5 percent of total U.S. energy use. Texas' per capita energy consumption ranks fifth in the U.S. at 506 MMBtu per year (2005).[2] Texas residential electricity consumption is significantly higher than the national average, due to high demand for air conditioning and the widespread use of electricity for home heating. Energy-intensive industries in Texas include aluminum, steel, chemicals, forest products, glass, and petroleum refining.

What has changed since the last report?

Texas' population and energy consumption is growing. Since the previous Renewable Energy Resource Assessment was written in 1995:

- The population of Texas has increased by approximately 28 percent, from 18.7 million to 24 million.
- ERCOT peak demand has increased by 33.6 percent, from 46,668 MW[3] to 62,339 MW.[4]
- Retail sales of electricity in Texas have increased by 30.2 percent, from 263,278,592 MWh to 342,724,213 MWh in 2006.[5]
- Texas retail electricity cost has increased by 221.8 percent, from $16.0 billion in 1995 to $35.5 billion in 2006.[6]
- The average retail price of electricity in Texas has increased by 70 percent, from $0.061 per kWh in 1995 to $0.104 per kWh in 2006.

As a result of our growing demand for energy and the increased cost of providing energy through fossil fuels, renewable energy has become an increasingly important source of energy. Over the last decade, the cost of renewables has been declining, while fossil fuel energy prices have been generally increasing. The U.S. Natural Gas Electric Power Price increased from $2.78 per MCF in 1997 to $7.31 in 2007.[7] For comparison, the cost of solar photovoltaics has decreased from an estimated cost of $0.40 per kWh in 1995 to $0.25/kWh in 2005, and is projected to continue to decrease, to approximately $0.10/kWh in 2015 and $0.05/kWh in 2025.[8]

Over this same time period, wind power, in particular, has grown dramatically. Worldwide wind generating capacity has increased by 1,439 percent, from less than 6,100 MW in 1996 to 93,864 MW in 2007.[9] U.S. wind power has increased by 1,152 percent, from less than 1,612 MW in 1995[10] to 20,152 MW in 2008.[11] Texas wind power has increased by almost 5,000 percent, from 116 MW in 1999 to 5,871 MW in 2008.[12]

Resource Quantification

In theory, Texas has the potential to satisfy all of its demand for energy with renewable energy resources. In fact, wind, solar, and geothermal energy each have the potential to provide more energy than Texas currently consumes. **Exhibit 1** provides estimates of the state's potential renewable energy resource base. The total physical resource is the amount available within the whole state per year, while the accessible resource is the amount that can feasibly be extracted each year with current technologies. The energy density for a good Texas site has been shown in Megajoules (MJ) per square meter per year.

Since the 1995 Renewable Energy Resource Assessment, there have been significant changes in the methods used to determine each quantity. For this reason many of the values have increased or decreased and in some cases changed by several orders of magnitude.

High-quality data for estimating the total solar resource for the state of Texas have been available since the 1970s. Updated data is now available from both ground stations and satellite observations. These enable greater precision in quantifying the state's solar resource at any given location, but do not significantly change the overall findings presented in the 1995 resource assessment. The energy density for a good Texas site was determined using monthly solar irradiation data from El Paso due to its ideal location. The data yielded approximately 8,000 Megajoules of energy per square meter over the span of a year, which gives it the highest energy density of any Texas site.

Estimates of the state's maximum wind resource capacity is based on 1 MW wind turbines spread out in alternating rows throughout Texas, with 7 diameter spacing for the first row and 9 diameter spacing for the second row. In practice, the spacing of wind turbines is often closer and the calculation would, therefore, yield an even larger wind resource. The accessible wind resource estimate is based on Wind Class 3 (14.3 to 15.7 mph at a height of 50 meters) and above, excluding urban land, highways, parks, wetlands, wildlife refuges, rivers and lakes, and slopes greater than 10 degrees. The main differences from the 1995 estimate are that in the previous report, the land considered useable had to be within a ten mile radius of transmission lines, spacing was 10 diameters apart and offshore wind generation was not taken into account. Based on current wind generation data, a good site produces 15 MW/km2, which equates to 500 MJ/m2 per year.

Exhibit 1 Estimates of the potential renewable energy resource base for Texas

RESOURCE	TOTAL PHYSICAL RESOURCE (quads/yr)	ACCESIBLE RESOURCE (quads/yr)	ENERGY DENSITY: GOOD TEXAS SITE (MJ/m^2/yr)	PRIMARY ENERGY USES				NON-ENERGY USES
				ELEC.	HEAT	MECH.	TRANS.	
SOLAR	4,300	250	8,000	X	X			
WIND	22	7	500	X		X		
BIOMASS	9	1	500	X	X		X	Food, feed, and fiber
WATER (as electricity)	0.10	0.02	10	X	X	X		Water supply; flood control
GEOTHERMAL	400,000	81,000	600	X	X			

Biomass is an important part of Texas' total renewable energy resource potential, consisting of energy from several different sources. The total physical biomass resource is made up of a combination of agricultural, forest, urban, animal waste, and algae production sources. Of these diverse sources, standing biomass, animal waste and algae production make up the majority of the total energy resource. Once algae production becomes financially viable, one acre of algae production is expected to produce about 15,000 gallons of biodiesel per year. Biomass is comparable to the other renewable resources because of the tremendous opportunity it provides for producing so much fuel on such a small amount of land. As a result, the production of biodiesel could considerably reduce the state's and the nation's dependence on oil.

Water has been harnessed to produce electricity for many years, but compared to other renewable resources it has the smallest future potential for additional development. Hydropower is currently the biggest contributor to the total water-to-energy resource base, but salinity-gradient solar ponds and pressure retarded electrodialysis may become considerable resources in the future. Estimates of Texas' hydropower resource were taken from federal studies, which found the total water resource for electricity production to be approximately 0.1 Quads per year, although only 20 percent of that is accessible. When looking at a site in Texas with good energy density, the total annual energy output can be found with respect to the area utilized. The number from the 1995 assessment, 10 MJ/m^2 per year, is still an accurate indication of a good Texas site for electrical production from water.

Geothermal energy potential is determined from four main sources: hydrothermal, geopressured, enhanced geothermal systems (EGS), and coproduced, of which EGS and geopressured make up about 98 percent of the total physical resource. The accessible resource is based on a percentage of the total, where the technology, geologic setting, and current economic threshold determine the percentage, which is 100 percent for hydrothermal, 70 percent for geopressured, 13 percent for EGS, and 25 percent for coproduced. The recently updated values for total and accessible resources are several orders of magnitude higher than the 1995 values because the new values were derived using different methods to approximate the energy potential from the four main geothermal sources.

While the state's recent efforts to promote energy efficiency through building construction energy codes and utility programs have proven quite successful, many opportunities to reduce energy use through cost-effective efficiency measures remain. Energy efficiency can be viewed as an energy resource, since the need for supply-side energy resources can be displaced by the adoption of more efficient equipment at homes and businesses or through changes in energy consumption patterns or practices. Avoiding the consumption of energy through energy efficiency measures provides a clean energy resource that is immediately available. There is abundant energy savings potential available at a low cost through energy efficiency measures in all economic sectors in Texas. Further energy efficiency can be realized through public education efforts, commitments to sustainable development and climate change mitigation by businesses and other organizations, more stringent building codes, accelerated research and deployment of new technologies, utility demand-side management programs, and equipment efficiency standards.

Resource-Specific Issues and Opportunities

Texas has the best renewable energy resource in the nation. From the sunny deserts in the west to the windy regions in the north, the state's geographical diversity provides an immense renewable energy resource. While many of Texas' renewable energy resources offer significant potential for further development, each provides specific opportunities and creates unique challenges. In evaluating the potential of these varied resources, it is important to consider the individual resources together, rather than separately, as they offer promising synergies for complementing each other, for example, through providing energy at different times. Renewable energy resources can also complement traditional energy resources, for example, through reducing or eliminating additions to the electrical transmission and distribution network.

Solar

Solar energy is a vast resource in Texas and is generally synchronized with daily and seasonal energy demand. Solar has the potential for large scale (central) production and for smaller scale (distributed) production and the latter has major advantages to our infrastructure. The most promising large scale solar technologies utilize solar thermal concentrators and thin-film photovoltaics (PV), while the most promising small scale, distributed technologies are passive applications, solar hot water, and photovoltaics (PV).

Solar energy is a vast resource for Texas, capable of supplying many times the state's total energy needs. It is environmentally benign and closely matches Texas' daily and seasonal energy demands, as noted above. Many solar electric applications are already cost-effective while the costs of others continue to decrease.

Several barriers to widespread utilization of solar energy exist: 1) solar energy requires relatively large amounts of collection area; 2) costs of large-scale solar generation are still relatively high; and 3) the intermittent nature of solar energy poses a challenge for integrating large-scale solar into the existing energy infrastructure.

Considerations for the large-scale utilization of solar energy include land use, water use, the availability of adequate electricity transmission, and the availability of feasible back-up power sources and/or storage technologies. The use of small-scale solar facilities can mitigate or eliminate these concerns but utility interconnection and net metering policies will greatly influence the degree to which these systems are installed.

Texas' best solar resource is located a considerable distance from large urban areas where energy demand is the highest, but the solar resource is adequate throughout the state for most distributed applications. Like wind resources, large-scale solar generation located in far west Texas requires an adequate electricity transmission system and imposes unique challenges on the grid. However, 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 more efficient utilization of transmission capacity and improved matching of generation to utility loading, including peak loading conditions.

Variations in solar energy tend to coincide with much of the demand for energy in Texas, with summer days representing the state's highest energy demand as well as the greatest abundance of solar energy.

Several different solar energy technologies have been developed to generate electricity at large-scale central power stations. Parabolic trough concentrators, that reflect solar radiation onto a fluid-carrying tube, have been the most common application, including the world's largest solar power plant in California's Mojave Desert, which has electrical generation capacity of 354 megawatts (MW).

Distributed solar applications are becoming increasingly common, and include solar electric (PV) systems, solar thermal water heaters, and passive solar design incorporated into buildings. Residential PV systems ranging from one to five kW and commercial/institutional PV systems of several thousand kW or more are becoming more prevalent as utilities offer their customers incentives for installation. PV systems are interconnected to the utility grid, enabling customers to meet all or a portion of their energy needs through self-generation and to export excess power to the utility distribution system for use by others. The use of stand-alone PV systems installed where it is expensive or impractical to extend a utility distribution line, passive solar applications and solar thermal water heating systems, largely reduces or eliminates many of the infrastructure challenges associated with large central power systems, including land use, water use and transmission adequacy. More than 1.7 MW of grid-connected PV has been installed in Texas.[13]

The current cost effectiveness of solar technologies varies widely. Passive solar architectural designs are very cost-effective. The cost of electricity from central solar power stations ranges from 12 to 18 cents per kWh. The cost of energy from photovoltaics has dropped dramatically during the last two decades and currently ranges from 20 to 35 cents per kWh. Based on current electricity rates, electricity from solar PV has a payback of 30 to 40 years. However, the cost of PV continues to decline, while conventional energy costs continue to rise, making electricity from PV increasingly attractive economically. The cost of installed PV systems is expected to decrease dramatically in the near future as production volumes increase and new producers come on line.

The solar energy industry, and in particular the photovoltaics industry, has grown in direct response to federal, state and local tax policies and subsidies. An obstacle to expanding the solar energy industry in Texas is the lack of a qualified workforce for installation and maintenance and the lack of equipment certification. Expanding the use of solar energy in Texas can have a significant positive impact on employment.

Wind

Wind is abundant and can be developed rapidly at competitive prices. However, wind power must have more transmission capacity to continue growing in windy areas of the state but wind generation can be constructed much more quickly than major expansions of the transmission system. Wind can deliver significant benefits (rural economic development, improved air quality, no water to generate electricity) but has challenges (large penetration into utility system, need for increased transmission, aesthetic/siting concerns).

Texas has the largest wind energy potential of any state in the country. Capturable wind power is estimated at 223,000 MW, which is several times the total electrical demand of the state. Texas is number one in the nation in installed wind capacity (estimated at 57 wind farms with 5,877 turbines providing 8,786 MW total capacity by the end of 2008), having surpassed California in 2006. Thirty-three percent of the new wind capacity in the U.S. in 2007 was installed in Texas and 2008 will be a record year, with an estimated 4,300 MW of additional wind capacity being installed in Texas. Texas' Renewable Portfolio Standard, approved by the state Legislature in 2005, set a goal of 5,000 MW of capacity from renewable energy by 2015, which was exceeded in 2008.

The major challenge to wind power in Texas is that most of the windy areas of the state are not close to the major urban load centers, so the transmission system needs to be upgraded and expanded in order to utilize the resource. Five Competitive Renewable Energy Zones (CREZ) have been designated by the Texas PUC for future wind development. The Commission ultimately chose a mid-level transmission expansion scenario which would accommodate 18,456 MW of wind-generated capacity in ERCOT.

ERCOT and the Texas PUC have been doing extensive research on the issues and operational risks associated with large-scale integration of wind power into the ERCOT transmission network. Variations in wind generation become more significant for system operation as the penetration of wind increases and wind forecasting will be increasingly important.

With federal production tax credits, wind is competitive with other new electric generation plants. Wind may become competitive without production tax credits if carbon regulation is implemented in the future and/or the "external costs" of fossil fuels are reflected in their price.

The development of wind energy provides important and diverse economic benefits to Texas. Wind farms provide important rural economic development, with both job creation and long-term stable royalty income to landowners. Texas could also benefit from expanding employment through increasing the manufacturing and assembly of wind turbines in the state. Wind energy can also provide significant sources of revenue for the State, including school taxes and royalty income for the General Land Office resulting from the installation of offshore wind farms.

Biomass

Texas has the potential to produce a significant amount of biomass for conversion to energy without conflicting with food or feed production. For example, biomass could provide approximately 15 percent of Texas' liquid fuel needs. Dedicated energy crops such as energy cane, grasses, and sorghums could support the operation of up to 15 cellulosic conversion plants within ten years. Residues such as crop residues, wood wastes, and municipal solid waste can also provide a large amount of biomass for energy production.

Texas has significant potential for diverse biomass production and bioenergy. Forest resources, municipal solid waste; construction residue; dedicated energy crops; crop residue; oilseed crops; grain; and algae are important potential sources of energy. This biomass can be converted into Generation II biofuels ranging from ethanol to green gasoline and diesel. However, Texas would require significant increases in grain production and/or importation to experience increased grain-based ethanol production.

Over 19 million tons of biomass could be used for biofuels production in Texas each year. Some of this might be used for thermal conversion for process heat or electricity production but it would be difficult for a power producer to compete with ethanol production for the feedstock. Feedlot biomass, forest/wood byproducts, poultry litter, cotton gin trash, and sugar cane bagasse are examples of biomass that are more appropriate for the thermal route.

Biomass represents a significant energy resource in East Texas and is primarily an unutilized resource. The demand for lower value woody biomass is currently low. House Bill 1090, *Agricultural Biomass and Landfill Diversion Incentive Program,* was passed in 2007 to encourage the construction of facilities that generate electrical energy using logging residue and urban woody biomass. Utilizing these resources for an array of bioenergy and bio-based products has several advantages including: year-round supply; complementary with existing sustainable forest management practices; and low energy and water input.

Municipal Solid Waste is an excellent source of biomass for energy recovery. In 2006, total waste disposal in Texas amounted to 30.45 million tons, an energy resource of approximately 365 trillion BTUs per year, or the equivalent of 6.3 million barrels of oil.

Algae have great potential as a feedstock for biofuels and bioproducts because they can regenerate in 5 to 72 hours. The potential for algae biodiesel production would be close to ten times the potential of palm oil and 100 times that of soy oil, the two most commonly used feedstocks for biodiesel production today.

Challenges for researchers, producers, equipment manufacturers, and end-users will be to develop production systems that are sustainable and efficient. A critical element in the success of biofuels production will be the linkage between biomass feedstock development, production, harvesting, transporting, storing, and processing into biofuels/bioproducts and/or energy. A key issue in the development of biorefineries will be the ability to continuously deliver biomass to the facility, which is significantly different than other agricultural commodities that tend to be seasonal in nature.

Water is potentially one of the more limiting inputs of biomass energy production. Other infrastructure considerations for biomass include: availability of land for dedicated energy crops; and production, harvest, storage and transport systems. The preferred areas will be those areas, such as those along the Gulf Coast, that have adequate rainfall, high quality available land, a long growing season, ability to provide just-in-time delivery, and strong producer networks.

Biofuel production can be an important force in the economy. The establishment of bioenergy production capability in Texas would have significant positive economic and energy implications. The utilization of biomass can provide rural development opportunities due to the numerous small facilities that would be required.

Energy from Water

Texas has limited potential for generating significant amounts of additional power and energy from water resources. Most good hydropower generation sites in Texas have already been developed. There are numerous sites for new hydroelectric sites, some with a potential of greater than 10 MW, but the hurdles related to siting and low generation potential will prevent most of them from development. Saline gradient solar ponds could prove to be a beneficial energy resource for the western region of Texas if there is a need for low grade hot water to assist in desalination or aquaculture temperature regulation.

Texas currently has 675 MW of conventional hydroelectric power, less than one percent of the state's total electric generating capacity. A 2006 assessment by the U.S. Department of Energy estimated that Texas had 18,000,000 MWh/yr of potential new hydropower generation although only 2,900,000 MWh/yr of this electricity is actually considered feasible. Much of this additional hydropower may never be developed due to economic and environmental constraints. Texas' existing hydropower plants could act as "pumped storage" facilities using inexpensive off-peak electricity to pump water behind the dam, then used later to generate power during high cost peak demand periods. This small, but possibly valuable, peaking resource capacity could complement intermittent wind power output

The total cost of hydropower production is low because there is no fuel cost. The average production cost in the US is less than 0.9 cents per kWh. Hydropower does not directly produce air pollution although it can result in other environmental impacts. Hydropower development may face regulatory impediments, including environmental protection, economic regulation of water and electricity, safety, and land use.

Texas has very limited potential to extract energy or electricity from ocean waves, ocean thermal gradients, currents, and tides. Wave energy systems require relatively large installations along the shoreline that could pose obstacles to development by interfering with marine animals, as well as boating and shipping traffic. Viable electricity costs have been estimated for wave farms along the California and Oregon coasts, however, Texas' offshore wave power densities are typically well below those considered to desirable. Power can also be produced from the ocean as the temperature differences between the surface and depths below 100 meters can drive a heat engine to produce electricity. Texas' ocean thermal energy potential is limited because the ocean depth near the Texas Gulf Coast is less than what is optimal for its development. Tides and ocean currents have also been explored for their energy potential but have not proven to be viable energy resources in Texas.

Useful energy can be produced using salinity gradients, through pressure retarded osmosis (PRO) and reverse electrodialysis (RED), or salinity gradient solar ponds (SGSP) that capture and store solar thermal energy. PRO and RED systems could be used at the saline gradient between Texas river mouths and bays, but only for very limited quantities of electricity. SGSP has the advantage of providing energy on demand and being able to use reject brine, often considered a waste product. Research has established the technical viability of using SGSP technology for electricity and water desalination, particularly in desert areas or where freshwater is not otherwise abundant. However, the demand for increased volumes of freshwater might promote the development of technologies that could reduce their cost for electric generation.

The potential for additional energy production from water resources in Texas is minimal and a substantial economic benefit is not anticipated for the state. However, some technologies, such as the use of SGSP for desalination or aquaculture enhancement, could prove beneficial to specific projects and locales.

Geothermal Energy

Geothermal resources are everywhere in Texas and are just waiting to be tapped. This source of energy has been used in some areas for over 50 years. Geothermal energy can be used to generate significant amounts of electricity from many oil and gas wells. In another geothermal application, using the constant temperature of the Earth's surface for cooling and heating in buildings can reduce energy use by up to 50 percent.

Geothermal energy consists of the natural, internal heat trapped within the rock and fluid found within the Earth. Geothermal energy is not dependent upon cyclical forces, as wind and solar energy are, but is available 24 hours a day, 365 days a year and, as such, can be considered a "baseload" energy technology. There are a number of promising geothermal applications in Texas.

Geothermal energy can be divided into electric and non-electric applications. One of the simplest non-electric ways to use geothermal energy is through a geothermal heat pump, which can work anywhere and represents the lowest cost application of the geothermal resource. Studies have shown that 70 percent of the energy used by a geothermal heat pump is renewable energy from the ground; the remaining 30 percent is electrical energy used to concentrate and transport the geothermal energy. More than 10,000 residential geothermal heat pumps have been installed in Texas. These systems cost approximately $3,000 to $5,000 per ton of cooling, compared to $2,000 to $2,500 for conventional HVAC systems. School districts and commercial buildings are increasingly utilizing geothermal energy. Over 160 schools in Texas have installed geothermal HVAC systems.

There are a number of other promising geothermal applications in Texas. Geothermal energy manifests itself in four distinct forms: 1) hydrothermal resources (hot steam or water), 2) geopressured-geothermal energy, 3) hot dry rock, and 4) magma. Space heating represents the largest potential use of low temperature (120° to 170°F) hydrothermal energy in Texas. Geothermal heat in the low to moderate temperature range can be extracted from subsurface hot water and used in various industrial and commercial processes, including district and space heating, greenhouses, and aquaculture facilities. Many hydrothermal resources, with low grade heat suitable for such applications, are distributed through Central Texas and the Trans-Pecos region.

Geothermal electric power can be generated using geothermal and geopressure fluids with temperatures of 200°F and higher. Temperatures in this range correlate with some of the oil and gas production in Texas, especially the East and South Texas fields. The most efficient way to develop this aspect is through coproduction of fluids. Other direct uses of the geothermal resource are enhanced oil recovery in south Texas, desalination, agriculture/aquaculture projects, and supercritical fluid processing for water and remediation. The geopressured-geothermal resources located along the Texas Gulf Coast provide higher temperatures, but are much deeper and more expensive to exploit and, therefore, may be most valuable for electric power production.

Issues related to hydrothermal and geopressure development include water availability, extraction, and disposal. The economics associated with utilizing high temperature geothermal resources depend on: 1) the quality of resource, principally its temperature, depth, and fluid characteristics; and 2) the ease and rate with which geofluids can be extracted and disposed of. The price of electricity will be important in determining whether geothermal electricity production in Texas remains economical until it becomes routine for oil and gas wells with fluid temperatures of over 200*F to be converted to geothermal energy production rather than simply plugged and abandoned. For increased applications of geothermal heat pumps and direct use, education and marketing will be important for giving potential users the knowledge that this resource even exists.

End-Use Energy Efficiency

Avoided energy use resulting from energy efficiency is the most immediately available clean energy resource in Texas and is as clean as any energy supply resource. There is abundant energy savings potential ("untapped reservoir") available through energy efficiency in Texas' residential, commercial, industrial, and transportation sectors. Some energy efficiency will arise naturally as fuel prices rise and carbon concerns increase, but much more can be realized through public education efforts, organizational initiatives, and building code enhancements, increased utility demand-side management programs, and other efficiency standards, incentives and programs.

Energy efficiency can be viewed as an energy resource, since the need for supply-side energy resources can be displaced by the adoption of more efficient equipment or through changes in energy consumption patterns. Avoiding the consumption of energy through energy efficiency measures provides a clean energy resource that is immediately available. Abundant energy savings potential is available through low cost energy efficiency measures in all economic sectors in Texas.

Some energy efficiency will arise naturally in response to high fuel prices and concerns about air pollution and climate change. Further energy efficiency can be realized through public education efforts, commitments to sustainable development, more stringent building codes, accelerated research and deployment of new technologies, utility demand-side management programs, and equipment efficiency standards.

In this report, energy efficiency is defined as the level of energy usage associated with performing a task at a minimum cost. Technologies that use more energy may be regarded as energy efficient if they are less expensive. Demand response, for example, changes the timing of energy use, lowering the cost of energy, but does not necessarily lower the overall consumption of energy.

Energy efficiency programs have been effective. U.S. energy consumption per dollar of economic output has been reduced to half of what it was in 1970. Texas has developed policies, rules, programs, and infrastructure to exploit the state's energy efficiency potential by establishing goals for energy efficiency, implementing goals for peak demand reduction via energy efficiency programs, and adopting statewide building codes. Programs administered by the state's investor-owned utilities have proven to be a particularly effective source of efficiency improvements, consistently exceeding their goals of meeting 10 percent of the projected growth in electrical demand through energy efficiency.

A state-of-the-art energy efficiency program at Texas A&M has produced energy savings in excess of $50 million at a cost of only $9.3 million. The LoanSTAR program, administered by the State Energy Conservation Office, the largest State-run building energy conservation program in the United States, has achieved energy savings of over $212 million. The revolving loan program will allow LoanSTAR to continue indefinitely and benefit generations of future Texans.

Some studies have argued that ambitious energy efficiency actions can eliminate over 80 percent of forecasted electric load growth at substantially lower costs than new electric supply. Market imperfections are thought to be responsible for the failure of consumers to achieve an optimal level of energy efficiency. Consumers may be unaware of opportunities to reduce energy consumption and cost or be unaware of the payback periods associated with energy efficiency investments. Consumers may lack the capital to purchase energy efficient products or the availability of energy efficient products may be limited. Homebuilders and homeowners and landlords and tenants may have competing interests concerning investments in energy efficiency. Environmental costs associated with energy use may not be adequately reflected in energy prices, leading to over-consumption of energy resources.

Summary and Conclusions

Texas' vast size, abundant resources, favorable business and political climates, and innovative, hard working citizens have helped to make Texas a national and international leader when it comes to energy. Texas' native energy resources and the success of industries built around them fueled Texas' economic growth for the past hundred years and has enabled the state to play a large role in shaping national and even international energy policies.

Among the contiguous 48 states, Texas has the highest potential for generating renewable energy from its solar, wind, biomass and geothermal resources[14] and these available renewable energy resources are almost entirely untapped. Texas' installed wind capacity comprises only about 4 percent of the state's estimated developable wind capacity, so there is plenty of potential for additional growth.[15] Likewise, Texas has only scratched the surface of the state's enormous developable potential solar, biomass, and geothermal capacity.

Texas possesses current energy demand and future growth rates that suggest the need to encourage development of the state's renewable energy resources. But this will not happen automatically. Capitalizing on the opportunities presented by Texas' renewable energy resources will require careful consideration of long-term strategies, formulation of shorter-term priorities, and identification and removal of barriers to development. Renewable energy cannot solve all of our energy problems, but have an important role in a diverse, stable energy supply and are certain to play a growing role in this century's energy supply. Yet the development of these vast resources hinge upon our ability to successfully address a variety of technical, economic, and policy challenges:

- Accommodating Intermittency
- Delivering Renewable Energy to Markets
- Valuing Distributed Generation
- Incorporating Energy Storage
- Economics of Renewable Energy Investments
- How Carbon Changes the Picture
- Government Subsidies
- Jobs and Economic Development
- Resource Allocation Consequences and Tradeoffs

Accommodating Intermittency

Resource intermittency is a significant issue for some renewable energy resources. Wind and solar resources are intermittent over short time periods and their intermittency poses unique challenges for integrating them into the electricity system at a large scale. Wind generation has achieved sufficient penetration on the Texas power grid that intermittency is beginning to emerge as an operational issue.

Strategies for accommodating intermittent resources include better short-term resource forecasting, geographical and technological diversification among intermittent resources, and utilization of demand response, storage, and backup generation.

Delivering Renewable Energy to Markets

Some renewable energy resources are located far from major energy markets, posing unique challenges in delivering renewable energy to customers. Wind energy is a prime example, with most Texas wind energy development to date being distant from load and population centers. Concentrating solar power plants face a similar electricity transmission challenge, while biomass must be transported to centralized production facilities and then to retail outlets. Energy transmission is an intra-state as well as an inter-state issue.

Valuing Distributed Generation

Small renewable energy generation systems can provide benefits of renewable energy while reducing utility costs. In addition to providing additional capacity and energy, distributed generation provides value through transmission and distribution cost deferrals, reduction in line losses, increased reliability, electricity price protection, and pollutant and greenhouse gas emission reductions.[16] Each of these benefits should be compensated at a fair value. Strategies may include the development of incentive programs to support adoption of distributed renewable generation and the adoption of fair and consistent interconnection and net metering practices by all Texas electric utilities.

Incorporating Energy Storage

Energy storage refers to wide range of technologies that can be used to store energy and release it later to perform some useful task. Development of economical storage is useful to intermittent energy resources, in particular, because it enables intermittent resources to comprise a larger portion of available capacity without compromising grid operations. Oil fields could be used for compressed-air energy storage. Market participants are exploring other options for compressed air storage or large-scale batteries.[17]

Economics of Renewable Energy Investments

Renewable energy projects tend to be even more capital intensive than traditional energy projects and lack ongoing fuel costs. As a result, up-front costs tend to be greater but financial returns on capital investments in renewable energy tend to more stable and predictable over the life of the project. The stability and predictability of renewable energy investments creates value that can be passed on to consumers of renewable energy through long-term, fixed price energy sales contracts. However, the higher initial cost and longer payback term does not always align with the interests of home- and building-owners who may not own the property long enough to reap the financial reward. As a result, some cost-effective distributed renewable generation projects will not be built without an up-front financial incentive.

How Carbon Changes the Picture

Regulation of greenhouse gases by the federal government could have a pronounced impact on Texas' energy future. Federal regulation of carbon dioxide and other greenhouse gases will have a large and disproportionate effect on Texas, due to the state's abundance of fossil fuel resources and the industries which have developed around them. In the U.S., mandatory carbon regulation has been considered but not adopted by the federal government. Some voluntary and regional efforts have taken hold, however. By increasing the cost of fossil fuel-derived energy, carbon regulation will make non-carbon emitting energy resources, such as many renewable energy resources, more cost-competitive. Texas' abundance of renewable energy resources means the state has a natural hedge against potential carbon regulation.

Government Subsidies

The abundance and diversity of subsidies for certain energy resources make a comparison of the relative costs and benefits of each energy resource a formidable task but some conclusions can be reliably drawn by examining incentives provided at the federal and state/local levels. More than three quarters of federal renewable energy subsidies, about $4.7 billion, went to ethanol production. Wind, solar, hydroelectric and biomass technologies together received $1.3 billion. Texas' state and local level government provided approximately $1.4 billion in direct financial subsidies to energy sources in 2006; however, 99.6 percent went to oil and gas production. The remaining $6.2 million, was split between solar, biodiesel, wind, and geothermal. Over $2 million of the solar subsidy was provided by Austin Energy.

Jobs and Economic Development

Expanding the use of renewable energy in Texas may have a significant positive impact on employment. Research has shown that renewable energy creates more jobs in the construction and manufacturing sectors than fossil fuel generation.[18] And because renewable energy resources are dispersed throughout the state, developing renewable energy can create new economic opportunities in rural areas of Texas. Renewable energy jobs are diverse and involve manufacturing, sales, construction, maintenance, service, and other skills.

Resource Allocation Consequences and Tradeoffs

Utilization of energy sources can impact air and water quality, land and water use, and wildlife, requiring decisions concerning competing uses of associated land and water. For example, many energy production technologies require vast amounts of water. Allocation of water between competing energy, agricultural, industrial, commercial and domestic demands will become a more important issue as each of these demands continues to grow. Certain distributed renewable energy generation technologies can help reduce water consumption by power plants, freeing water resources for other uses.

Barriers to Renewable Energy Development

The U.S. Department of Energy recently conducted a study of "non-technical barriers" to renewable energy use.[19] The study identified impediments that are holding back the acceptance of renewable energy technologies. Barriers identified included:

- Lack of government policy support,
- Lack of information dissemination and consumer awareness,
- High up-front capital cost,
- Difficulty overcoming established energy systems,
- Inadequate financing options,
- Failure to account for all costs and benefits of energy choices,
- Inadequate workforce skills and training,
- Lack of adequate codes, standards, and interconnection and net-metering guidelines,
- Poor perception by the public of renewable energy system aesthetics, and
- Lack of stakeholder/community participation in energy choices and renewable energy projects.

The U.S. is one of the world's major energy producers and consumers, and Texas is at the epicenter of U.S. renewable energy development. Texas' success in developing its wind resource, coupled with its enormous solar, geothermal and biomass potential, lead one study to conclude in mid-2008 that Texas was the most attractive U.S. state for long-term renewable energy development, ranking first among the states in wind and infrastructure, second in solar, and third in biomass and geothermal.[20]

As renewable energy sources emerge as a dominant contributor to future energy supplies, benefits will accrue to those regions with abundant renewable energy resources and policies that successfully encourage their development. With the right focus, Texas can be well-situated to benefit from its renewable energy resources and to maintain and expand its leadership role in energy well into the next century.

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[20] United States Renewable Energy Attractiveness Indices, Q1 2008, Ernst & Young Tax Credit Investment Advisory Services. These rankings consider not only the current climate for business development (in which Texas' installed wind capacity and CREZ transmission efforts secure the state's top rankings) but also the raw resource potential (which, due to Texas large size and abundant resources, leads to high rankings in every resource category).

Chapter 1

INTRODUCTION

Much has changed since the state of Texas completed its first comprehensive renewable energy resource assessment in 1995.[1] The cost of energy resources has risen, with the world price of crude oil reaching new heights in mid-2008. Concerns over the contribution of fossil fuel use to global climate change are reported in the press on a daily basis. By some measures, Texas has become a net importer of energy resources.

In response to concerns over the cost, availability, and environmental impacts of some traditional energy resources, Texas has taken a number of steps to tap into its vast renewable energy resource base. Goals for renewable energy were established as part of the legislation which restructured portions of the state's electric utility industry in 1999. Texas has emerged as the leading state in the production of electricity from wind farms. Aggressive goals for solar energy development have been established by the city of Austin. In addition, energy efficiency efforts—including utility programs and building codes—are increasingly being relied upon to help reduce the state's growing power requirements.

The Demand for Energy in Texas

A number of factors contribute to Texas' leadership in energy use. The hot and humid climate that dominates much of the state is responsible for a high demand for summer air conditioning. Until the recent increases in natural gas prices, the price of electricity in Texas tended to remain below national averages. Relatively low energy prices, the availability of crude oil and natural gas reserves within the state, and an expanding economy made Texas an ideal site for the development of energy-intensive industries, such as petroleum refining and chemicals production, steel mills, aluminum smelting, and electronics.

Texas consumes almost 12 percent of all energy used in the United States, as can be seen in **Exhibit 1-1**.[2] In 2005, Texas' energy consumption of over 11,500 trillion BTUs exceeded that of California (8,400 trillion BTUs), the US's second largest energy consumer, by 38 percent.[3]

Exhibit 1-1 Energy Consumption, Texas versus U.S.

Total Energy Consumption by Sector (Trillion BTU), 2005	Texas	U.S.	Texas Percent of Total U.S. Consumption
Residential	1,618	21,652	7.5%
Commercial	1,399	17,971	7.8%
Industrial	5,812	32,733	17.8%
Transportation	2,730	28,331	9.6%
Total	11,558	100,687	11.5%

Source: Energy Information Administration.

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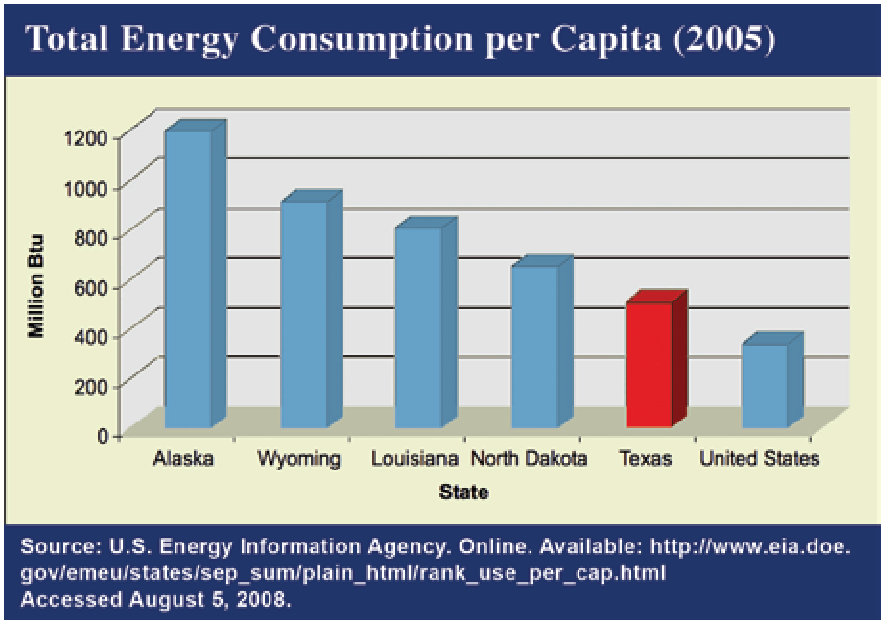
Exhibit 1-2 Total Energy Consumption per Capita (2005)



Source: U.S. Energy Information Agency. Online. Available: http://www.eia.doe.gov/emeu/states/sep_sum/plain_html/rank_use_per_cap.html Accessed August 5, 2008.

Texas ranks fifth in the nation in terms of total energy consumption per capita, at 506 million BTU in 2005 (**Exhibit 1-2**).[4] Although total energy consumption has increased by 2.2 percent annually since 1960, per capita usage has declined. In 2005, energy consumption per capita dropped to 1965 levels.[5]

Energy consumption is often broken down into four end-use sectors: industrial, transportation, residential, and commercial. Texas's industrial sector accounts for 50 percent of the state's energy consumption and nearly one-fifth of all U.S. industrial consumption.[6] The demand for transportation has increased steadily over the past four decades at an average of 2.7 percent annually.[7] As of 2005, Texas ranked second behind California in energy consumption for this sector. Residential and commercial consumption has also increased over this time span. In 2005, Texas ranked first and second in the nation, respectively.[8] **Exhibit 1-3** shows the annual consumption in Texas by sector between 1960 and 2005.

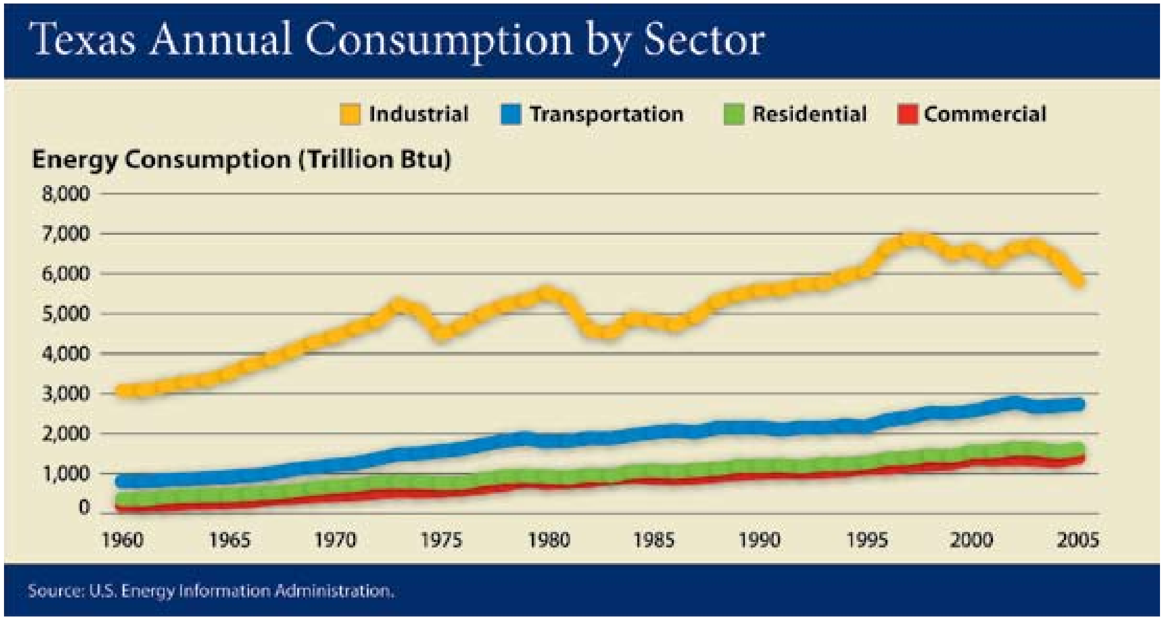
The demand for electricity, encompassing all sectors, is growing faster than any other type of energy consumption. Between 1995 and 2006, electricity generation increased by 21 percent in the US.[9] Accounting for over 30 percent of Texas' energy use in 2005, demand for electricity is expected to continue growing.[10] A fast growing population is expected to further increase energy demand across all sectors.

Texas at an Energy Crossroads

Historically, Texas has been a national leader in the production of petroleum products, crude oil and natural gas, and in the generation of electricity. This trend persists today as Texas continues to produce the most oil and gas of any state in the country; however, production of these precious resources has been in a downfall since their heyday in the 1970s.[11] At the same time, energy consumption in Texas and the nation have continued to steadily climb as the population expands and everyday energy demands increase (**Exhibit 1-4**).

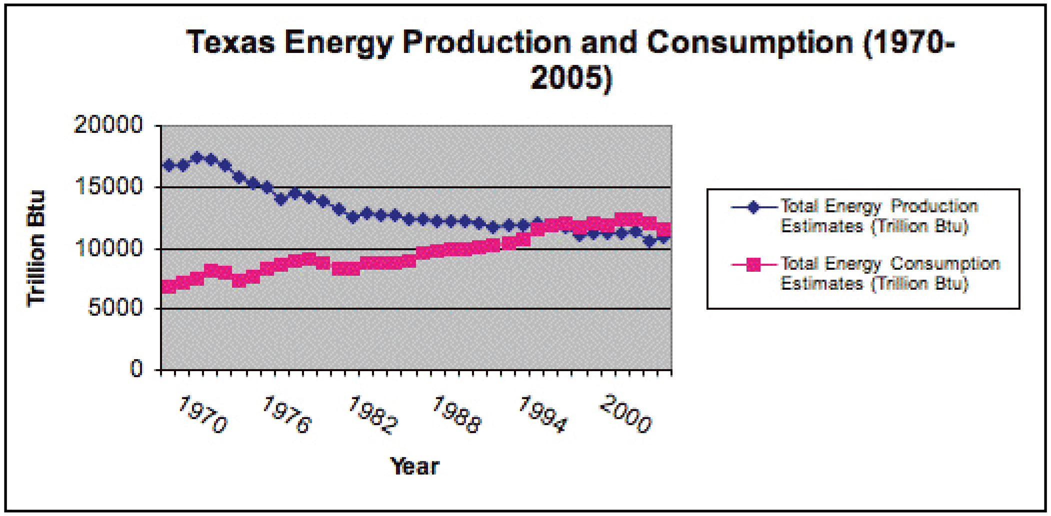
The steady decline in production levels combined with the growth in consumption has led to an energy crossroads never before seen in the state of Texas. During the early 1990s, consumption overtook production, effectively establishing Texas as a net importer of energy resources, forcing the state to increasingly rely on outside sources of energy to meet demand (**Exhibit 1-5**). This gap will continue to widen over time based on historical trends, thereby illustrating the fact that traditional energy sources will not be enough to satisfy the nation's growing thirst for energy. Texas' large, yet underutilized supply of renewable energy resources will make up a larger percentage of our total energy supplies in the future.[12]

Exhibit 1-3 Energy Consumption Estimates in Texas by Sector, 1960 to 2005



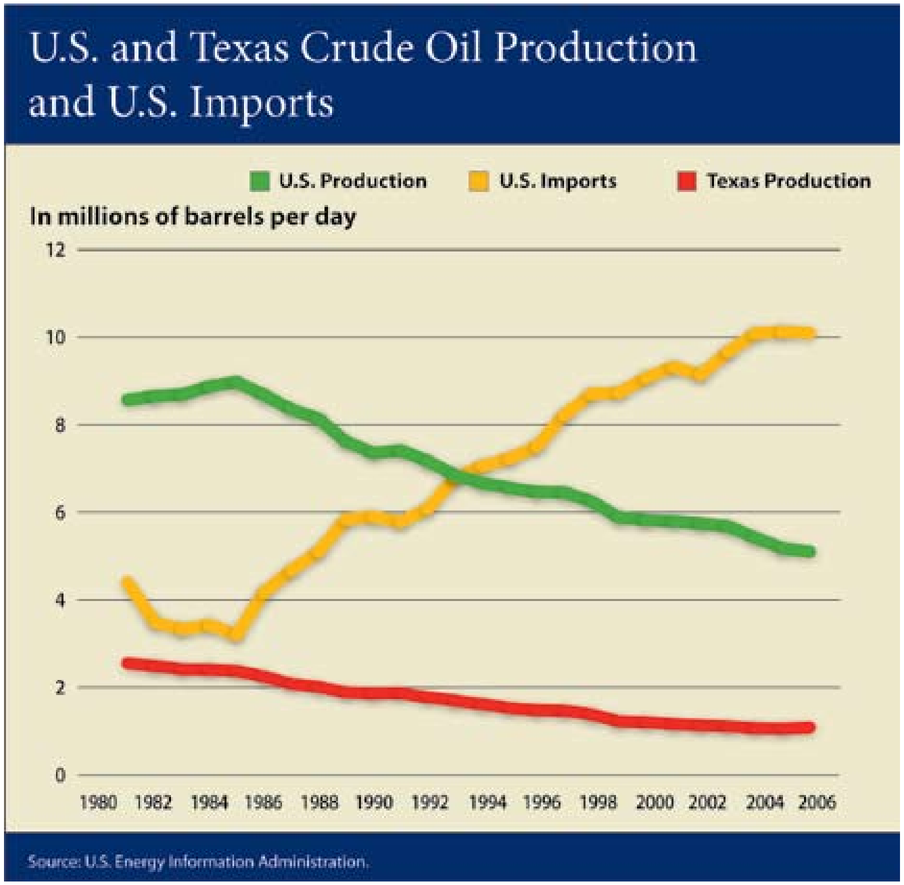
Source: Texas Comptroller of Public Accounts, The Energy Report 2008 (Austin, Texas, May 2008), p. 5, http://www.window.state.tx.us/specialrpt/energy/ (Last visited May 30, 2008.)

Exhibit 1-4 Texas Energy Production and Consumption (1970-2005)



Source: Energy Prod Estimates: http://www.eia.doe.gov/emeu/states/sep_prod/P7/PDF/P7_tx.pdf
Consumption Estimates: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_tx.html

Exhibit 1-5 Production and Imports



Source: Texas Comptroller of Public Accounts,
The Energy Report 2008 (Austin, Texas, May 2008), p. 15,
http://www.window.state.tx.us/specialrpt/energy/ (Last visited May 30, 2008.)

Fueling Texas

Due to rising energy costs, volatility in the prices of some energy resources, variation in the suitability of different types of energy resources in different applications, national security issues, and environmental concerns, Texas must rely on a diversity of energy sources to fulfill its ever-growing energy needs. The mix of energy resources produced in Texas has not changed drastically since 1995. Natural gas, petroleum products, and coal continue to make up the vast majority of Texas' energy portfolio; however, 2005 production levels for each source were slightly below 1995 levels. Nuclear electric power provides a relatively small percentage of total production. Renewable energy resources, including wind, solar, biomass, and hydroelectric power contribute a small but increasing percentage of total energy production.[13] **Exhibit 1-6** lists the major energy sources in Texas, denoting the primary uses for each.

Non-renewable resources are the dominant energy source in Texas and the nation as a whole. Coal, natural gas, crude oil and natural gas plant liquids accounted for 78 percent of domestic energy produced in 2006, equal to 56 quadrillion BTU (quads) of energy.[14] Texas is the top producer and consumer of non-renewable fuels in the nation with 95 percent of the state's total energy produced from fossil fuels in 2005.[15]

Exhibit 1-7 and **Exhibit 1-8** show the 2005 breakdown of energy production by source for the US and Texas, respectively.

Used primarily for transportation as a direct use energy source (including heating and manufacturing), petroleum products have played a major role in the state's energy make-up and economy for decades. Texas is home to approximately one-fourth of the nation's oil reserves and leads the nation in the production of oil and gas (excluding federal offshore areas).[16] However, crude oil production has been declining since its peak in 1972 (**Exhibit 1-9**),[17] contributing to the state's and the nation's increased dependence on foreign oil. The price of crude oil has increased from approximately $17 per barrel (bbl) in July 1995 to over $141 bbl in July 2008 (West Texas Intermediate spot prices).[18]

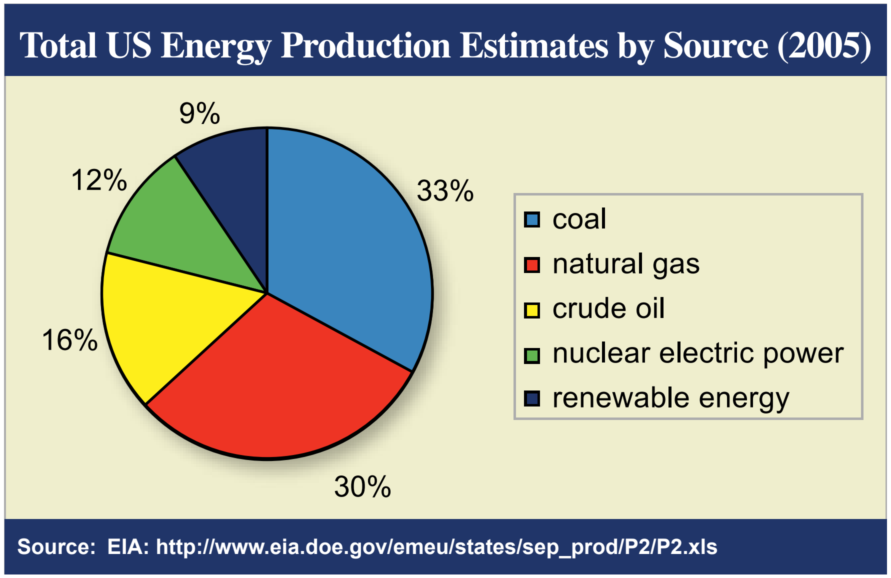
Natural gas from Texas accounts for approximately 30 percent of the nation's total energy supply[19] and accounts for over 60 percent of energy production within the state.[20] Production of natural gas has remained fairly steady since 1995; however, the substantial jump in oil prices has resulted in an increase in production over 2005 output.[21] The electricity and industrial sectors account for the majority of natural gas demand, consuming approximately four-fifths of the state's total usage.[22] The average price of natural gas delivered to US residential customers has doubled since 1995.[23]

EXHIBIT 1-6 Primary Uses of Energy

Energy Source	Direct Use	Electricity	Transportation
Petroleum	X		X
Natural Gas	X	X	
Coal		X	
Uranium		X	
Solar	X	X	
Wind		X	
Biomass	X	X	X
Water		X	
Geothermal		X	

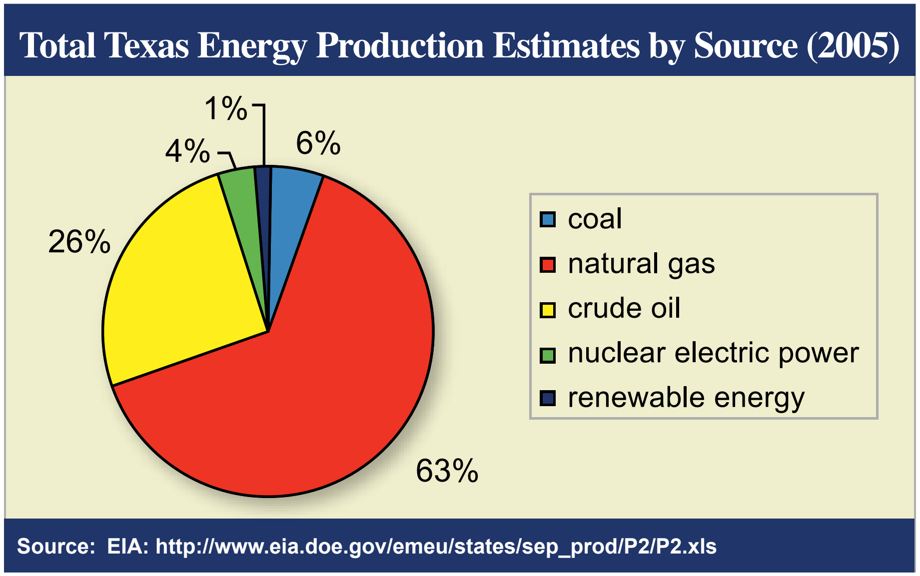
Source: Virtus Energy Research Associates, Texas Renewable Energy Resource Assessment, Report for the Texas Sustainable Energy Development Council, July 1995.

EXHIBIT 1-7 Total US Energy Production Estimates by Source (2005)



Source: EIA: http://www.eia.doe.gov/emeu/states/sep_prod/P2/P2.xls

EXHIBIT 1-8 Total Texas Energy Production Estimates by Source (2005)



Source: EIA: http://www.eia.doe.gov/emeu/states/sep_prod/P2/P2.xls

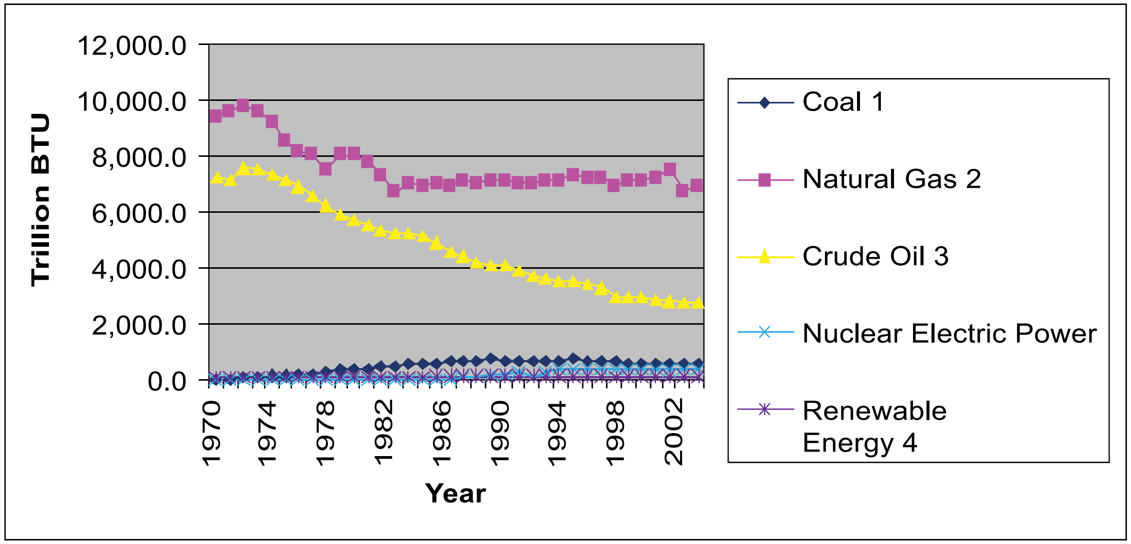
Coal, in the form of lignite, is yet another non-renewable resource found within the state. Despite the fact that Texas has some of the largest coal mines in the country, the majority of the state's coal supply is imported from Wyoming.[24] This resource accounted for approximately 595 trillion BTU (6%) of total energy produced in the state, compared to 33 percent for the US. Coal consumption in 1995 totaled 1,365 trillion BTU; in 2005 this number had increased to 1,628 trillion BTU.[25] As the price of petroleum products and natural gas continue to increase, domestic coal resources may be used in increasing amounts to offset the price of electricity production. Unfortunately, this may lead to an increase in emissions, affecting air quality throughout the state. As the biggest coal consumer in the nation, Texas is also one of the largest emitters of carbon dioxide and sulfur dioxide in the nation.[26]

Nuclear power accounted for 398 trillion BTU (4%) of Texas' total energy production in 2005.[27] This number has not changed significantly since 1995; however applications for new nuclear development could potentially turn Texas into a nuclear power leader within the nation. As of 2005, the state "ranked 7th among the 31 states with nuclear capacity"[28] and, with two plants located in Texas (South Texas Project and Comanche Peak), the state is considered a "major nuclear power generating state."[29] South Texas' application to the US Nuclear Regulatory Commission (NRC) for two new reactors was still under review as of June 30, 2008. Comanche Peak is also expected to apply for an additional two units in 2008. If these four new units are approved and built, they would have a combined generating capacity of over 6,000 megawatts (MW).[30]

Renewable Energy

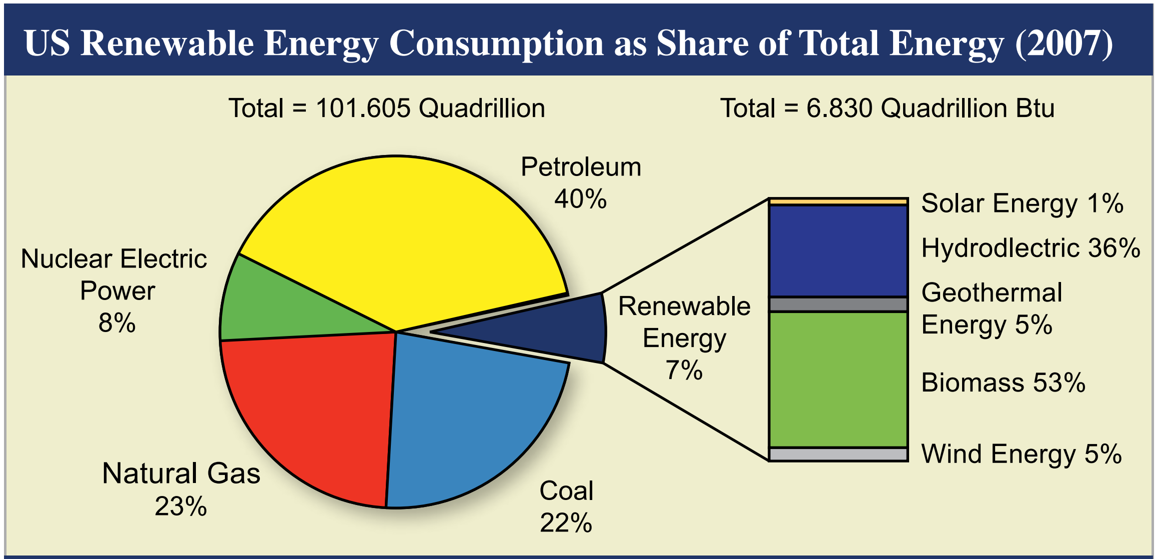
Interest in renewable energy in the US and Texas has experienced a rebirth in recent years due to an increase in environmental awareness, skyrocketing oil and gas prices, and national security concerns. In 1995, renewable energy accounted for approximately 7.6 percent (6.8 quadrillion Btu) of total energy consumed in the US.[31] After a decrease in consumption during the early 2000s, renewable energy usage is on the rise with US consumption increasing 7 percent (up to 6.9 quadrillion Btu) between 2005 and 2006.[32] Preliminary data for 2007 shows a slight decline in total consumption over 2006 levels; however the breakdown by source is almost identical (**Exhibit 1-10**).

Exhibit 1-9 Energy Production Estimates by Source in Texas, 1960-2005



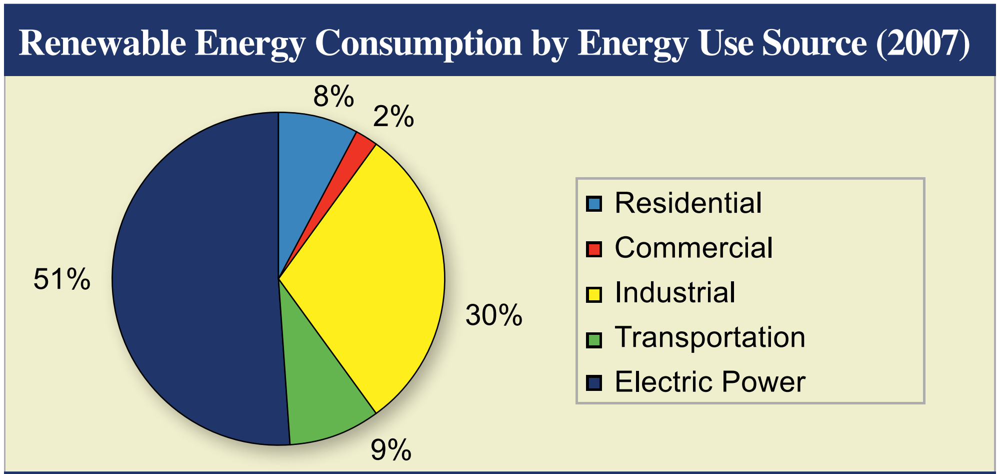
Source: EIA: http://www.eia.doe.gov/emeu/states/sep_prod/P7/PDF/P7_tx.pdf

Exhibit 1-10 US Renewable Energy Consumption as Share of Total Energy (2007)



Source: EIA, Window on Renewable Energy Consumption and Electricity Preliminary 2007 Statistics. Online. Available: http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html. Accessed August 7, 2008.

Exhibit 1-11 Renewable Energy Consumption by Energy Use Sector (2007)



Source: EIA, "Renewable Energy Consumption and Electricity Preliminary 2007 Statistics," Online. Available: http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html. Accessed September 30, 2008.

Note: The electric power sector comprises electricity-only and combined-heat-power (CHP) plants within North American Classification System (NAICS) 22 category whose primary business is to sell electricity, or electricity and heat, to the public.

Source: EIA, "Renewable Energy Consumption and Electricity Preliminary 2007 Statistics," Online. Available: http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html. Accessed September 30, 2008.

Fundamentals of Renewable Energy

Renewable energy is obtained through a variety of sources; hydropower, geothermal, biomass, wind and solar resources are all utilized in some manner to produce energy. The majority of renewable energy produced is consumed by the electric power sector. (**Exhibit 1-11**).[33] This percentage has dropped over the past few years (down from 60 percent in 2004[34]) as other sectors are utilizing renewable energy in increasing amounts.

Renewable resources are fundamentally limited in terms of how they can be used and their availability in certain areas or at particular times. **Exhibit 1-12** lists the characteristics of each of the major renewable resources, denoting its energy type (how the energy is generated), intermittence (if the resource is continuous or not) and spatial variability (relative location/availability of the resource). For example, the opportunity to harness solar power is not always available due to rain or thick clouds; however, at the same time the majority of the earth is exposed to sunlight on a daily basis. Therefore, it is coded as an intermittent resource with low spatial variability.

Renewable Energy Sources in Texas

Hydropower and biomass (including wood, waste, and biofuels) resources have historically led the way in terms of energy production and consumption in the state. Geothermal energy has been steadily increasing over the past few decades as a reliable resource in the US; however Texas does not currently use it to generate electricity.[35] Solar and wind power have experienced huge leaps in production and consumption over the past ten plus years.[36]

Wind is currently the dominant source of renewable energy in the state. According to ERCOT data, between 2002 and 2007 wind energy production increased by 280%, while total renewable production increased by 79%.[37] This increase in wind production resulted in Texas providing 2 percent of the total renewable energy generated in the US for 2006, ranking it eighth in the nation.[38]

Potential for Renewable Energy in Texas

The potential for increased production of renewable energy in Texas is large, barring a few key issues. As of June 2008, Texas ranked first in the nation for installed wind capacity with a generating capacity more than twice that of second place California. The state also leads the nation in biodiesel production as a transportation fuel and is starting to capitalize on solar power as a viable energy resource. Ernst & Young ranked Texas number one in its “All Renewables Index” for the first quarter of 2008. Looking at the state’s long-term potential for wind, solar, biomass, and geothermal energy production, the index analyzes a state’s capacity for renewable production in terms of renewable energy infrastructure, political climate, technology factors, and transmission issues. In terms of individual resources, the state topped the wind index and ranked third in the long-term solar index, behind California and Arizona.[39]

Transmission-related obstacles are the major barriers to new renewable electricity generation in the state. More often than not, areas where renewable resources are abundant, e.g. wind in west Texas, are areas of low energy demand. Inadequate transmission to more populous areas of the state, where additional energy resources

Exhibit 1-12 Fundamental Characteristics of Renewable Energy Resources

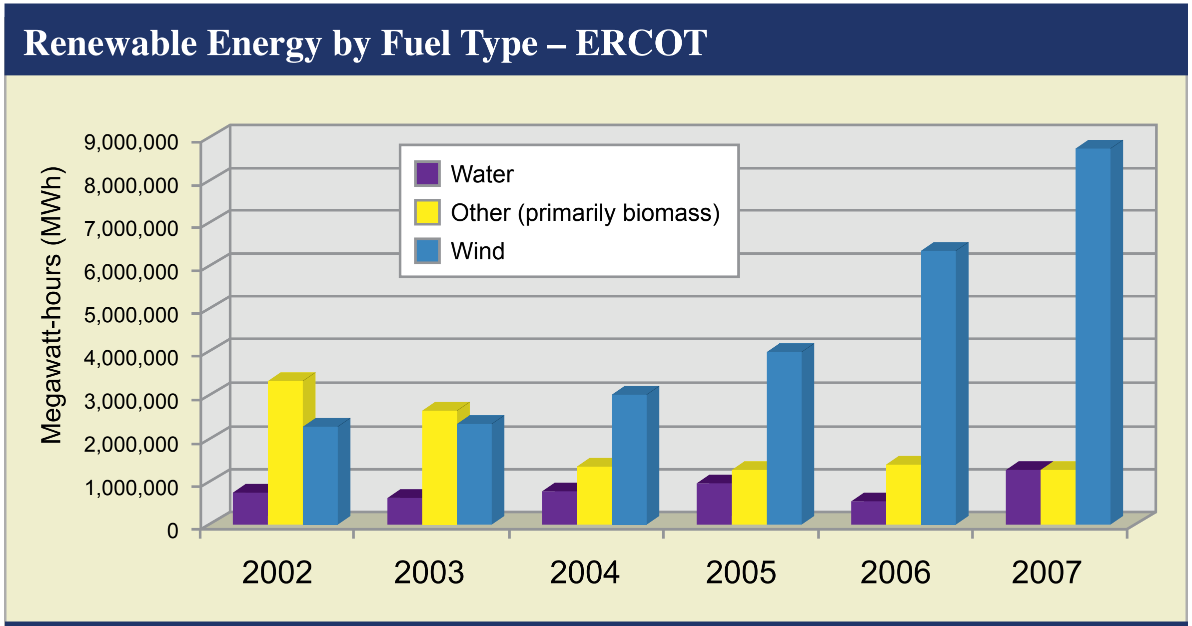
Resource	Energy Type	Intermittence	Spatial Variability
Solar	Radiative/Thermal	Yes	Low
Wind	Kinetic	Yes	High
Biomass	Chemical	No	Very High
Water	Kinetic/Thermal	Some	Extreme
Geothermal	Thermal	No	High

Source: Virtus Energy Research Associates, Texas Renewable Energy Resource Assessment, Report for the Texas Sustainable Energy Development Council, July 1995.

are needed, has hampered the overall growth of alternative energy. Overcoming this issue is seen by some as critical to the future of renewable energy production in Texas.

In July 2008, the Public Utility Commission of Texas (PUCT) took the first step in addressing the transmission problem by granting preliminary approval of a $4.93 billion plan to build new transmission lines from the windy west to the more populous urban areas of the state. If completed, transmission capacity would increase by 18,456 MW.[40] The additional wind power would displace energy production from more traditional power plants (i.e. lignite and coal plants), substantially reducing emissions and improving air quality throughout the state. Moreover, the plan has been deemed economically viable and beneficial to both producers and consumers of energy.[41]

Exhibit 1-13 ERCOT Renewable Generation by Fuel Type (2002-2007)



Source: Electric Reliability Council of Texas, December 11, 2007.

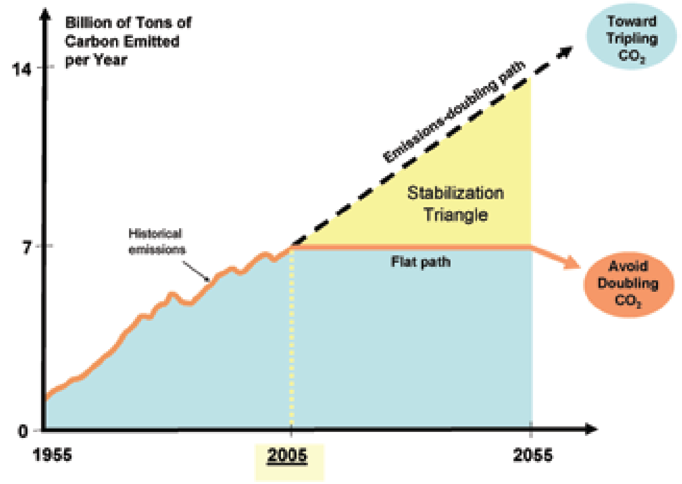
Socolow Wedge Theory

Since the creation of this report in 1995, the phrase "climate change" has become part of the average vocabulary. Burning fossil fuels to produce energy releases carbon dioxide. As a greenhouse gas, these carbon emissions blanket the earth, trapping greater amounts of heat within the atmosphere. This results in the Earth warming above the temperatures that would otherwise occur, causing changes in long-term weather patterns across the globe. Scientists believe that if greenhouse gas concentrations in the atmosphere continue to rise, weather patterns could change dramatically, resulting in potentially dire consequences for the Earth's inhabitants.

A number of studies have explored the potential role of renewable energy and energy efficiency in mitigating climate change. For example, Robert H. Socolow and Stephen W. Pacala formulated a "wedge theory" in 2004 that proposed a multifaceted approach to mitigating carbon emissions. The scientists envisioned two 50-year futures. In one, emissions are frozen at the current rate over the next 50 years through various measures. Over the following 50 years, emissions are then reduced by half. The second future takes a different direction in which the "emissions rate continues to grow at the pace of the past 30 years for the next 50 years". The first scenario would prevent the drastic increase in CO_2 levels anticipated to occur if action is not taken, thus maintaining the greenhouse gas at a less volatile level. The second scenario would result in atmospheric levels of CO_2 three times that of the pre-Industrial atmosphere; a level thought to cause potentially irreversible climate change.[42]

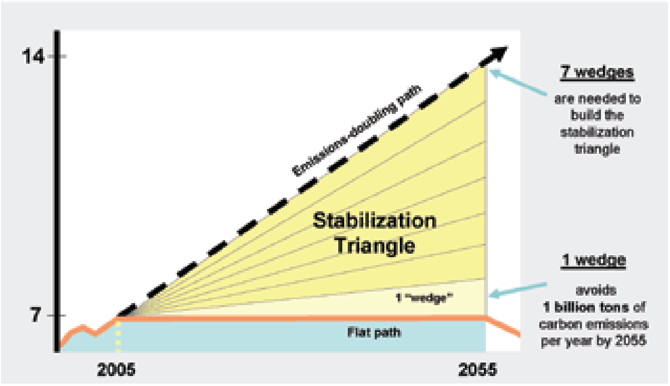
The difference between the carbon emissions released by the two futures creates a "stabilization triangle [that] can be divided into [eight[43]] 'wedges,' each representing a reduction of 25 billion tons of carbon emissions over 50 years"[44] (**Exhibit 14** and **Exhibit 15**). The reduction wedges proposed by Socolow can be accomplished through a variety of means. Two of the major wedge categories involve efficiency/conservation and alternative energy sources, specifically renewable energy. For example, cutting electricity use in homes and offices through basic efficiency measures could reduce CO_2 emissions by one wedge. In addition, increasing wind power 40-fold and doubling current nuclear capacity to avoid the use of coal could each provide a reduction of 25 billion tons of emissions over 50 years.[45]

Exhibit 1-14 Stabilization Triangle



Source: Princeton University. Carbon Mitigation Initiative. Window on Stabilization Wedges. Online. Available: http://www.princeton.edu/wedges/presentation_resources/. Accessed May 24, 2007.

Exhibit 1-15 Stabilization Wedge



Source: Princeton University. Carbon Mitigation Initiative. Window on Stabilization Wedges. Online. Available: http://www.princeton.edu/wedges/presentation_resources/. Accessed May 24, 2007.

The ultimate goal of Socolow's wedge theory is to provide a way of looking at reducing carbon emissions through the use of clean energy resources, energy efficiency standards, and other realistic measures without unduly hampering economic growth. As carbon emissions continue to grow and concerns surrounding climate change mount, renewable energy resources could become a major player in the development of a cleaner, less carbon intense energy policy for Texas and the nation.

Summary

The potential for renewable energy in Texas is bright. Today, the state has the natural resources, cost-effective technologies and manpower to turn Texas into *the* dominant leader in the renewable energy industry. At this juncture, forward-thinking policies are critical to the establishment of a robust and sustainable renewable energy market. An increased focus on the renewable market would ultimately result in environmental benefits and substantial economic rewards to the state in terms of new business, more jobs, and overall growth in the Texas economy.[46] In addition, integrating renewable technologies and efficiency measures into the state's current energy plan will help ensure a more stable energy future and reverse the trends toward an increase in imported energy sources through the development of the state's renewable potential.

Objectives of this Study

The update to the Texas Renewable Energy Resource Assessment is sponsored by the State Energy Conservation Office (SECO) through the Office of the Comptroller, as required by Rider 15, Comptroller Fiscal Programs, House Bill 1, 80th Legislature, Regular Session, 2007.

The study's objective is to provide an update to the Texas Renewable Energy Resource Assessment, originally produced by Virtus Energy Research Associates in July 1995. Partnering with the state's leading experts on renewable energy resources, opportunities and impediments to the development of Texas' renewable energy resource base have been identified and assessed in terms of its potential as part of the state's future energy plans. New research and updated statistics have been included and were used to evaluate Texas' total renewable energy resource base.

Overview of this Report

The next chapter gives an overview of the Texas climate and is followed by six sections highlighting each of the major renewable energy resources. Each resource is described in terms of its current and potential use and how it is being incorporated into the overall energy make-up of the state. Characterizing the energy base in Texas, technologies necessary to convert renewable resources into useable forms is discussed. The final chapter provides a discussion of the issues and opportunities concerning renewable energy resources, compares the economics of each resource, and delineates a variety of energy policy options for consideration.

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CHAPTER 2

Texas Climate

Introduction

Texas has more diverse weather on a typical day than any other state within the union—with the possible exception of California. The assortment of weather elements that characterizes Texas' climate is due not merely to its inordinate size, but also to its strategic position on the North American continent. Its proximity to the relatively warm waters of the Gulf of Mexico, as well as its susceptibility to wind flow from the eastern North Pacific, ensure that the Texas atmosphere will be amply fed with enough energy to keep its weather in an almost constant state of flux. Moreover, during much of the year Texas is within reach of the migration of cool air from Canada, and the inevitable interaction of air masses of varying densities impacts the quality and variety of renewable energy resources available to Texans on a daily basis.

For example, the coupling of Texas' location in the mid latitudes of the northern hemisphere with its predominantly flat or gently-rolling terrain contributes to an almost incessant flow of air at Earth's surface in all seasons of the year. In much of the northern and western sectors of the state, where the topography consists largely of vast open spaces with minimal forested areas, wind flow is particularly substantial. The state's climate is sufficiently subtropical to ensure that even when the lower atmosphere is quite moist the sun shines the majority of the time, thereby furnishing a generous supply of solar radiation (insolation). The subtropical nature of the atmosphere also ensures a hefty amount of precipitable water (at least one inch) is present much of the time. This cloud water, within convective towers that form when a "trigger" is present (such as a frontal boundary), gets converted into rainwater, which upon reaching the ground may translate into increases in hydroelectric generation.

Fundamental to any understanding of available and renewable energy resources is the realization that energy is transferred from one place to another through radiation, convection, or conduction. Obviously, a superabundance of energy is propagated throughout the Texas atmosphere on a daily basis by means of radiation. In every season, but particularly in spring, summer, and autumn, the process of convection plays an integral role in the free exchange of energy as well, much of which is renewable. Whereas radiation transfer occurs with the speed of light and can happen without the presence of matter between the object radiating and the object receiving the energy, the other two avenues of transfer require the presence of some intermediate substance such as air. The lower atmosphere of Texas, with its deep boundary layer of heat and moisture, is well suited for the expeditious processing of reradiated energy through the mechanism of convection.

Extremes in the Weather

Any attempt to assess the weather's role in sustaining the renewable energy resources of Texas must begin with the recognition that the incoming supply of energy and moisture varies widely over both space and time. This huge disparity in available energy and moisture is responsible for the existence of both deserts and rain forest-type conditions in the Lone Star State. The dissimilarities that typify Texas weather are evidenced by a wide range of extremes in temperature and precipitation across the state (**Exhibit 2-1**).

Exhibit 2-1 Extremes in Texas Weather[1]

Category	Record	Location	Date
TEMPERATURE			
Coldest °F	-23°	Tulia Seminole	February 12, 1899 February 8, 1933
Hottest °F	120°	Seymour Monahans	August 12, 1936 June 27, 1994
RAINFALL			
Greatest in 24 hours	29.05 inches	Albany	August 4, 1978
Greatest in 1 month	35.70 inches	Alvin	July, 1979
Greatest in 1 year	109.38 inches	Clarksville	1873
SNOWFALL			
Greatest in 24 hours	24.0 inches	Plainview	February 3, 1956
Greatest in single storm	61.0 inches	Vega	February, 1956
Greatest in one season	65.0 inches	Romero	1923-1924
WIND			
Highest sustained speed	145 mph	Matagorda Port Lavaca	September 11, 1961 September 11, 1961
Highest peak gust	180 mph	Aransas Pass Robstown	August 3, 1970 August 3, 1970

The state's weather history illustrates how a wide array of weather—from an epic drought to devastating floods and catastrophic Arctic cold waves to relentless, killer heat—has been endured by Texans in every decade. It is the extremes in the weather that distinguish the state as a land of contrast and emphasize the degree to which Texas has at its disposal an immense atmospheric reservoir of renewable energy resources. An accurate characterization of Texas weather could not be made without due recognition of the extent to which the weather oscillates from one atypical level to another.

Average Weather as Indicator of Available Resources

Yet, it is not the extremes that provide clues as to how much renewable energy is available in Texas for consumption and preservation. Rather, it is the mean, or average, set of climatic conditions that best quantifies the extent to which Texas has been endowed with multiple and replenishable natural assets. For sure, several elements of the weather are particularly influential in the realm of renewable energy resources. These elements exert much more than mere nuisance value on a host of operations, and even on whole industries. For example, high humidity can lead to deterioration, mildew, and rotting of raw materials, or corrosion of metals. Poor visibility (due to fog, smoke, or dust) may impair the movement of workers and materials, though the restrictions imposed may be short-lived. Electrical storms with lightning and heavy rainfall or a strong, straight-line thunderstorm wind (downburst) can contribute to a significant curtailment of industrial operations.

Thus, it is imperative that a concerted effort be made to measure and quantify the whole array of climatic parameters that defines the state's renewable energy resources. Some parameters, most notably temperature and precipitation, have been well documented by a network of weather offices and volunteer weather stations maintained by the National Weather Service and its predecessor, the U. S. Weather Bureau. But many of the parameters (such as measures of wind speed and incoming solar radiation) that are critical to an accurate assessment of renewable resources have been poorly and inconsistently quantified until rather recently. For solar radiation, the instrumentation deployed has been shown to be only marginally helpful in characterizing how much energy is available, especially in sparsely-populated areas of the state. Wind data are considerably more plentiful, particularly for the period of the past two decades. Still, the bulk of the most reliable weather-observing equipment (such as anemometers and pyrheliometers with digital recording capability) continue to be predominantly cloistered around airports in the state's most heavily populated areas, where only a modest fraction of the total amount of renewable energy resources is distributed. Moreover, there is no centralized facility where these data are routinely collected, examined for quality-control purposes, and archived for ready accessibility. In those parts of Texas where such resources as solar radiation and wind flow are particularly ample, the sensors that detect them have been sparse and poorly positioned, or they have not been in operation for a long enough period to quantify what is considered to be "normal" weather. Over the years, existing networks of weather observations have been geared primarily to serve the interests of aviation and not those of energy capture, distribution, and consumption.

Precipitation

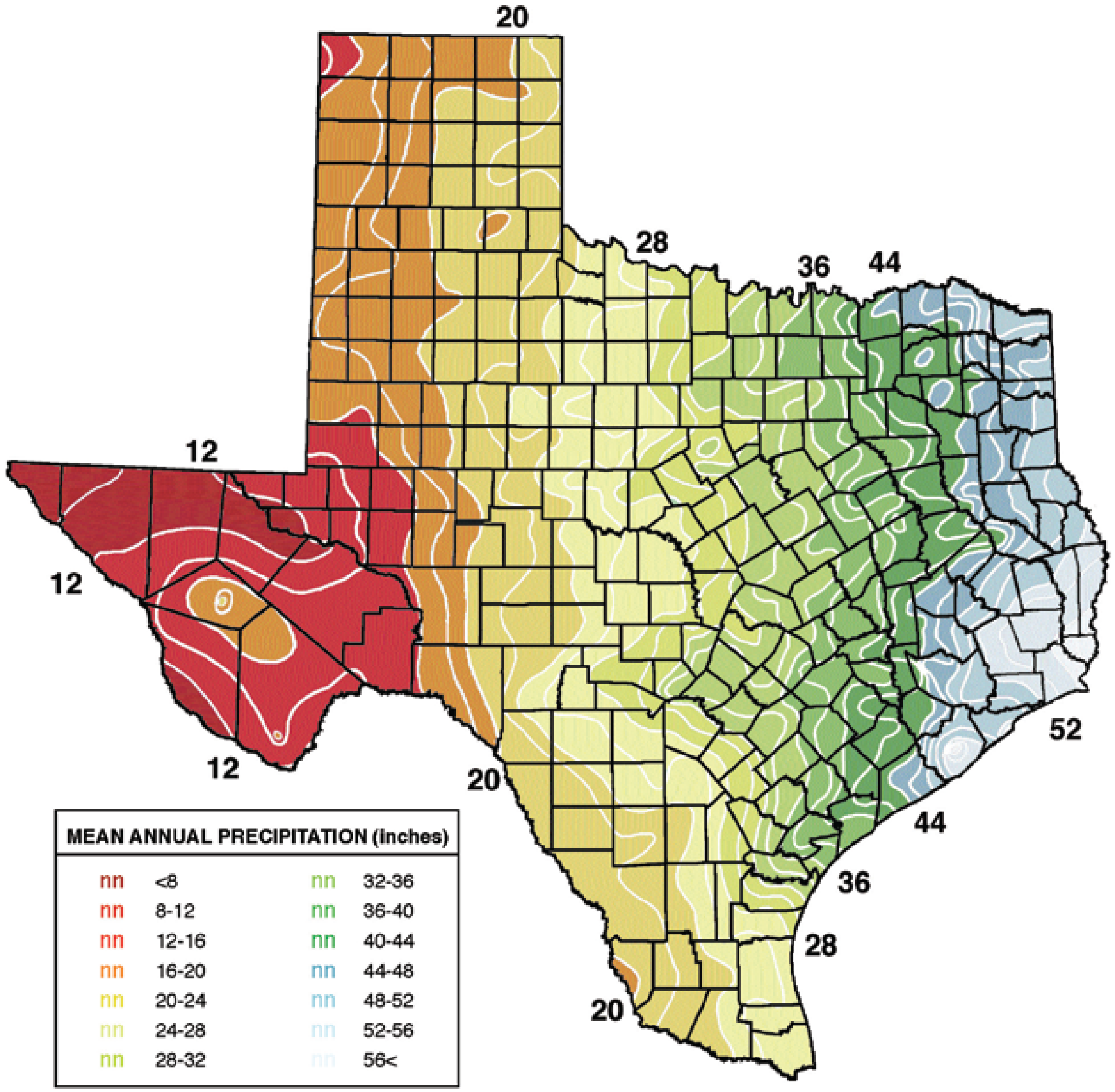
Nevertheless, enough data have been collected for long enough periods to allow a reasonable characterization of renewable climatic resources. The best-documented climatic resource, without a doubt, is precipitation, the bulk of which occurs in liquid form as rainfall. In a typical year, over half of Texas collects less than 30 inches of precipitation (**Exhibit 2-3**). The mean annual rainfall distribution is so diverse and disparate that the extreme western tip of Texas gathers a mere 8 inches while the easternmost edge along the Sabine River garners over 62 inches in a year. A rule of thumb is that precipitation, on an annual basis, decreases about 1 inch for each 15-mile displacement from east to west across Texas. So the Trans-Pecos region, with an average annual region-wide precipitation of under 12 inches, perennially is the driest climatic division of the state. By contrast, the eastern portion of the Upper Coast is the wettest region of the state, with a mean annual precipitation total of 55 to 60 inches.

Precipitation in a typical year is seldom spread even remotely uniformly across Texas. Virtually every region of the state has its "dry" and "wet" seasons (**Exhibit 2-2**). Spring is the wettest season of the year in most of Texas, with precipitation in the month of May somewhat more bountiful than in April. The exception is the western third of Texas (High Plains and Trans Pecos), where summer and early autumn furnish the bulk of the year's average rainfall. Thunderstorms, a sizeable number of which are nocturnal, are responsible for the bulk of rainfall in these regions.

Exhibit 2-2 Average Seasonal Precipitation (inches)

Location	Winter	Spring	Summer	Autumn	Annual
Abilene	3.37	5.91	7.39	7.11	23.78
Amarillo	1.79	4.96	8.90	4.06	19.71
Austin	6.32	9.68	8.09	9.56	33.65
Brownsville	3.65	5.37	7.69	10.84	27.55
Corpus Christi	5.21	7.27	9.07	10.71	32.26
Dallas-Ft Worth	6.84	11.41	7.38	9.10	34.73
El Paso	1.61	.87	4.11	2.84	9.43
Fort Stockton	1.57	2.69	4.99	4.81	14.06
Galveston	10.22	9.02	11.71	12.89	43.84
Houston	10.35	12.11	12.36	13.02	47.84
Laredo	2.55	5.20	7.20	6.58	21.53
Lubbock	1.88	4.36	7.47	4.98	18.69
Lufkin	12.06	11.95	9.86	12.75	46.62
Midland-Odessa	1.76	2.94	5.37	4.73	14.80
Port Arthur	14.29	13.42	16.66	15.52	59.89
San Angelo	2.94	5.68	5.67	6.62	20.91
San Antonio	5.37	9.21	8.90	9.44	32.92
Texarkana	12.66	13.66	10.85	14.07	51.24
Victoria	6.95	10.34	10.91	11.90	40.10
Waco	7.09	9.93	7.16	9.16	33.34
Wichita Falls	4.38	8.81	7.66	7.98	28.83

Exhibit 2-3 Average Annual Precipitation



Note: Based on 1961-1990 precipitation data from the cooperative weather observing network of the National Weather Service.[2] Intermediate contours (white lines) are indicated at 2 inch intervals. Throughout the data-sparse Trans-Pecos region, countours reflect higher uncertainty than in other parts of the state.

Exhibit 2-4 Average Monthly Minimum and Maximum Temperatures (°F)

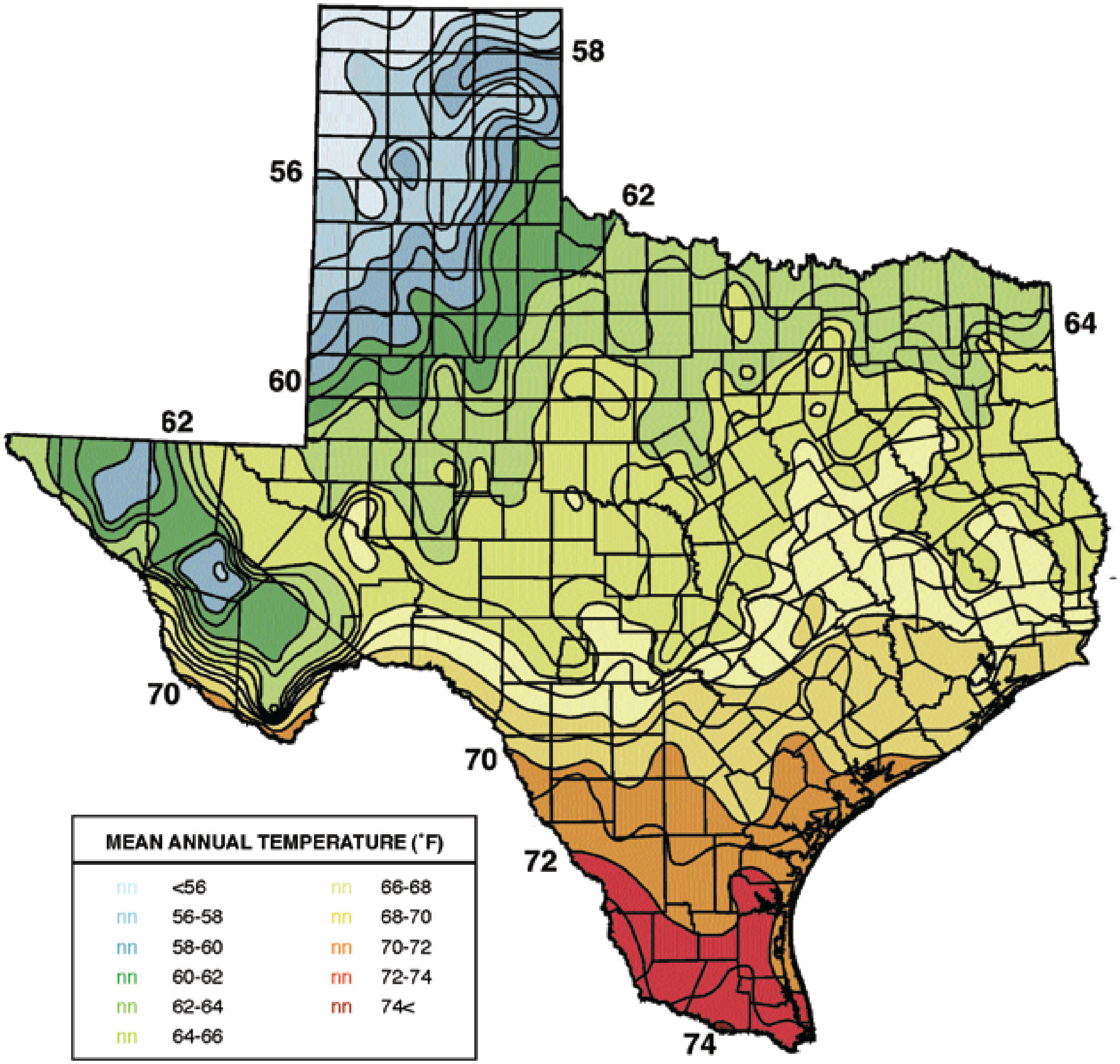
Location	January		April		July		October	
Abilene	32	55	52	77	72	95	54	78
Amarillo	23	49	42	71	65	91	45	72
Austin	40	60	58	79	65	91	45	72
Brownsville	51	69	65	82	75	92	66	84
Corpus Christi	46	66	62	81	74	93	64	84
Dallas-Ft Worth	34	54	54	76	75	95	56	78
Del Rio	40	63	59	83	74	96	61	82
El Paso	33	57	51	78	72	95	50	78
Houston	41	62	58	79	74	94	59	82
Laredo	44	68	63	89	75	102	63	87
Lubbock	24	52	45	75	68	92	47	74
Midland-Odessa	30	57	49	79	69	94	51	77
Port Arthur	43	62	59	78	74	92	60	81
San Angelo	32	58	51	79	70	94	53	84
San Antonio	39	62	57	80	74	95	62	83
Texarkana	36	53	54	75	73	93	55	77
Victoria	44	63	60	79	75	93	62	83
Waco	35	57	54	78	74	97	57	80
Wichita Falls	29	52	49	76	72	97	52	77

Temperature

An assessment of the state's renewable energy resources must also take into account how energy in the form of heat is expressed as air temperature, the distribution of which is influenced to a very large degree by the amount of solar radiation reaching the surface. This quantity of energy is of no small value owing to the fact that Texas covers a broad range of latitude (26˚N in the extreme south to 36˚N in the northern fringe) and, hence, is on the equatorial side of the mid-latitude regions. But its subtropical latitude is only one of the controlling factors related to the way solar radiation is used. Another is the influence of the Gulf of Mexico, which is best evidenced by the prevailing winds that blow from the sea surface inland for much of the year. Cold-air outbreaks in winter are quickly moderated once they reach Texas because they are readily mixed with air previously supplied from the Gulf.

Unlike mean annual precipitation, mean annual temperature varies not so much from east to west as, quite consistently, from north to south (latitudinally). The coldest temperatures anywhere in Texas are observed in the extreme northern sector of the High Plains, which also features the lowest mean annual temperatures anywhere in the state (**Exhibit 2-5**). Conversely, the highest (warmest) mean annual temperatures occur in Southern Texas along the Rio Grande, from Eagle Pass to Falcon Reservoir. In some years, the hottest temperatures of summer are observed in this region. (Average maximum daily temperature is shown in **Exhibit 2-6**; minimum average daily temperature appears in **Exhibit 2-7**.) In winter (January), the coldest mean minimum temperatures (in the low 20s), are observed in the High Plains (at Amarillo, for example), while in the summer (July), hottest mean daytime readings (in the upper 90s), are measured in the area along the Red River (at locations such as Dallas and Wichita Falls) (**Exhibit 2-4**).

Exhibit 2-5 Average Annual Temperature



Note: Based on 1961-1990 data from the cooperative weather observers network of the National Weather Service.[2] Intermediate contours (black lines) are generally indicated at 1 degree intervals. Throughout the data-sparse Trans-Pecos region, countours reflect higher uncertainty than in other parts of the state.

Exhibit 2-6 Average Daily Maximum Temperature

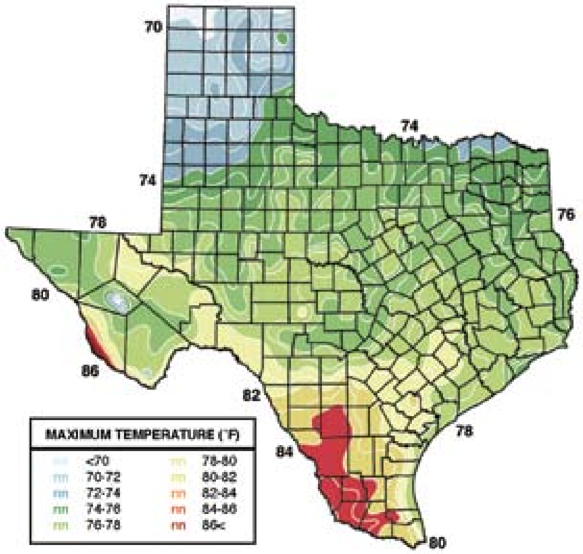


Exhibit 2-7 Average Daily Minimum Temperature

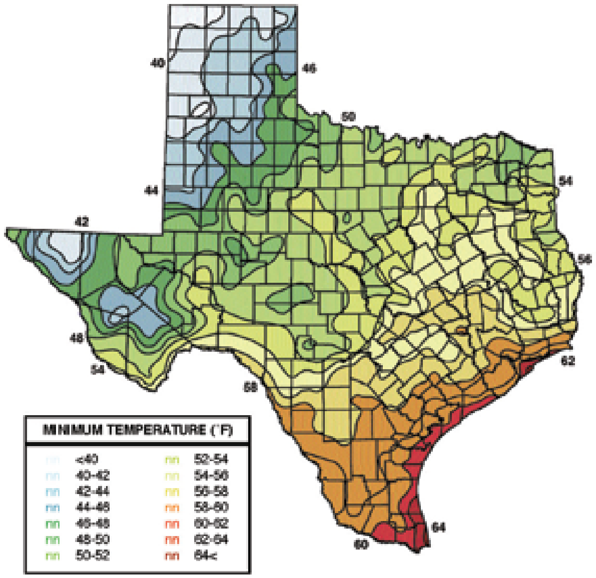


Exhibit 2-8 Average Wind Direction and Speed (mph) for the Mid Month of Each Season*

Location	January	April	July	October
Abilene	S 11.7	S 13.8	S 10.8	S 11.0
Amarillo	SW 12.8	SW 15.2	S 12.7	SW 12.8
Austin	S 9.3	S 10.1	S 8.3	S 7.9
Brownsville	S 11.1	SE 13.6	SE 11.3	SE 9.4
Corpus Christi	S 12.0	SE 14.3	SE 11.5	S 10.4
Dallas-Fort Worth	S 11.0	S 12.4	S 9.8	S 9.7
El Paso	NW 8.3	W 11.0	SE 8.3	SW 7.5
Houston	S 8.1	SE 9.0	SE 6.7	S 6.9
Lubbock	SW 12.0	SW 14.7	S 11.4	S 11.2
Midland-Odessa	S 10.4	SW 12.5	SW 10.8	S 10.1
Port Arthur	S 10.7	S 11.5	S 7.4	S 8.8
San Angelo	SW 10.2	S 12.1	S 9.8	S 9.3
San Antonio	S 8.8	S 10.1	S 9.1	S 8.3
Waco	S 11.3	S 12.6	S 10.7	S 10.0
Wichita Falls	N 11.3	S 13.1	S 11.1	S 10.7

*Typically measured at heights of 7 to 10 meters above the ground.

In spite of Texas' proximity to the Gulf of Mexico, day-to-night (diurnal) variations in temperature across the state are appreciable in all but parts of the state's coastal plain. On most days the moisture content of the lower atmosphere is sufficiently dry that, with the setting of the sun, air temperatures drop steadily. Mean annual diurnal temperature variations of 30˚F or more are observed in much of Texas west of the Pecos River where the air is exceptionally dry, while along the upper Texas coastline (most notably, Galveston Island) more than ample moisture much of the time keeps extreme minimum and maximum temperatures from varying more than 15˚F (**Exhibit 2-8**).

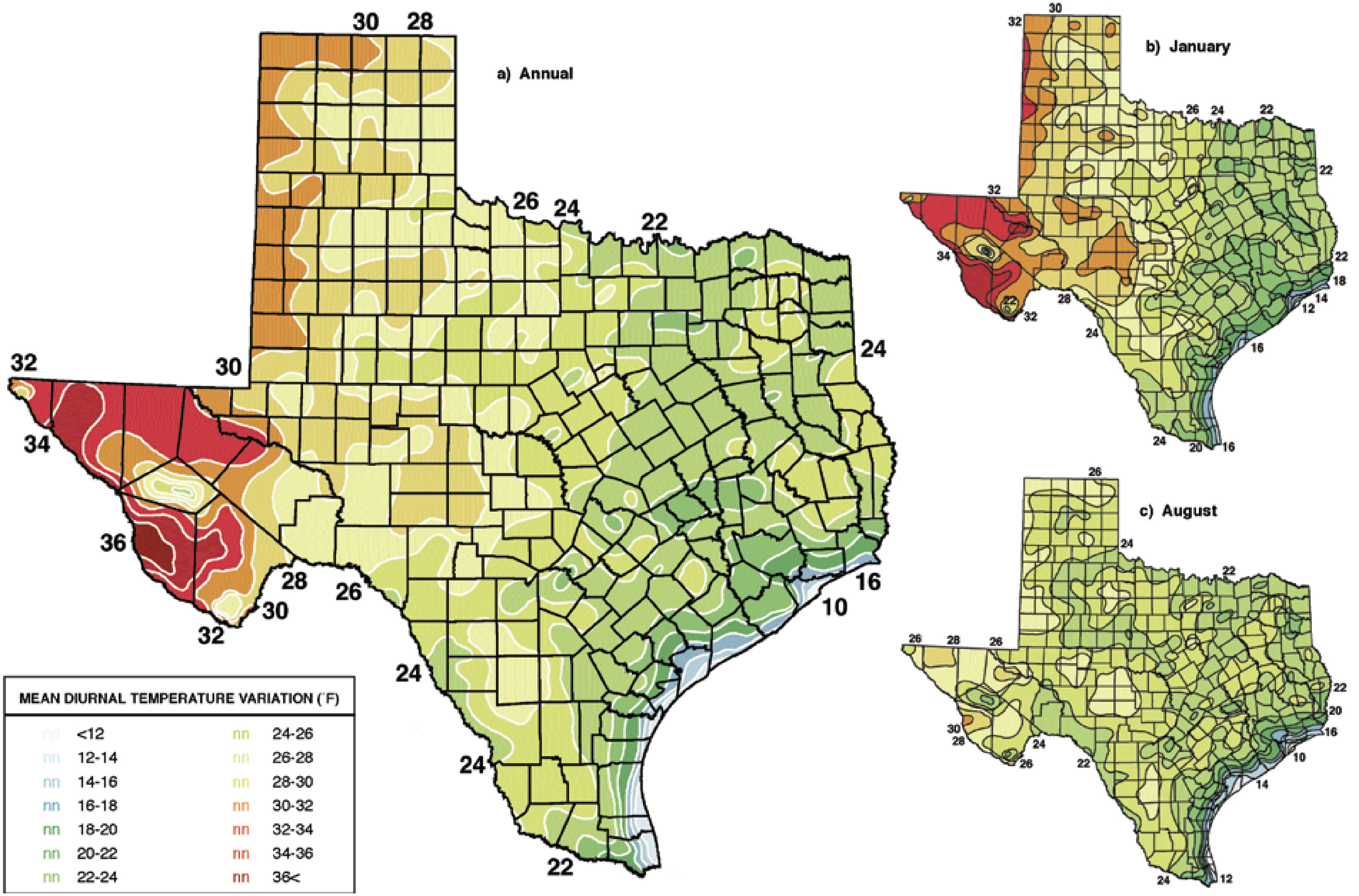
Occasionally, and particularly in winter, the air may be so laden with moisture that the diurnal range in temperature is only a few degrees. A blanket of clouds excludes much of the incoming solar radiation, thereby preventing the temperature from rising substantially above morning minimum values, and the same cloud cover can restrict outgoing heat energy at night so that minimum temperatures do not fall appreciably. The preponderance of cloud cover explains why, in a typical winter month, the range in diurnal temperature readings in the coastal plain is markedly less than that in the higher elevations in West Texas, where the air is much drier and the sky is usually cloud-free (**Figure 2-5b**). While the average diurnal variation is as little as 15-20˚ in that strip of coastal terrain within 20-30 miles of the coastline, the variation can be as little as 5˚ or less on as many as a half-dozen days in each of the months of December, January, and February. In the summer, because the air is warmer (and hence capable of holding more moisture), the diurnal temperature variation is not quite so small in the coastal plain (**Figure 2-5c**).

Wind Energy

The product of differences in atmospheric pressure between locations (pressure gradient), the strength and ubiquitous nature of the wind offers substantial promise as a source of renewable energy. While the wind is not merely a horizontal flow of air (its myriad of circular-moving eddies provides both upward and downward-moving pulses of energy), it is the lateral component of air motion that is of primary interest to energy providers and consumers. Though it has been poorly documented, the action of these individual eddies and the sum total of the vertical movement of the air at a particular place over a period of time may prove to be an additional and appreciable source of energy.

A southerly wind—or some component of it (southwesterly or southeasterly)—is the predominant wind condition in Texas for much of the year. In most sections of the state, the average wind speed varies between 7 and 15 miles per hour (**Exhibit 2-8**). A southerly wind is especially dominant in summer, when wind shifts induced by advancing cool fronts are much less common. In the southern half of Texas, where cool fronts often do not extend, a southerly wind is present some 90 percent of the time. In the north, northerly winds do blow on occasion, but southerly winds are observed at least 80 percent of the time. By contrast, the frequent intrusion of polar air in winter ensures a northerly wind about half of the time in much of Texas. Northerly winds are far from uncommon in both spring and autumn, though southerly flow remains dominant during those two seasons.

Exhibit 2-9 Mean Diurnal Temperature Variation (°F): a) Annual, b) January, and c) August. All three maps use the legend located at the bottom left of the page.[2]



Note: Throughout the data-sparse Trans-Pecos region, countours reflect higher uncertainty than in other parts of the state.

EXHIBIT 2-10 Average Number of Days with Various Sky Conditions

	January			April			July			October		
Location	CR	PC	CD	CR	PC	CD	CR	PC	CD	CR	PC	CD
Abilene	11	6	14	12	8	11	14	10	7	15	7	9
Amarillo	13	7	11	12	9	9	13	12	5	17	7	8
Austin	9	6	16	8	8	15	12	13	6	12	9	9
Brownsville	6	7	18	5	10	15	11	14	6	11	12	7
Corpus Christi	7	7	17	6	9	15	11	14	6	12	10	8
Dallas-FtWorth	10	6	16	9	8	13	15	10	6	14	7	10
El Paso	14	7	10	17	8	5	12	13	5	19	7	5
Houston	7	5	18	7	7	16	7	16	8	11	9	11
Lubbock	12	6	12	12	9	9	14	11	6	17	7	8
Midland	12	6	12	13	8	9	13	11	7	17	6	8
Port Arthur	7	6	18	6	8	16	7	15	9	12	10	9
San Angelo	12	6	13	11	8	11	15	10	7	15	7	8
San Antonio	9	6	16	7	8	15	9	15	7	11	10	9
Waco	9	6	16	9	7	14	14	10	6	13	8	9
Wichita Falls	11	6	14	11	8	11	15	9	7	15	7	9

CR = clear; PC = partly cloudy; CD = cloudy

For the year as a whole, the vast tableland known as the High Plains is the windiest region in the state, though some coastal locations also benefit from vigorous wind movement much of the time. In fact, with winds in the spring averaging from 13 to 17 miles per hour, the High Plains of northwestern Texas is one of the windier sectors of the North American continent. On many days during spring, and not infrequently in other seasons, the wind habitually gusts to a velocity two or three times as much as the daily average wind speed. Gusts in the vicinity of thunderstorms may exceed 60 miles per hour several times in any one season. The winter in the High Plains is almost as windy, however, as frequent invasions of polar or Arctic air sometimes make outdoor activity hazardous for human beings and livestock.

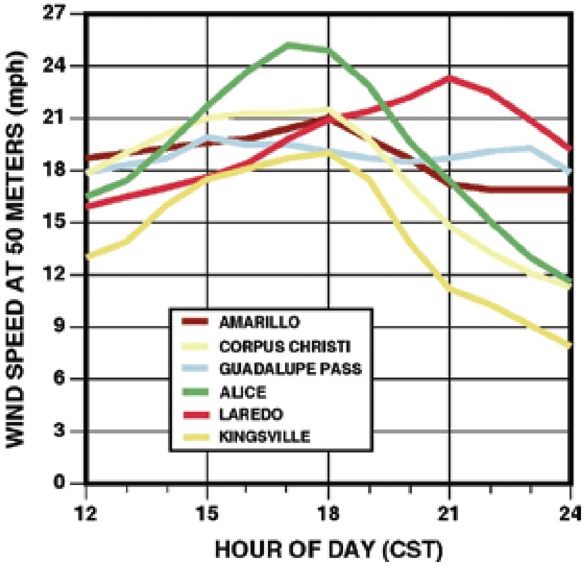
Wind speeds vary in relation to time of day. As a general rule, and in the absence of a “forcing mechanism” such as an approaching frontal system or thunderstorm, the wind attains a maximum velocity from midday through the late afternoon, in response to the peak flow of incoming solar energy (warmth). This is especially true during the warmest season of the year, when the demand for electric power for cooling also is maximized during the hottest portion of the day. Yet, as **Exhibit 2-11** illustrates, even at locations near one another and within the same climatic region, wind speeds can vary dramatically. The peak wind of 20 miles per hour or greater at some coastal sites suggests the influence of the sea breeze, while locations more distant from the coastline may feel less effect from that phenomenon and, hence, sustain lower maximum wind speeds.

The intensity and timing of maximum winds may also depend upon a community's proximity to marked topographic features, such as mountain ranges and basins. In more arid climes (such as the Guadalupe Mountains), where the dry air allows the temperature to reach a maximum earlier in the afternoon, the peak wind occurs not much beyond midday. Some locales within reach of the sea breeze (such as Corpus Christi) experience highest winds in concert with the migration of the breeze inland, or some four to five hours after high noon. Cities far removed from the effect of the sea breeze (such as Laredo), but in the path of outflow from a desert, may not experience fastest winds until nearly sunset, or when the gust from hot air radiating from the desert reaches the city.

Insolation and Cloud Cover

The availability of insolation as an abundant renewable energy resource is evidenced in a number of ways. One means of quantifying the resource is by the number of days characterized by cloudy or cloud-free skies (**Exhibit 2-10**). A clear sky, or the equivalent of a maximum of incoming solar energy, is most common in the western sector of Texas, particularly during the colder half of the year. In much of the Trans-Pecos, for instance, the sky is cloud-free on an average of two of every three days during both the autumn and winter. Even in the warmer half of the year, the sky in this region is overcast on only one day of every six. By contrast, over half of the days in winter and spring are overcast in southeastern Texas, and only one in four days during these seasons is free of cloud cover. In that part of Texas east of the 100th meridian, the least likelihood of overcast skies occurs during the summer, even though partial cloud cover is more prevalent in this season than in any other.

EXHIBIT 2-11 Average Summer Afternoon Wind Speed at 50 Meters Above the Ground.



Note: Estimated from measurements taken closer to the ground, typically at 7-10 meters.

EXHIBIT 2-12 Average Amount of Sunshine (as Percent of the Total Possible)

	Winter			Spring			Summer			Autumn		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Abilene	62	62	64	70	72	70	78	80	78	71	72	67
Amarillo	67	69	68	72	74	71	78	79	77	73	75	72
Austin	49	49	51	55	54	56	69	75	75	66	64	54
Brownsville	42	41	48	53	58	63	73	80	76	68	65	51
Corpus Christi	43	44	49	54	56	59	72	79	76	68	67	54
Dal-Ft Worth	52	52	54	58	61	57	67	75	73	67	63	57
El Paso	77	78	82	86	89	90	90	82	81	83	84	83
Houston	51	45	50	54	58	62	68	70	68	66	64	52
Lubbock	65	65	66	73	74	71	76	77	76	71	75	69
Midland	65	66	69	73	78	78	81	81	77	77	72	74
Pt Arthur	47	42	52	52	52	64	69	65	63	62	67	57
San Antonio	48	47	50	57	56	56	67	74	74	67	64	54

Obviously, the time of day when cloud cover is most likely to occur has an appreciable impact on available solar energy. In winter, for instance, an opaque cloud layer has a peak occurrence in the few hours following sunrise (**Exhibit 2-13**); it is least likely during the mid-afternoon hours, or just after the peak period of incoming solar insolation. This pattern of maximum cloud cover at mid-morning and minimum cloud cover in mid-afternoon is observed in most of Texas. It is most pronounced in the coastal plain (at locations such as Houston, Corpus Christi, and Brownsville). Only in the area west of the Pecos River (for example, El Paso) is the frequency of occurrence of opaque cloud cover spread almost uniformly throughout the day.

During the peak heating season, however, when solar insolation is at a maximum, the pattern of opaque cloud cover is not nearly so uniform statewide. In semi-arid West Texas, where the bulk of the year's substantive rainfall is produced by deep convective cloud formations, opaque cloud cover reaches a maximum at midday or in the early afternoon hours, when thunderstorms have matured and spread a shield of far-reaching cirrus clouds across the sky (**Exhibit 2-14**). The near-surface layer of air is hardly moist enough to allow a morning overcast to develop, hence the frequency of occurrence of opaque cloud cover is quite small (less than 35 percent of the time). The pattern is almost reversed in lower elevations, however. A thick near-surface layer of moist Gulf air foments the formation of a deck of stratus clouds on nearly half of the mornings in the month of August. The rising sun usually dissipates the stratus by late morning. A secondary peak of opaque cloud cover results from the eruption of scattered deep convection (thunderstorms) during the peak heating period of the day.

An even better indicator of available solar energy for specific sites in Texas is the measure of sunshine, usually expressed as the percent of the total possible for the given location (**Exhibit 2-12**). As a general rule, sunshine is more abundant in the higher elevations of western Texas, no matter the season of the year. The region where sunshine is superabundant almost year-round is the area west of the Pecos River, particularly in the vicinity of the Rio Grande. There, from mid-winter until mid-summer, uninhibited sunshine is available more than 90 percent of the time during daylight hours. On the other hand, sunshine is most scarce in the coastal plain during the three coldest months of the year (December through February). In this region of low elevation, sunshine is most plentiful (at least two-thirds of the time) during the summer.

Exhibit 2-13 Average Opaque Cloud Cover for January

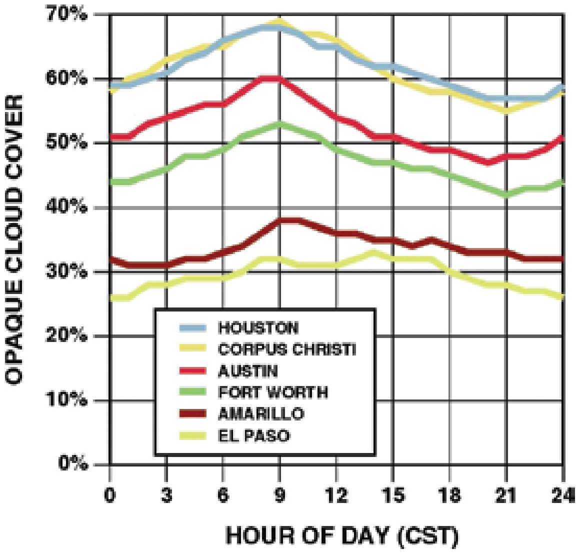
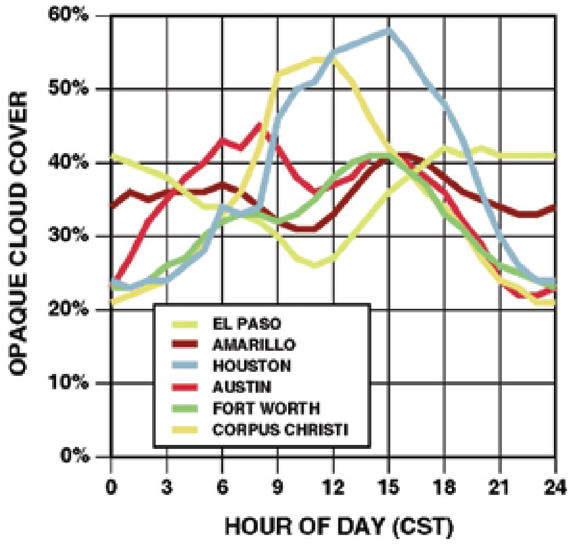


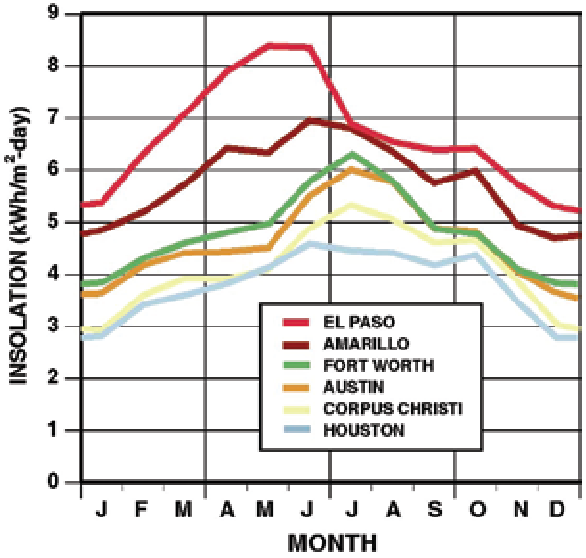
Exhibit 2-14 Average Opaque Cloud Cover for August



Direct measurements of incoming solar energy reflect a maximum in semi-arid West Texas that is coincident with the occurrence of the summer solstice (June 21) (**Exhibit 2-15**). The rainy season west of the Pecos River usually does not get underway until some weeks after the solstice, and the onset of an almost daily occurrence of significant thunderstorm development sometime in July brings about a rather sharp diminution of normal insolation.

In the east, especially in the coastal plain, a seasonal rainfall maximum in the late spring coincides with a relative minimum in normal insolation at locations such as Houston, Corpus Christi, and Brownsville. This is followed by a respite in thunderstorm frequency in early summer, when normal insolation increases appreciably. However, insolation drops proportionally in late July or early August with a tropical-cyclone season increasing the frequency of daytime showers and thunderstorms along the coastline and tens of miles inland.

Exhibit 2-15 Average Direct Solar Radiation by Month



Regrettably, while it is a key element in the spectrum of renewable energy resources in Texas, solar radiation may be the most poorly quantified, and hence least understood. This is due to the lack of an extensive observation network in Texas that detects sunshine. Where sensors are deployed, most have operating characteristics that are hardly uniform from one location to another. Solar energy is a resource marked by great variability over short distances, owing to cloud or turbidity conditions that are highly erratic. For the most part, reliable sunshine data are available for only a few of the largest metropolitan areas of the state. This means that vast areas of the High Plains, Low Rolling Plains, Edwards Plateau, Trans-Pecos, and Southern Texas are not well represented by existing data on sunshine availability. Even the more densely populated regions of northeastern and East Texas are lacking in good-quality sunshine data. That is all the more reason why the need for expanded coverage of radiation sensors and better standardization of instrument usage should be recognized and addressed. Nonetheless, the reliable data that do exist corroborate the fact that Texas is well endowed with this resource.

Summary

Texas, by virtue of its proximity to a surface energy source (the Gulf of Mexico) and its strategic position beneath a potent stream of energy aloft in the atmosphere (the subtropical and polar jets), is rich in renewable energy resources. The degree of abundance of each climate-related resource can be attributed to the intensity of solar insolation and by the gradient of that insolation from place to place across the state. After all, it is the disparity in incoming solar energy, from season to season and from locale to locale, that dictates the temperature gradients observed from west to east and from north to south across the Lone Star State. These temperature gradients ultimately determine the pressure gradients and the fluctuations in wind associated with them. The differential in pressure, in turn, determines the origin of air masses that migrate into and out of Texas with a striking degree of regularity throughout much of the year. How the weather behaves from year to year, in relation to this intricate energy budget, provides us with some measure of just how energy-rich the state really is.

References

[1] George W. Bomar, Texas Weather, 2nd Edition. The University of Texas Press: Austin, TX. 1994.

[2] Climatography of the United States NO. 81: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1971-2000. National Oceanic and Atmospheric Administration: Asheville, NC. 2003.

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.

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.

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.

The Characteristics of Solar Radiation

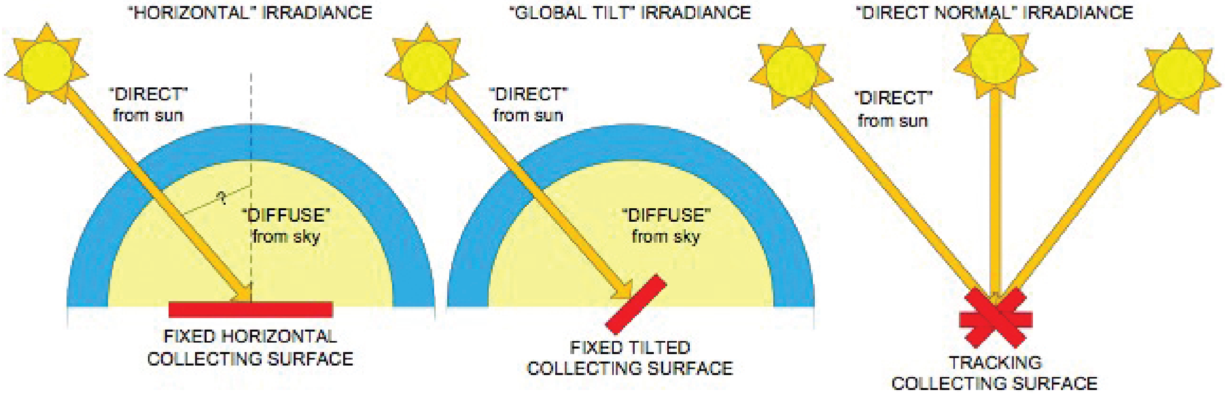
The various solar energy applications/technologies are influenced by the character of the resource, such as its directional nature (whether the sunlight is direct of diffuse—by clouds, for example—and it's angle of incidence on the collector surface), its spectral nature (what specific wavelengths of 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

Global Horizontal (GHI) = Direct Normal (DNI) × cos(θ) + 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.

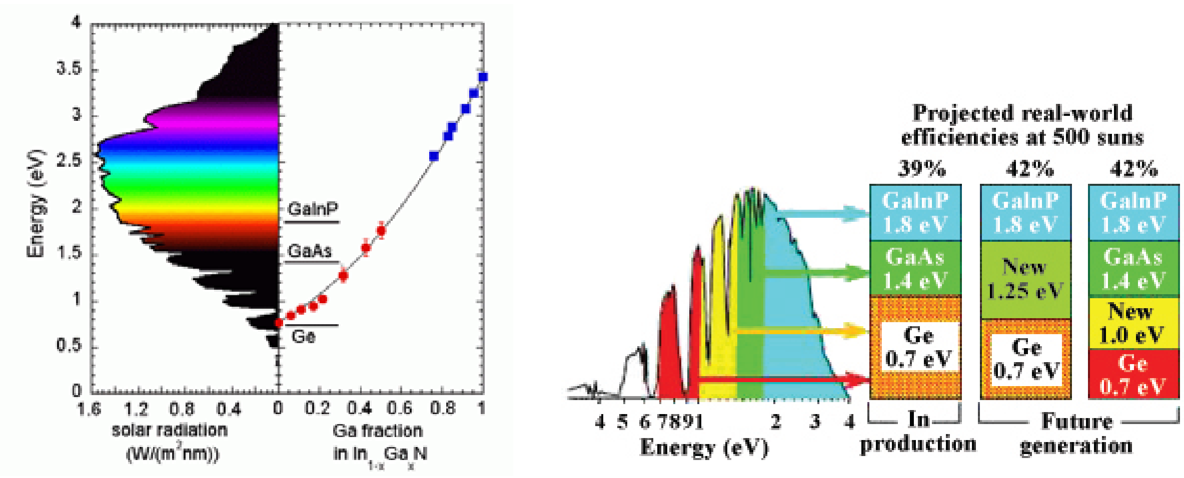
Variability

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

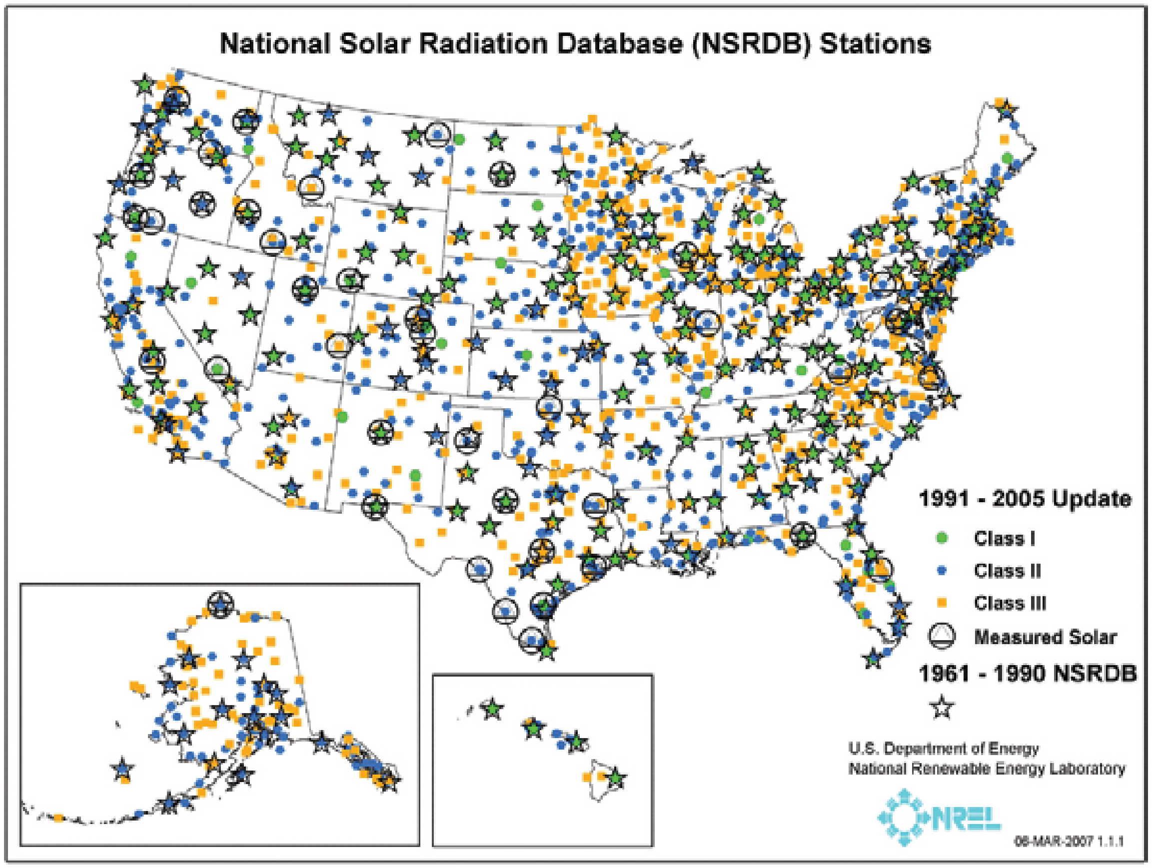
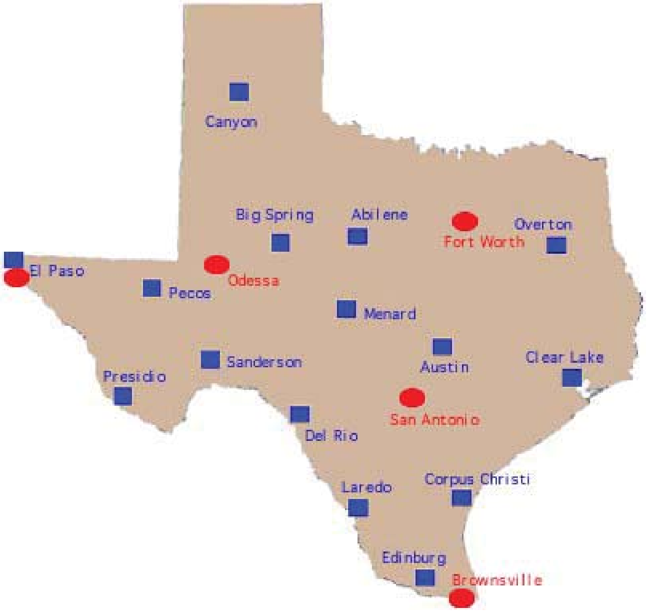


Exhibit 3-5 TSRDB Sites



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

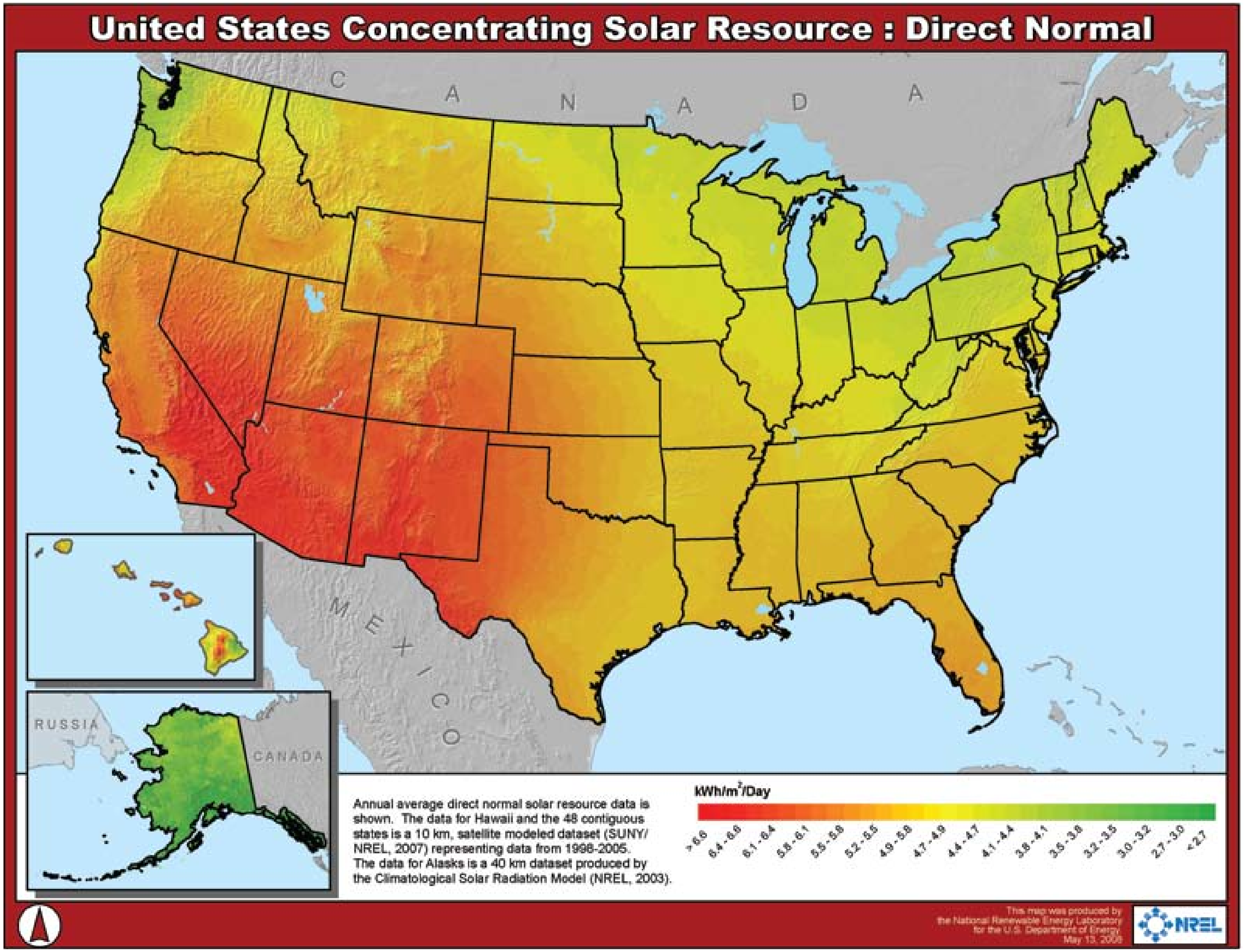
The average annual daily solar radiation (kWh/meter^2/day) at a specific location is of prime importance, as it is a good indicator of the long-term performance and economics of solar energy systems at that location. Since most common solar applications use either concentrating collectors (which collect 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.

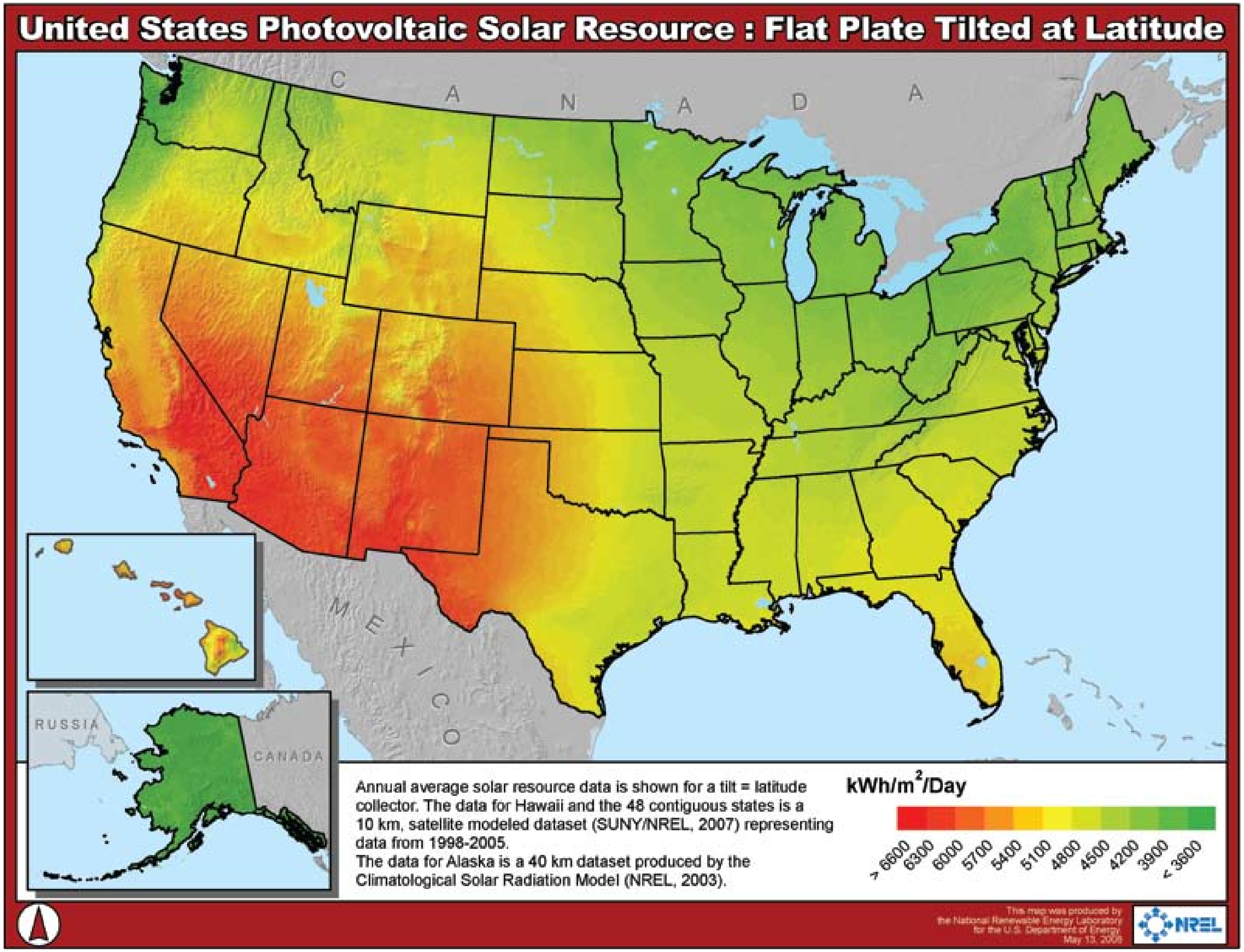
Exhibit 3-6 Direct Normal Solar Insolation (applicable to concentrating solar energy technologies, such as large-scale CSP power plants)



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).

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)

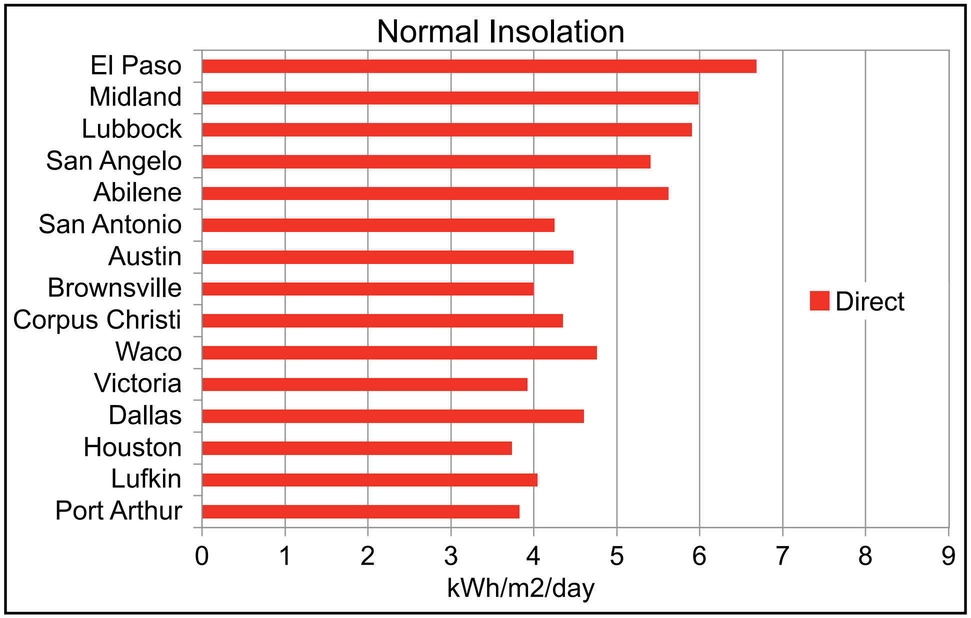


Exhibit 3-9 Horizontal Insolation (kWh/m2/day) (cities appear in order from west to east)

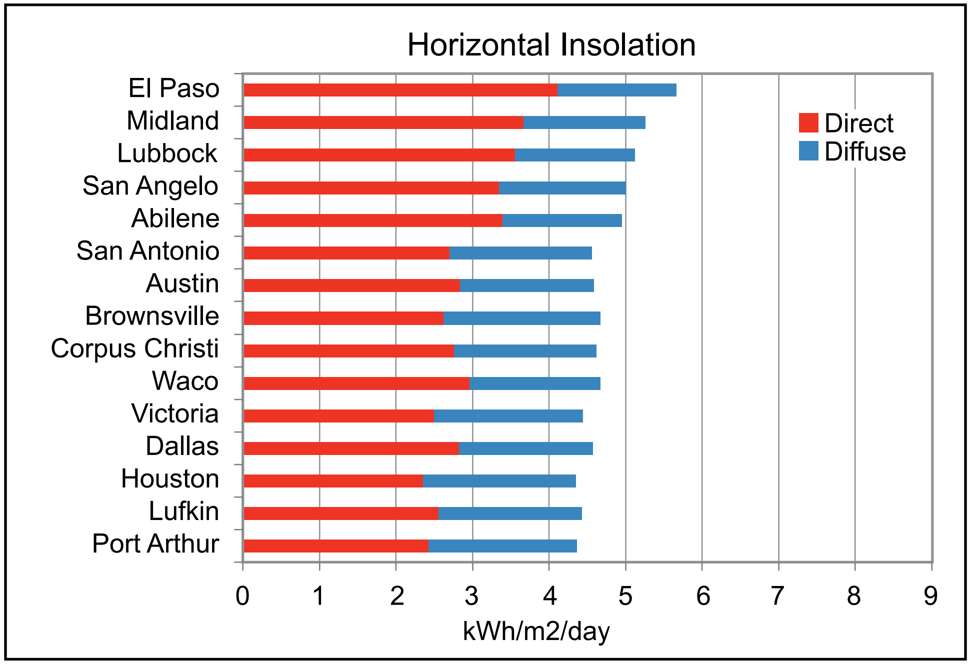
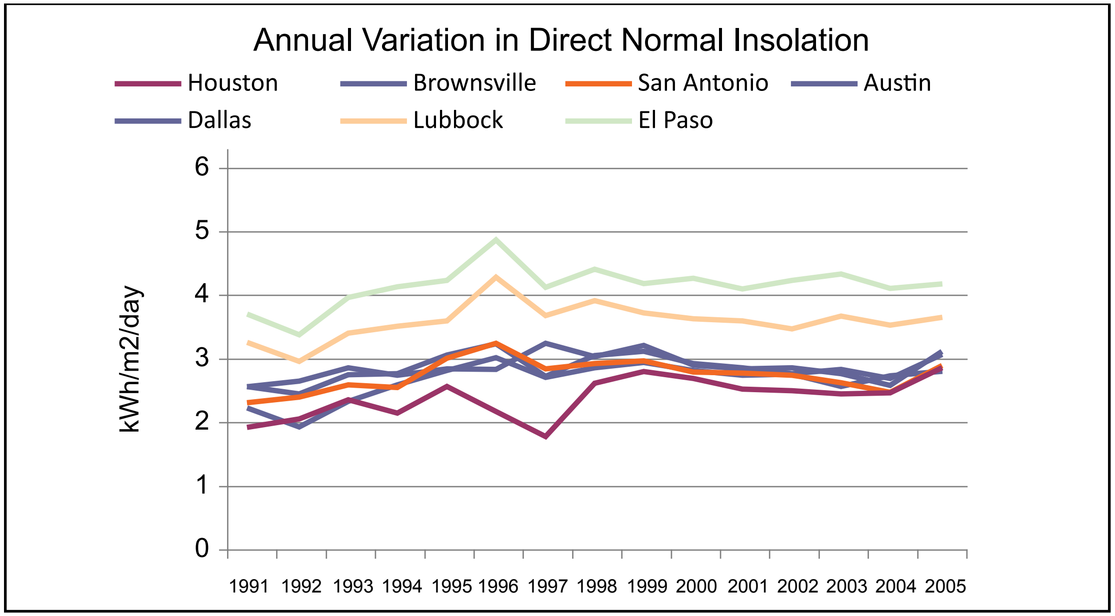
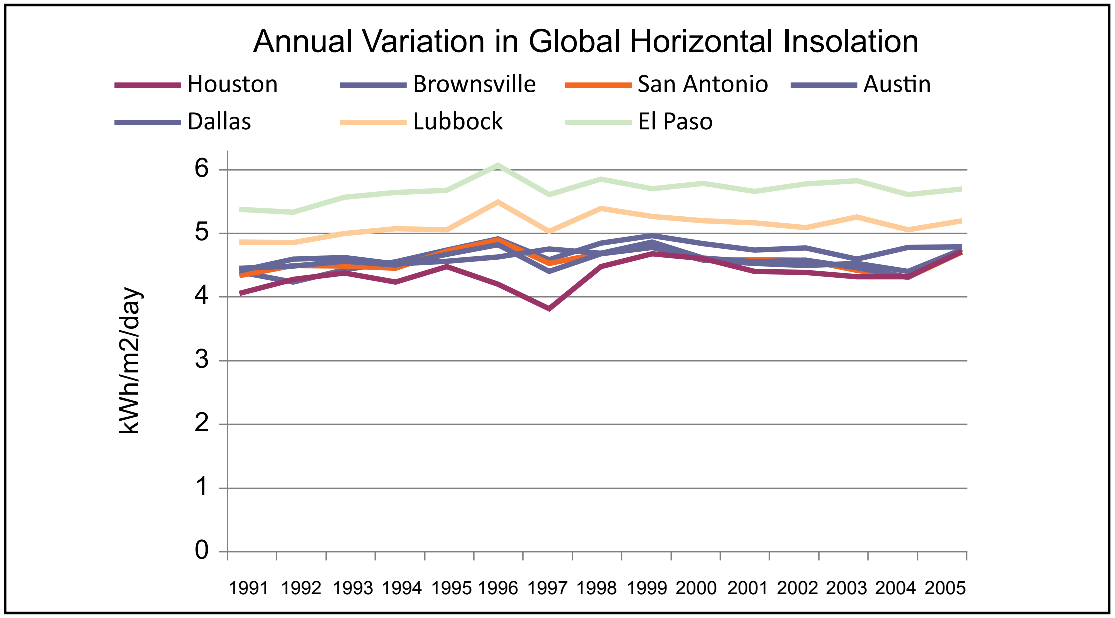


Exhibit 3-10 Annual Variability





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

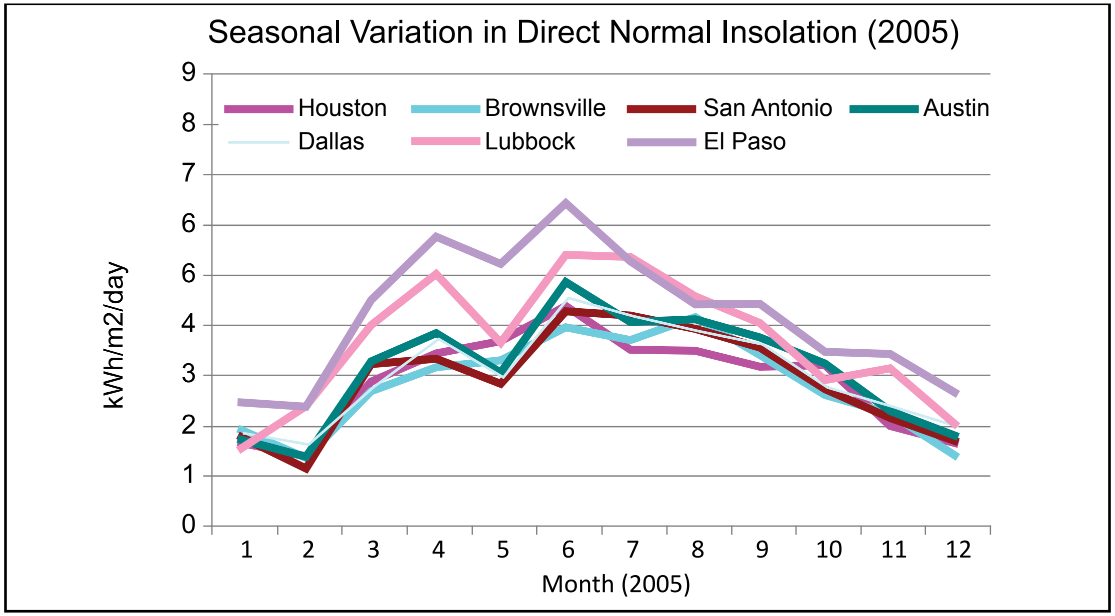
The annual variability in direct normal and global horizontal insolation by year from 1991 to 2005 is shown for several Texas locations in **Exhibit 3-10**. Variability in annual insolation from year to year is small, typically about 15%. Low and high insolation years typically occur simultaneously for 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



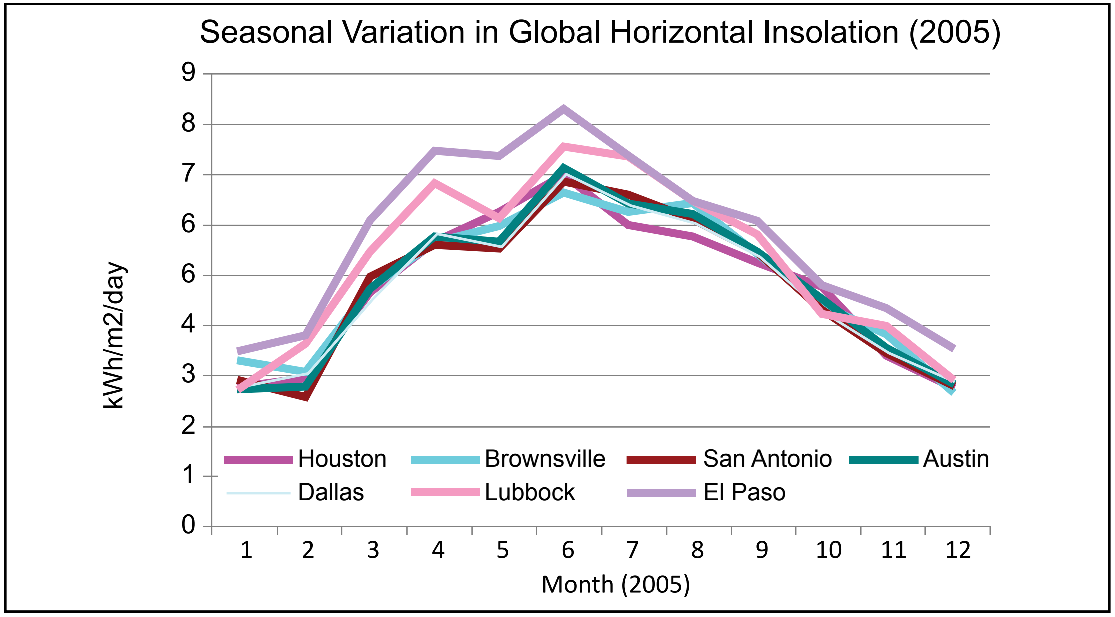
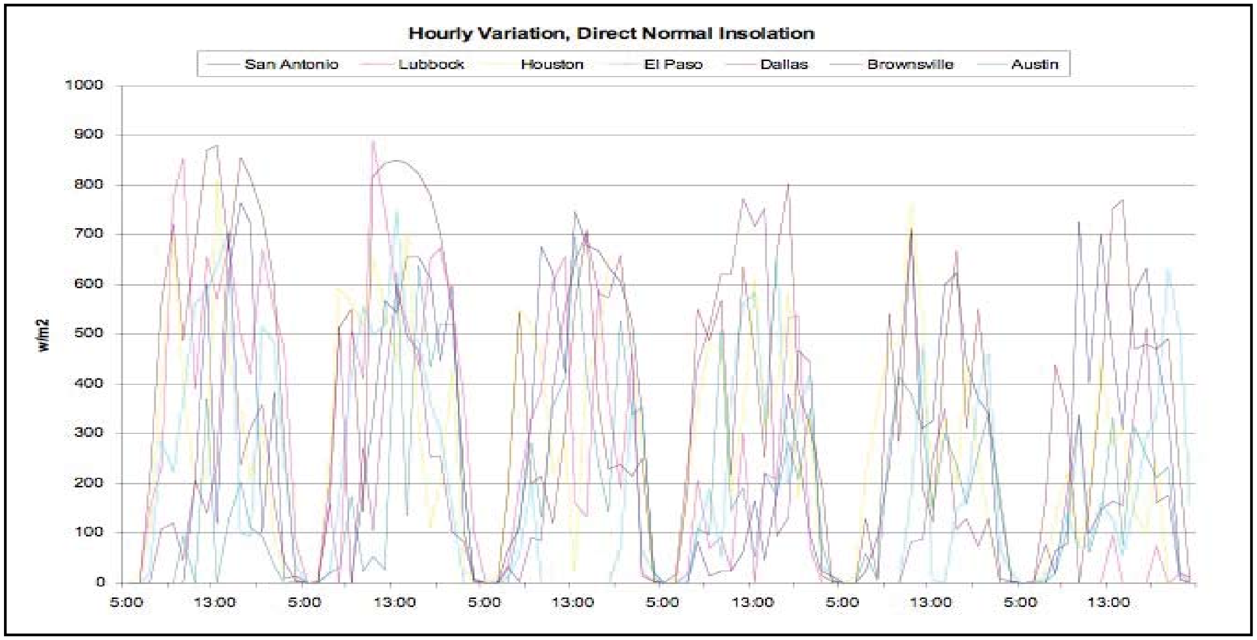
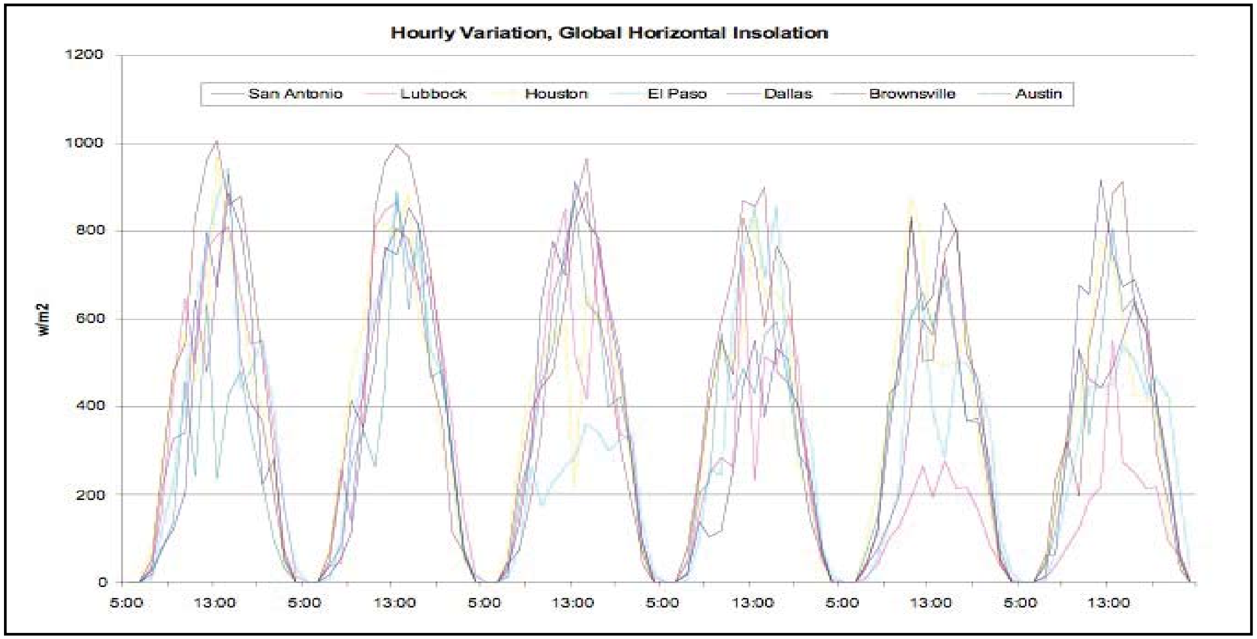


Exhibit 3-12 Daily and Short Term Variability[19]





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 mi^2 / 1.6 km^2), while the solar collectors cover 300 acres (1.2 km^2). 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)

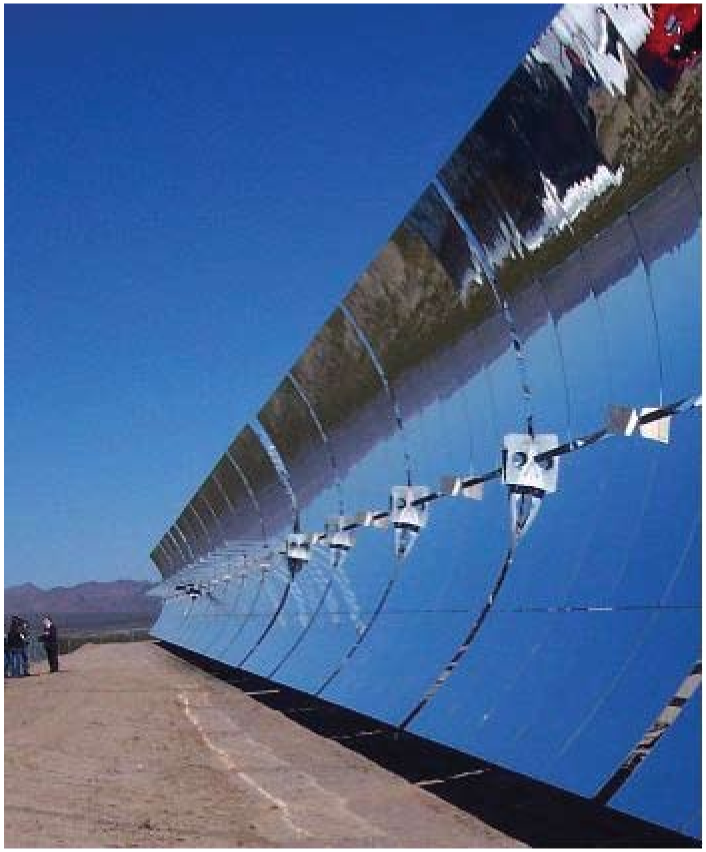


Exhibit 3-14 Solar Two (central receiver design)

Exhibit 3-15
Dish concentrator
(dish Stirling design)

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

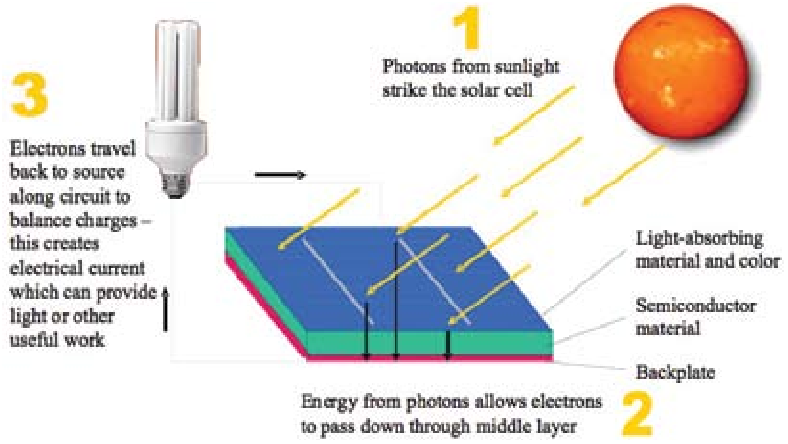
The use of 'dish concentrators' is a third promising design. The heart of the design is a parabolic dish reflector, which tracks the sun and concentrates the direct solar radiation to its focal point. Depending on the design, the radiation either: 1) heats a fluid, which drives a steam turbine-generator; 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.

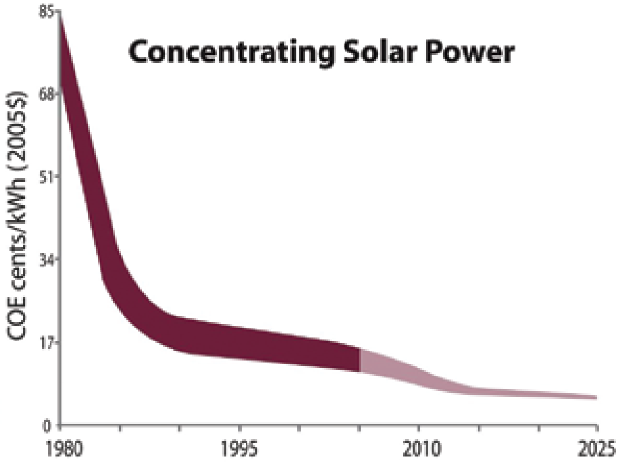
Photovoltaics

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.

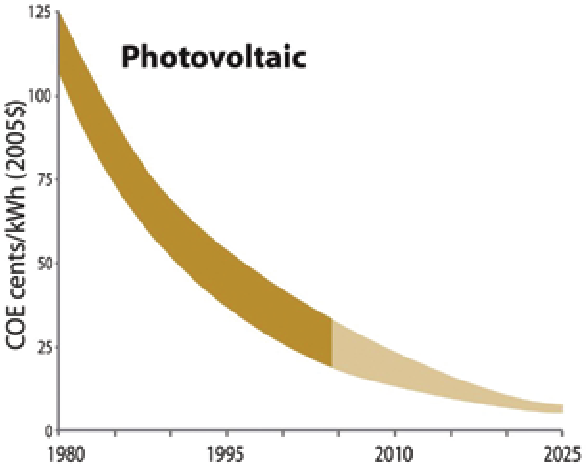
Exhibit 3-22 Levelized Cost of Concentrating Solar Power, Historical (1980-2005) and Projected (2006-2025)



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.

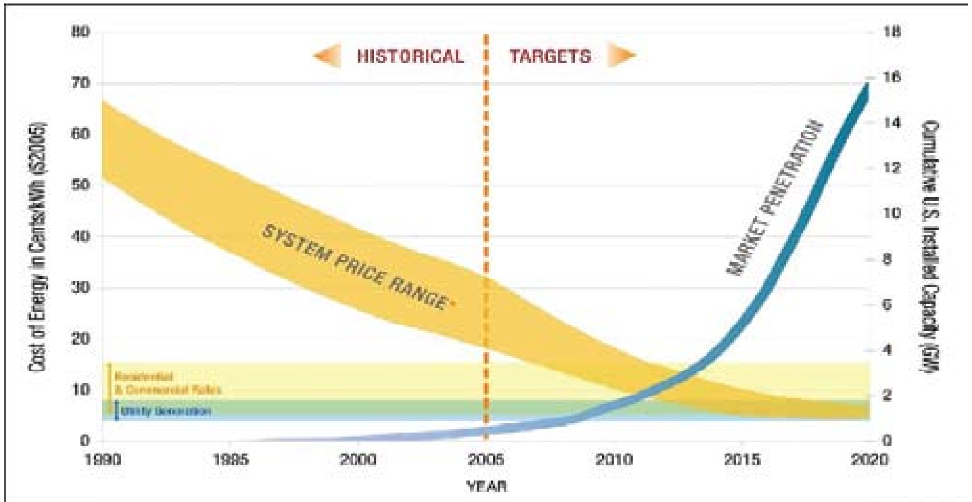
Source: Renewable Energy Cost Trends, Levelized cost of energy in constant 2005, NREL Energy Analysis Office

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.

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[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/.

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CHAPTER 4

WIND ENERGY

Introduction

The use of wind as an energy source has its roots in antiquity. At one time wind was the major source of power for pumping water, grinding grain and long distance transportation (sailing ships). The farm windmill was instrumental in the settlement of the Plains of Texas. The advantages of wind are: renewable, ubiquitous, and does not require water for the generation of electricity. The disadvantages are: variable and low density, which means high initial costs. In general windy areas are distant from load centers, which means transmission is a problem. The installation of wind farms in Texas (estimated to total approximately 8,800 megawatts by the end of 2008) has been the major change since the previous Texas Renewable Energy Resource Assessment in 1995. In 2006, Texas surpassed California and became number one in the United States in installed wind capacity.

Farm Windmill

The farm windmill proves that wind power is a valuable commodity. Although the peak use of farm windmills was in the 1930's and 1940's when over 6 million were in operation, these windmills are still being manufactured and are being used to pump water for livestock and residences. In Texas, there are an estimated 30,000 to 40,000 operating farm windmills. Even though the power output of each is low—equivalent to 0.2 to 0.5 kilowatt (kW)—collectively they provide up to 20 million watts (20 MW) of power. If these windmills for pumping water were replaced by electricity from the grid, it would require 60 MW of thermal power from a conventional generating station, not to mention an extensive investment in transmission lines, electric pumps and other equipment. This says nothing of the energy (and money) saved by not using fossil fuels to satisfy this energy need (equivalent to 80,000 barrels of oil per year).

Small Systems (up to 100 kW)

During the 1930's, small wind power systems (100 Watts to 1 kW) with batteries were installed in rural areas, however these units were supplanted with power from rural electric cooperatives. After the first oil crisis in 1973, there was a resurgence interest in small systems. Today there are around 600,000 small wind units installed in the world, with the majority in China. The small wind industry in the United States is dominated by Southwest Windpower and Bergey Windpower, manufacturing units from 200 W to 10 kW. A small number of 50 kW units are also produced. However due to the high price of oil, Entegrity Wind expects to produce up to one hundred 50 kW units in 2008.

Future Uses

One development is the wind electric-to-electric water pumping system[1]. The wind turbine is coupled directly to an electric generator, just as in larger systems. The generator is then connected directly to a motor, which is connected to centrifugal, or turbine pump. This is a better match between the characteristics of the wind rotor and the load. This results in an overall efficiency of 12 to 15 percent for pumping water, double the performance of the standard farm windmill. The costs of the two systems are almost the same, however the wind-electric system pumps more water from the same depth. Large wind-electric systems can pump enough water for small communities or for low volume irrigation. Wind has been and will continue to be a major source of energy for pumping water for livestock in Texas.

If economical energy storage becomes feasible, then wind will be even more valuable. The three main possibilities are batteries[2], hydrogen production[3] and compressed air[4]. The Xcel project in Minnesota to store wind energy consists of twenty, 50-kW battery modules to store about 7.2 MWh of electricity. Another example to increase firm power is a proposed hybrid offshore wind-hydrokinetic ocean current project off the Texas coast (www.hydrogreen.com and www.windenergypartners.biz/home.html).

When carbon dioxide trading becomes part of the energy policy in the United States, wind energy will also be more valuable (a 2¢ to 3¢ per kWh increase). This is based on the average equivalent carbon produced per kWh at conventional fossil fuel power plants and a metric ton of carbon having a value of $30/ton or greater.

Development Issues: Considerations for Large Scale Use

Wind Farms

The three main considerations for development of wind farms are: 1) windy land, 2) access to transmission and 3) a power purchase agreement. Power purchase has been driven by Federal (today, the production tax credits) and State regulations (renewable portfolio standards).

The development of wind farms began in the early 1980's in California with the installation of wind turbines ranging from 25 to 100 kW. Today, wind turbines are available in megawatt sizes with rotor diameters of 60 to over 100 meters and installed on towers of 60 to over 100 meters. At the end of 2007, there were 94,200 MW of installed capacity in the world, with the majority in Europe (**Exhibit 4-1**) followed by the United States (**Exhibit 4-2**).

As of 2007, there were 31 wind farms in Texas (**Exhibit 4-3**), with an installed capacity of 4,494 MW (**Exhibit 4-4**) from 3210 wind turbines. The estimated numbers by the end of 2008 are 56 wind farms, 8,876 MW, and 5877 wind turbines. By the end of 2008 there will be five wind farms in Texas ranging in size from 523 to 782 MW.

The renewable portfolio standard (RPS) for Texas (1999) in conjunction with the Federal production tax credit (1992) gave rise to the wind farm boom in Texas. Notice that in the 2000, 2002, and 2004 there was no installation of wind power due to the late passage of extension of the production tax credit. The last four years show that the RPS and consistent production tax credit have driven the uninterrupted growth of wind farms in Texas to number one in the United States.

Exhibit 4-1 Installed capacity of wind farms in the world.

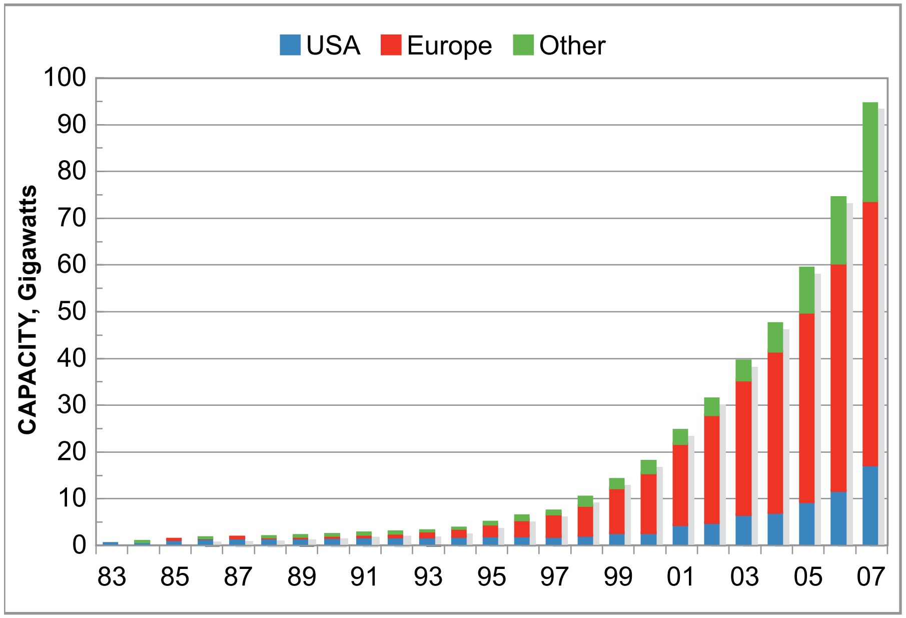


Exhibit 4-2 Installed capacity of wind farms in the United States.

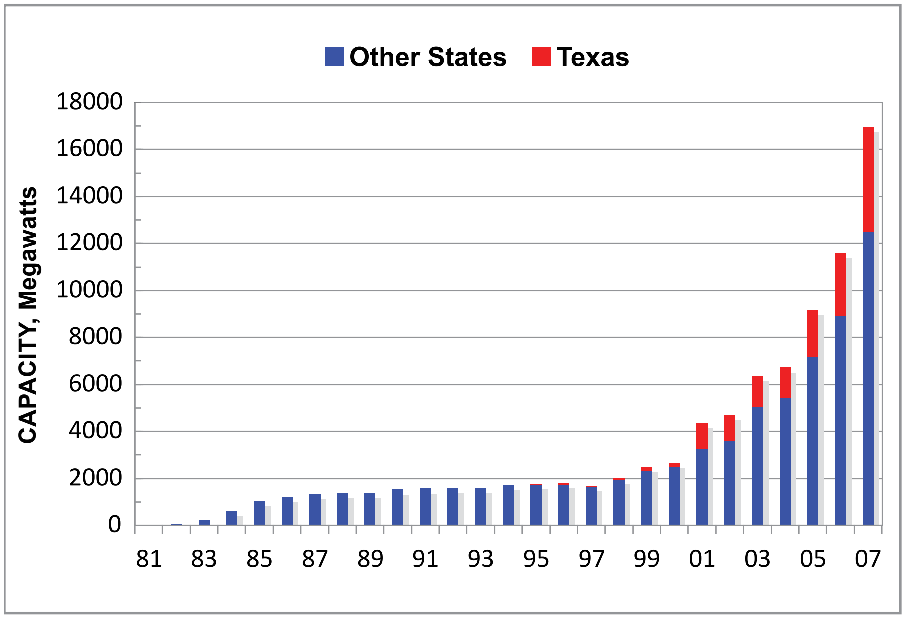
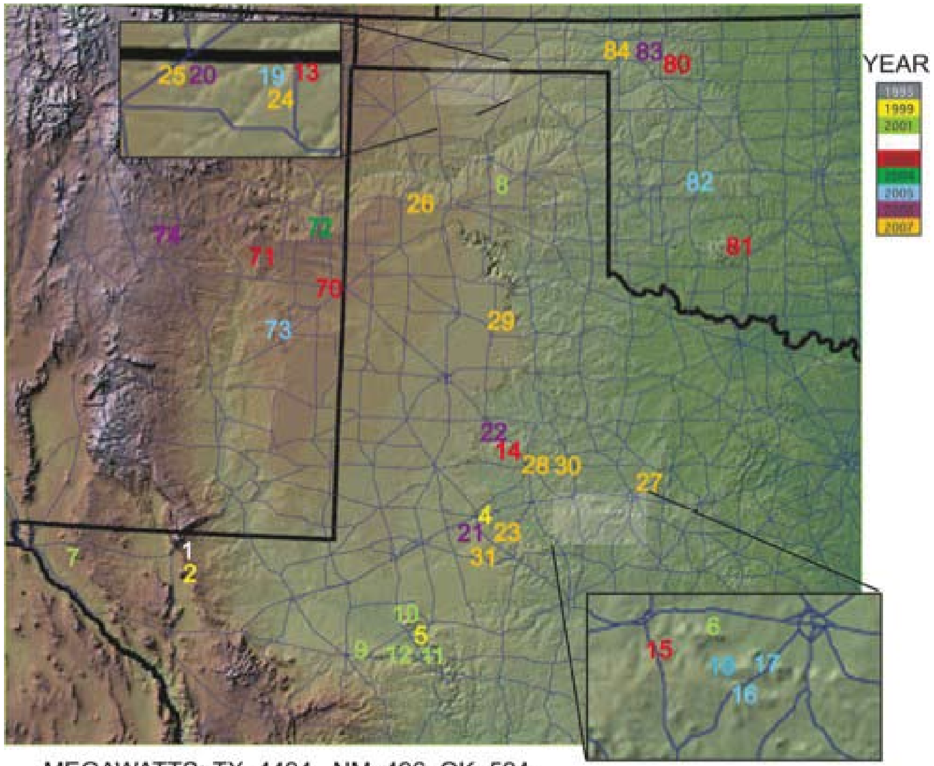


Exhibit 4-3 Location of wind farms (2007) in Texas, New Mexico and Oklahoma.



MEGAWATTS: TX 4494, NM 496, OK 594
Alternative Energy Institute, West Texas A&M University

The Texas Legislature passed Senate Bill 20 (SB 20) in 2005 in order to increase Texas' goal for renewable energy and to set up a process to facilitate the construction of electrical transmission facilities to interconnect a significantly larger amount of wind power. SB 20 increased Texas' mandated Goal for Renewable Energy to 5,880 MW in 2015 and set a target of 10,000 MW of wind power for 2025. Texas has already met the 2015 goal and is on track to meet the 2025 goal by 2010.

Through 2007, there were seven manufacturers represented in Texas with General Electric Wind having the largest number of turbines installed, followed by Siemens (**Exhibit 4-5**). Kenetech is no longer manufacturing wind turbines. Wind turbines installed in 2007 ranged from 1 to 3 MW (average size1.8 MW), 60-96 meters in diameter and on 60-105 meter towers. Wind turbines from these six manufacturers will account for most of the installations in Texas in 2008, estimated at 2,667 turbines with a capacity of 4,292 MW.

Exhibit 4-4 Installed capacity of wind farms in Texas.

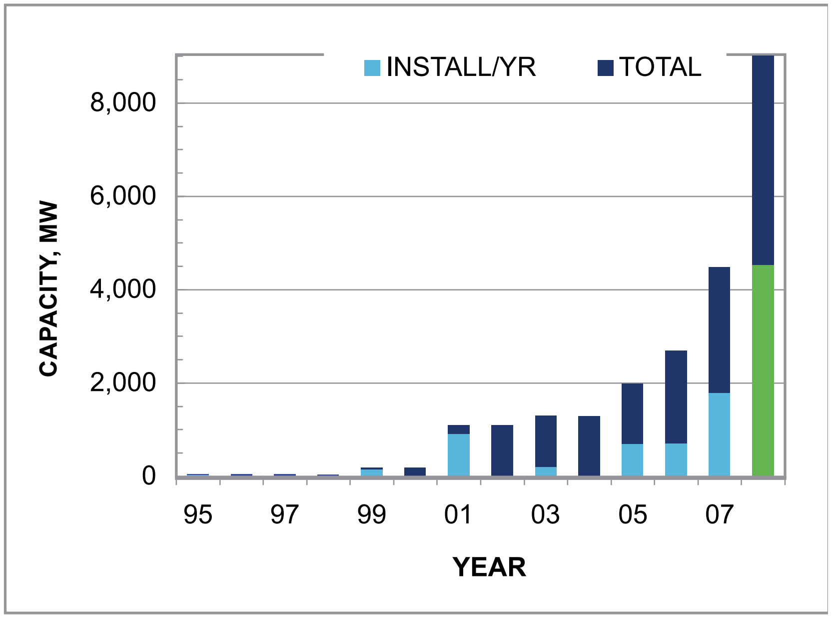
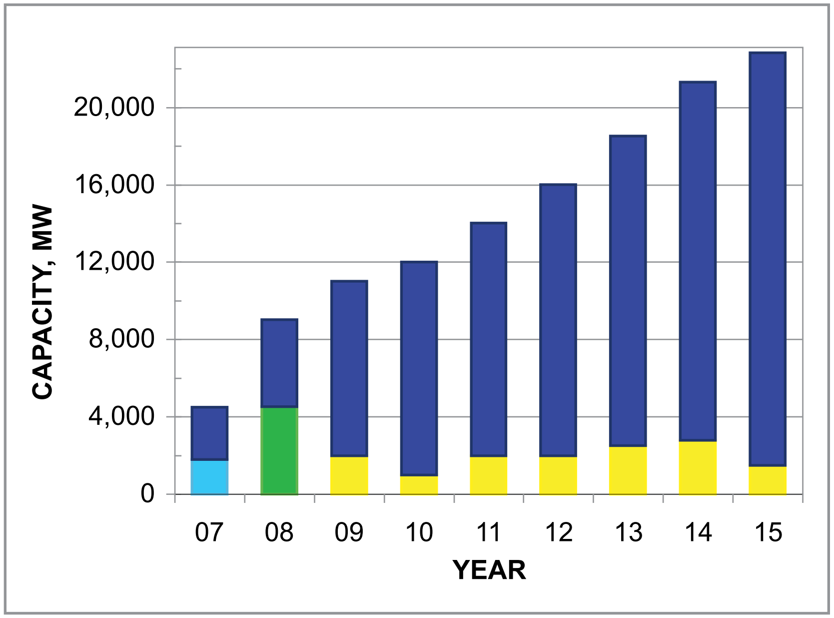


Exhibit 4-5 Manufacturers and number of turbines installed on wind farms in Texas, 2007.

	# turbines	MW
GE/Enron/Zond	1229	1815
Siemens/Bonus	640	1258
Vestas/NEG-Micon	612	542
Mitsubishi	375	375
Gamesa	167	367
Suzlon	78	98
Kenetech	109	39 (36)
Total	3210	4494

Texas Wind Power Project (Kenetech), rerated 2005.

Exhibit 4-6 Speculation on future installed capacity of wind farms in Texas.



Further wind farm development in Texas will still be driven by the production tax credit, the date of its extension, and availability of transmission line capacity. The "mid case" (**Exhibit 4-6**) makes the following assumptions; production tax credit extended to 2011, transmission upgrades in West Texas by 2010, national carbon trading by 2010, construction of transmission from the Panhandle to the ERCOT by 2012, and a national RPS by 2012. The installed capacity in Texas is projected to reach 12,000 MW by 2010 and could easily reach 22,000 MW by 2015. Note that the projected installed capacity per year is below the large installed capacity of 4,800 MW in 2008. A feasible goal for wind is 25,000 MW, which could be reached before 2020. The 25,000 MW represents a 25% penetration of peak electric load.

ERCOT and the Southwest Power Pool (SPP) in the Texas Panhandle have a large number of interconnection requests for wind generation. As of August 2008, ERCOT was tracking 243 active generation interconnection requests, which included 46,000 MW of wind. As of May 29, 2008 the Southwest Power had over 8,000 MW of active requests of wind generation interconnection in the Texas Panhandle. Of course there are many interconnection requests for wind generation that will not ultimately be constructed.

Exhibit 4-7 Capacity (MW) of new CREZ wind by scenario[9].

Wind Zone	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Panhandle A	1,442	3,191	4,960	6,660
Panhandle B	1,067	2,293	3,270	0
McCamey*	829	1,859	2,890	3,190
Central	1,358	3,047	4,735	5.615
Central West	474	1.063	1,651	2,051
Total**	12,053	18,456	24,859	24,419

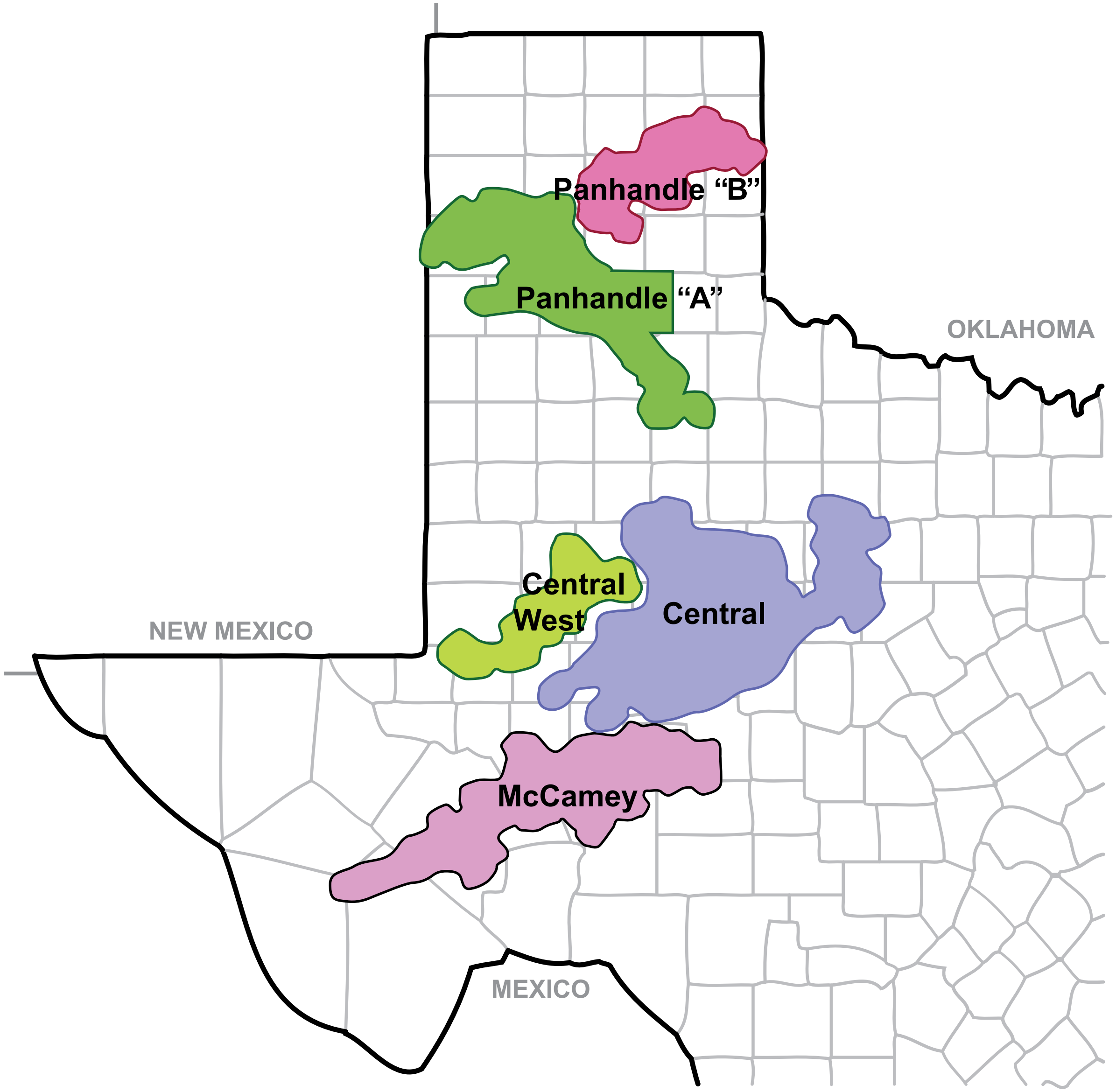
* The McCamey Area includes two CREZ areas
** Assumes 6,903 MW of existing wind capacity

Institutional Issues

Environmental issues associated with wind generation are related to birds, bats, noise and visual impacts. In California there was a problem with raptors, especially with truss towers as perches, however after numerous studies this problem has been alleviated[5]. In West Virginia there was a problem with bats. The US Fish and Wildlife Service is developing a comprehensive set of national guidelines for siting and constructing wind energy facilities to help protect wildlife resources, streamline the site selection and design process and to assist in avoiding post-construction environmental concerns[6]. They have just established an advisory committee for wind turbines.

Noise from gearboxes and blades has been reduced to less than ambient noise. It is still noticeable at the tower because the wind turbine noise is not random. Then the other major problem is that some people do not like the visual impact of wind turbines, especially if they are on ridges and mountains.

Exhibit 4-8 Competitive Renewable Energy Zones selected by ERCOT.



Problems

Texas has a huge amount of windy land and most of that land is flat, so siting is not a major problem. The environmental issues and regulatory framework, along with impact analysis and mitigation are covered in the AWEA Siting Handbook[7]. Permits and archeology issues on private land are more lenient in Texas than in other states. In general around one to two acres per wind turbine are removed from production, primarily for roads.

However the major problem is that most of the windy land is not close to the major load centers so the electric transmission system needs to be upgraded in ERCOT. Another part of the problem is that the Texas Panhandle is not a part of ERCOT. Competitive Renewable Energy Zones (CREZ) were selected for the state, based on areas of the state with the highest wind potential and the transmission of wind power to the load centers in ERCOT[8]. Eight zones were selected and ultimately combined into five zones (**Exhibit 4-8**) from the original 24 potential zones. Different transmission scenarios (**Exhibit 4-7**) have been proposed which include construction of transmission loops into the Panhandle for power to ERCOT (**Exhibit 4-9**). The PUC selected Scenario 2 in July 2008, which would increase the amount of wind power in ERCOT by around 10,000 MW. The estimated costs are summarized in **Exhibit 4-10**. Current wind farm operators and developers have even offered to build transmission lines into the Panhandle and in 2008 T. Boone Pickens purchased 1000 MW of wind turbines as the first phase of a 4000 MW wind farm in the Panhandle. He has proposed to build a transmission line to ERCOT, using a water district board to obtain the right of way for the transmission line.

Exhibit 4-9 Scenario 2 transmission lines for CREZ.

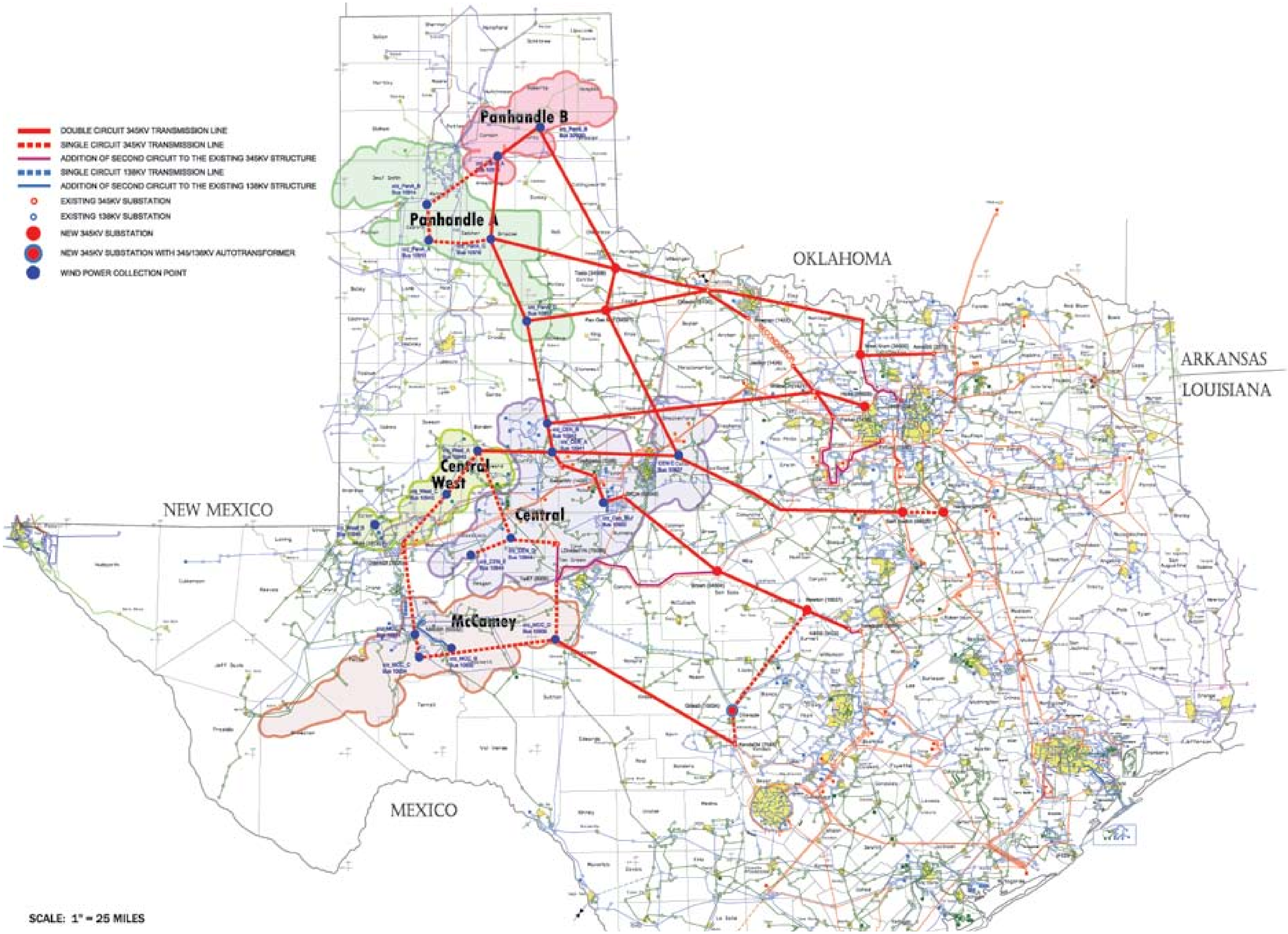


Exhibit 4-10 Estimated cost summary and miles of transmission lines for the CREZ scenarios.

Scenario	Wind Installed MW	Transmission Cost $B	Collection Cost $B	Total New ROW miles
1 A	12,053	2.95	9.35-0.41	1,638
1 B	12,053	3.78	0.41-0.53	1,831
2	18,456	4.93	0.58-0.82	2,376
3	24,859	6.38	0.72-1.03	3,036
4	24,419	5.75	0.67-0.94	2,489

Areas not included in the five zones will continue to have growth of wind power, so the estimations for installed capacity are probably on the low side. The CREZ designations have no implication for wind power potential for areas outside the five zones, for example those areas in the Panhandle that were not selected have equal or better wind potential. The zones were partially selected on the basis of transmission constraints for transporting power to the major load centers in ERCOT.

The Southwest Power Pool is the electric reliability council that covers the Panhandle, and there are only a couple of small AC to DC to AC interconnections to the ERCOT grid. Therefore existing transmission lines in the Panhandle are not large enough and the connections are not large enough to transmit substantial power to ERCOT. However SPP proposed two plans to interconnect 1,500 to 4,500 MW of new wind capacity and provide firm delivery to North Texas. By the end of 2008, Southwestern Public Service (part of Xcel Energy) will have approximately 850 MW of wind on their system. With that growth and requested interconnections for wind, the Southwest Power Pool has revised their estimate of the amount of wind power[10] and the need for high voltage transmission lines.

Most farmers and ranchers want wind farms on their land, as it is a long-term source of income. However there are residents who are opposed, the not in my backyard group. For example, in Jack County, about 10 percent were in favor, 10 percent were opposed, and the rest were neutral to the installation of the Barton Chapel wind farm. This means more emphasis is needed on public outreach on the cost/benefits of wind farms, and this needs to be done early in the project development.

There are ancillary costs for utilities as wind farms are connected to the utility grid: 1) spinning reserve, 2) system stability, and 3) penetration of wind farms. The cost and who pays for new transmission lines is a concern. As a general rule, up to 20% penetration of peak capacity does not present any major problems. However, in the Southwestern Public Service service area, their average load is around 3,600 MW, and now there are 622 MW of wind farms. In spring at night with a low load of 2,500 MW, they already can have 25 percent penetration on their system and in spring 2009, it will be 36 percent. However, unlike ERCOT, which has limited electrical connections with other transmission systems, SPP is part of a much larger transmission network.

On February 26, 2008, the ERCOT transmission system experienced a problem that required system operators to declare an emergency electric curtailment[11]. The curtailment followed a sudden drop in system frequency that occurred as the result of a mismatch between load and generation. The magnitude of this event caused ERCOT to implement the second stage of its Emergency Electric Curtailment Plan (EECP). Under EECP Stage 2, system operators activated a demand response program, in which large industrial and commercial users are paid to curtail their electricity use as needed for reliable grid operation. This measure added approximately 1,100 MW of resources within a 10-minute period and successfully restored system frequency in 3 minutes. Most of the interruptible loads were restored in 90 minutes and no other customers in the ERCOT region lost power due to the event. In explaining the causes of this event, ERCOT reported that its day-ahead forecast had led to a resource plan that indicated 1,000 MW of wind that ultimately was not available. According to ERCOT, discrepancies between forecast and actual load of this magnitude are not unusual. A new wind forecasting system, that will be included in the new nodal wholesale market, had predicted the actual wind generation situation very accurately.

The Electric Reliability Council of Texas (ERCOT) implemented the second stage of its emergency grid procedures Tuesday evening following a sudden drop in the system frequency. Preliminary reports indicate the frequency decline was caused by a combination of events including a drop in wind energy production at the same time the evening electricity load was increasing, accompanied by multiple power providers falling below their scheduled energy production. In addition, the drop in wind energy led to some system constraints in moving power from the generation in the north zone to load in the west zone, resulting in limitations of balancing energy availability. The wind production dropped from over 1700 megawatts (MW) three hours before the event, down to 300 MW at the point the emergency procedures were activated." (ERCOT press release, February 27, 2008, http://www.ercot.com/news/press_releases/2008/nr02-27-08)

Another view of the event is available from the American Wind Energy Association, www.awea.org/utility/pdf/ERCOT_Backgrounder.pdf. Over the 40-minute period preceding the start of load curtailment, wind generation declined by 80 MW relative to its schedule, non-wind generation decreased by 350 MW relative to its schedule, and load rapidly increased to a level that was 1,185 MW more than forecast.

ERCOT contracted with General Electric (GE) for an analysis of wind generation impact on ERCOT ancillary requirements. The objectives were to determine the level, type, and cost of additional ancillary services that might be required to maintain the reliability of the ERCOT System with increasing levels of wind generation. The Study was intended to inform both the current operation of the ERCOT System and the policy discussion associated with the Competitive Renewable Energy Zone (CREZ) process. The study used the 2006 load and weather patterns and used 5,000, 10,000 and 15,000 MW of wind power to drive the simulations. Some key conclusions of the study are:

- With 15,000 MW of installed wind capacity in ERCOT, the operational issues posed by wind generation will become a significant focus in ERCOT system operations. However, the impacts can be addressed by existing technology and operational attention, without requiring any radical alteration of operations.

- ERCOT's Regulation procurement methodology can be improved by including wind forecast information and wind capacity growth.

- Inclusion of wind forecasting in operations planning is critical.

- ERCOT's unit commitment may need to be altered to provide ancillary services.

- Variation of wind tends to be or out of phase with the daily load curve, but the errors in load and wind forecast are virtually independent. That means that it is improbable for the most severe load and wind forecast errors to occur in the same hour.

- Energy production from wind tends to be offset primarily by reduction in production from combined-cycle natural gas plants.

- The cost of the additional ancillary services will be small relative to the cost savings from the additional wind generation.

It was estimated that total system energy production costs decreased by approximately $54/MWh for each MWh of wind energy produced.

The GE Study addressed the impact of extreme weather events on wind generation output, noting that changes in wind output are almost always due to predictable weather phenomena. However, the study found that the frequency and severity of extreme short-term wind generation output changes increase at a faster rate with increasing wind generation capacity. GE estimated the maximum 30-minute drop in wind generation to be 2,836 MW for the 15,000 MW scenario, with a mean recurrence of once every three to five years, but noted that a 2,400 MW drop might occur once per year. The GE Study suggested that, although the timing and magnitude of extreme weather events may not be precisely predictable it is possible to predict periods of risk when weather conditions are likely to result in drastic changes in wind

For summer peak capacity, ERCOT counts 8.7 percent of wind nameplate capacity in accordance with ERCOT's stakeholder-adopted methodology, based on a study of the effective load serving capability of wind.

Small and Distributed Systems

The large-scale use of small wind systems depends primarily on economics. For wide spread use, life cycle costs will need to be comparable to costs from the utility. In some states there are credits and/or subsidies for purchase of small wind systems. Presently there is net energy billing for systems 50 kW and smaller in Texas, however this has not increase the use of small wind systems.

In Texas, so far there has not been any development of distributed, cooperative and/or community wind systems. A couple of school districts have installed 50 kW units and there is a 660 kW unit at the American Wind Power Center and Museum in Lubbock. A cottonseed oil plant in Lubbock installed ten 1 MW wind turbines and it is anticipated that all energy will be used on site.

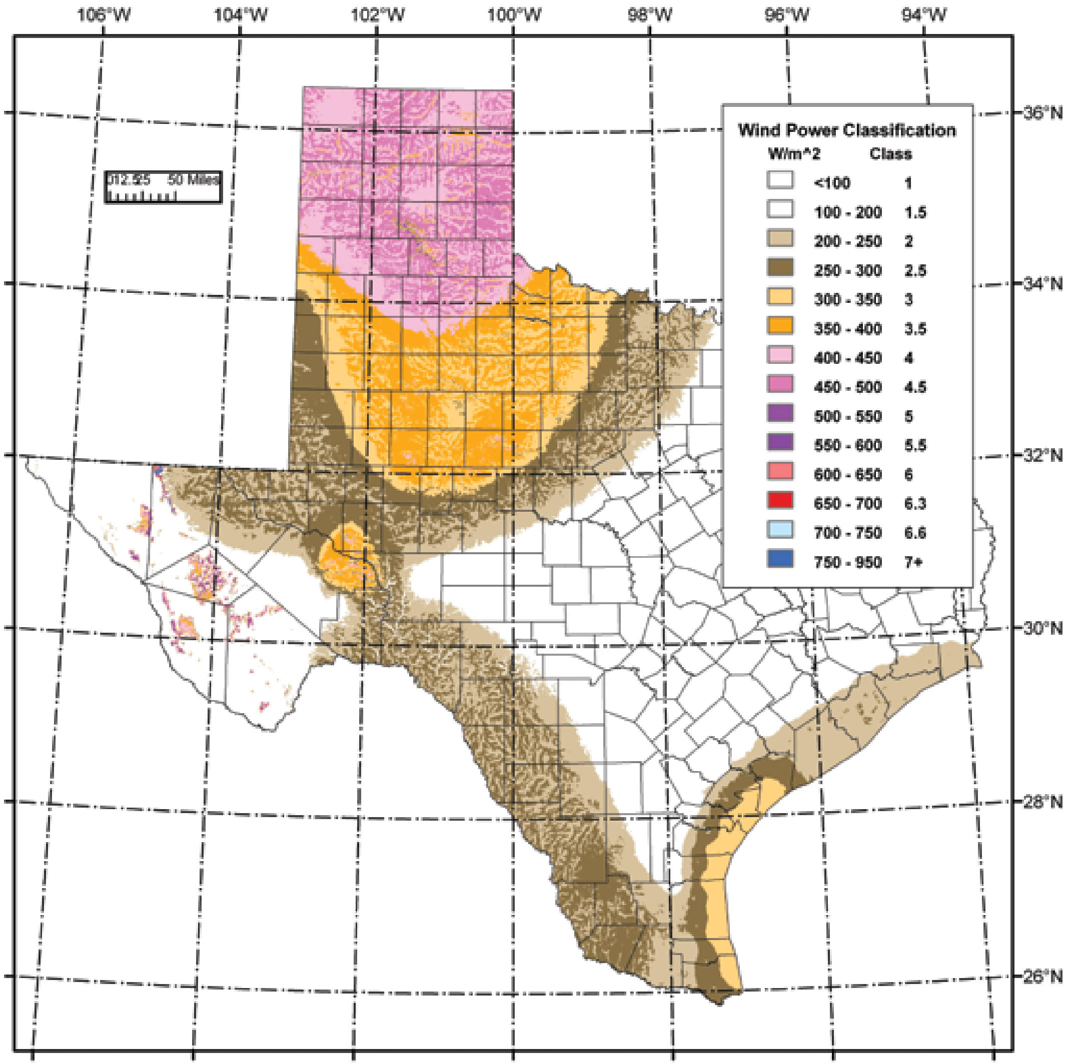
Resource

Texas has the best wind resource (**Exhibit 4-11**) in the United States with the amount of wind power at a height of 50 meters estimated to be 723,000 MW, and the capturable wind power estimated at 223,000 MW (**Exhibit 4-12**). This changes the rank of an earlier estimate, which had North Dakota number one with 138,400 MW and Texas with 136,100 MW. Offshore refers to the area from the coast out to a distance of 10 miles (16 km). The "capturable power" is based on Wind Class 3 and above and excludes the following land: 1) urban, 2) highways (does not include county roads), 3) parks, wetlands, wildlife refugees, rivers and lakes, and 4) slopes greater than 10 degrees. The estimated maximum capacity is based on 1 MW wind turbines, 60 meters in diameter (D), with a spacing of 7D within a row and 9D between rows, and a 30 percent capacity factor for Wind Class 3 land and a 35 percent capacity factor for Wind Class 4 and above land. In reality, the numbers would be even larger as the selected spacing is larger than that of actual wind farms. Of course the current numbers for estimated capacity are larger than the 1995 estimate, since the previous estimate was based on land within 10 miles of major transmission lines (69 kV and greater) and did not include the offshore area.

Another general way to estimate the installed wind power for Wind Class 3 and above is to use 15 MW per sq mile or 6 MW per sq km (for flat areas, 4D by 8D spacing) and 18 MW per linear mile or 11 MW per km for ridges, small mesas and hilltops (2 to 3D spacing). Using this method, the estimated installed capacity would be around 983,000 MW.

Because the wind resource is so large compared to the electrical generation capacity of the State (approximately 100,000 MW in 2008), a feasible goal for wind power for the State would be 25 percent penetration of peak load, which would be 25,000 MW by 2020. By end of 2008, Texas will already have an installed wind power capacity of over 8000 MW, which is 30 percent of that amount. The main short-term problems are transmission from windy areas to the load centers and the amount of penetration into the utility grid[12]. There are wind farms now being constructed in the upper Wind Class 2 areas, which are closer to major load centers.

Exhibit 4-11 Wind power map for Texas, Alternative Energy Institute, WTAMU.



Source: Alternative Energy Institute 2008

Exhibit 4-12 Land area suitable for wind power, estimated installed wind capacity and capturable wind capacity at 50 m height.

	Area, km2	%	Area, km2	%	Capacity	Capturable	Capacity
Class	No Exclusion	State	Exclusion	State	MW	MW	MW
3	91,000	13	80,000	12	355,000	106,000	483,000
4	80,000	12	74,000	11	324,000	114,000	441,000
5	700	0	100	0	400	140	600
6-7	200	0	100	0	400	140	600
3-5	Offshore		9,600		42,328	3,010	57,600
	Total		164,000	23	723,000	223,000	983,000

1 square mile = 2.5 square kilometers

Wind Characteristics

The main difference between wind and solar is that the power per area in the wind is proportional to the cube of the wind speed.

$$P/A = 0.5\,\rho\,v^3 \qquad W/m^2$$

where ρ is the density of air. In general the air density decreases around 10% for each 1000 meter increase in elevation. The wind power potential will vary by year, season, month and day. In general the winds are high in the spring with the lowest months being July and August. More detail information on wind characteristics can be found in reports and books[13].

Measurement and Histograms

Data loggers at meteorological stations collect data from two to three levels of sensors (anemometers and wind vanes) on towers at least 40 to 60 meters in height. One reason towers higher than 62 meters are more expensive is the requirement of lights by the FAA. Temperature and pressure data are also needed, although an average pressure can be derived from elevation or weather station data. Sensors are sampled every second and then averaged for 10 minutes (or in the past, 1 hour). Data are generally sent to a base station, weekly by cell phone, or data cards are exchanged monthly. Data are then checked for quality assurance, with a goal of 95 percent or greater data recovery. Information on data collection and analysis is available[14, 15]. Wind speeds and wind direction are placed in histograms for the month and wind speeds and power are calculated for an average day for the month. Wind shear is then calculated from the average day wind speeds. Finally annual average values are calculated. That general data is valuable for potential wind farm developers and for landowners. Meteorological station costs are around $28,000 for the first year and then $6,000 per year (**Exhibit 4-5**).

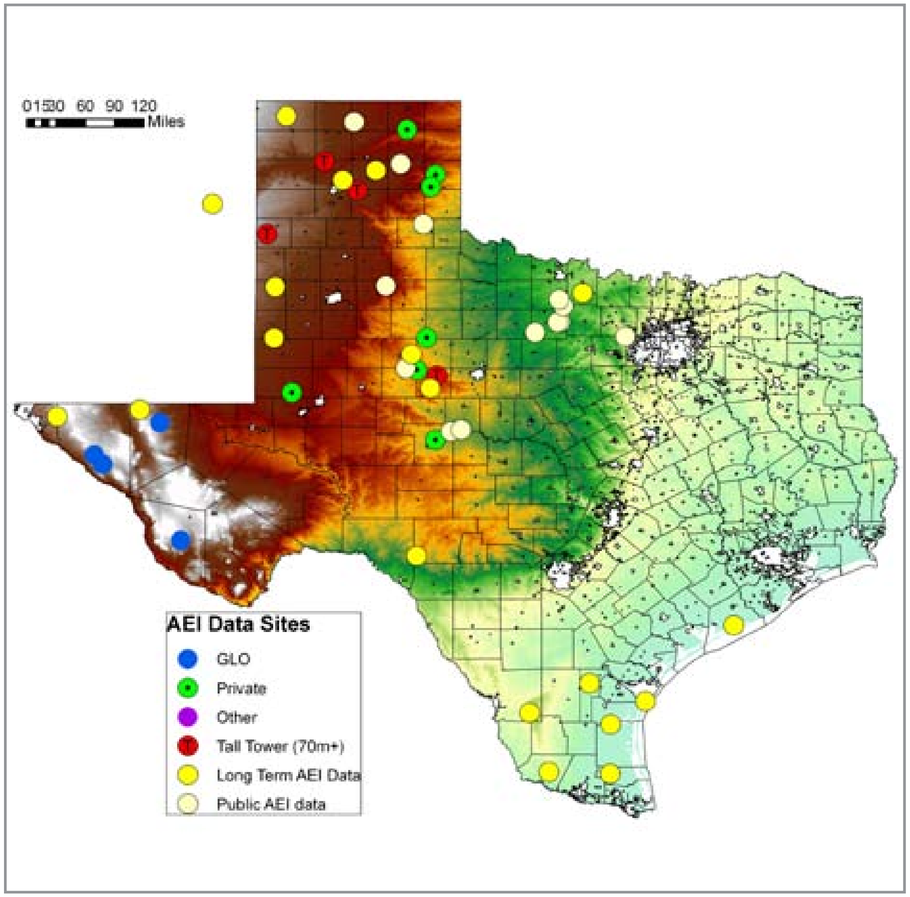
Exhibit 4-13 Estimated costs ($ 2008) for met station, 60 m pole tower, 3 levels of sensors, and call-in datalogger.

Tower, datalogger, sensors	$19,500
Installation	5,000
Yearly	6,000
O&M	2,000
Equipment replacement (10%/yr)	1,000
Data collection & analysis	3,000

Texas Winds

The wind power map was modified with data from the Alternative Energy Institute (AEI) meteorological sites with 40 meter and higher towers (**Exhibit 4-14**), again using terrain enhancement[16] to revise the Wind Classes. The wind power map for 50 meter height (see **Exhibit 4-14**) is available online with a zoom feature with a resolution of one square km[17]. As an example, a regional map shows the mesas (**Exhibit 4-15**) and now there are wind farms on many of the mesas, especially in the Pecos area, (see **Exhibit 4-3**).

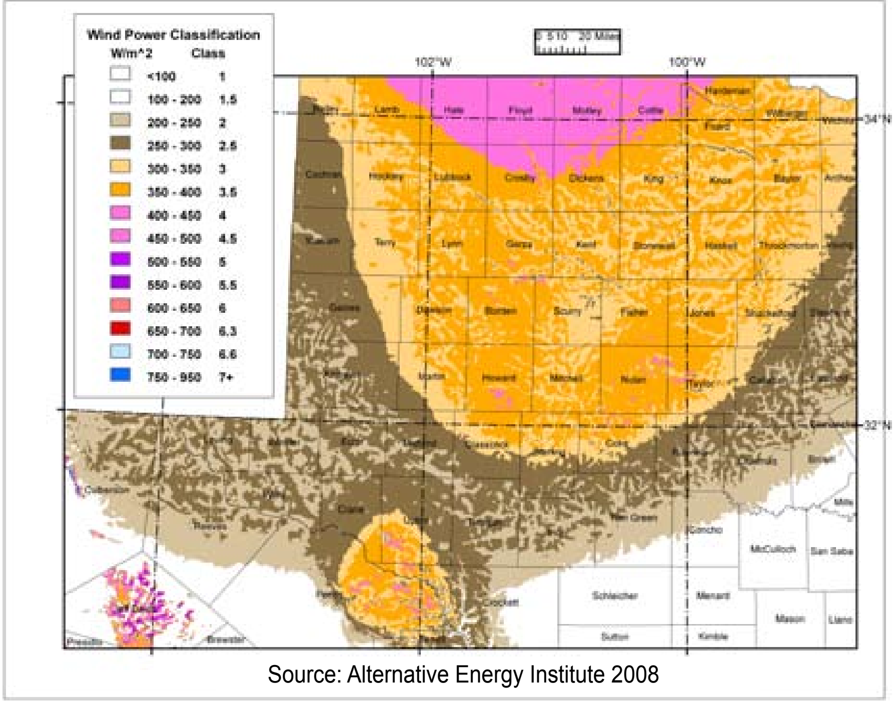
Exhibit 4-14 Location of met sites with towers 40 m and higher, Alternative Energy Institute, WTAMU.



Ocean winds from satellite data (radar reflection from waves) show that the Gulf of Mexico has Class 3 winds[18]. However the satellite data are not useful within 25 miles of the shore due to reflection from the ocean floor. A meso scale model for the Gulf Coast of Texas indicates Class 3 to 5 winds at a height of 50 meters (**Exhibit 4-16**)[19]. Two wind farms (487 MW total) next to the coast are under construction (2008) south of Corpus Christi in Kenedy County.

Winds are high in the spring with July and August being the low months. Notice that the yearly variations are essentially the same over the State (**Exhibit 4-17**). The annual wind speeds by hour (**Exhibit 4-18**) for five regions of Texas, High Plains, Mid Plains, Coastal, Rio Grande Valley, and Trans Pecos.

Exhibit 4-15 Wind power map of the West Central Texas, showing mesas with a higher wind class.



Source: Alternative Energy Institute 2008

Exhibit 4-16 Texas offshore wind power potential, W/m2, at 50 m height.

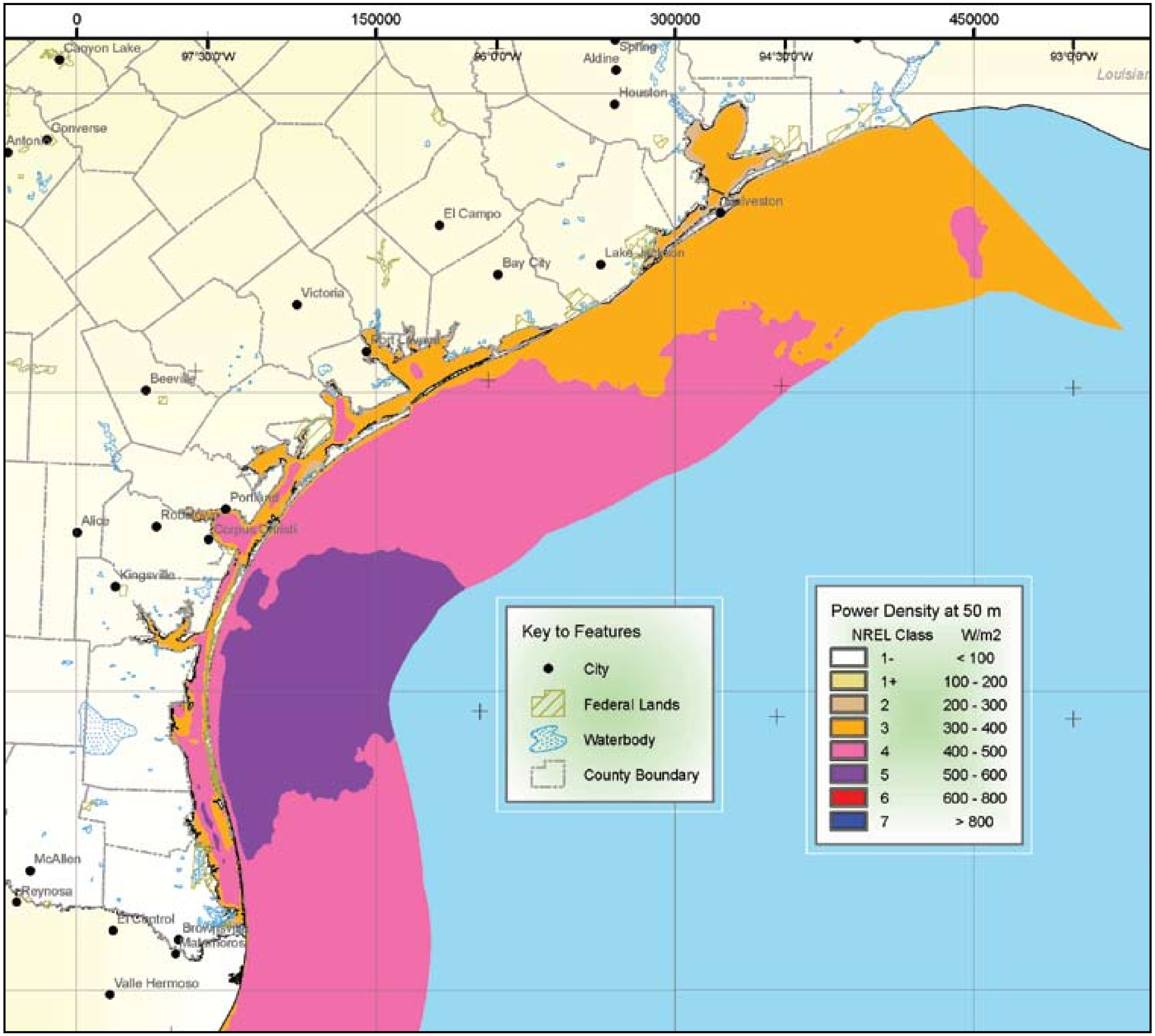


Exhibit 4-17 Yearly wind power potential at 50 m height for three sites.

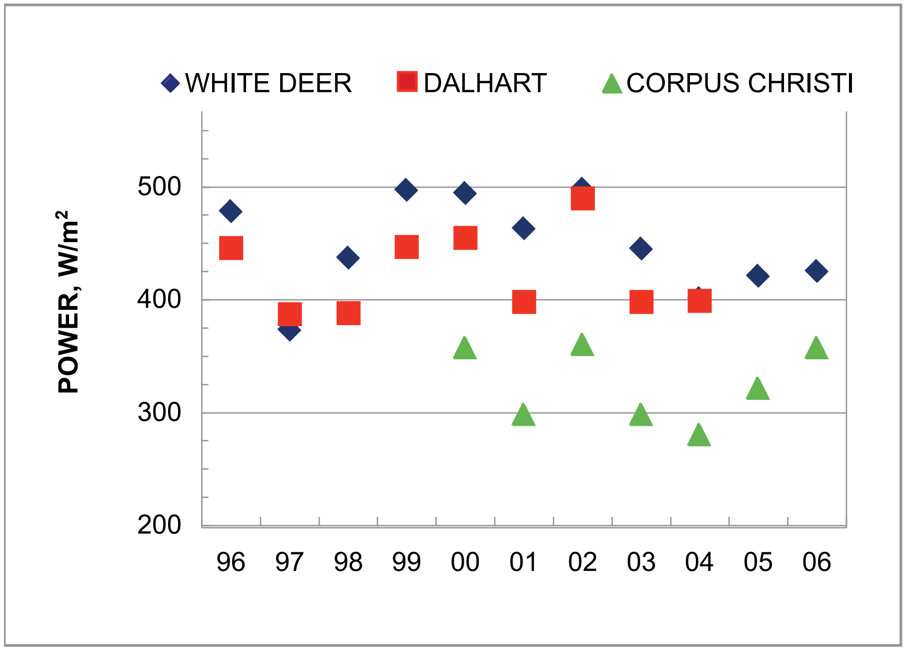
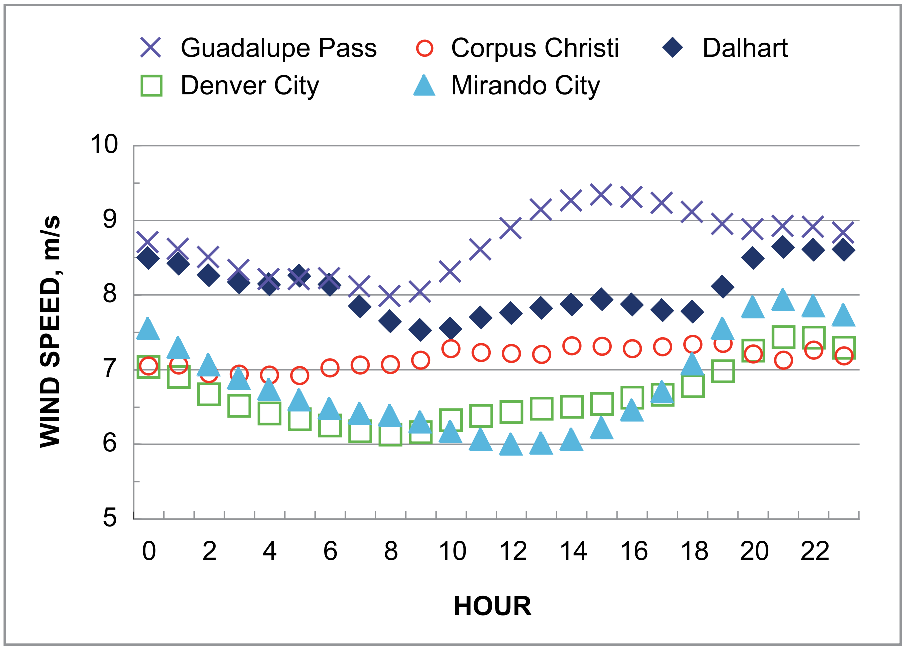


Exhibit 4-18 Yearly average wind speed by hour at 50 m, for representative sites in different regions.



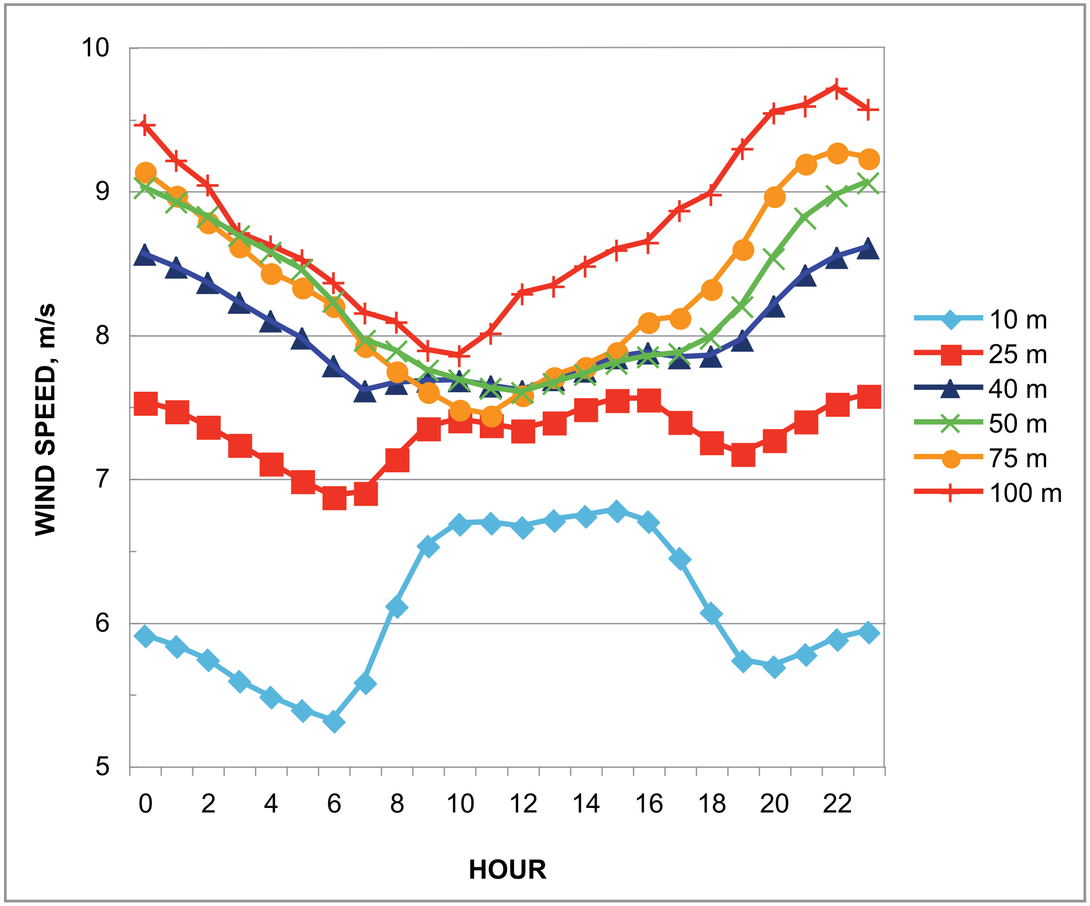
There is a change in the pattern of the daily winds at around 40 m, which continues to higher elevations for most of the State. Wind speed data for White Deer and Tall Tower North at Washburn show this pattern (**Exhibit 4-19**). White Deer and Tall Tower North meteorological towers are 25 miles apart. However data taken at 40 meters and 50 or 60 meters can be used to predict wind speeds and power at higher heights at the same location.

The probability of extreme wind events[20] is of interest to wind farm developers. Tornadoes, hurricanes, thunderstorms and high winds (straight high winds and microbursts) can affect wind farms in two ways: (1) wind turbines do not produce power because winds are greater than the "cut-out" wind speed (most are 25 m/s, 60 mph); and (2) damage to wind turbines because gusts are above the survival wind speed (55 to 65 m/s, 120-145 mph). Tornadoes have the highest winds, however typical widths are around 50 m (150 ft) and typical lengths are 2 to 3 km (1 to 2 miles). Tropical storms and Category 1 and 2 hurricanes may be beneficial for wind farms as they increase wind speeds over fairly large areas, however Category 3-5 hurricanes have damaging wind speeds for wind farms located offshore and near the coast. Typical widths of hurricane eyes are 30 to 65 km (20 to 40 miles) and Category 3 to 5 hurricanes (Saffir-Simpson intensity scale) have wind speeds greater than 50 m/s (110 mph) over that width of 100 to 200 km (60 to 120 miles).

Data Sources

The longest-term source of wind data is the National Weather Service, hourly data, which is available in digital format. However that data at a height of 10 m is only useful as a broad indication of yearly winds (good, average, poor). Wind power maps are now derived from data collected at heights of 40 to 60 meters, and in some cases even to 100 meters.

Exhibit 4-19 Annual, average wind speed by hour for White Deer (10 to 50 m height) and Tall Tower North (75-100 m height); 3 to 6 years of data.



Wind power maps for others states[21] used a meso scale model, which includes effect of the terrain and with validation from ground data available. In any case, before a wind farm is installed, meteorological data is typically collected on site for one to three years. This is proprietary data and is not available to the public.

The Alternative Energy Institute (AEI) collected data at a number of sites across Texas and one site in New Mexico (see **Exhibit 4-14**), starting in 1995, with funding from the National Renewable Energy Laboratory (NREL), the Texas State Energy Conservation Office (SECO) and AEI. Most of the sites were dismantled after 2000. Report and data from these sites are available online[22]. The first two years of data from two tall tower sites (50 to 100 meters), near Amarillo and Sweetwater, are public and available from AEI.

AEI added other sites by using surplus met equipment for an anemometer loan program to individuals or counties. However AEI still served as the base station for data storage and analysis. The anemometer loan program was expanded with support from SECO, as more stand-alone dataloggers and sensors were purchased. For the anemometer loan program, the landowner furnishes the tower and monthly average values are available to AEI. In general, the data are public and available from AEI after two years. Two cases in the anemometer loan program are known where wind farms are now installed.

Other

Since wind farms have been installed and are under construction in Wind Class 2 areas, data need to be collected or proprietary data need to be obtained to verify the extent of Wind Class 2 areas and in order to update the Texas wind map. One possibility for accomplishing this is to use the annual kWh energy output reported to the ERCOT from individual wind farms and then use the characteristics of the turbines to make a backward estimation of the wind resource. Capacity factors by year for several years can also be calculated for wind farms, and would provide an indication of reliability. Data on wind energy and wind farms in Texas should be placed online, similar to the wind information that is available for California[23].

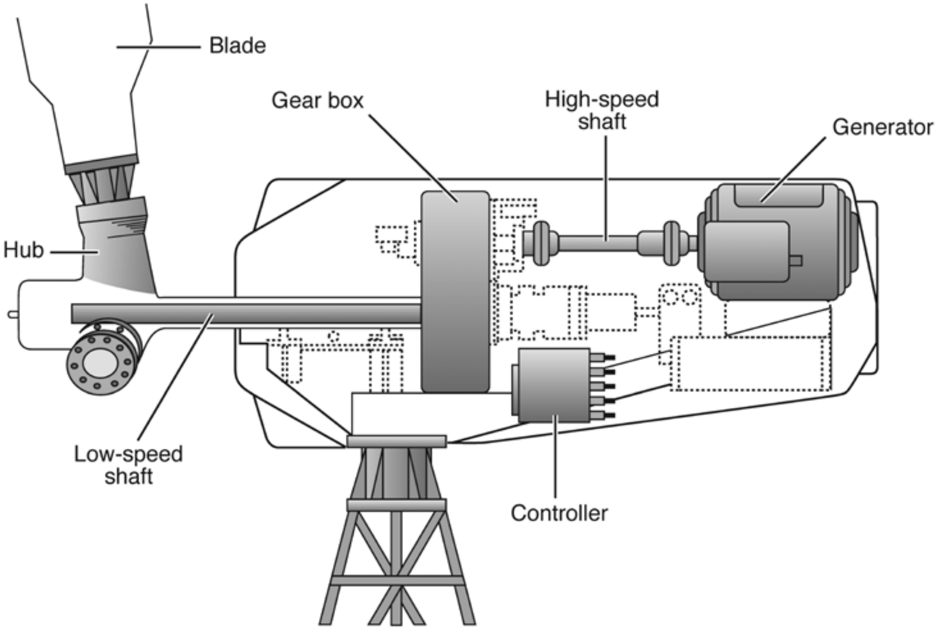
Technology

The general types of wind turbines are: (1) drag and (2) lift devices. Drag devices are where the blades or sail move parallel to the wind and they can never move faster than the wind. There are no commercial drag devices for generating electricity. Lift devices use blades, like propellers and airplane wings, which are perpendicular to the wind and can move faster than the wind. For wind turbines the speed of the tip of the blade divided by the wind speed (tip speed ratio) can be 5 to 8. Lift devices are also classified according to orientation of the rotor axis: (1) horizontal axis wind turbine (HAWT) and (2) vertical axis wind turbine (VAWT). Further the HAWT can be upwind and downwind, which is the relation of rotor and tower to the wind. A power curve is the power output of the wind turbine by wind speed. At this time there are no large commercial VAWTS.

Large Systems

Most of the large wind turbines are HAWT, upwind, 3 blades with full span pitch control, a gearbox to increase rpm, and an induction generator (**Exhibit 4-20**) with a variable speed range of around 40%. Enercon has large wind turbines with no gearbox, which requires a large generator. Permanent magnet generators in megawatt size are available. Power electronics, which convert variable frequency to constant frequency, allow wind turbines to operate at variable frequency for improved efficiency and reduction of power spikes as these can be absorbed by rotor inertia.

Exhibit 4-20 Electric generating wind turbine. The major components of this device are the blades, shaft, gearbox and generator. On large machines, additional controllers and drive motors ensure that the machine is positioned for optimal capture of the wind.



Source: http://www.infinitepower.org/newfact/96-817-No17.pdf

Exhibit 4-21 Annual capacity factor for wind farms with Mitsubishi (1 MW) wind turbines, White Deer D = 56 m D, Fluvana, 60 turbines D = 56 m, 100 turbines D = 61.4 m D, San Jon and Elida, D = 61.4 m. Capacity factors provided by Brian Vick, ARS, USDA, Bushland, TX.

	Annual Capacity Factor (%)					
Year	2002	2003	2004	2005	2006	2007
White Deer	39.5	38.4	37.4	35.1	36.2	33.8
Fluvanna			33.3	32.8	36.7	33.5
San Jon, NM				38.1	45.6	42.5
Elida, NM					38.9	36.8

“Capacity factor” is the average power divided by the rated power. Average power is generally calculated from the annual energy production, although monthly and seasonal capacity factors have been calculated. Wind turbines are now available with the same size generator but different diameter rotors for installation in different wind regimes. In Wind Class 3, capacity factors are 30 to 35 percent and in Wind Class 4 and above, capacity factors are 35 to 45 percent. A very general rule for capacity factor is to take the wind power potential at 50 m height and divide that number by 11. Capacity factors for wind farms are calculated from the annual energy production and number of turbines in the wind farm (**Exhibit 4-21**). If there are different types of turbines, or turbines with the same generators but different rotor diameters, than the individual contributions need to be estimated if individual data are not available.

“Availability” is the amount of time that a wind turbine is available for operation, regardless of whether the wind is blowing. For third generation wind turbines, availabilities of 98 percent are common.

Annual energy production can be estimated from (1) generator size, (2) rotor area and wind map value, (3) average wind speed and calculated energy using Rayleigh distribution and (4) manufacturer’s power curve, and calculated energy production using wind speed histogram and power curve[24]. The last method is the one used for securing financing by wind farm developers with on site data referenced to the hub height of the selected wind turbine. The generator size method is the simplest.

Annual kWh = capacity factor*generator size (kW)* 8760 (hr).

For example, a 1 MW (1,000 kW) wind turbine should produce around 2,800,000 kWh in a mid Wind Class 3 area. Annual KWH = 0.32* (capacity factor) × 1,000 (kW) × 8760 (hours per year) = 2,803,200 kWh.

There have been economies of scale as turbines have increased in size, with the largest commercial unit now available being 6 MW, 126 meters in diameter. Ten megawatt units are in the design stage and the optimum size has not been determined as this depends on economics, as well as the difficulties in transportation and installation of these size units.

Small Systems

Small wind turbines with fixed pitch, stall control and permanent magnet alternators are available. Even though there are around 600,000 small wind turbines in the world, primarily 100 to 300 Watts, the costs per rated power are much higher than the large turbines installed in wind farms.

Innovative Systems

A number of innovative systems have been proposed [24]. None of these have gone beyond the conception, design or prototype stage.

Infrastructure Needs

The primary infrastructure requirement for wind power is electricity transmission from the windy areas to the load centers. Of course if cheap storage becomes available, no new power plants would be needed for fossil, nuclear, or renewable energy. Energy would be stored at night when demand is low and then used during the day when demand is high. Possible storage systems are large-scale batteries, compressed air, chemical, primarily hydrogen, superconducting magnets, and flywheels. If plug-in electric cars become wide spread, that makes wind power a better load match due to higher nighttime winds.

Economics

The levelized cost of energy for the 20 to 25 year life of a wind turbine is estimated from Electric Power Research Institute-Tag-Supply method. The big difference for renewable energy systems, there is no fuel cost in the formula.

$$\text{COE} = \frac{(\text{IC} * \text{FOR}) + \text{AOM} + \text{LRC}}{\text{AEP}}$$

where IC = initial installed cost, $

FCR = fixed charged rate (cost of borrowing money)

AOM = annual operation & maintenance, $/yr

LRC = levelized replacement costs, $/yr

AEP = annual net energy production, kWh/yr

As an example, a 1 MW wind turbine, which produces 3,000,000 kWh per year. Installed costs are $1,500,000, FCR = 10%, and AOM = $0.01/kWh = $30,000/yr, LRC = 10% of IC = $15,000/yr. The installed cost is representative of wind farms installed in 2006 and 2007 and the fixed charge rate was chosen at 10%, which could be higher or lower depending on the present rate of borrowing money.

$$\text{COE} = \frac{1{,}500{,}000 * 0.1 + 30{,}000 + 15{,}000}{3{,}000{,}000} = \frac{195{,}000}{3{,}000{,}000} = \$0.7/\text{kWh}$$

The main drivers of the COE are the installed cost and the annual net energy production. The net energy production is primarily due to the Wind Class. Because of economies of scale the numbers are for 30 MW or greater wind farms. The COE for the John Deere wind farms (10 MW each, however 2 or more in same general area) will be a little less because they do not have a substation for connection to the grid.

Installed costs have increased from around $1 million per MW in 2003 to $1.8 to $2 million in 2008, due to increase in the prices of steel, copper, and cement. An installed cost of $2 million per megawatt in the above example would increase the COE by 1.3¢ per kWh. The price is also higher because of the demand for wind turbines is greater than the current production capacity. The installed cost for offshore wind farms is around 1.5 times larger.

The important number for a wind project is the sale price of electricity (power purchase agreement). For some older contracts for wind farms in Texas, the sale price of electricity was around $0.025/kWh for a 20 year contract. The only way this could be achieved was with production tax credits, accelerated depreciation, tax abatements, and Renewable Energy Credits (RECs). In 2007, RECS were around $0.005/kWh. For wind farms being installed today, the production tax credit is still the main driver of economic viability.

Today wind farms are receiving power purchase agreements in the range of $0.03 to $0.04 per kWh and some wind farms are selling electricity in the wholesale or merchant market, where the rate can range from $0.03 to $0.065 per kWh. However the ancillary costs for the utility are $0.005 to 0.008/kWh. The Montana Public Service Commission set a rate up to $0.00565/kWh for integrated wind power into the Northwestern Energy utility from a wind farm.

The cost of energy for small systems is higher, with some economies of scale (**Exhibit 4-22**). In general the AOM is around $0.005/kWh.

Exhibit 4-22 Range of cost of energy for small systems, wind class 2-4 (capacity factors 25-35%).

System, kW	$/kWh
1	0.20-0.30
10	0.18-0.23
50	0.12-0.18

Benefits

Wind farms can provide rural economic development with the primary benefit being long-term stable income to the landowner. Representative economic values are for a 100 MW wind farm using capacity factors of 30% in Wind Class 3 and 35% in Wind Class 4. A 100 MW wind farm would require 6,000 acres, which can include 10 to 30 landowners (**Exhibit 4-23**). Around 1 to 3 percent of the land is removed from production, primarily for roads. The return on land removed from previous use is around $4,000 per acre per year, a much greater return per acre than farming or ranching. During 2008, the 4,500 MW of wind power already installed in Texas will generate around $18,000,000 for landowners.

Exhibit 4-23 Representative lease for wind farm.

Resource	0.5 to 3 yr
Flat fee	$10,000
acre/yr	$1-4
Contract	30 yr
option	2 (10 yr)
Construction, road, etc	$15 to 20/rod
or flat fee	$4,000/MW
Income	
royalty and/or	4%
per turbine (minimum)	$4,000/MW
Escalation	0.5% every 5 yr

A number of seminars for landowners have been presented across the State, and more information is available online [www.windenergy.org]. Some landowners have begun forming associations for dealing with wind farm developers. Wind turbines can be installed on land currently under the Conservation Reserve Program (CRP), however there may be a penalty or reimbursement, which is decided by the CRP district.

The benefit of rural economic development also includes construction and then operation. During construction there will be 100 to 200 jobs for 4 to 8 months for a 100 MW wind farm, around 1 man-year per MW. In 2008, the estimated installation of 4,000 MW in Texas will generate around an estimated $16 million payroll. The administration and operation and maintenance of wind farms proved 10 to 14 full time jobs per 100 MW. Installation of 20,000 MW of wind power by 2015, would lead to 2,000 or more full time jobs in rural areas. The economic impact of wind (2,500 MW) for just Nolan County[25] is estimated at $315 million for 2008 and $396 million for 2009. Cumulative school property taxes 2002 through 2007 were $22,670,680. Landowner royalties on 2,500 MW is estimated at $12,264,000 (annual) and is projected to increase to over $17 million by end of 2009.

Wind power also provides important environmental benefits. Wind generated electricity does not require water and does not emit gases such as CO^2, NOX, SOX and particulates. In Texas, fossil fuel power plants use 440 gallons of water per MWh of generation[26], which for 2003 amounted to 100 billion gallons. In 2008, the 4,500 MW of wind generation already installed in Texas will save 5 billion gallons of water per year. The anticipated installation of 20,000 MW of wind power by 2015 would save an estimated 20 billion gallons of water per year.

Coal and natural gas power plants emit an average of 700 kilograms (over 1,500 pounds) of CO^2 per MWh. In 2008, the 4,500 MW in Texas will reduce CO^2 emissions by 9 million metric tons per year. If 20,000 MW are installed by 2015, then the reduction in CO^2 emissions is estimated at 40 million metric tons per year. The present value for CO^2 trading in Europe is $30 per metric ton, which is equivalent to $20 per MWh.

When CO^2 trading becomes a national policy in the United States, the projected 20,000 MW of wind to be installed by 2015 will produce an additional value of approximately $1 billion per year. This could be used to offset the loss of the production tax credit after the initial 10 years and reduce the need for the PTC in the future.

Subsidies

The primary government subsidy for construction of wind farms is the federal production tax credit, which was set in 1992 at $0.015/kWh for 10 years with an inflation factor for installation in later years. The PTC has been extended a number of times and is now valid through 2009 at $0.02/kWh. Wind farm developers, like every other business want subsidies. The most common in Texas is tax abatement from 5 to 7 years. If a tax abatement is secured, the wind farm generally makes payment in lieu of taxes for education.

There is net metering (see Solar Chapter) in Texas for renewable energy systems up to 50 kW. If the renewable energy system produces more energy than is needed on site, the utility meter runs backward, and if the load on site is greater the meter runs forward. The bill is determined at the end of the time period, which is generally one month. If the renewable energy system produced more energy over the billing period than was used on site, the utility company pays the avoided cost. Most of the states have net metering which ranges from 10 to 1000 kW, with most in the 10 to 100 kW range. However net metering in Texas did not increase the implementation of small wind systems.

Key issues

The following are key issues, more or less in order of priority.

1. Utility transmission capacity, especially from Panhandle to ERCOT.
2. Subsidies – production tax credit, property tax exemption. If the PTC is not extended, the installation of wind farms will decrease significantly after 2009.
3. Penetration of wind power on the transmission grid in excess of 20% of peak load and associated utility ancillary costs. In Denmark in 2007, wind power provided 20 percent of their electricity, and during high winds penetration was way above 20%.
4. Forecasting winds 6 to 36 hours in advance.
5. Future income from emissions trading, including carbon dioxide.
6. Should electric cooperatives be required to accept wind farms, community wind turbines, and/or distributive wind turbines on their lines? In general, community and distributive wind turbines are one to ten wind turbines, ranging in size from 50 kW to a megawatt. Examples: The Shallowater Independent School District has five 50 kW wind turbines. The city of Lamar, Colorado has four 1.5 MW wind turbines.

Other issues that will affect the installation of wind systems are:

1. Siting and permitting which will become more of a challenge especially for areas like the hill country and offshore.
2. The treatment of various subsidies for small wind systems (up to 100 kW), and whether these are the same for all small renewable systems. There is a new Federal investment tax credit for small wind turbines for home, farm or business use installed from October 3, 2008 through December 31, 2016. Credit is for 30% of total installed cost (maximum of 100 kW capacity), maximum of $4,000. For homes, credit is limited to lesser of $4,000 or $1,000 per kW of capacity.
3. Whether renewable Energy Credits will be the same for all renewable systems.
4. The availability of net energy billing for small renewable energy systems without additional cost to the producer. Should net energy billing be for longer periods, up to a year?
5. Availability of wind turbines for wind farm construction through 2011.

Information Sources

There are numerous books, articles, and online information from general to technical on wind energy and wind turbines.

Alternative Energy Institute, West Texas A&M University, www.windenergy.org

Also at AEI, Texas Wind Power Map, plus data at 40 to 100 meters at different sites across Texas.

USDA, ARS, Conservation and Production Laboratory, www.cprl.ars.usda.gov

Texas State Energy Conservation Office, www.seco.cpa.state.tx.us/re_wind.htm

Texas General Land Office, www.glo.state.tx.us/energy/sustain/index.html

Texas Tech University, www.wind.ttu.edu

Texas National Large Wind Turbine Research and Test Center, www.egr.uh.edu/wind

Texas State Technical College West Texas, www.windenergyeducation.com

National Wind Technology Laboratory, NREL, www.nrel.gov/wind

Energy Efficiency and Renewable Energy, DOE, www1.eere.energy.gov/windandhydro

Also site of Wind Powering America

Electric Reliability Council of Texas, www.ercot.com

System Planning Division, Monthly Status Report, information on generation interconnection requests

Southwest Power Pool (SPP), www.spp.org

SPP Wind Integration, www.spp.org/publications/SPP_Wind_Integration_QA.pdf

SPP Generation Interconnection, https://studies.spp.org/GenInterHomePage.cfm

American Wind Energy Association, www.awea.org

American Wind Power Center and Museum, www.windmill.org

Global Wind Energy Council, www.gwec.net

Danish Wind Industry Association, guided tour, www.windpower.org/en/tour.htm

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Chapter 5
Biomass Energy
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Chapter 5

BIOMASS ENERGY

Introduction

Texas encompasses vast areas of land with significant potential for diverse biomass production and a measurable collection of bioenergy. Forest resources in East Texas, mesquite/cedar in the Hill Country and West Texas; municipal solid waste and urban waste; construction residue; dedicated energy crops such as energy cane, switchgrass, and sorghum; crop residue; oilseed crops; grain; and algae are important potential sources of energy. In 1995, the Texas Sustainable Energy Development Council produced a comprehensive assessment of renewable energy.[1] Chapter 6 of that report provides an excellent assessment of Texas' biomass potential. Also, in May 2008, the Comptroller of Public Accounts released a report on Texas energy resources that details the status and potential of 17 energy resources ranging from oil to hydrogen.[2] Ethanol, biodiesel, wood, feedlot waste, and municipal solid waste are characterized. This chapter on biomass will augment the information from these two reports regarding the biomass opportunities and challenges for Texas.

The establishment of bioenergy production capability in the United States (and Texas) can have significant positive economic and energy implications. Some optimistic projections indicate that up to 30 percent of our liquid fuel demand could be supplied by biomass. According to the U.S. Department of Energy, the nation has the potential to produce approximately 1.3 billion tons of biomass from forestry and agriculture for biofuels production, which would supply 30 percent or more of the U.S. transportation fuel requirements.[3] The U.S. DOE report anticipates that about 800 million tons per year of the U.S. biomass requirement will need to be supplied from crop residues and a new generation of dedicated bioenergy crops—which are sustainable and integrated with existing food, feed and fiber cropping systems—that are designed for biofuels production. Also, almost 400 million tons of forest resources will need to be utilized to meet the goal. The 25 × '25 organization anticipates that 25 percent of our energy supply could come from renewable resources such as solar, wind, and biomass by 2025.[4]

For Texas, the 25 × '25 estimate, prepared by the University of Tennessee, projects that by 2025, Texas' wind, solar and biomass resources will have the potential to produce 3.79 billion gallons of biofuels and 145.7 billion kilowatt-hours of renewable electricity. For biomass, this would result in the demand of nearly 44.2 million dry tons of crop residues, waste biomass, and dedicated energy crops and 4.8 million dry tons of wood. It should be noted that the 25 × '25 report for biomass also represents an optimistic projection; however, biomass still has significant potential, especially for non-grain bioenergy production. If biomass could account for 10 to 15 percent of our liquid fuel supply, this would be a significant benchmark because Texas imports roughly that amount of oil, much of which comes from the currently unstable Middle East.[5]

Below is a listing of biomass feedstocks of varying implementation potential for Texas.

Texas Biomass Feedstocks

- Animal wastes
- Crop residues
- Forest products/mesquite/cedar
- Grain
- High-tonnage sorghums
- Microalgae
- Municipal solid waste/urban waste
- Oilseed crops
- Sugar cane/energy cane
- Sweet sorghum
- Switch grass

Regarding grain-based production of ethanol, Texas is a grain deficit state and would require significant increases in production and/or importation to increase grain-based ethanol production. As such, Texas is at a disadvantage in competing in the grain-based ethanol market currently dominated by the Midwest. Animal agriculture, which is Texas' largest agricultural sector, has been stressed by the recent market situation for feed grains. Currently, three ethanol plants are in operation in Texas and another is under construction. These four plants would represent about 355 million gallons of ethanol production, about 50 percent of current MTBE replacement demand in Texas. A spring 2008 report by Texas A&M analyzed the dynamics of grain-based ethanol production in Texas.[6] The report concluded that:

1. $100+ per barrel oil is driving food/feed prices

2. Energy and fertilizer costs are major factors impacting crop production

3. Corn price increases have little to do with food price increases

4. Speculative fund activities are a significant contributor to high oil and grain prices

Regardless of the actual potential, biomass resources must be produced, harvested/collected, transported, stored, and processed based on new paradigms associated with input costs, production schedules, capacities and capabilities. The challenge for researchers, producers, equipment manufacturers, and end users will be to incorporate production systems that are sustainable and efficient, using existing systems when appropriate. In addition, improvements in the conversion—biochemical, physico-chemical, and thermal-chemical—of ligno-cellulosic biomass to biofuels must rapidly progress within the next five to seven years to meet U.S. biofuels production goals. A critical element in the ultimate success of this country's biofuels production will be the linkage between biomass feedstock development, production, harvesting, transporting, storing, and processing into biofuels/bioproducts and/or energy.

For Texas-derived biomass, a number of questions must be addressed to determine the initial viability and long-term sustainability of a biofuels sector in Texas. Some questions are:

- What is the realistic, feasible, economically affordable level of production?
- What are the leading viable feedstocks?
- What conversion technologies might persist or emerge?
- How will biomass production affect the food vs. fuel issue?
- What are the impacts on water usage and soil erosion?
- What are the carbon impacts?
- What are the impacts on animal agriculture?
- How can bioenergy crops be produced in a sustainable manner?
- Is there available land?
- How far can bulky biomass be affordably hauled?

Although each of these questions is critically important, this chapter is limited to alternative feedstocks and outlook. Further, issues related to conversion technologies, input and consumption issues, sustainability, and environmental/policy issues must be thoroughly vetted to assure a firm foundation for the potential of biomass to bioenergy (where it is economically feasible).

Resources

Texas contains one of the most diverse and most accommodating growing environments in the United States, and boasts a plethora of potential biomass-based renewable energy sources. From the seemingly endless stands of pine in East Texas to brackish water algae farms in West Texas, statewide agriculture incorporates a wide variety of crops in between. Be it the energy potential of mesquite brush found in the extensive rangelands of the south and west or the sucrose content of hybrid sugarcane varieties grown along the coast and the south, the following information related to Texas' biomass sources will show that Texas' biomass inputs are as varied and diverse as the regions in which they grow.

Dedicated Energy Crop Production

Classification of Energy Crops—Dedicated energy crops can be divided into three subgroups based on the utilization of the plant materials in the conversion process to bioenegy/biofuel: 1) sources of sugar and starches (non-structural carbohydrates); 2) ligno-cellulosic feedstocks; and 3) sources of vegetable oils. Later in this report, an estimate of the energy potential and liquid fuel potential from Texas biomass will be given. The variation in available land, rainfall, competing crops, producer interest, economic incentives, and infrastructure will determine actual production. As mentioned above, several studies have attempted to estimate the production potential, but they are speculative.

The most important potential sources of ligno-cellulosic feedstock for Texas are high biomass sorghum, energy cane, and switchgrass.

High biomass sorghums—have promise as a dedicated bioenergy crop due to their high yield potential and growth habit, which allows more flexible management of the crop. McBee et al. described the efforts to combine characteristics of both grain and sweet sorghums into a new class designated as high energy sorghums. These sorghums produced biomass yields in excess of 36 tons per acre (fresh weight) and 9 tons per acre (dry weight). They reported that expected improvements could extend the potential of these types of hybrids to a wide range of environments.[7]

Energy cane—is a vegetatively propagated perennial grass. Unlike sugar cane, energy cane is selected not for high sucrose content in the stalk, but for high biomass production. The climatic requirement of energy cane will restrict its cultivation to South Texas and the state's coastal regions.

Sweet Sorghum and Sugar Cane—The two most important potential sources of dedicated energy crops for non-structural carbohydrates from Texas are sweet sorghum and sugar cane (corn is an important source both in Texas and nationally, but is not considered a dedicated energy crop). Currently, 40,500 acres of sugarcane are grown in the lower Rio Grande Valley of Texas. Although all sugar derived from cane is currently converted to refined sugar for human consumption, fermentation of sugar cane and molasses to ethanol is feasible, but there are questions of economic viability. Sweet sorghums produce high levels of sugar in the stalk and these cultivars can also be milled and fermented to ethanol using the same methods employed by sugarcane processors. Sweet sorghum is being used for ethanol conversion in India and Brazil and its efficacy is also being tested in other countries such as China, Uruguay, and Colombia. Sweet sorghums have the advantage over sugarcane of being applicable over a much wider area of Texas.

Switchgrass—A native warm-season perennial grass that can be grown throughout Texas. Yield potential will be determined by the amount and timing of precipitation.[8] Average yield in Texas was estimated by scientists at the Texas Agrilife's Blacklands Research Center to be 6.25 tons per acre.[9]

Miscanthus—A tall perennial grass having been developed for biofuel usage in Europe over the past decade. Some of the beneficial characteristics noted in European trials thus far include: relatively high yields (three to six tons/acre dry weight), tolerance to cold weather, low moisture content (as low as 15 to 20 percent depending on time frame), low mineral content, and an annual harvest pattern providing yearly income to growers. However, there is very little experience with commercial production of Miscanthus in the U.S.[10]

Giant Reed—*Arundo donax* grows in many parts of Texas, but it is classified as a noxious invasive plant. Along the Rio Grande, it has demonstrated growth rates of as much as four inches per day and reaches six to eight meters (20 to 25 feet) in height. It consumes large quantities of water and creates serious issues in and around the banks of rivers that can disrupt the flow line of water ways. The implications of cultivating Arundo as a dedicated energy crop have not been studied, but there are issues related to getting a permit from the Texas Department of Agriculture and then assuring that it can be controlled within the cropped area.

Leauceana Lucacephala—This plant has the potential to both fix its own nitrogen and to accumulate high biomass. It is a perennial crop, but currently has the winterhardiness for only small portions of Texas. Other related species are being investigated for their cold hardiness, and the potential for future genetic crosses.

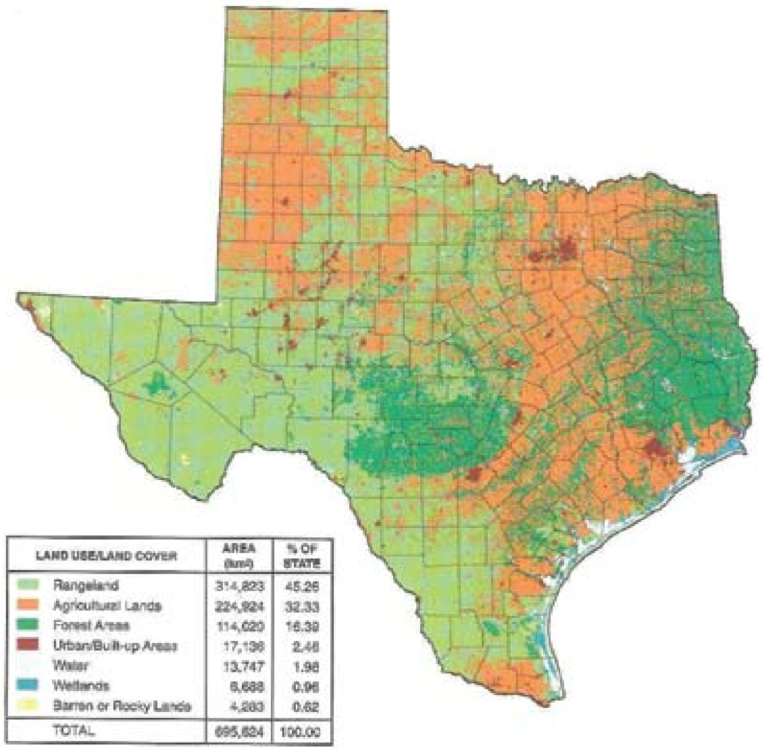
Production systems, logistics, and mass delivery systems are important elements to be taken into consideration in relation to biofuels. In the case of biofuels, production systems can be divided into perennial systems (switchgrass, sugar and energy cane, leauceana, jatropha, Chinese tallow and others) and annual systems for all the other crops. Sugar and energy cane stands are maintained for three to seven years. The crop is harvested annually. As yields decline over time, stands will be terminated (destroyed) and land can be rotated into another crop. After an establishment year, switchgrass can be in production for as long as 20 years. As a perennial crop, a switchgrass stand's productivity and its useful lifespan are mostly a function of the crop's ability to persist and stay free of weeds. Both production of cane and switchgrass will tie up the land resource for several years. All annuals can readily fit into existing cropping systems in Texas.

Logistics—The logistics of sugar cane and sweet sorghum production are complex. Once harvested, the sucrose must be extracted within 24 to 48 hours because sucrose starts to break down almost immediately after harvest. With sugar cane, one harvest per year is performed. Harvest requirements of sweet sorghum vary by location: one harvest in West Texas, two harvests in Central and East Texas, and as many as three harvests in the lower Rio Grande Valley.

The ligno-cellulosic feedstocks (biomass sorghum, energy cane, switchgrass, and similar crops) are generally harvested once a year. Two harvests may be economical with biomass sorghum grown in favorable environments. The harvested biomass can be handled fresh (moisture content 70 percent to 80 percent) and stored as silage/haylage (preserved green biomass, a fermented high moisture fodder that can be used as a biofuel feedstock in anaerobic digesters). Alternatively, it might be attractive to field dry the crop, thereby reducing its moisture, and allow for storage as hay. By varying planting and harvesting schedules, it may be possible to supply a cellulosic bioenergy plant in Central and East Texas with fresh harvested biomass from early to mid June through the end of November.

The logistics of producing vegetable oil for biodiesel are rather simple. The oil is contained in the seeds of crops. The seeds are harvested when ripe with conventional agricultural machinery or, in the case of perennial oilseeds, with modifications to existing equipment and can then be easily transported.

Exhibit 5-1 Growing Regions of Texas



LAND USE/LAND COVER	AREA (km²)	% OF STATE
🟩 Rangeland	314,823	45.26
🟧 Agricultural Lands	224,924	32.33
🟩 Forest Areas	114,020	16.39
🟥 Urban/Built-up Areas	17,136	2.46
Water	13,747	1.98
🟦 Wetlands	6,688	0.96
🟨 Barren or Rocky Lands	4,283	0.62
TOTAL	695,624	100.00

Source: Faidley, Richard. Energy From Biomass, 1995

Biomass Delivery

—A key aspect in the development of biorefineries will be the ability to provide low cost biomass to operate the facility 24 hours per day, seven days per week, 365 days per year. This paradigm is significantly different than for other agricultural commodity processors which tend to be seasonal in nature. For example, cotton gins and country grain elevators only receive farm produced commodities for a few months during the year. Thus, when a production region is evaluated for a biorefinery the following factors need to be considered:

- Biomass production capacity (dry tons per acre)
- Biomass production duration (months per year)
- Additional available biomass resources (to provide year round supply)
- Consistency of production (rainfall, soil quality)
- Compact production region (to reduce hauling distance)
- Willingness of producers to participate in long-term contracts (~10 years)
- Infrastructure to support a biorefinery (personnel, water, utilities, roads, trucks, harvest equipment)
- Storage for seasonally produced biomass that is affordable and minimizes biomass loss/deterioration
- Buffering storage to possibly supply needs on nights, weekends, and holidays

In Texas, the preferred areas will be those areas that have adequate rainfall, high quality available land, a long growing season, ability to provide just-in-time delivery, and strong producer networks. Specifically, areas along the Gulf Coast and Northeast Texas have strong potential to provide this infrastructure. Other areas of Texas also have noteworthy potential, but greater developed input factors of production logistics will be required to support a year-round supply. In these areas, just-in-time delivery of dedicated energy crops, regimented delivery of crop residue, and feedstock stockpiling/storing will be necessary. **Exhibit 5-1** shows the diversity of growing regions in Texas that vary from forest lands to range lands.

Oilseed Crops

— Worldwide, oilseed crops are the largest source of commercially available fats and oils. Oilseed crops can be classified as major, minor or potential. Based on their growth habits, oilseed crops are also classified as cool-season or warm-season and perennial or annual. The major oilseed crop in Texas is cotton; however, soybeans far exceed cotton as an oilseed crop on a nationwide level. Neither has been developed solely as an oilseed crop, but oil has traditionally been a valued co-product with lower historical value than the fiber or protein. Worldwide, palm oil and rapeseed (canola) oil are of strategic importance as well, but in the U.S., the only other crops with major acreage (greater than 3 million acres) are soybeans and cotton. Minor crops include sunflower, rapeseed, peanut, flax, safflower and sesame. Potential oilseed crops not currently produced commercially in Texas include jatropha, Chinese tallow, and castor.

Exhibit 5-2 U.S. Oilseed Crop Acreage, 2007

Additional Significant Energy Crops	Acreage
Major	
Soybeans	63,600,000
Cotton	10,800,000
Minor	
Sunflower	2,100,000
Rapeseed	1,200,000
Peanut	1,200,000
Flax	400,000
Safflower	200,000
Sesame	100,000

Cool-season oilseed crops have the potential to be planted in the fall or late winter (similar to winter wheat or spring wheat) and be harvested in time to also grow a summer crop (double cropping). Texas AgriLife Research is exploring several cool-season oilseed crops to potentially fit into double crop systems. Research is being conducted to improve stand establishment, winter survival and either heat tolerance or avoidance through early maturity.

Warm-season crops are responsive to the late spring and early summer climate in Texas. They are frost susceptible both as seedlings and near maturity, so they must be produced during the frost-free period.

Perennial oilseed crops have the advantage of not needing to be reestablished each year, but many have yet to be well adapted to mechanical harvest. Once established, they have much higher oil production potential per year than annual crops. Conversely, annual crops fit into rotations with other major crops and increase the producer's flexibility to: establish more productive varieties as they are developed, rotate crops, and respond to market demands.

Exhibit 5-3 Oilseed Crops

Crop	Major, Minor or Potential (World)	Cool or Warm Season	Perennial or Annual	Oil Percentage
Cotton	Major	Warm	Annual	17
Soybean	Major	Warm	Annual	18
Peanut	Minor	Warm	Annual	45
Canola	Major	Cool	Annual	40
Flax	Minor	Cool	Annual	35
Sunflower	Major	Warm	Annual	42
Safflower	Minor	Warm (and cool)	Annual	42
Sesame	Minor	Warm	Annual	50
Tung	Potential	Warm/ Subtropical	Perennial	35
Palm	Major	Warm/ Tropical	Perennial	35
Camelina	Potential	Cool	Annual	40
Brown Mustard	Potential	Cool	Annual	40
Castor	Potential	Warm	Annual	50
Chinese Tallow	Potential	Warm	Perennial	31
Jatropha	Potential	Warm/ Subtropical	Perennial	35

Source: Dr. David Baltensperger, Texas A&M University, Soil and Crop Sciences

Cotton—Texas ranks first in cottonseed production in the U.S. and produces nearly half of all U.S. cotton seed, with annual production near 5 million acres. Most cottonseed is used as food grade oil or fed whole to dairy cattle. Currently, food and feed uses exceed the value as biofuel.

Soybean—Soybean has been produced on limited acreage in Texas due to the less than favorable climate. Texas ranked 25th in production in 2005 and 2006; however, the potential acreage is significantly higher given a stable market demand.

Peanut—Texas is second in peanut production nationally, but the food quality peanut market demands production inputs at a level that make the oil production less economical than other crops. As such, current research is focused on the development of a high oil non-food peanut and the development of alternative production techniques that would maximize oil yields.

Canola—It has become recognized as a high quality biofuel crop in Europe and Canada. It has seen a rapid increase in production in the northern U.S. Farmers in Texas, Oklahoma and Kansas are evaluating canola in wheat, sorghum and cotton rotations.

Camelina—A relatively under-exploited crop with a shorter growing season than canola or brown mustard that may have potential for double crop systems in the drier climatic regions of Texas.

Brown Mustard—Very similar to canola and another of the rapeseed complex like canola, but with limited adaptation work for Texas. Brown mustard does not have a food or feed grade oil or meal.

Flax—Historically, flax has been grown as a cool season oilseed in Texas, but the state is not yet a low cost producer of flax oil. Research is identifying flax genetics and production systems to make this crop competitive with currently produced crops.

Sunflower—Acreage has increased rapidly over the past few years, but biofuels are in direct competition with the food oil market, where sunflower oil carries a premium. Its yield potential and drought/heat tolerance make it a strong candidate for expanded Texas production.

Safflower—Grown for several years in Texas due to its exceptional drought tolerance; unfortunately, has seen limited acceptance as high-yielding varieties have not been developed. Both cool season and warm season types of safflower may have adaptation to Texas conditions.

Castor—Contains a highly toxic compound, ricin, but low ricin types are being developed that may open this crop species to wide-scale bioenergy production. Its drought, heat and salinity tolerance as well as high oil yield make it a promising oilseed candidate.

Jatropha—Dry subtropical species with adaptation potential for marginal lands in southern Texas.

Chinese tallow—Weedy species with wide adaptation in coastal regions of Texas. This under-utilized species has great potential for oil production if management, harvesting and high oil types can be developed and implemented.

Crop Residues

Tyson reviewed agricultural crop and orchard residues generated in the Western U.S. in a 1990 study.[11] Her results were based on 1987-88 production numbers of the following crops: wheat, corn, sorghum, sunflower, barley, oats, rye, cotton, and orchard trimmings. The numbers for collectable residues were based on the following assumptions: a minimum of 1 ton per acre must be left behind for soil conservation, 20 percent of the residues will be lost in collection, and a yield of less than 0.5 ton per acre after allowing for soil conservation and collection losses was assumed to be uneconomic. In Tyson's report, the highest concentration of collectable residues in Texas was found to be in the Gulf Coast counties of Wharton, Jackson, and Matagorda. Wharton County's total of 490,000 tons ranked eighth. Statewide, agricultural residues sum to over 5.3 million tons. This amounts to an energy potential of 0.085 EJ, or about 7.1 billion kWh of electricity (given 30 percent conversion efficiency). More recent crop residue figures, as shown in **Exhibit 5-5**, point to the High Plains region of Texas as the greatest source of collectible crop residue.

While the Tyson (1991) study gives some indication about the potential use of residue as a source of bioenergy, the underlying assumptions also reveal the limits of our knowledge. In traditional agriculture, residues are returned to the soil where they play an important role in maintaining a stable and sustainable agroecosystem. Returning residue to the soil is important to maintain soil organic matter, soil structure, productivity, and soil carbon content. Data on the impact of repeated residue removal on Texas' soils is lacking, and thresholds for sustainably doing so have not been established.[11]

Cotton gin trash has a potential as a cellulosic biofuel. Much of the logistical problem associated with energy crops is not an issue with gin trash, as it is accumulated at a cotton gin as a co-product from cotton lint harvest. Gin trash is comprised of the leaves, burs, stems, and soil stuck to the cotton fiber after harvest, and it is separated at the gin. Texas leads the nation in production of gin trash with about one million tons created per year. This has been estimated to produce 1.7 billion kWh of electricity.[12] Cotton hulls could be added, but hulls are traditionally consumed as an animal feed. Currently, the return of nutrients to the land is the only value assigned to gin trash.

While much has been suggested about crop residue, the complexity of crop harvest is such that few have been interested in further complication by harvesting residue at the same time. This leads to a secondary harvest of the residue adding significantly to cost, especially in marginal yield situations. Even in high yield corn production, it is estimated that more than half the residue needs to be left in the field to avoid soil degradation, and systems designed to collect a specific amount of residues while leaving an alternative desired amount in the field are not as efficient as primary collection strategies. Furthermore, crop residues are generally a highly seasonal source of input, and are thus considered a short term source or a source requiring a significant storage effort.

The total energy potential from the agricultural residue (leaves and stalks) left in the fields after harvesting corn, wheat, and sorghum is significant. However, these feedstocks present significant collection, transportation, and storage challenges for a large energy producer depending on such inputs for a significant amount of energy production.

Uses—If the agricultural residues were collected and stored for use on a large scale, the use could be for cellulosic ethanol, or electricity production. Cellulosic biofuels companies view large concentrations of row crop residue as prime feedstock and, therefore, prime locations for an ethanol facility. It is unlikely that a power producer would be able to compete with cellulosic biofuels for the feedstock because of the current subsidized nature of cellulosic ethanol.[13] However, power producer competition with cellulosic ethanol could be contingent upon a greenhouse gas offset price, a carbon cap and trade policy, or a sorted carbon output tax that would substantially alter the aforementioned situation.

Challenges include:

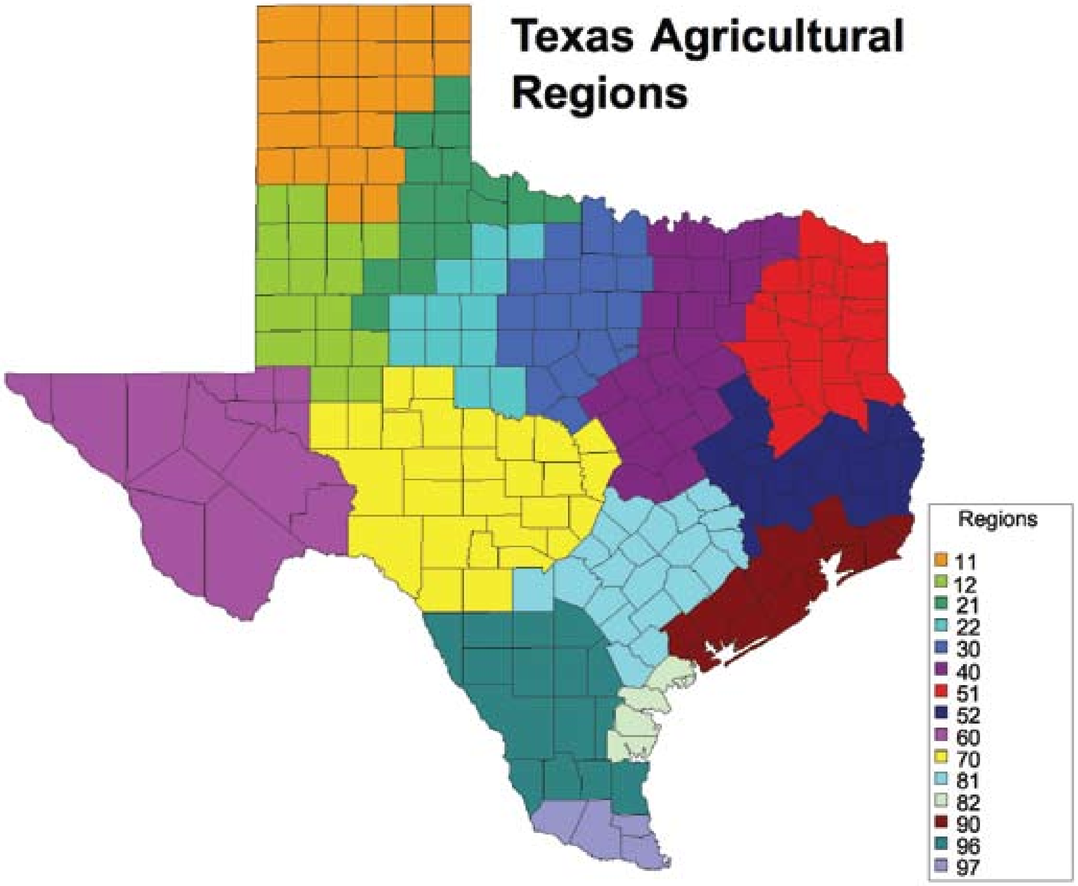
- **Non-perennial nature of the feedstock** – In most regions of Texas, crop residues will only be available in the field for a 6 to 12 week window. During this time, all of the material must be harvested, used, or put into protected storage to maintain its usefulness.

- **Diffuse Nature of the Feedstock** – The amount of stover or wheat straw collected is small, perhaps one to two tons per acre can be collected off of the land in a sustainable fashion. This means that while the total amount of row crop residue available is large, the amount available in any one place is relatively small and the cost of collection and delivery are relatively large.
- **Cost of Collection and Storage** – The diffuse nature of the feedstock also means that it is expensive to gather and store in large quantities in a central location. U.S. Department of Energy and State Agriculture Extension Service reports forecasted expected gathering, delivery and storage costs for very large quantities of agricultural residue to be in the $60/delivered ton range. This is much more expensive than delivered costs for broiler litter (commercially reared chicken waste) and logging waste.

A 2002 Oak Ridge National Laboratory report analyzed the costs associated with short-range transportation and intermediate storage of corn stover, a crop residue that is abundant in today's high-priced corn markets.[14] In order to estimate a cost range associated with corn stover transportation and storage, the authors analyzed field shredding, raking, baling, short-range hauling (five miles with farm equipment), and covered storage. In 2002, given the variability inherent in all farming operations, the costs were determined to range from $23/dry ton up to $45/dry ton. In today's marketplace, one would expect the baseline and upper-range costs to be greater given recent increases in farm grade dyed diesel (red-fuel), machinery (steel, copper, etc.), and labor. This is evident in the difference between projected costs in the Oak Ridge study and the predictions provided by the DOE and State Agriculture Extension Service.

Texas is divided into a number of reporting districts which provide agriculture production statistics (**Exhibits 5-4** and **5-5**)

Exhibit 5-4 – Texas Agricultural Regions



Source: United States Department of Agriculture, NASS

Exhibit 5-5 Total Energy Potential of all Crop Residues

	Tons of Biomass	BTU/Year (Millions)
Northern High Plains	3,404,400,000	25,533,000
Southern High Plains	388,600,000	2,914,500
Northern Low Plains	363,200,000	2,724,000
Southern Low Plains	430,200,000	3,226,500
Cross Timbers	180,600,000	1,354,500
Blacklands	2,254,500,000	16,908,750
East Texas North	80,600,00	604,500
East Texas South	78,600,000	589,500
Trans-Pecos	9,800,000	73,500
Edwards Plateau	229,200,000	1,719,000
South Central	412,600,000	3,094,500
Coastal Bend	424,200,000	3,181,500
Upper Coast	850,800,000	6,381,000
South Texas	79,000,000	592,500
Lower Valley	560,400,000	4,203,000
Combined Districts	5,100,000	38,250
STATE	9,751,800,000	73,138,500

Source: Cornwell, Bret, David Sandhop, Lauralee Shanks, Lauralee Phillips, and Deborah Webb

Texas Woody Biomass Sources

Forest Sources—The forestry sector is important to the Texas economy. In 2005, timber ranked sixth in agricultural cash receipts with cattle/calves, cotton, broilers, greenhouse/nurseries, and milk ranking from one to five respectively. In East Texas, timber ranks even higher and is the number one agricultural crop in several rural counties. The direct economic impact of the Texas forest sector in 2004 was $17.5 billion of total industry output, $5.5 billion of which was value-added. It employed almost 76,000 workers and paid $2.7 billion in wages, salaries, and benefits. The total economic impact the same year was $30.6 billion, of which $12.4 billion was value-added, and generated more than 173,000 jobs and paid $7.6 billion in labor income.16

Of the 21.4 million acres in the 43 East Texas counties, 11.9 million acres (56 percent) are covered by forests.[15] Historically, family forest owners held nearly 2/3 of the East Texas forests, forest industry owned nearly 1/3, and a small percentage was publicly owned. However, since 2000, ownership patterns have changed rapidly with forest industry lands being sold to investment groups (**Exhibit 5-6**).

Although the number of forest products manufacturing facilities has declined during the last few years, demand for the higher value timber products continues to be elevated. Conversely, demand for lower value woody biomass is depressed. Sources of lower value woody biomass include logging residues, thinnings for improving forest productivity and health, and biomass damaged or killed by insects, diseases, fire, storms, and others. Utilizing these resources for an array of bioenergy and bio-based products has several advantages including: year-round supply; complements with existing sustainable forest management practices (reducing site preparation costs and fire risk, mitigating disturbances, etc.); and low energy and water input. H.B.1090, Agricultural Biomass and Landfill Diversion Incentive, was passed by both the Texas House and Senate in 2007 to encourage the construction of facilities that generate electrical energy using logging residue and urban woody biomass.

Exhibit 5-6 Dry Tons of Logging Residue in East Texas, 2005

Region	Species Group	Stump	Top/ Limbs	Unused Cull	Total Residue	Available Residue
Northeast	Softwood	6,891	274,068	99,693	460,652	373,761
	Hardwood	65,292	210,513	101,056	376,860	311,569
	All	152,183	484,581	200,749	837,512	685,330
Southeast	Softwood	156,155	495,141	182,572	833,868	677,713
	Hardwood	44,584	141,794	64,305	250,683	206,099
	All	200,739	636,935	246,877	1,084,550	883,811
East Texas	Softwood	243,046	769,209	282,265	1,294,520	1,051,474
	Hardwood	109,876	352,307	165,360	627,543	517,667
	All	352,922	1,121,516	447,625	1,922,062	1,569,141

Source: Texas Forest Service

Standing Biomass—The total above-ground biomass of the East Texas forests is estimated at 472 million dry tons.[16] The energy content of this immense resource is nearly 8.7 EJ (8.2 quads, or quadrillion BTUs). Commercial and residential thinnings are the residue/waste resulting from forest/tree management practices. Both are presently considered premerchantable because of the small diameter of the trees, and provide excellent potential for use as bioenergy feedstock due to the small existing markets for those fiber sources. Inventories of those resources are currently being conducted by the Texas Forest Service (TFS) and will be posted to the http://texasforestservice.tamu.edu website by early fall 2008. Although catastrophic losses from insects, storms, fire, etc. are unpredictable, they frequently regenerate large volumes of woody biomass and should, therefore, be factored into the biomass supply chain.

Outside of East Texas, substantial woody biomass in the form of brush species occupies much of the remainder of the state. An inventory of 25 major brush species compiled by the United States Department of Agriculture's Soil Conservation Service (Natural Resource Conservation Service now) in 1982 revealed that: (1) "dense" brush infestations (greater than 30 percent canopy cover) occurred on over 33.7 million Texas acres, or about 20 percent of the state's land area, and (2) that some degree of brush canopy is present in nearly 60 percent of the state.[17] Mesquite is the most common brush species and occupies over 51 million acres, of which 19 million is moderate to high cover (greater than 10

Exhibit 5-7 Dry Tons of Mill Residue in East Texas, 2005

Region	Species Group	Chips	Sawdust	Shavings	Bark	Total
Northeast	Softwood	441,210	67,204	64,282	271,457	844,153
	Hardwood	88,597	54,779	8,775	163,917	316,068
	All	529,807	121,983	73,057	724,847	1,160,221
Southeast	Softwood	1,071,737	119,415	114,223	517,268	1,822,643
	Hardwood	36,745	23,149	3,708	109,503	173,105
	All	1,108,482	142,564	117,931	626,771	1,995,748
East Texas	Softwood	151,2947	186,619	178,505	788,725	2,666,796
	Hardwood	125,342	77,928	12,483	273,420	489,173
	All	1,638,289	264,547	190,988	1,062,144	3,155,969

Source: Texas Forest Service

percent). These values are much greater today than they were in 1982. Recent data indicate dense mesquite (300 trees/acre) in North Texas have a standing dry mass of 5 to 15 tons/acre. Required time after harvest for regrowth to attain 10 tons/acre is 10 years, or 1 ton/acre/year.[18] This production rate is below the 5 tons/acre/year yields of short rotation woody crop systems in the slightly wetter site of the upper Midwest.[19] Thus, management of brush in Texas for bioenergy may need to encompass more land area to allow for the longer regrowth interval as compared to short rotation woody crop systems. There are issues related to the costs and efficiency levels of harvesting brush on rangelands.

Logging Residues—Logging residues are the unused portions of harvested trees left in the woods. Types of logging residue include stumps, tops, limbs and unutilized cull trees. In East Texas, this biomass represents a significant energy resource. The amount of unused forest biomass in East Texas is significant. For 2006, the Texas Forest Service estimated these residues at 1.1 and 0.8 million dry tons for Texas pines and hardwoods, respectively.[20] However, this resource is for the most part not utilized, perhaps due to issues of harvest and transportation.

Mill Residues—The forest products industry produces considerable volumes of mill residue in their manufacturing process. However, these facilities utilize 97 percent of the residues to produce steam, electricity, and for other uses.[21] The forest products industry leads all other industries in the use of biomass energy. The 2004 data indicate that 77 percent of the fuel used at wood products facilities and 60 percent of the fuel used at pulp and paper mills are biomass fuels.[22] The Texas Forest Service estimates that total mill residue, including chips, sawdust, shavings, and bark in primary mills such as sawmills, panel mills and chip mills in 2006 was 3.3 million short tons; softwood and hardwood mill residue generation was at 2.7 and 0.5 million dry tons, respectively.[23] The annual survey of mills by the Texas Forest Service illustrates the distribution of the industry and mill residues (**Exhibit 5-7**).

Urban Woody Biomass—Although reliable, local estimates regarding the volume of urban biomass are generally unavailable, the National Renewable Energy Laboratory estimated the annual per capita generation of urban wood resources to be 0.17 dry tons.[24] Using that estimate, 22 million Texans produce nearly 3.7 million tons of woody biomass each year. A significant volume of this resource is currently being sent to landfills (**Exhibit 5-8**).

Exhibit 5-8 Available Woody Biomass in Texas

Source	Dry Tons/Year
Logging residues	1,569,141
Mill residues	3,155,969
Forest Thinnings	Estimate available fall 2008, [TFS website]
Insect & Disease	46,800
Mesquite	19,000,000
Urban Woody Biomass	3,663,000

Sources: Xu, W. and B. Carraway
Pye, J.M., T.S. Price, S.R. Clarks, and R.J. Huggett, Jr.
Ansley, R.J.
Wiltsee, G.

Exhibit 5-9 Available Tons of Animal Waste Biomass per Year and Energy Potential

	Tons of Dry Solids/Year	Energy potential, HHV, BTU/Year (Millions)
Beef Feedlots	2,302,000	32,230,000
Dairies	1,140,000	16,180,000
Swine	34,000	1,070,000
Poultry	1,649,000	15,260,000
STATE	5,125,000	64,740,000

Animal Wastes

Environmental quality and natural resources management issues are important drivers of industry structure and location, production practices, and growth opportunities for concentrated animal feeding operations (CAFOs). Key issues include: energy efficiency, bioenergy/biofuel opportunities, and mortality disposal/utilization, along with more traditional issues such as adequate water supply, protecting water and air quality, efficient manure/nutrient utilization, and holistic environmental management. Livestock retain less than 25 percent of the nutrients they consume; resulting in harvestable manure, which can be managed as a valuable fertilizer (traditional use) or as a biomass/biofuel resource.

Feedlot Biomass—Texas feedlot operations define where the feedlot biomass is available in large quantities and available for little to no cost at the source; however, recent dramatic increases in fertilizer costs have created an emerging market for animal wastes. These feedlot operations are concentrated in the Texas Panhandle. Most beef cattle on the High Plains are fed in open pens with native soil surfaces. Manure is normally scraped from the pens after each lot of cattle is finished (120 to 200 days). The quantity and quality of manure produced is highly dependent upon the diet the cattle are fed.[25] Most feedyard rations are highly digestible, so the feces excreted is comprised mostly of undigested fiber and minerals, metabolic excretions, sloughed cells, and microbial biomass. When the grain portion of the diet is not highly processed, appreciable quantities of starch may also be excreted.[26]

Each year, the nearly 5.5 million cattle finished at feedyards in the Panhandle and South Plains excrete about 2.3 million tons of manure on a dry basis.[27] The main use of feedlot manure is fertilizer. Nearly all of this manure is harvested for use as organic fertilizer for crop or pasture lands. About half of the feedlots keep their manure and apply it to their own fields. The majority of the remaining manure is given to manure haulers at a price ranging from a tipping fee of $1/ton to a price as high as $3 to $5/ton with some upward pressure on the price of manure. Feedlots have traditionally made their manure available at no cost to a manure hauler. The manure haulers then transport the manure for land application elsewhere and charge a transportation and/or spreading fee, typically averaging about $2.25 per ton plus $0.15/ton-mile one-way.[28] The fertilizer value of manure may preclude its availability as a feedstock for energy.

The quantity and chemical content of as-excreted manure changes on the feedlot surface due to many factors, such as decomposition and potential soil incorporation. On an “as removed” wet basis, nearly 7 million tons of manure at 33 ± 28 percent moisture, or 4-5 million dry tons/yr, is scraped from these feedyards annually. The nutrient value of this manure is estimated at 82,000 tons of N, 79,000 tons of P_2O_5 and 87,000 tons of K_2O.[29] Sweeten et al. determined that the higher heating value (HHV) of as-harvested cattle feedlot manure ranged from approximately 2,500 to 6,000 BTU/lb, primarily due to variations in (a) moisture content and (b) ash content, which includes entrained soil.[30] However, the HHV averages 8,500 BTUs per pound of dry/ash-free basis. Using this as a reference value, the total energy content of as-excreted feedlot manure in Texas is about 30×10^{12} BTUs.

Dairy—Nearly 40 percent of the 333,000 milking cows in Texas are now reared in the Panhandle with proportions increasing annually. On average, these herds excrete nearly 440,000 tons of dry manure with an approximate N, P_2O_5 and K_2O content of 2,800 tons, 1,140 tons, and 1,640 tons per year, respectively. Total energy from excreted dairy manure in the Panhandle is estimated (assuming a HHV of 8,500 BTUs per pound of dry/ash-free dairy manure) to be 6×10^{12} BTUs.[31] Assuming 80 percent of the cows in the Panhandle are raised in open lots, nearly 1.5 million tons of manure is scraped from earthen lots annually. The corresponding nutrient value of as-scraped manure is estimated at 10,482 tons, 8,576 tons and 12,040 tons of N, P_2O_5 and K_2O, respectively.[32]

Swine—The Panhandle also finishes nearly all (92 percent) of the estimated 565,000 pigs in Texas each year. The resulting manure is generally produced in liquid or slurry form. This manure is highly diluted when flushed to a lagoon or other storage facility. Flushed manure from finishing barns is stored in manure treatment lagoons, evaporation ponds, or slurry tanks, and is ultimately irrigated as a fertilizer, contributing both nutrients and moisture for row crops (mostly corn) in the area. On a dry basis, about 34,000 tons of manure is excreted by finishing pigs annually.[33] It is estimated that each year, nearly 1.2 million tons of diluted manure having a nutrient value of 2,387 tons of N, 1,913 tons of P2O5 and 2,434 tons of K2O may be available for irrigation from these swine finishing facilities.[34]

Poultry Litter—Based on data provided in the USDA National Agricultural Statistics Service Census, nearly 72 percent of all commercial broiler production in Texas originates in the state's 24-county northeast region designated as District 5-North by the USDA. Nearly 450,000,000 of the state's 628,300,000 broilers come from this region. Poultry litter has two primary market applications in the region, a substitute for commercial fertilizer and cattle feed. Poultry producers first spread litter on adjacent lands and crops as fertilizer. It is an easy decision for poultry operators if they have additional land and crops. According to the EPA, approximately 90 percent of all poultry litter is hauled away and used in the external marketplace, so the internal uses of poultry litter have only a nominal effect on market availability. Taking into account that roughly 10 percent of production is used internally and not available on the fertilizer market, the available poultry litter for sale on the open market in Texas is approximately 1,200,000 tons.

Mortality Disposal—Beginning with federal regulations restricting the use of rendered bovine by-product as animal feed in 1997, the cost of rendering has increased, and rendering companies now charge a sizeable pick-up fee for carcasses, causing producers to look for practical, on-farm alternatives. Studies have shown that on-farm management of cattle and swine mortalities by carcass composting is a viable and economical method, and the end product can be utilized as a plant nutrient and organic soil amendment material.[35] Several large, commercial feedyards have successfully incorporated carcass composting with feedlot manure guided by ongoing applied research and outreach efforts by TAMU's agricultural engineers.[36] An extension of this technology would be to manage composted mortality, whether for cattle feedlots, dairies, swine or poultry, as a biofuel resource for thermochemical processing, where the composted residue contributes to higher heating values and provides for environmentally-secure disposal.[37] Greater research is needed in this area.

Municipal Solid Waste (MSW)

MSW is solid waste resulting from or incidental to municipal, community, commercial, institutional, and recreational activities. MSW includes garbage, rubbish, ashes, street cleanings, dead animals, abandoned automobiles, and all other solid waste not deemed industrial solid waste. Except for glass and metal, MSW is an excellent source of biomass for energy recovery. Solid waste management has been a practice in the United States for well over a century and there are currently two main methods that are likely to be employed to utilize the energy content of municipal solid waste in the United States: landfill gas (methane) capture and municipal solid waste combustion. In the case of landfill gas capture, the methane released at the landfill sites (having half of the energy content of natural gas) is collected and burned to reduce air pollution and harness the inherent energy by generating electricity or powering boilers.[38] Municipal waste combustion began with the sole intention of reducing the volume of waste, but current practices harness the heat being generated for operations such as heating, steam generation, and electricity production.[39] It is neither the intention of this report to demarcate between the two most widely utilized MSW energy generation processes nor to identify a dominant process, as situational circumstances including budgetary and pollution constraints play a significant role in process selection.

In classifying MSW, Texas considers the source, rather than the constituents or properties of the waste. Distributors, retailers, repair services and the general public are considered municipal generators. Texas also considers construction and demolition (C&D) debris and municipal sludge to be a part of the aggregate MSW figures. Conversely, manufacturers are not considered MSW contributors, but rather industrial solid waste generators. As Texas includes construction and demolition

(C&D) debris and municipal sludge, the per capita MSW disposal and generation rates appear significantly higher than those of other states in the nation.[40] MSW is demarcated into hazardous or non-hazardous. In Texas, industrial solid waste may similarly be defined as hazardous or non-hazardous with non-hazardous defined by classification.[41]

- Class 1 non-hazardous includes waste that may pose a danger to human health or environment if not properly managed (based on its constituents and properties, i.e., solidified industrial sludges contaminated with metals or organics).
- Class 2 is for industrial solid waste that cannot be described as hazardous, class1, or class 3. Examples include waste activated sludge from industrial biological wastewater treatment and regular trash from plant offices.
- Class 3 wastes are inert and essentially insoluble industrial solid wastes not readily decomposed: demolition debris and bricks that are insoluble, do not react with other materials, and do not decompose.

Quantity—For 2006, total disposal in the state was 30.45 million tons.[42] This represents 365 trillion BTUs, assuming an average BTU content of 6,000 per pound. Of course, only a fraction of this might be suitable for practical application. At a consumption rate of ten percent (36.5 trillion BTUs) this would be the equivalent of 6,293,105.5 barrels of oil.[43] Utilizing the EPA definition of MSW (which excludes C&D debris and treatment plant sludge), the per capita disposal rate in Texas was 5.8 pounds per person per day, which is above the U.S. EPA national average for 2005 of 4.5 pounds per person per day. The per-capita landfill disposal rate for Texas for 2006 was 7.1 pounds per person per day. The total remaining landfill capacity in Texas at the end of 2006 was 2.11 billion cubic yards.

Classification—The largest single type of waste disposed of in MSW landfills in Texas in 2006 was residential waste, comprising 35 percent of the total waste stream, followed by commercial waste with 33 percent of the waste stream, and C&D with 19 percent. These three types compose the vast majority of the waste stream, 87 percent of all the waste disposed of in the state.

Exhibit 5-10 A breakdown of waste types in 2008 in Texas:

Residential	35%
Commercial	33%
C&D	19%
Class 2/3	5%
Sludge	2%
Brush	2%
Soil	1%
All Others	3%

Algae

Algae have great potential as a feedstock for biofuels and bioproducts. Microalgae can regenerate in 48 to 72 hours. Cyanobacteria can regenerate in 5 to 20 hours. These short generation times (compared to seed crops such as soybean, jatropha, and castor) lead to the high potential for biodiesel production from algae.

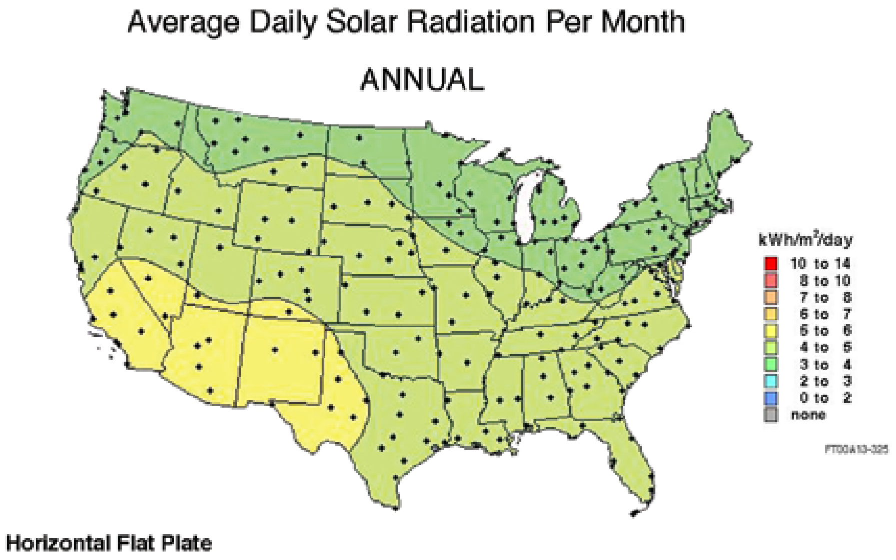
Exhibit 5-11 Production potential of biodiesel from dedicated fuel crops

Dedicated Fuel Crop	Biodiesel Production Potential (gallons/acre/year)
Algae	5,000
Palm	560
Jatropha	250
Castor	140
Canola	90
Sunflower	90
Soybean	57

The theoretical potential biodiesel production from algae is 15,000 gallons/acre each year, assuming optimal growth conditions. For large-scale production of algae in outdoor ponds (raceways), actual production may be 3,000-5,000 gallons/acre per year. Even so, the potential for algae biodiesel production would be close to ten times the potential of palm oil and 100 times that of soy oil, the two most commonly used feedstocks for biodiesel production today.

Some algae strains have been identified that produce especially high levels, 25 to 55 percent by weight, of lipids, the precursor to oil.[44] Environmental conditions and nutrient availability affect the growth of algae and production of lipids. Algae require three ingredients to grow: 1) high solar radiation (sunlight), 2) carbon dioxide (CO_2), and 3) brackish water, or water high in salt content (up to 30,000 ppm). The logical location for growing algae under high levels of solar radiation would be the desert southwest.

Exhibit 5-12 Annual average daily solar radiation for the U.S.



Source: National Renewable Energy Laboratory

In Texas, large parts of West Texas and along the Gulf Coast represent excellent sites for algae production. An ideal match may be to couple Gulf Coast petrochemical facilities and power plants with algae production, in order to capture CO_2 and produce biofuels/bioproducts feedstocks.

Temperature control is also important, as algae grow optimally in steady temperatures with little fluctuation. Temperature extremes in the water, such as seen in winter and summer, may require heating or chilling of the water for continuous production. Circulation of water is required to keep the algae water mixed and assure there is no occurrence of flocculation, the formation of clumps or masses that would likely sink to the bottom of the raceways.

Two possible system approaches to algae production are: (1) raceway ponds; and (2) photo bioreactors (PBRs). Raceway ponds allow for high production of algae and typically cost less per acre to construct; however, because they are open to the environment, they require control of contaminants and management of evaporation. PBRs on the other hand are more costly to build per acre but can operate year round because they are enclosed, typically in glass or film tubes.

After generation and production of lipids, algae must be harvested, concentrated, and forced to lysis (a disintegration of the cell wall) to release lipids. Harvesting processes include processes such as pumping the algae to settling tanks and using rakes or skimmers. Algae cell walls can be made to lysis by the application of ultrasound.

The lipid/algae carcass/water slurry must go through an oil separation and purification process. Chemical extraction and mechanical extraction are the primary methods for oil separation. Hexane is used successfully in separation applications, but may be cost prohibitive. Centrifuge processes have also been successful, but require high energy inputs for large-scale production. Research is underway to develop high capacity separation technologies.

Algae production as a dedicated biodiesel feedstock provides for an area of extensive research. Academia, private industry, and governmental agencies are ramping up investigation into these topics. Theoretically, algae could supply the entire U.S. diesel demand on only 2.7 million acres of land. In comparison, 970 million acres are utilized for crops and grazing.[45] Algae are not a food crop and would likely be farmed with high saline ground water sources where traditional field crops cannot be sustained, and would not, therefore, compete for the same land.

Currently, the only commercial algae production is for high value products such as cosmetics and nutritional items. In Texas, several entities are developing pre-commercial demonstration projects for biofuels and bioproducts. General Atomics and Texas AgriLife Research have received major funding from the Governor's Emerging Technology Fund and the Department of Defense to build and operate an algae research and demonstration facility at Pecos, Texas. Several other projects are in various stages of development.

Utilization

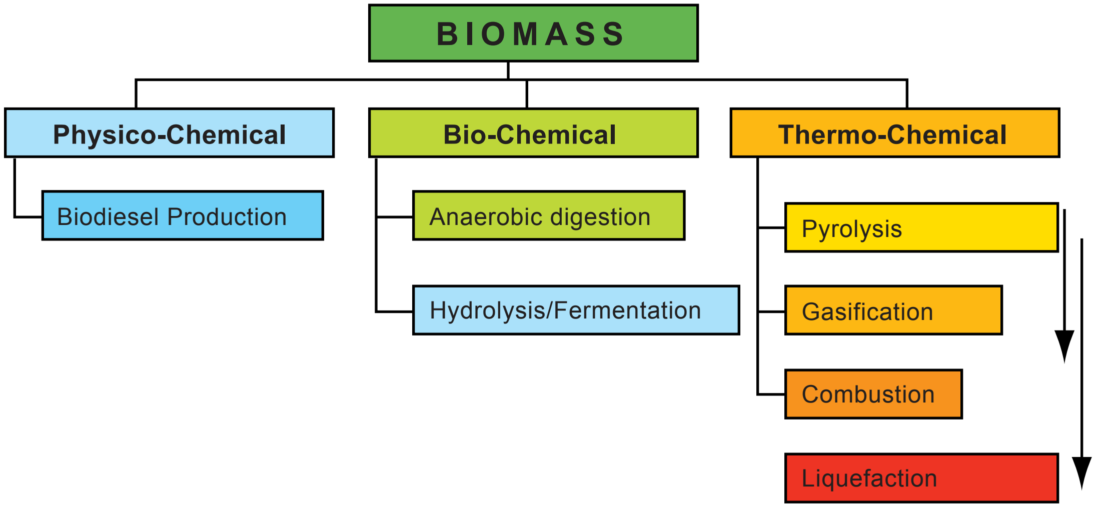
The generation of vast quantities of biomass is just one part of the effort in developing sustainable energy. Issues of conversion, available resources, infrastructure, and logistics must additionally be addressed as related to developing energy.

Conversion Technologies

There are three general pathways to produce energy from biomass. Thermo-chemical biomass conversion processes involve the treatment of biomass under high heat with or without an oxidant. Included in this category are: pyrolysis, gasification, and combustion. Biochemical conversion processes make use of specific microbial populations to convert biomass resources into high energy liquid (e.g. ethanol) or gaseous compounds (methane). Processes under this category include: anaerobic digestion for biogas production and fermentation into ethanol. An example of a physico-chemical process is a simple oil extraction from plant or animal sources for biodiesel production (**Exhibit 5-13**).

There are inherent limitations in each of the processes. Two key factors in thermal conversions are moisture content and ash, to prevent slagging and fouling.[46] For bio-chemical conversion processes, such as ethanol production, sterility of the process needs to be ensured so that only the selected microbes are retained. Contamination with other unwanted microbes is to be avoided at all times. This will make the reaction proceed with the highest efficiency. The different processes will be discussed in more detail in the following sections.

Exhibit 5-13 Biomass Resource Conversion Processes



Source: Capareda, Sergio

Physico-Chemical Conversion Technologies—The simplest process of producing liquid transportation fuel from biomass is through trans-esterification of fats and oils. This is made by mixing refined, bleached, and deodorized vegetable oil or animal fats with an alcohol (methanol is the most common), in the presence of base or acid catalysts (e.g. sodium methoxide) this exposure would yield esters of oil (biodiesel). The theoretical rate of conversion is about 100 pounds of biodiesel (B100) with about 10 pounds of unpurified glycerin produced from every 100 pounds of oil and 10 pounds of methanol.[47] Vegetable oils and fats are never alike. There are different levels of saturated and unsaturated fatty acids and the yields per acre are highly varied. In addition, the use of biodiesel as fuel for engines will generate different emissions as a result of the burning efficiencies of the biodiesel components.

Bio-Chemical Conversion Technologies—There are two important biochemical conversion processes: (1) anaerobic digestion for biogas ($CH_4 + CO_2$) production; and (2) ethanol (C_2H_5OH) fermentation. These biochemical conversion processes require substrates that are well suited to the type of microbial population used.[48] Ethanol production from sugary compounds requires the use of yeast, while those coming from starchy materials need enzymes (e.g. amylases from different microbial groups) to convert starch into sugar. The production of methane from anaerobic digestion of biomass requires the use of acid producing and methane producing microbes.

Anaerobic Digestion—The anaerobic digestion process begins with the breaking down of cellulosic biomass compounds into organic acids by enzymes from acid producing microbes. This is followed by conversion into methane by the methane producing microbial population.[49] The reactor must be free of oxygen to ensure that anaerobic microbes will be kept alive. In addition, methane producing microbes are very sensitive to low pH and thus, conversion efficiency will diminish when the microbe population is decreased due to low pH. Two types of anaerobic digesters are used commercially: the low rate (conventional) and the high rate digesters. Conventional anaerobic digesters have retention times of several days or weeks, making the digester volume large; while high rate digesters offer a smaller reactor footprint and shorter retention times of a few days or hours.[50]

Ethanol Fermentation—Conversion of ethanol from biomass resources differs based on the form of substrate used. Sugar compounds, such as sweet sorghum or sugarcane juices, only need ethanol-producing yeasts for conversion. However, starchy materials need amylase-producing microbes to convert the starch into sugar, followed by the use of yeast to convert the resulting sugar into ethanol. Cellulosic biomass needs an additional step to convert the cellulosic materials into organic acids, sugars, and ethanol. There are numerous ways to replicate the process. Some methods use steam explosion to break cellulose down into simpler organics, while others use high strength acid for the same purpose.[51] More recently, thermal conversion systems have been designed to convert cellulosic biomass into liquid fuel via a thermal catalytic process, a combination of the thermal and biochemical conversion processes.

Thermo-Chemical Conversion Technologies—There are three major thermo-chemical conversion processes: pyrolysis, gasification, and combustion. While combustion is the most mature of the thermal conversion processes, it is likely not the best candidate for biomass conversion processes due to the high ash content of most biomass resources. These inorganic ash materials found in most biomass resources have a very low eutectic point (melting point), and these inorganic materials may solidify and attach to thermal conversion surfaces. Such incidences may lead to slagging and fouling problems after several hours of operation.

Pyrolysis—Pyrolysis, or destructive distillation, is the thermal conversion process of biomass in complete absence of oxygen or an oxidant. Products of this process include medium calorific value gas (MCV), liquid condensates (bio-oil, water and tar), and char (carbonaceous solid products with greater than 2 percent carbon). There are different variations of the pyrolysis process (depending upon the rate of heating, temperature, and pressure used). Flash, or fast pyrolysis, is known for the production of high yields of bio-oil and is done under medium temperatures, 400 to 500°C (750 to 930°F), in a very short period of time (milliseconds). Generally, low temperatures and slow heating result in high yields of char, whereas rapid heating and high temperatures produce high yields of gaseous compounds.[52] The gaseous products are primarily CO and H_2 (also termed synthesis gas, syngas, or producers gas), char, and organic liquids (bio-oils).

Gasification—Gasification is thermal conversion with limited amounts of oxidant. Products of the process are very similar to those of the pyrolysis process. Gasification is an endothermic reaction and, thus, would not need supplemental fuels or heating once the process had begun. There are two general types of gasifiers: the fixed bed (downdraft or updraft) and the moving bed gasifier (fluidized bed). When wood is used as fuel, with air as an oxidizing medium, the typical gas composition is as follows: CO_2 (10 percent); CO (20-22 percent); H_2 (12-15 percent); CH_4 (2-3 percent), N_2 (50-53 percent) with a heat content of about 5,500 kJ/m3.[53]

Combustion—Direct biomass combustion systems are now technically and economically viable for some biomass resources (specifically wood). There are numerous biomass-fueled power plants currently installed in the U.S. for this purpose. Most biomass power plants are wood-based due to the low ash content of most wood residues. Some biomass, particularly those with low ash content (e.g. sugarcane bagasse) have been proven viable for combustion systems and in boiler applications. The total heat produced during the combustion process is similar to the heating value of the fuel.[54]

Thermo-Catalytic Conversion to Bio-fuels—A number of thermo-chemical processes exist for converting biomass into liquid fuels. The synthesized gas (CO and H_2) produced from either pyrolysis or gasification processes could be reformed either catalytically or with the use of steam to produce synthetic gasoline or diesel-like liquid fuels. The majority of these processes were originally developed for the conversion of natural gas into liquid fuels. Examples of these biomass liquefaction processes include the Fischer-Tropsch (F-T) process and the Mobil processes.[55] The F-T process was developed in the 1920s and was used extensively in Germany during World War II to produce synthetic fuels. It is currently being used in South Africa for coal conversion.[56]

Infrastructure Considerations

Availability of land for dedicated energy crops—Texas consists of approximately 171 million acres of land area, including fresh water bodies. More than 55 percent of Texas land area is currently rangeland (see **Exhibit 5-1**), which occupy land that is marginal for agriculture due to soil or climate limitations. Cropland occupies approximately 15 percent of the area (20 percent of cropland is under irrigation), and pastureland occupies approximately 10 percent of the area.[57]

There are three main avenues by which acreage devoted to dedicated biomass production will expand. The first course of action involves incorporating new dedicated energy crops into the traditional crop rotation pattern with the underlying goal of intensifying overall production in the cropland area. Secondly, converting agriculturally suitable pastureland to cropland would potentially increase the overall supply of biofuel feedstocks. Finally, the goal of production expansion could be achieved by incorporating perennial crop production in areas deemed marginal for agriculture and currently under pastureland or rangeland. The latter option is only feasible in areas with relatively high rainfall (greater than 31.5 inches/year) and is, thereby, restricted to the eastern part of the state. In that area (Blackland Prairie, Oak Woods and Prairie, Piney Woods, and Gulf Coast and Prairies), there are approximately 8 million acres of pastureland and 20 million acres of rangeland, of which a fraction could be converted to biofuel production. Likewise, the prime farmland is already dedicated to cropland, or is being developed. Recently, much talk has been centered on devoting USDA Conservation Reserve Program (CRP) land to biofuel production. In Texas, there are an estimated 4 million acres under CRP.[58] This area is located primarily in West Texas, where annual precipitation is low, and it is unlikely that irrigation for high tonnage biomass production would be economically viable.[59]

The development of a significant biomass-based energy industry requires a reliable supply of cellulosic biomass with consistent energy content, physical properties, and chemical makeup. A bio-energy conversion plant producing 100 million gallons of cellulose-based ethanol would require approximately 1.1 million dry matter tons annually. If high yielding dedicated crops are used (assuming a yield of 10 dry matter tons/acre), 172 square miles of production will be required to produce 100 million gallons of ethanol. Removing non-productive lands from consideration, and accounting for crop rotation and partial participation by landowners, the total region size to supply the plant could be in excess of 2,000 square miles. If the biomass is delivered by fully loaded semi-trailers, a truck will have to be unloaded at the plant every 14 minutes or less. No existing agricultural supply chain system currently meets this level of intensity year round. While using diverse feedstock sources can mitigate supply risk, differences in the machine systems required, achievable yield levels, and energy content will complicate supply chain logistics.

Production Systems—Existing agricultural production systems are capable of producing biomass for energy from both annual and perennial crops. The development of a profitable bio-energy industry will generate refinements in production practices and equipment, but dramatic improvements will not be required. Studies by DOE on the feasibility of biomass energy have frequently been based on an assumption of using “no-till” production systems.[60] However, these have proven unsuccessful for crops and soils in some parts of Texas, with problems of maintaining long term productivity.

Harvest Systems—Forage harvesting systems have limitations for biomass harvest under Texas conditions. The direct relationship between available moisture and high yields will require that biomass for energy production be located in regions of the state with higher humidity. The larger stems found in higher yielding crops such as energy cane, miscanthus and biomass sorghum require more time to field dry in order to prevent storage and transport problems: storage with excessive moisture contents can present serious problems with material quality, and transporting high-moisture material is more expensive than transporting low-moisture material. Field drying of the stems to 20 percent moisture or less will result in greater levels of dry matter loss, particularly leaves and smaller diameter plant parts. Silage chopping is an alternative harvesting approach that can accommodate high moisture crops, but handling of chopped materials results in additional requirements for storage and additional expense for harvest and hauling.

Most studies of biomass harvesting systems have emphasized baling, in either the large square or round form, resulting in packages of 1,000 to 1,500 lbs. Bales can be formed at moistures above 20 percent, but wrapping in plastic is then required to avoid degradation. Baling of high-tonnage field mass may be less effective because five to seven days of field exposure might be required prior to baling. Existing mower/conditioners are marginally acceptable for the tall (12 to 16 feet) thick-stemmed biomass crops that would be grown. If field conditions are less than optimal, existing mower/conditioner designs will result in excessive harvest losses and soil accumulations in the harvested material. New machine designs and modifications will be required to enable crop moisture loss to be accelerated, to handle crop matter stuck in the machinery, to minimize the amount of soil mixed into the crop and to maintain the high throughput rate of current designs.

Storage and Transport Systems—Harvest periods of six to seven months are potentially available in most regions of Texas. This extended period will enable approximately half of the biomass to be processed without incurring the cost of storage depending on the moisture content and the method by which it is removed.

This longer harvest season makes Texas more competitive than many other states. However, if biomass from dedicated energy crops is needed year round, storage will be needed (both for the portion of the year when the crop is growing to an economically justifiable harvest size and to provide a buffer at the processing plant for delays in delivery).

Harvest systems that rely on baling have the disadvantage of requiring the handling of large numbers of small packages. Systems are needed that can load and unload trucks with minimal labor and time. The harvest storage and transport model used by the cotton industry could be emulated to obtain needed efficiencies. Knowledge of the system and the existence of support industries in the state provide an additional advantage for Texas. However, the direct adaptation of existing cotton module builders as a means of preparing loose biomass for transportation and storage is not likely to be successful. Compressed biomass will have significantly higher density, resulting in illegal truck weights if current module specifications are used. Higher compressive stresses that will likely be required with biomass mean that heavier module builders will be necessary. The economic need to maximize load size will mean that the tilt bed trucks used with cotton will not be optimum, and alternative means of loading the modules on, for example, the more common and less expensive flat-bed trailer, will likely be required.

Finally, Texas has a large number of rural bridges that are weight limited, making certain areas inaccessible to fully loaded semi-trailers. The development of an extensive biomass energy system will likely place demands on the state for improvements to bridge and road capacity.

Water Supply—Water is a limited resource in much of Texas, and it is potentially one of the more limiting inputs of a biomass energy production system; if irrigation is required.

Texas consumes approximately 18 million acre-feet of water per year, and water use is projected to increase steadily through 2060, particularly for municipal use in the Dallas-Fort Worth, Houston, Austin, and San Antonio areas.[61] Currently, an estimated 60 percent of water use is for agricultural irrigation, but the trend (in both relative and absolute terms) is for agriculture to consume a decreasing amount. The state has devised a plan to develop water supplies that is aimed at matching the increasing demand. The cost of the plan is $30.7 billion. In addition, water shortages are projected to cost the state $9.1 billion by 2010. In these projections, no specific allowance has been made for irrigation for biomass production, nor to attend industrial demands for bioenergy production.

Availability of water for crop growth will be a key issue. In seasons of drought, irrigation will be required to maintain expected yield levels and ultimately the availability of the crop. This is further complicated by the potential implication of global climate change.

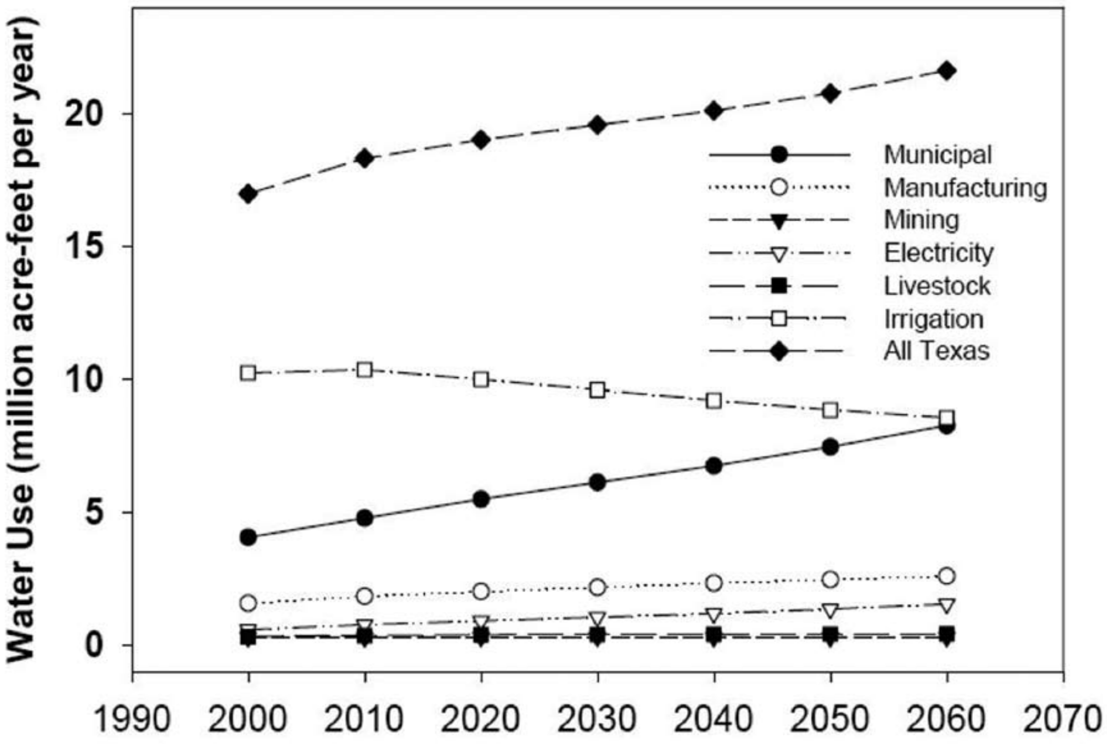
Water supplies for bioenergy may be available in regions with a projected surplus of water (precipitation or new reservoirs). These regions exclude most of West Texas and include areas north and east of Houston, and particular locations within the Brazos River watershed and Colorado River watershed. All of these areas are projected to have large increases in population, and competition with municipal water use can be expected. Irrigation is possibly feasible in the rice belt of Texas where water supplies are available and bioenergy crops may play a role in annual crop rotation. Ethanol production (distillation process) from corn consumes approximately 4 gallons of water per gallon of ethanol produced. Further, if one considers the amount of water required to grow corn in Texas, the quantity per gallon of ethanol skyrockets to cases as much as one thousand gallons of water per gallon of ethanol. If these same consumption trends were continued for renewable fuels, and the amount of renewable fuels production/demand increases at a significant rate, it is highly likely that water-use conflicts will arise. **Exhibit 5-14** shows competing water uses for Texas.

Economics

Biofuel production can be an important force in the economy. Forms of ethanol are expected to be produced for less than petroleum based fuels, with crude oil prices in excess of $100 per barrel. At the same time, the opportunities for ethanol production place pressure on commodity markets. In the spring of 2008, the combination of a number of factors including bioenergy production, energy costs, inputs, world demand, and market speculation contributed to a significant rise in commodity prices; however, by the end of 2008 commodity prices had significantly retreated because market forces and a slowing economy. Higher commodity prices benefit crop farmers but place economic stress on animal agriculture. Furthermore, high commodity and energy prices have caused substantial increases in the prices and costs of agricultural inputs. For example, recent land values in certain areas have doubled, and fertilizer and fuel prices have risen roughly 40 percent, with labor and machinery costs also steadily increasing.

The rise in commodity prices has made some biofuel production less desirable, slowing the extraordinarily rapid industry expansion. For example, in late April 2008 soybean oil prices hovered near 60 cents per pound (with a gallon weighing 7.6 pounds), driving the oil cost to about $4.50 per gallon. Soaring prices combined

Exhibit 5-14 Projected water use by economic activity for Texas



Source: Texas Water Development Board

with a transformation cost of $0.50 per gallon, and a similar conveyance cost, result in a production cost of about $5.50 per gallon for a product selling at the pump for around $4.00 per gallon. Even with the $1.00 per gallon subsidy discussed below, this has led to an industry currently operating with more than 50 percent of its capacity idle. Furthermore, the 2008 Farm Bill did not extend the biodiesel subsidy and it is due to expire in December of 2008.

Biofuels have been encouraged by federal government policies. Originally, the ethanol subsidy reduced the federal excise tax on gasoline by 5.2¢ per gallon for any gallon containing at least 10 percent ethanol meaning a gallon of ethanol could earn the subsidy 10 times by blending into 10 gallons of product; thereby creating a 52¢ per gallon ethanol subsidy. In 2004, the subsidy was simplified to a 51¢ per gallon tax credit for the ethanol content in all blends. In 2008, the Farm Bill reduced this to 45¢ per gallon. Biodiesel producers also receive a tax credit first established in the American Jobs Creation Act and extended through 2008 by the 2005 Energy Policy Act. Under these acts, the tax credit amounts to one dollar per gallon of biodiesel created from virgin oil and 50¢ per gallon for biodiesel created from animal fats, oilseeds, or recycled cooking oil. Numerous states have followed suit in providing additional subsidies for the production of biofuels.[62]

Biofuels are encouraged by the oxygenate provisions of the Clean Air Act and the Renewable Fuels Standard (RFS) as instituted under the 2005 Energy Bill and the 2007 bill.[63] Oxygenates are gasoline additives used to reduce carbon monoxide. The oxygenate provision requires an amount of renewable fuels in blends in air pollution non-compliance areas. The 2005 renewable fuel standard mandates a level of ethanol in gasoline blends, however, industry expansion has surpassed these requirements.

The 2007 Energy Bill requires significantly higher levels of blending, mandating 9 billion gallons of "conventional biofuel" (grain-based ethanol) in 2008, and rising to 13.2 billion gallons by 2012 (with increased minimum usage quotas from 5 and 7.5 billion gallons in the 2005 RFS). Furthermore, these provisions are specific to energy types and do not allow biodiesel or other biofuel forms to apply under the older, more flexible RFS.

Ultimately, the Renewable Fuels Standard will require a total of 36 billion gallons of biofuels or ethanol by 2022 with corn ethanol capped at 15 billion gallons per year starting in 2015. The remaining ethanol is to be provided by "advanced biofuels" defined as:

- Ethanol produced from cellulose, hemicelluloses, and lignin;
- Ethanol derived from sugar other than from corn starch;
- Ethanol derived from waste materials, including crop residue;
- Butanol or other alcohols produced via conversion of organic materials;
- Biomass-based diesel;
- Biogas (including landfill gas and sewage waste treatment gas) produced through the conversion of organic matter from renewable biomass; and
- Other fuels derived from cellulosic biomass.

The 2007 Energy bill also requires minimum greenhouse gas (GHG) emission reductions beginning at 20 percent; biomass-based diesel must deliver a 50 percent reduction in GHG, and cellulosic biofuels must deliver a 60 percent improvement in lifecycle GHG emissions.

Texas Biofuel Production Potential

This section has discussed the numerous biomass resources available in Texas and how they might be converted into useable energy. Because of the diversity of biomass feedstocks and the variation in availability across Texas, it is difficult to estimate total production of biofuels from the various sources. Several studies have projected biofuels production possibilities and each utilizes different assumptions and resource assessments. In an attempt to provide a conservative, base-line projection for Texas, the following estimates were made to reflect a realistic and conservative total number of energy and petroleum product gallon equivalents that could be produced using current feedstock, land, and other input factor availability. Furthermore, it was assumed that all technological innovations are more or less fixed at the current rate, and that near term crop production in Texas will closely mirror the 2007 figures used for the calculations (one or more variable inputs must be fixed in the short-run).

Currently, technological innovations, input availability, and economic feasibility qualify ten potentially significant sources of biomass for liquid fuel production. Crop residue, forest resources (woody biomass), grain ethanol, high-tonnage sorghum, oilseed crops, algae, municipal solid waste, energy cane, sweet sorghum, and switchgrass comprise the feedstocks for short-run petroleum replacement. Energy estimations were reported in terms of Btu's and in gallons as a reference point for comparison between total renewable energy and the equivalent energy in the form of traditional petroleum fuel products. Current conversion technologies can range from 60-120 gallons per dry ton of input depending upon the type of feedstock.[64] For the purpose of the provided estimations, the conversion rate of 75 gallons per dry ton was applied for the final estimation. Other inputs, such as oilseed crops, algae, and sweet sorghum were calculated at a more specific measure of the given feedstock's energy potential per acre. **Exhibit 5-15** estimates that nearly 2 billion gallons of biofuels from all sources of biomass could be produced in Texas, almost immediately.

Btu, or British Thermal Unit is the measure of thermal energy most commonly employed in the United States. From a technical standpoint, a Btu is the energy required to increase the temperature of a pound of water by one degree Fahrenheit. As applied to biofuels, Btu's are a means of comparison. According to the United States Energy Information Administration, the only means by which to make meaningful comparisons of energy commodities is to convert the listed units (including weight or volume) into similar units; thus, Btu's are essential in comparing the various types of biofuel sources in Texas. As a means of comparison between biofuels sources and traditional fuels, the relative Btu levels are as follows:[65]

- 1 barrel of crude (42 gallons) – 5,800,000 Btu
- 1 gallon of gasoline – 124,000 Btu
- 1 gallon of diesel fuel – 139,000 Btu
- 1 cubic foot of natural gas – 1,026 Btu
- 1 gallon of propane – 91,000 Btu
- 1 short ton of coal – 20,681,000 Btu
- 1 kilowatthour of electricity – 3,412 Btu

Exhibit 5-16 provides an estimate of the Btu content of some of the biomass sources provided in **Exhibit 5-15** (adjusted for availability) which might be converted to heat energy. However, it should be noted that each source could not be converted to both direct heat energy and liquid fuel.

Crop residue, as applied to Texas, is mainly a function of wheat, corn, grain sorghum, soybeans, rice, and cotton production. Of the 3.8 million acres of wheat production in the state, it was assumed that ten percent would be utilized for crop residue harvest at a rate of one dry ton per acre. Corn and grain sorghum were also calculated at a ten percent acreage allotment. However, total corn acreage was comprised of the High Plains production only, and corn residue was calculated at a rate of two dry tons per acre. Soybeans, while a crop of interest, are not a significant portion of Texas agriculture and do not contribute to crop residue potential. Currently, rice presents the possibility for forty percent of its residue to be utilized, totaling nearly 58,000 dry tons of crop residue. The final crop of interest is cotton. Cotton crop residue utilized at twenty five percent of total acreage and an assumed .26 dry tons per acre rate will be one of the largest potential sources of residue in the state. Converted into gallons of petroleum products displaced at the assumed conversion rate of 75 gallons per dry ton, crop residue presents the near-term potential to replace 72,105,000 gallons of traditional fuel consumption. The feasibility of cotton residue as a biofuel will be tempered with low per acre yields and relatively higher logistical costs. **Exhibit 5-17** provides an estimate of biofuels production from crop residue referenced in **Exhibit 5-15**.

A 2007 survey of available biomass feedstocks in Texas by Cornwell, Sandhop, Shanks, Phillips, and Webb estimated that available forest biomass resources totaled nearly 14 million dry tons in Texas.[66] At a general conversion rate of 75 gallons per dry ton of forest resources and an assumed utilization rate of 20 percent of overall tonnage, **Exhibit 5-18** provides an estimate of biofuels production from forest resources as referenced in **Exhibit 5-15**.

Exhibit 5-15 Texas Biofuels Potential

	Input Volume/ Acreage	Units	Yield	Gallons
Crop Residue	961,400	Dry tons	75 g/dt	72,105,000
Forest/Wood Resources	3,000,000	Dry tons	75 g/dt	45,000,000
Grain (Ethanol)	355,000,000	Gallons	Fixed production rate	355,000,000
High-tonnage Sorghum	348,300	Acres	75 g/dt at 10 dt/ac	261,225,000
Oilseed Crops	108,110	Acres	100 g/ac	10,811,000
Algae	100,000	Acres	3,000 g/ac	300,000,000
Municipal Solid Waste	2,530,279	Dry tons	75g/dt	189,770,897
Energy Cane	6,375	Dry tons	75 g/dt at 10 dt/ac	4,781,250
Sweet Sorghum	42,130	Acres	300 g/ac	12,639,000
Switchgrass	2,162,291	Acres	75 g/ac at 4 dt/ac	648,687,300
TOTAL				1,900,019,447

Exhibit 5-16 Btu Content of Texas Biofuel Sources

Biomass Resource	Volume	Units	Rate per Unit	Total BTU's
Crop Residue	1,922,800,000	Lbs	6,000	11,536,800,000,000
Forest Sources	6,000,000,000	Lbs	7,500	45,000,000,000,000
High-Ton. Sorg.	6,960,000,000	Lbs	6,000	41,760,000,000,000
Mun. Solid Waste	5,060,558,000	Lbs	6,000	30,363,348,000,000
Energy Cane	12,750,000	Lbs	6,000	76,500,000,000
Animal Wastes	10,250,000,000	Lbs	6,000 – 8,000	64,740,000,000,000
Switchgrass	17,298,328,000	Lbs	6,000	103,789,968,000,000
TOTAL				297,266,616,000,000

Exhibit 5-17 Crop Residue

Biomass Resource	Acres	Dry Tons/Acre	% of Acreage Collected	Total dt/Crop
Wheat	3,800,000	1	10%	380,000
Corn	847,200	2	10%	169,440
Grain Sorghum	469,000	1	10%	46,900
Soybeans	86,000	0	0%	—
Rice	145,000	1	40%	58,000
Cotton	4,724,000	.26	25%	307,060
TOTAL DRY TONS				961,400

Exhibit 5-18 Forest Resources

	Dry Tons Available	Percentage Utilized	Total Applied Tonnage
Forest Residues	3,000,000	20%	600,000 dry tons

Grain ethanol production in Texas is a function of 4 plants currently producing roughly 355 million gallons (as of 2007). In the short run, it is not likely that the number of plants will change, as the plants will need to continue to operate to allocate high front-end investment costs and the outlook for an increasing number of grain ethanol processing plants is dim, as plants currently under construction have recently been placed on hold. Processors now face increasing costs of production coupled with smaller than desired returns on energy/resources invested. **Exhibit 5-19** provides an estimate of grain ethanol production referenced in **Exhibit 5-15**.

Exhibit 5-19 Grain Ethanol

	Inputs	Production Plants	Total Production
Ethanol	Grains	4	355,000,000 gallons

As cellulosic technologies have evolved to become increasingly efficient, crops such as high-tonnage sorghum have come to the forefront of the renewable fuels sector. Pertaining to Texas, high-tonnage sorghum has the potential to be grown in many areas; Areas now comprised of wheat, corn, grain sorghum, rice, and cotton were the focus of this estimation. As with almost all various energy crops, the goal of high-tonnage sorghum substitution with regard to more traditional crops is to minimize the impact on feed and food by allocating a small percentage of nearly each listed crop's acreage to a renewable fuel. In the short-run, none of the 2007 wheat production was assumed to transition into high-tonnage sorghum, but ten percent of corn acreage was applied to sorghum production for biomass. In the South Central and Coastal Bend agricultural districts, ten percent of the 2007 grain sorghum production was allocated to high-tonnage production, as sorghum is already successfully grown in these regions. As with the crop residue estimation, none of the 2007 soybean production acreage was allocated to high-tonnage sorghum production, as soybeans are not a highly produced crop in Texas, and the existing production was not estimated to be allocated to any other crops. High-tonnage sorghum was allocated to 2007 levels of production at a rate of fifteen percent, for both rice and cotton. As a result, at an estimated yield of ten dry tons of biomass per acre, high-tonnage sorghum crop allocation resulted in an estimated harvest of 3.48 million dry tons. **Exhibit 5-20** provides an estimate of biofuels production from sorghum referenced in **Exhibit 5-15**.

Exhibit 5-20 High-tonnage Sorghum

	Acres	Dry Tons/ Acre	% of Acreage Utilized	Total Utilized Acreage
Wheat	3,800,000	10	0%	—
Corn	1,025,000	10	10%	102,500
Grain Sorghum	469,000	10	10%	46,900
Soybeans	86,000	10	0%	—
Rice	145,000	10	15%	21,750
Cotton	4,724,000	10	15%	177,150
TOTAL				348,300
TOTAL DRY TONS				3,483,000

Exhibit 5-21 Oilseed Crops

	Acres	% of Acreage Collected	Total Utilized Acreage
Wheat	42,500	10%	4,250
Corn	2,150,000	0%	—
Grain Sorghum	469,000	10%	46,900
Soybeans	86,000	0%	—
Rice	145,000	15%	21,750
Cotton	352,100	10%	35,210
TOTAL			108,110

In the oilseed crops subsection, ten percent of the 2007 wheat production in the South Central and Coastal Bend agricultural districts was allocated to the renewable fuels estimation. As well, ten percent of grain sorghum production was allocated from the same regions. Corn was not included in the oilseed crops subsection, as corn is a major input factor of production to grain ethanol, and corn was already taken into consideration when calculating the estimations for high-tonnage sorghum and crop residue. As with the previous subsections, soybean acreage was not allocated to the renewable fuel production possibilities estimation. Rice was included in the estimation at fifteen percent of total Texas production acreage, and cotton was included at ten percent of production acreage in the South Central and Coastal Bend agricultural districts. **Exhibit 5-21** provides an estimate of biofuels production from oilseeds referenced in **Exhibit 5-15**.

Algae have the potential to yield up to 5,000 gallons per acre each year under commercial production conditions. However, as commercial production of algae for biofuel is relatively uncharted, the per acre yield for algae was estimated and calculated at 3,000 gallons per acre to be on the conservative side of total production feasibility. **Exhibit 5-22** provides an estimate of biofuels production from algae referenced in **Exhibit 5-15**. In the 1950s, there were over 250,000 acres of irrigated crops near Pecos, suggesting a much greater potential for the area.

Exhibit 5-22 Algae Production

	Acres	Gallons/Acre	Total Production
Algae	100,000	3000	300,000,000 gallons

If only ten percent of the 2007 levels of municipal solid waste were to be used as an input for renewable energy production, it would serve to act as a two-fold benison to the state of Texas by appeasing a portion of the demand for traditional fuel sources and eliminating over 3 million tons of municipal solid waste (which would have otherwise occupied local landfills). At a general conversion rate of 75 gallons per dry ton of municipal waste diverted from landfills, even a ten percent rate of waste reclamation can have a big impact on energy generation and landfill space. **Exhibit 5-23** provides an estimate of biofuels production from municipal solid waste referenced in **Exhibit 5-15**.

Exhibit 5-23 Municipal Solid Waste

	Dry Tons Available	% of Utilized MSW	Total Applied Tonnage
Forest Residues	30,000,000	10%	3,000,000 dry tons

The near-term potential for energy cane production was assumed to be portioned from current levels of sugarcane production in Texas. At a utilization of 15% of 2007 sugarcane production acreage and ten dry tons per acre, energy cane poses a source of equivalence to nearly 4.8 million gallons of traditional petroleum energy products. **Exhibit 5-24** provides an estimate of biofuels production from energy cane referenced in **Exhibit 5-15**.

Exhibit 5-24 Energy Cane

	Total Acreage	% of Utilized Cane	Total Utilized Acreage
Sugar Cane	42,500	15%	6,375

The sweet sorghum estimation was calculated from ten percent of the sugarcane production in Texas as well as ten percent of the 2007 sorghum production in the Coastal Bend agricultural district. At a conversion ratio of 300 gallons per acre, near-term sweet sorghum production could easily reach over twelve million gallons. **Exhibit 5-25** provides an estimate of biofuels production from sweet sorghum as referenced in **Exhibit 5-15**.

Exhibit 5-25 Sweet Sorghum

	Acres	% of Acreage Collected	Total Utilized Acreage
Sugar Cane	42,500	10%	4,250
Coastal Bend Sorghum	378,800	10%	37,880
TOTAL			42,130

Because switchgrass is a warm-season perennial grass native to Texas, it has the ability to thrive in various Texas climates, and has minimal need for tillage/cultivation. As well, it possesses a notable potential to be commercially grown while mitigating any perceived threat to feeds and food. While it is true that every acre of land dedicated to energy crops cannot jointly be used for food production, switchgrass is aimed to minimize viable farmland substitution, as it is estimated to replace certain portions of what is typically listed in Texas as "pastureland", "cropland idle", and CRP land. According to the 2002 Census of Agriculture's Land Survey Data, pastureland and cropland idle account for more than 17 million acres of growth-sustaining land in Texas. The switchgrass estimations for near-term petroleum replacement assumed that ten percent of these 17 or more million acres combined with ten percent of the 4.05 million acres of land in the 2007 Conservation Reserve Program could generate more than 8.6 million dry tons of convertible biomass in the state of Texas each year. However, Texas Agrilife's Blacklands Research Center estimates that switchgrass' yield potential in Texas could be even greater than calculated in the above estimation (4 dry tons per acre), at 6.25 tons per acre. **Exhibit 5-26** provides an estimate of biofuels production from switchgrass as referenced in **Exhibit 5-15**.

Exhibit 5-26 Switchgrass

	Acres	Dry Tons/ Acre	% of Acreage Utilized	Total Utilized Tonage
Pastureland	12,937,991	4	10%	5,175,196
Cropland Idle	4,609,293	4	10%	1,843,717
CRP	4,075,626	4	10%	1,630,250
TOTAL ACREAGE			2,162,291	
TOTAL DRY TONS				8,649,164

Key Issues

A number of key issues surround the future of biofuels and bioenergy in Texas:

Food–Feed–Fuel–Poverty–Environmental Concerns — the rapid expansion in ethanol production has been accompanied by a rapid expansion in commodity prices and an explosion in the news media of concern about food prices, poverty, and the environment. Concerns over these issues are rising and they could potentially cause RFS provisions of the Energy Bill to be modified. In particular, ethanol production has taken some corn out of the marketplace which, coupled with other supply and demand factors, has increased corn prices from $2 per bushel in 2000 to 2008's prices in excess of $6 per bushel. The resulting land competition and substitution possibilities have caused other commodity prices to increase, potentially making food prices higher domestically and internationally. Issues related to poverty (particularly concerns about the price of food) are partially offset by the fact that agricultural incomes worldwide are rising, and a large number of people identified as poor derive their income from agricultural employment. Recent increases in retail food prices in the U.S. are largely a function of higher wage rates and increasing oil prices. A portion of the increases are attributed to elevated corn prices.[6] A recent study by Texas A&M University, has determined that there are a number of factors affecting the increased cost of food and feed. Some of the factors include energy costs, fertilizer prices and supply levels, commodity speculation, and ethanol production. Data presented at the 2008 Texas Ag Forum showed that only fifteen percent of food price increases could be linked to ethanol production. Conversely, a 2008 study done for Kraft Foods Global by Keith Collins, while it did identify economic growth, declining U.S. dollar values, reduced commodity supplies, higher energy prices, foreign agricultural policies, and speculative investment as contributing factors, the study estimated that 60% (or $20 billion) of expected food price increases from 2006 to 2009 is accounted for by biofuels.[67]

Ethanol production has additionally put pressure on lands judged to be environmentally sensitive. Such lands include US CRP/forest land and international forested areas including land in rainforests.

An inevitable consequence of ethanol market expansion is, at least in the short run, higher commodity prices and land conversion pressures. Future ethanol forms using residues and byproducts that are not in competition with food production will partially alleviate such concerns.

Gasoline and energy price future—The oil embargo situation of the late 1970s, and the corresponding high oil prices, caused an explosion of interest in biofuel that continued into the early 1980s. However, interest waned when oil prices dropped; suggesting that oil prices must remain high to stimulate biofuel production. Even though fluctuations are anticipate because of economic conditions, indications are that oil prices will remain high, because the supply of conventional oil is peaking; non-conventional sources exist, but are more costly to extract, while global demand is rising fast and expected to remain high.[68] In particular, Asia is rapidly expanding its demand for energy.

Greenhouse Gas policy—Climate change and associated GHG emission concerns are prominent and expanding. Over 80 percent of U.S. emissions come from fossil fuel combustion. Policies such as carbon taxation, carbon cap and trade, and subsidizing energy efficiency are being discussed and could influence the future of biofuels. Biofuels are not all equal in GHG offsets, as different amounts of energy are consumed in the corresponding production processes. For example, corn ethanol offsets 20 to 30 percent of the emissions that would be generated by the fossil fuels it replaces (including production and land use change), cellulosic processes displace 50 to 70 percent, and electricity more than 85 percent.[69]

Technological advances in processing—Cellulosic ethanol is a widely discussed "second generation" form of ethanol production, while pyrolysis and gasification are discussed as other routes to alternative liquid energy forms such a bio-crude. Despite their theoretical potential, pyrolysis and gasification will not reach commercialization for at least three years. Production of cellulosic ethanol today is generally very small scale, and the pace at which cellulosic technologies will develop is uncertain.

Technological advances in production—The 2007 U.S. corn crop set a record, reaching over 13 billion bushels compared to 10 to 11 billion bushels in the several preceding years. This increase came about due to acreage expansion and technological change. High corn prices will stimulate additional production through improved practices and genetic developments. A key issue in the food vs. fuel debate involves the rate of growth/development in future corn yields.

Sustainable production capacity for biomass—While Texas has large agricultural areas and production capabilities, some limitations (especially water) will affect the future of feedstock production. Areas that are currently large agricultural producers, like the Rio Grande Valley and the High Plains, may not be able to sustain large biomass-based industries due to water availability. East Texas may be more suitable with a dependence on forest products and byproducts, along with energy crops.

Hauling, harvest, seasonality and transport—Biofuel refineries need large quantities of biomass on a year-round basis. Materials handling, suitability for year-round harvest, large potential crop density near refinery sites, storage, and adequate road systems are all key issues in industry location.

Climate change and production suitability—When discussing the future of Texas agriculture, potential climate change is a key issue. The recent trend has shown a warmer, drier state with more concentrated rainfall. The future is projected to have more of these same conditions with some indication that significant regions will be as dry as the affected areas observed during the Dust Bowl.[70]

Forms of preferred fuels—While ethanol is the dominant fuel being produced today, many in the energy industry prefer other forms of energy closer to gasoline or conventional crude oil because of ethanol's corrosiveness and water interactions. The issues then are: To what extent can technology develop pyrolysis, gasification, or chemical processes that deliver more desirable energy forms? And, how soon can this be commercialized?

Financing for ethanol plants—For the past 5 years, CoBank has financed the majority of new ethanol plants. Following the establishment of the 2005 Renewable Fuels Standard, venture capitalists began financing ethanol plants and now provide a significant share of the financial input.

Environmental permitting—Ethanol plants are required to obtain state and federal permits related to water, air, and waste disposal. This process takes a year, but has become a standardized procedure that is readily handled by experts.

Intellectual Property—New bioenergy technologies will contain significant value and will need to be protected by patents and appropriately commercialized.

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Chapter 6

ENERGY FROM WATER

Introduction

Water and energy are two of the most fundamental and interrelated elements of an industrial economy. Annually Texas generates approximately 1 million megawatt-hours (MWh) of electricity directly from water resources via 675 MW of hydroelectric power capacity. This hydroelectric generation amounted to only 0.3% of the total electricity generation during 2007, and further development of feasible hydropower resources could result in approximately 4 more million MWh per year. The use of Texas water resources together with other technologies that can exploit saline gradients between water sources is possible, but limited to several million MWh/yr. Texas has poor potential to extract energy from ocean waves and tides.

The number one use of water in Texas is for cooling at thermoelectric power plants. Although very little of the cooling water is actually consumed (less than 1.5 percent statewide at an average 0.39 gallons per kilowatt-hour (kWh)), this use accounts for 40 percent of total freshwater withdrawals in the state — roughly 30 gallons for every kWh generated.[1] While the withdrawal quantity sounds high, over 95 percent of this withdrawn water is continually cycled between the power plant facility and adjacent cooling ponds and lakes without loss.

While availability of dependable water supplies for cooling, fuels production (e.g. for secondary oil recovery or biofuel feedstock irrigation), process makeup and plant maintenance is critically important to many types of traditional fossil generating sources as well as some emerging renewable sources such as biomass, this chapter will be restricted to the review of energy derived directly from Texas' renewable surface water resources. These sources are comprised of hydroelectric power from lakes and rivers; ocean energy in the form of temperature gradients, waves, currents and tides; and energy from salinity gradients in water bodies.

Significance of Resource: Historical, Present, and Future

Hydropower

Hydropower is among the most efficient means of producing electricity. From its primitive beginning as mechanical power in grist mills to today's hydroelectric power plants, efficiencies have increased to almost 90 percent. Hydropower plants convert the stored potential energy of water as it flows from a higher to a lower elevation into electrical energy through the use of turbines and generators. In this report, hydropower plants that use water from a lake, river, or reservoir in a single pass through turbines will be termed "conventional" hydropower plants. Hydropower plants that take advantage of the difference in cost of electricity between peak and off-peak consumption times to economically recycle water between two reservoirs for multiple turbine passes are known as "pumped storage" plants. Pumped storage plants do not produce new power; rather, they merely act in analogous fashion as batteries for storing energy generated by other means.

Hydroelectric power development began with the electrical age. On July 24, 1880 the Grand Rapids (Michigan) Electric Light and Power Company demonstrated the generation of electricity by a dynamo belted to a water turbine at the Wolverine Chair Factory. From that modest beginning hydropower production progressed rapidly and by 1907 accounted for 15 percent of the electric generating capacity of the U.S. By the 1930's hydropower provided 40 percent of the nation's electric energy. While hydropower capacity has continued to grow, its share of the total electric generation has steadily declined as the adoption of other fuels has occurred at a relatively faster rate. United States hydropower capacity leveled at about 77,400 MW, and in 2006 accounted for about for 7 percent of the nation's 4 billion MWh of electrical energy generation.

Texas currently has 675 MW of hydropower generating capacity typically operating with a capacity factor[2] of 14 to 31 percent.

Ocean Power

Oceans cover more than two thirds of the earth's surface and represent a vast source of primary energy. For energy generation schemes to be practical, however, they will typically be located close to shore, which limits the total resource that can be economically extracted. Four types of ocean energy resources are reviewed here: wave energy, energy from ocean temperature differentials (ocean thermal energy conversion, or OTEC), currents, and tidal energy.

Wave Energy

Oceans extract energy from the wind, through friction between the moving air and the water, which is transformed into waves. Because water is very dense, the energy absorbed from the wind is stored in a concentrated form.

Interest in harnessing energy from ocean surface waves began in the United States in the 1800's. The earliest patents on wave energy machines were issued in the 1880's, and patents continue to be issued on them today. These devices vary widely in scale and sophistication, but generally involve some type of floating buoy connected to the sea floor such that the oscillating wave motion causes relative motion between the floating section and a section that is fixed or has high inertia.[3] This relative motion and driving force is used to pump fluids that flow through turbines connected to generators.

In the last few years, the world has seen its first commercial order of a multi-unit wave farm project: the 2.25 MW Agucadoura Pelamis Wave Power project off the northern coast of Portugal (www.pelamiswave.com).

Ocean Thermal Energy Conversion (OTEC)

Because sea water is translucent to a large proportion of the incident sunlight, the oceans act as a huge solar collector. Sunlight only penetrates about 65 meters of the ocean surface so most of the sun's thermal energy is trapped in its uppermost layers. Beyond a depth of about 100 meters, the oceans remain perpetually dark and cold. The basic premise of OTEC is the utilization of the difference in temperature between the surface water and that at depth to drive a heat engine such as a Rankine engine.

The concept of harnessing the power available due to the temperature difference between the surface water and that at depth was first proposed by d'Arsonval in the late 19th century.[4] In 1929 an open cycle pilot power plant was built and operated in Cuba by Georges Claude. Claude's plant produced only a very small power output and ceased to operate when the cold water pipe was destroyed. In the 1950's, the French government partly sponsored a company called "Energie de Mers" which began construction of an open cycle plant near Abidjan, Nigeria. This plant was never finished although several of the subsystems were demonstrated.

A closed cycle OTEC design, which was first proposed in the early 1900's, uses a secondary working fluid, such as propane, that possesses a relatively high vapor pressure. Many significant attempts at demonstration of OTEC systems were made in the 1970's (e.g. McGowan and Heronemus, 1976) and led to U.S. government sponsorship of research and development in this area. Funded activities included Mini-OTEC, artificial upwelling activities, materials research, and research and development on critical aspects of OTEC plant designs such as the heat exchangers.[5] The U.S. government stopped its sponsorship of OTEC research in 1984, but the state of Hawaii and private industry have continued a substantial level of research and development activities. Hawaii, via its Natural Energy Laboratory of Hawaii Authority (NELHA), operated a 210 kW open-cycle OTEC between 1992 and 1998 (www.hawaii.gov/dbedt/info/energy/renewable/otec). Due to the increase in oil prices since 2003 and the fact that Hawaii generated 78 percent of its electricity from petroleum products in 2006[6], OTEC off the shore of Hawaii has been reconsidered as private companies are proposing new OTEC power plants in the 1-2 MW range. In addition, a variety of deep ocean water application (DOWA) activities are also ongoing (fresh water production, mariculture, air conditioning, etc.).

Current Energy

Water can flow as a current down rivers, in oceans, and through bay channels during tidal changes. This flowing current of water presents opportunities to extract energy from the water just as one does from flowing wind. Current energy is also often termed kinetic hydropower because it describes the energy within flowing water that undergoes no appreciable change in elevation. While river and ocean-driven currents move much slower than typical breezes, the density of water is about 1,000 times the density of air, resulting in significantly higher power density for brisk ocean currents than for windy land areas. The corrosive underwater environment, however, poses significant challenges that are being addressed in pilot studies.

Locations such as below the San Francisco Bay Bridge present opportunities for large amounts of water flow. Prototype and commercial development for current energy systems have advanced significantly in the past decades. In 2006, the Roosevelt Island Tidal Energy pilot project by Verdant Power installed an array of six 35 kW water current turbines in New York City's East River to send electricity to customers on Roosevelt Island and could possibly expand to up to 300 turbines (www.verdantpower.com). Other companies, such as Marine Current Turbines Ltd. with their SeaGen design (www.seageneration.co.uk), have varying designs of turbines and blades that can closely resemble wind turbines in order to extract energy from ocean tidal currents. Individual units are now rated at over 0.5 MW.

Tidal Energy

Tidal energy has fascinated geographers and engineers since the time of the ancient Greeks, and the existence of tidal mills in England and Wales was documented as early as 1066.[7] In the 1700's, Belidor of the French Military Academy taught the importance of harnessing tidal energy. Ocean-powered mills have been employed in Europe and until the early 1900's were in use in the northeastern U.S. as well. Over the past two centuries numerous patents have been issued dealing with tides.

Any geographic location that provides a basin that can be enclosed to capture and hold rising tides could possibly be utilized to generate tidal power. However, extraction of tidal energy is considered practical only when the differences between high and low tides are large (for example, with a total difference between high and low tide of at least ten feet). Many areas with these differences in tide levels are being analyzed for future power plant construction. Several tidal barrage power plants have been constructed to date: La Rance (1967, France, 240 MW), Kislaya Guba (Former Soviet Union), Jiangxia (China), and Annapolis (Canada, 20 MW, Nova Scotia Power).

Energy from Salinity Gradients

There are two approaches to using salt gradients to produce useful energy. The first utilizes the differential osmotic pressure and chemical potential difference that exist at the interface between fresh water (e.g. rivers) and salty water (i.e. seawater or brine). Techniques that extract energy from these principles are pressure retarded osmosis (PRO) and reverse electrodialysis (RED). The second approach employs a man-made salinity gradient, usually in a man-made reservoir. Fresh water is injected into salt brine such that a salinity gradient is formed that suppresses natural convection and allows preferential heating of the bottom zone of the reservoir by solar thermal input. This approach is known as salinity gradient solar pond (SGSP) technology. These two technologies are discussed individually below.

Pressure Retarded Osmosis and Reverse Electrodialysis

The history of using salinity gradients for the production of useful power generation only dates back to 1939. In 1954 Pattle suggested the use of the osmotic pressure differential between river water and sea water to generate power and actually constructed an apparatus that produced power.[8] To date no appreciable amount of electricity has been generated from this fresh and sea water interface. The major hurdle for osmotic pressure technology is the cost-effective manufacture of semi-permeable membranes. In 2003 the Norwegian company Statkraft (www.statkraft.de) opened a laboratory dedicated to saline gradient power research with a focus on high performance membranes for PRO. A Dutch company KEMA (www.kema.com) is attempting to make low cost membranes for RED.

Salinity Gradient Solar Ponds (SGSP)

SGSP technology was not invented, it was discovered. Naturally occurring salinity gradient solar lakes are found in many places on earth. The phenomenon was first observed in Transylvania in the early 1900's where natural salinity gradient lakes formed when fresh water from melting snow flowed onto salt brine lakes and mixed to create a salinity gradient allowing the sun to heat the bottom layers of the lake.

The capability of salinity-gradient solar ponds to capture and store solar thermal energy is unique. One of their main advantages over other solar technologies is that this energy is available on demand, decoupled from short-term variations in solar input, which is an important factor in examining potential applications for this technology. Another advantage is that this concept can utilize what is often considered a waste product, namely reject brine, as a basis to build the salinity gradient. This feature is important when considering the use of solar ponds for inland desalination and fresh-water production, or for brine concentration in salinity control and environmental cleanup applications. The energy applications for SGSP technology are mainly to use the heat for water desalination, process heat, and electricity production. Solar ponds have been the focus of considerable research over the past several decades, with The University of Texas at El Paso having performed much of the leading research.[9]

Development Issues: Considerations for Large Scale Use

Hydropower

Although hydroelectricity generation does not directly emit air pollution, there are other environmental concerns associated with its development. Decaying plant matter in a lake emits methane, a greenhouse gas. Stream flow alterations can adversely affect aquatic life and can alter components of water quality such as oxygen content and temperature.[10] Dam diversions and damming streams also impede the upstream and downstream movement of fish. Finally, the potential impact of flooding from a hydropower facility on upland areas requires assessment. These concerns must be addressed on a case-by-case basis.

There are significant legal and regulatory impediments to hydropower development. Local, state, and federal governments, Indian tribes, and public interest groups have become involved in the regulation process. Disagreement can exist over who should develop the resource and how to compensate existing landowners where a hydropower facility would require a dam and reservoir to be built. The major regulatory categories associated with hydropower are environmental protection, economic regulation of water and electricity, safety, and land use.

Ocean Power

OTEC

The U.S. Department of Energy has funded a number of studies into the environmental impact of OTEC plants. Some of the potential impacts are: (1) disturbance of the seabed due to construction, especially areas of ecological importance such as coral reefs; (2) attraction of marine organisms to the structure and lighting which can then become trapped in the warm water intakes; and (3) disturbance of the natural thermal and salinity gradients and levels of dissolved gases, nutrients, trace metals, and carbonates. Current evidence suggests that these impacts are minimal. On the other hand, leaks of the working fluid (typically ammonia) could have a serious environmental impact. However, an initial study of the 40 MW OTEC test plant at Kahe Point Hawaii[11] showed the probable impact upon marine life to be minimal.

Wave Energy

Because of the low power density of the resource, wave energy systems would require relatively large installations for bulk power generation. For example, an EPRI feasibility study estimated that a 90 MW (~300,000 MWh/yr) wave farm off the Oregon coast could encompass approximately 4000 acres of ocean surface.[12] While relatively environmentally innocuous, wave energy device could face numerous regulatory hurdles for development depending upon how installations could interfere with marine animal life, as well as boating and shipping traffic. An exception to these hurdles might be installation of wave energy equipment on a local basis, such as supplying power to a remotely-sited hotel. Wave energy conversion devices might have an impact on ocean views, but less of one than, for example, offshore wind farms, because the devices sit only a few meters above the ocean surface at maximum. One significant near-term stumbling block is the demonstration of an economically feasible wave energy machine capable of withstanding the rigors of extreme ocean events. One early attempt in Scotland during 1995, the OSPREY wave generator, was caught in extreme weather during installation and ended up being destroyed. This aspect of necessarily installing wave devices in areas where wave energy is high presents a fundamental design challenge that must be heavily considered, but is not insurmountable.

Tidal Energy

For barrage style tidal energy systems, there is potential interference with tourism and fishing. Additionally, adverse environmental impact on the estuarine ecosystem is a primary drawback of tidal energy development. Barrages, however, can provide protection from coastal flooding. A site specific environmental impact study would be required for any proposed plant. The output of a tidal power plant is proportional to the square of the tidal range. Because tides throughout Texas are so small, a tidal facility with meaningful output would require a barrage of such length that poor economics and the environmental impact would probably prohibit its use.

Current Energy

Extracting energy from flowing currents in “run of the river” or tidal current scenarios can present some environmental issues. If these systems take up substantial cross-sectional areas perpendicular to river flow, they can potentially disrupt and impinge marine life moving with or against the flow. Designers of current energy systems also desire to prevent marine life and debris from contacting underwater turbines and other energy-extracting devices to maintain their proper function and maximize efficiency. Water current energy systems also need to allow room for shipping and boating traffic by being placed near shores and/or far enough below the water surface to avoid ships (e.g. in coastal channels and deep rivers). For current, or kinetic hydro, energy devices in Texas rivers, there is likely to be no localized large scale use; the Idaho National Laboratory assessment estimates there are approximately 80 to 150 feasible projects scattered throughout Texas rivers.[13] Each kinetic hydro project would not be large (< 10 MW rating) and likely take up less than a couple of miles of river for diversion into the small hydrokinetic turbine. The determination of impact would lie with the local landowners along the river sites.

Salinity Gradients

SGSP technology moved forward significantly over the last several decades through the 1990s, but interest has lagged in the last 10 years. This reduced interest is typified by the ¾-acre solar pond in El Paso, TX (www.solarpond.utep.edu), which was shut down due to lack of continued research interest as it was determined that only about 1 percent of solar energy input to a SGSP can be converted into electricity. This low efficiency is largely a result of SGSPs having a low temperature differential between the top and bottom of the pond (i.e. the bottom of the pond cannot go past boiling temperature). Because the thermal difference is limited, the maximum thermal conversion efficiency (i.e. Carnot efficiency) is limited to a range of 16 to 21 percent. Nonetheless, research over the last 20 years established the viability of using SGSPs for electricity and water desalination, especially in desert areas where fresh water is not abundant.[14] There may also be beneficial opportunities to use SGSPs to moderate temperatures in aquaculture ponds, such as those used to grow algae for biofuels.

Impediments to SGSP technology center around the salt water resource. For large-scale development, the salt water resource must be abundant in regions of good solar radiation and inexpensive land. More importantly, salt water cannot be allowed to leach into fresh ground water. For this reason, solar ponds should not be built above moving ground water that is close to the surface. In many cases, a liner is necessary to contain the brine.

Salt and brine are typically considered to be environmentally harmful products rather than resources. Inland desalination for surface water cleanup, chloride control projects, or disposal of "produced water" pumped coincidentally with petroleum from oil wells yield concentrated brines that have posed a disposal problem. Solar ponds can utilize these waste brines. There is no near-term SGSP development at the moment, but the future may still hold promise for desalination programs where the economic and environmental synergism between application and technology gives them a competitive edge. There are also potential synergisms with future algae production for biofuels as SGSPs operate well in similar conditions.

For pressure retarded osmosis (PRO) and reverse electrodialysis (RED), reducing the cost of membranes necessary for the processes will be the largest impediment to achieving commercially-viable project sizes and this cost reduction is particularly important for RED because large numbers of more highly selective membranes are needed. On the other hand, when considering total system installed costs (membranes, pumps, pipes, turbines, etc.), the overall cost of electricity from each technique should be similar.[15] The cost of these membranes has decreased in the last decade due to the focus on desalination. Because desalination is essentially salinity gradient electricity in reverse, research into membranes assists in both fields. The environmental impact of creating PRO or RED systems along the Texas bay system is also a large unknown. Significant amounts of river water would need to be diverted through a PRO or RED power plant before being discharged into the bay. This diversion would alter the normal freshwater inflow patterns to which the aquatic life is accustomed.

Exhibit 6-1 Existing Hydroelectric Power Plants in Texas grouped by river basin.[16]

Basin	Dam	Reservoir	Capacity (Mw)	Totals (Mw)
Red	Denison	Lake Texoma	70.0	70.0
Trinity	City of Lewisville	Lewisville	2.8	2.8
Sabine	Toledo Bend	Toledo Bend	81.0	81.0
Neches	Sam Rayburn Robert D Willis	Sam Rayburn Robert D Willis	52.0 8.0	60.0
Brazos	Morris Sheppard Whitney	Possum Kingdom Whitney	25.0 30.0	55.0
Colorado	Buchanan Roy Inks Alvin Wirtz Max Starke Mansfield Tom Miller	Buchanan Inks LBJ Marble Falls Travis Austin	47.8 15.0 60.0 30.0 102.5 16.0	271.3
Guadalupe	Dunlap (TP-1) Abbot (TP-3) TP-5 H-4 H-5 TP-4 Canyon City of Gonzales Small Hydro of Texas	Dunlap McQueeny Nolte H-4 H-5 Seguin Canyon	3.6 2.8 2.4 2.4 2.4 2.4 6.0 1.5 1.5	25.0
Rio Grande	Amistad Eagle Pass Falcon	Amistad* Canal Falcon*	66.0 12.0 31.5	109.5

*Mexico has matching generating capacity at these sites: Amistad (66 MW) and Falcon (31.5 MW).

Resource

Quantification of Resource

Hydropower

Texas currently has 675 MW of conventional hydroelectric power generating capacity, which represents less than 1 percent of the state's total electric capacity. **Exhibit 6-1** lists the individual facilities and their capacities by river basin.

An assessment by Idaho National Laboratory (INL) in 1993 (*U.S. Hydropower Resource Assessment: Texas*) estimated that Texas had approximately 1,000 MW of potential new nameplate capacity at 89 sites.[17] Of this 1,000 MW capacity potential approximately 830 MW lie at undeveloped sites. The 1993 study was based upon undeveloped hydropower sites for which a Federal Energy Regulatory Commission preliminary permit was issued. **Exhibit 6-2** shows the undeveloped capacities for each of the Texas river basins from the 1993 study. These data include green field sites, existing dams without powerhouses, and existing hydroelectric plants.

A hydropower assessment completed in 2006 (*Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*) estimates the total resource potential focusing on small hydro (each less than 30 MWa, but greater than 1 MWa[18]) and low power sites (each less than 1 MWa).[19] The INL defined the small hydro sites facilities as using conventional hydropower turbines but with the maximum average power rating of 30 MWa. The 2006 study estimates the power potential using both conventional and unconventional technologies.

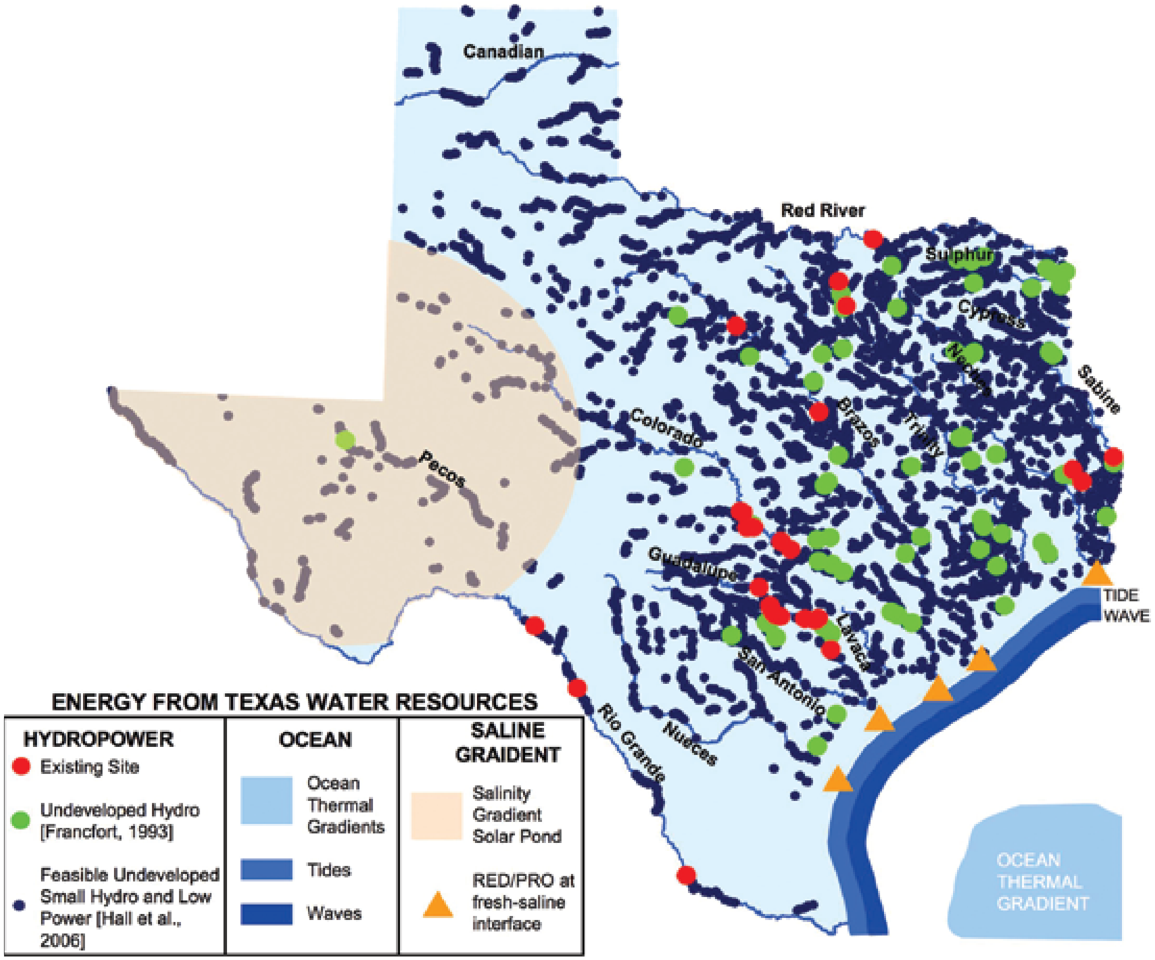
INL's 2006 resource assessment of the gross hydropower resource in Texas was 2,300 MWa with 104 MWa already developed and 2,040 MWa "available" (521 MWa of small hydro and 1,519 MWa of low power) after excluding federal and other restricted lands.[20] The feasible hydropower projects amount to 328 MWa, or 2.9 TWh of annual generation, with 75 MWa of small hydro and 253 MWa of low power hydro projects. Table 6-2 indicates the location of the 4,315 feasible sites by river basin, and these sites from the INL 2006 study are plotted in **Exhibit 6-3**.

Existing sites without hydroelectric generating facilities would require retrofitting and re-permitting. Additionally, most of the undeveloped sites referred to in this study may not be built for many decades, if at all. Much of the estimated additional hydropower identified in Texas may never be developed due to economic and environmental constraints.

Exhibit 6-2 Number of sites and associated traditional hydroelectric potential of Texas rivers[21] as well as "small hydro" and "low power hydro" feasible potential.[22] The "conventional undeveloped" and "small and low power" sites have some overlaps. The feasible installed capacity calculated in reference[23] (2nd and 3rd columns) does not account for plant availability of the sites, whereas the average power listed in reference[24] (4th and 5th columns) does account for plant availability.

River Basin	Conventional Feasible Undeveloped Potential		Small And Low Power Hydro Feasible Undeveloped Potential	
	Number Of Sites	Rated Capacity (Mw)	Number Of Sites	Available Resource Average Capacity (Mwa)
Canadian	—	—	90	7
Red	13	371	450	36
Sulphur	—	—	149	11
Cypress	—	—	136	5
Trinity	16	180	548	48
Neches/Sabine	10	20	660	37
San Jacinto	—	—	167	9
Brazos	12	52	814	79
Colorado	14	368	444	39
Lavaca	—	—	29	1
Guadalupe	18	19	204	12
San Antonio	—	—	159	6
Nueces	2	4	155	6
Rio Grande	4	2	310	32
TOTAL	89	1,016	4,315	328

Exhibit 6-3 Summary of Energy from Texas Water Resources.[25]



Texas has small amounts of potential operating pumped storage facilities. The Lower Colorado River Authority operated one such facility between Inks Lake and Lake Buchanan in the past. Theoretically Texas total potential pumped storage capacity is equal to the total hydroelectric capacity if all hydroelectric facilities were operated as such. However, it may not be practical to operate all hydropower sites as pumped storage due to responsibilities such as fisheries and ecosystems management, flood control, and water supply. It should be noted that although Texas' pumped storage potential capacity is relatively small compared to the total generation capacity in Texas, it could be a valuable resource in that it represents a source of electrical generation that is available on demand and could offset the need for new peaking capacity supplied from conventional fuels or act as an ancillary service to help stabilize some intermittent wind power output.

Ocean Power

Wave Power

The worldwide power potential from waves is estimated at nearly 2 TW, and the resource is concentrated in the mid to high latitude temperate storm latitudes of both hemispheres (between 40° and 60°). The United Kingdom has some of the most powerful wave activity in the world and since 2000 some prototype and commercial developments have been constructed near the UK and offshore of Portugal. The European Marine Energy Centre (http://www.emec.org.uk) on the Orkney Islands of Scotland is a major center of ocean power technology development and demonstration for all ocean energy technologies, with two sites for testing wave and tidal current devices.

In the United States, there are plans to develop ocean power resources on the northern Pacific coast, where wave resources are good. The potential power (kW/m, kilowatts per meter of wave crest) from waves can be calculated based on the density of seawater, the force of gravity, the time period of the waves, and the average wave height.

Exhibit 6-4 Mean significant wave height and wave power for wave stations adjacent to Texas.

Station Number	Mean Wave Height (m)	Adjusted Mean Wave Height, H (m)	Mean Period, T (sec)	Potential Power (kW/m)	Recoverable Power* (kW/m)
2	1.5	1.4	6.8	6.5	2.0
3	1.4	1.3	6.8	5.5	1.6
4	1.4	1.3	6.6	5.5	1.6
5	1.4	1.3	6.1	5.0	1.5
6	1.5	1.4	6.5	6.2	1.9
7	1.3	1.2	5.9	4.2	1.2
8	1.3	1.2	6.2	4.4	1.3
9	1	0.9	5.7	2.3	0.7
10	1	0.9	5.9	2.3	0.7
11	1.1	1	5.6	2.7	0.8

*Estimated by assuming that 30% of potential can be realized.

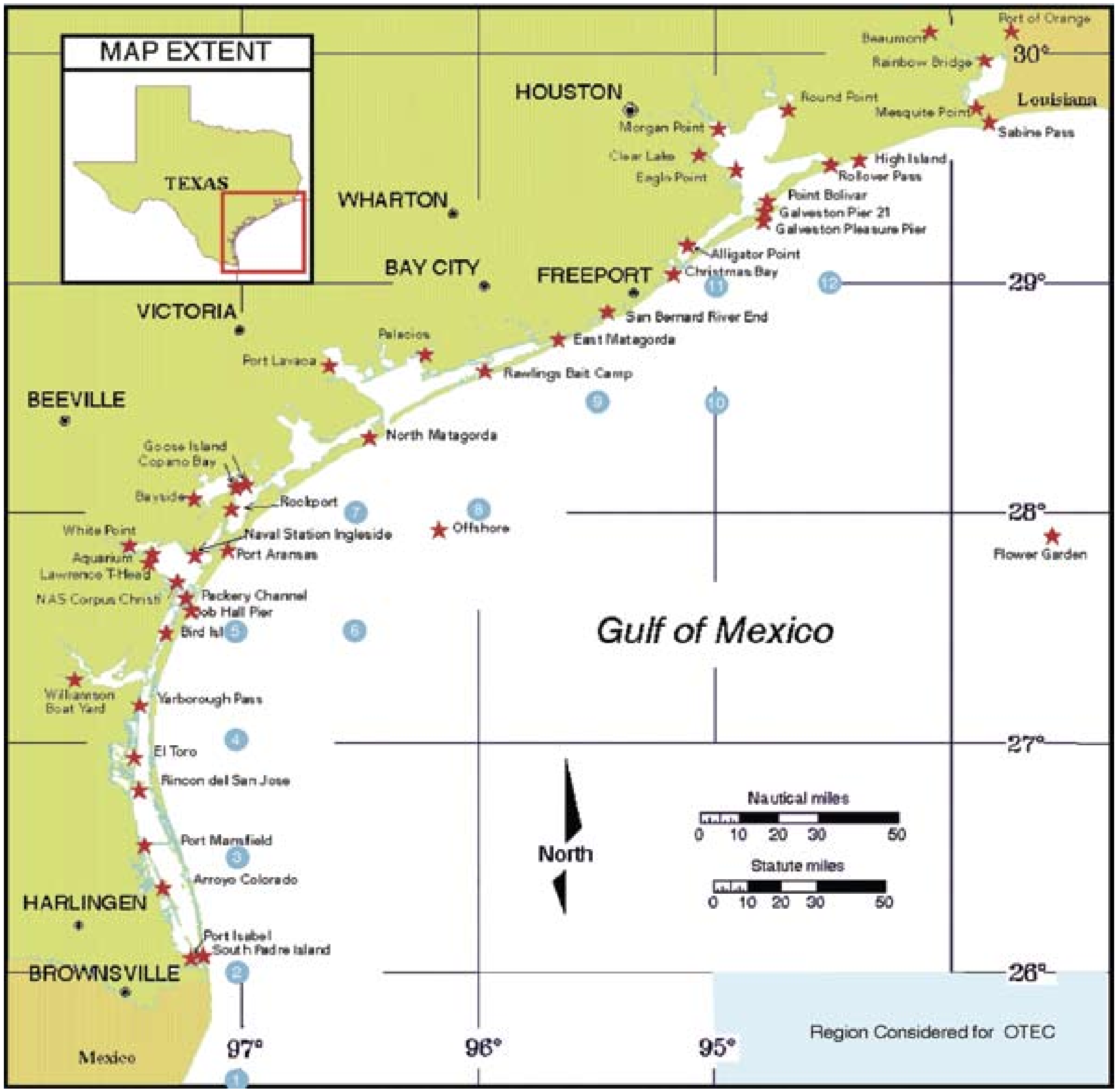
Good resources are considered to have power densities of at least 20 kW/m and densities near 40 kW/m are desirable. Texas' offshore wave power densities are typically well below 10 kW/m (**Exhibit 6-4**). For comparison, performance estimates of the Pelamis wave energy technology off the coast of Oregon showed an approximate capacity factor of 40 percent for a region with a wave power density of 21 kW/m.[26]

The greatest average wave height in Texas is located off the southernmost tip of Texas and is approximately 1.4 meters. The average wave heights of eleven locations off the Texas Coast range between 0.9 and 1.4 meters. These figures compare favorably with wave heights charted along the US Atlantic Coast but are somewhat smaller than those along the US Pacific Coast.

For those who have been to all three US coastal areas, the statement regarding the relative size of Gulf waves may seem curious. It is important to remember that wave height estimates are made for locations miles off shore. The Texas Gulf Coast is much shallower than along the Atlantic and Pacific coasts and, as a result, tends to dissipate waves to a greater degree and observers will witness greater waves reaching the beaches in California and Florida than in Texas.

This phenomenon is relevant when proposing wave energy plants in Texas because waves would have to be harnessed while they still have a significant amount of energy, many miles off the shore. Conduction of electrical power from a remote sea location into the land-based electric transmission network becomes more costly the further offshore the project lies.

Exhibit 6-5 Texas Coastal Ocean Observation Network (TCOON) Tide Measurement and wave hindcast sites.[27] Active TCOON sites are indicated by red stars, and inactive sites are indicated by blue stars (see TCOON website for full list of measurement sites). Also shown are the locations of the wave hindcast stations used by the Army Corps of Engineers (blue dots with numbers) and the ocean area nearest to Texas evaluated for OTEC potential (due east of Brownsville).



Ocean Thermal Energy Conversion (OTEC)

Texas' OTEC potential is limited. For several hundred miles off the Texas coast, the ocean depth in the Gulf of Mexico is less than the 1,000 meters suggested for OTEC development. In addition, the average annual temperature differentials at the sites closest to Texas are in the 18° to 20°C range, which is considered a very marginal temperature difference for OTEC development. The best OTEC resource areas will be in equatorial regions of the world with sufficient depth and ocean temperature differentials as high as 25°C. For example, the best U.S. OTEC resources are off the coasts of Hawaii and Puerto Rico.

These facts point to the difficulty in classifying any energy conversion from this source as a Texas resource. The Texas coast has never been seriously considered as an OTEC resource area and the possibility of developing OTEC here in the near future is remote.

Tidal Power

The Texas Coastal Ocean Observation Network (TCOON) contains more than 40 tide gauges located along the Texas Gulf Coast (see **Exhibit 6-5**).[28] This network is sponsored by the Texas General Land Office, the Texas Water Development Board, Texas A&M University's Conrad Blucher Institute for Surveying and Science in Corpus Christi. The National Oceanic and Atmospheric Administration (NOAA) also cooperates in the endeavor. The primary function of the TCOON network is to precisely determine mean tide levels for boundary delineation between state and private lands.

Mean tidal ranges in Texas vary from a minimum of 0.5 feet at Port O'Connor, Matagorda Bay to a maximum of 2.8 feet at Sabine Bank Lighthouse. Median predicted diurnal tide range for Texas coastal locations is estimated to be 1.3 feet. Texas' tidal ranges are dwarfed by Passamquoddy Bay's (Maine) mean tidal range of 18 feet. Because tidal power generation varies as the square of the tidal range, the available tidal power at Passamquoddy is 190 times greater than that of the average Texas location. This comparison becomes especially meaningful when one considers that the development at Passamquoddy was abandoned due to its marginal economic feasibility.

While mean tidal range is an important criterion in site analysis, other factors also affect a site's feasibility. For instance, even if an area experiences great tidal fluctuations, it may not be suitable if it has limited available basin area or if its required barrage would be prohibitively large and expensive. Conversely, a site with marginal energy availability may still be viable if its geographic features offer exceptional storage potential and an opportunity to construct a relatively inexpensive barrage. However, the relatively minute amount of available tidal energy in Texas helps explain why the Texas coast has never been seriously considered for tidal power development.

Current Power

The resource potential for energy from water currents is addressed in the hydropower (e.g. for river-based systems) and tidal energy (e.g. for ocean-based systems) sections.

Salinity Gradients

Texas could potentially take advantage of energy from salinity gradients in water by two slightly different methods: salinity gradient solar ponds and salinity gradients between river mouths (e.g. fresh water) and bays (e.g. salt water) using pressure retarded osmosis or reverse electrodialysis.

The worldwide power output from saline gradients in estuaries caused by freshwater flowing into seawater is estimated at 2.6 TW[29], or 2/3 of the current worldwide installed electric capacity.[30] When fresh water from a river mixes with seawater, approximately 1.5 MJ/m^3 (25,000 times less energy density than the equivalent volume of oil) is available due to the chemical potential difference before mixing.[31] The average amount of water entering Texas bays and estuaries is approximately 27.5 billion cubic meters per year.[32] Therefore, the estimated energy resource from Texas river water mixing into the bays is 12 TWh, and the gross energy potential from using existing membrane technologies for pressure retarded osmosis or reverse electrodialysis (without losses from pumps, turbines, friction, etc.) is about 35 percent of the resource, or 4 TWh, approximately one percent of Texas' current annual electricity consumption.

Saline gradient solar ponds require significant amounts of both water and salt. The lower convective zone of a SGSP is approximately 27 percent salt by weight, and the main gradient zone is assumed to transition from 27 to zero weight percent salt. Thus, for a 1 acre solar pond three meters deep approximately 2 million metric tonnes of salt and 2.4 million gallons of water are required. The salt would most likely be left from evaporating ponds, possibly used for desalination of brackish water for fresh water needs. The brackish groundwater resource in potential areas for SGSPs (West Texas from the southern panhandle, south to the Rio Grande, and then west to El Paso) is approximately 0.6-190 trillion gallons.[33]

Past research, development, and testing of a SGSP in El Paso showed that technologies can convert approximately 1% of sunlight (global horizontal insolation) into electricity.[34] Assuming 2.4 Mgal (7.4 ac-ft) of water per acre of SGSP is needed, there is water for 250 – 80,000 acres of SGSP by using only brackish groundwater. Thus, with West Texas enjoying approximately 5.25 kWh/m^2-day global horizontal insolation, a maximum of 0.02 – 6.2 TWh/yr electricity could be generated via SGSPs based upon the size of the regional saline groundwater resource.

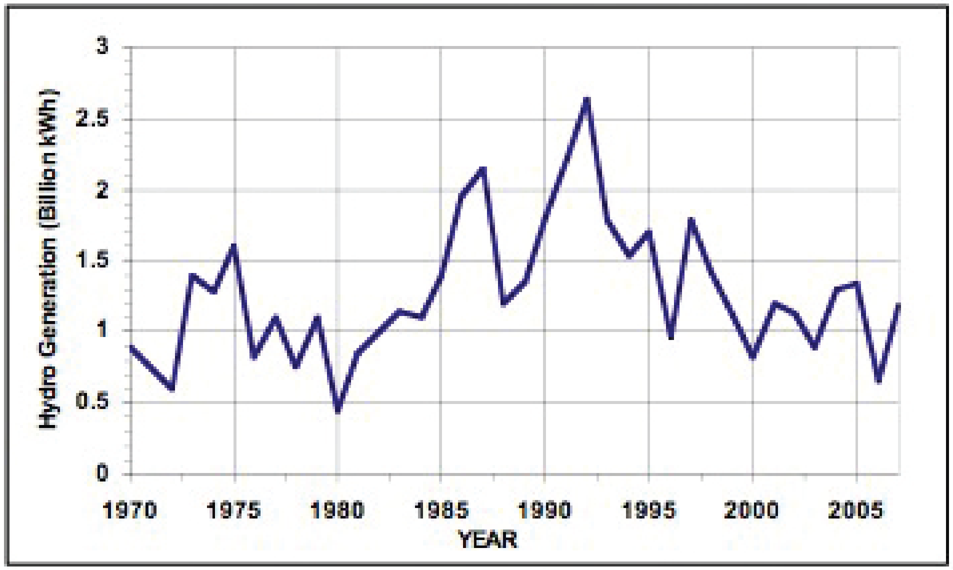
However, given the general scarcity and high value of water resources in West Texas, the use of almost all regional brackish groundwater for less than 2% of Texas' electricity is difficult to imagine. Because water used in SGSPs continually evaporates, the sustainability of the saline reservoirs to supply even a small number of SGSPs would need to be assessed. Therefore, given the imprecise range of the assessed West Texas saline groundwater resource and low electricity conversion efficiency, SGSPs are unlikely to be used for electricity generation. Using the low-grade heat of SGSPs as part of desalination of brackish groundwater can possibly prove economically feasible.

Variability

Hydropower

Rainfall in Texas varies significantly from season to season, east to west and year to year. In addition, the primary purpose of most Texas reservoirs is for flood control and/or water supply. Hydroelectric production at these installations is a desirable by-product of normal operation, but seldom is it the primary influence in the daily operation of the facilities.

Exhibit 6-6 Hydropower generation in Texas since 1970.[35]



The capacity, or instantaneous power rating, of a hydropower facility is only one measure of its potential contribution to the state's energy mix. To determine the total amount of energy produced from hydropower, one must examine the capacity factors of various facilities. An annual capacity factor is the ratio of the amount of energy a facility generates in a year to the total possible energy it could generate if it ran at full power all year long.

The extent of variability in the State's hydroelectric resource is demonstrated in **Exhibit 6-6**, which reveals the total annual electric energy production from all hydroelectric facilities in Texas since 1970. Even though the state has had relatively steady hydroelectric installed capacity over this period, aggregate annual output is shown to vary by more than a factor of five from the lowest (1980) to highest (1993) year. Capacity factors for individual Texas hydro plants typically range from 5 to 50 percent. Historic annual capacity factors for the aggregate of Texas hydropower facilities average 22% and usually vary (within one standard deviation) between 14 and 31 percent (e.g. if 1.5 billion kWh were generated with the existing hydropower facilities, that would represent a 25 percent capacity factor).[36]

It should be noted that aggregating generators together and averaging their output over a long time scale (yearly) will reduce the range of variation compared to the actual maximum and minimum output experienced at individual sites. The typical variability for shorter time scales (months, daily profiles) for any individual hydroelectric facility can be more or less extreme than that indicated in Exhibit 6-6 depending upon the local climate and regional water situation.

Ocean Power

Wave Power

Waves vary almost continuously in height, direction, and period. There is also significant variability in day-to-day, month-to-month, and year-to-year average wave characteristics. Since waves are driven by winds, variability in the wave resource will follow variations in the wind. Hindcast data, which relies on historical wind data, can be used to examine statistical wave variability.[37]

Ocean Thermal Energy Conversion (OTEC)

The temperature difference between the ocean surface off the Texas coast and at OTEC depth varies significantly with season. During the winter months, the temperature difference can fall below 17°C. Nonetheless, normal seasonal temperature variations are relatively easy to predict, especially in regions such as the Gulf of Mexico where there is a lack of large scale events such as El Niño and La Niña. Periodic unpredictable events, such as cold core eddies and hurricanes, can dramatically affect the surface temperature making the longevity and economics of an OTEC plant in the Gulf very difficult to predict.

Tidal and Ocean Current Power

Tides vary with the rising and setting of the moon. Therefore, the times at which the maximum and minimum tidal heights occur changes from day to day, but can be predicted quite precisely. Within any given month the height of the high tide on a given day may be 25 percent or more above or below the average tide for that month. In Texas there is also some seasonal variability in the tidal range, with the highest absolute tide levels generally occurring in the spring and fall and the lowest tide levels occurring in the fall and winter. However, the height change from high to low tide, or amplitude of the tide fluctuation, remains relatively consistent throughout the year. For example, NOAA data for Port Aransas, Texas shows typical maximum tide fluctuations, measured from baseline average of 0.0 ft, of -0.5 to 1.0 ft in summer and winter and 0.0 to 1.5 ft in spring and fall.[38]

Salinity Gradients

An important advantage of salinity-gradient solar ponds is their inherent energy storage capacity that provides independence from short-term solar fluctuations and daily cycles. Even impacts from multi-day weather patterns are small. Thus, energy from solar ponds is dispatchable and quite predictable.

Performance does, however, vary seasonally. More solar radiation can be collected by the horizontal surface of a solar pond in the summer when the sun is higher in the sky. Winter ambient temperatures also contribute to higher heat loss from the pond. Neither of these conditions prevents salinity gradient solar applications from being viable in the colder periods of the year or in colder regions of the state. Results from the El Paso Solar Pond indicate that throughout the year the temperature differential could be maintained within a range of 60-70 °C.[39]

Utilization

Overview

Hydropower generation had an important role in Texas' past, helping bring electricity to the rural areas of the Hill Country during the 1930s and 1940s. Today hydropower is responsible for less than 1 percent of Texas electricity generation, and there are no known plans for additional substantial development in the future. Additionally, ocean power and saline gradient technologies will more likely be developed in other parts of the world where the resources are more substantial. However, some use of saline gradient solar ponds for non-electric generation applications could prove useful in Texas for specific projects involving desalination and aquaculture.

Conversion technology

Hydropower

Hydroelectric generation is driven by water flowing under the force of gravity. The reservoir water that is held behind a dam flows through an opening in the dam and along a tubular path called the penstock. At the end of the penstock rests the turbine. The water flowing over the turbine blades causes mechanical rotation. By connecting the turbine shaft to an electrical generator, electricity is produced from the falling water.

Ocean Power

Wave Power

There are many different designs for wave energy conversion devices with some designed to operate onshore, near shore, and off shore. These are generally categorized into four types: point absorbers, attenuators, oscillating water columns, and overtopping devices.

Oscillating water columns are fixed structures, built on a coastline or moored on the near shore seafloor, where the rising and falling of the waves in a column of air and water cause the air pocket to expand and contract. This expansion and contraction of the air pocket volume is facilitated by air flowing bi-directionally through a turbine that is connected to a generator for electricity generation.

Another near-shore wave power technology is device called the Wave Dragon (http://www.wavedragon.net). The Wave Dragon is a floating slack-moored "overtopping" wave device that operates by using two "arms" that face oncoming waves to focus them up a ramp and into a small reservoir (i.e. "over the top" of the walls). The water in the reservoir has a higher elevation than the surrounding ocean and the force of gravity forces the reservoir water back to the ocean through a hydropower turbine connected to an electric generator.

Offshore technologies include the Pelamis Wave Energy Converter, a type of attenuator, and power buoys (point absorbers). The Pelamis technology consists of a series of connected links that can articulate up-and-down and side-to-side. Waves cause relative angular motion between the links, and this motion drives an internal fluid through turbines connected to electric generators. Power buoys have a section that is moored to the ocean floor, either slacked or fixed, and another more buoyant section that rises and falls with the waves as they pass. The vertical relative motion between the moored portion and the buoyant portion creates mechanical energy that can be converted into electrical energy via a linear electrical generator or a rotational generator via a linkage and gear system.

Ocean Thermal Energy Conversion (OTEC)

OTEC systems generally operate via a simple or modified Rankine cycle in a closed or open loop configuration for the working fluid. Because the temperature differentials used for operation are in the range of 20° to 25°C (68° to 77°F), and the surrounding water temperatures are the energy drivers, a working fluid with a lower boiling point than water is needed. Typically this fluid is ammonia or an ammonia-water combination. The working fluid is vaporized by warm ocean surface waters and this relatively high pressure vapor expands through a turbine connected to an electric generator. The lower pressure vapor is then condensed by the cooler deep ocean water to restart the cycle.

Tidal Power

Tidal power conversion devices fall into two basic types: barrages and current flow devices. Typically, a barrage is constructed across the opening of an estuary. As the tide rises, water enters the basin through sluices in the barrage. As the tide ebbs, water is retained in the basin while seas outside the barrage reach low levels. The water is then released through turbines into the surrounding seas, generating electrical power. Variations such as bidirectional turbines have been proposed as an improvement over the sluice-turbine scheme.

Current flow devices operate on the same principles as wind power turbines but by extracting energy from flowing water instead of flowing air. Because the energy flow in a fluid is proportional to the density of the fluid and water is 1,000 times more dense than air, the blades for water current flow power generation can be much shorter and compact. Water current energy devices usually resemble a horizontal axis turbine with blades varying from those in traditional dam hydropower facilities to those on traditional wind turbines (http://www.verdantpower.com). Some current flow devices are modeled after hydrofoils that oscillate up and down, much like a swimming dolphin, to extract energy from the flowing water.

Salinity Gradients

Pressure retarded osmosis (PRO)

In a pressure-retarded osmosis system, two fluids of different salinity (namely river water and sea water), are brought into contact via a semi-permeable membrane.[40] Due to the chemical potential difference, the more dilute fresh water permeates into the more concentrated sea water. Water transport can be partially 'retarded' if hydrostatic pressure is applied to the concentrated solution. As water moves from the low-pressure diluted solution to the high-pressure concentrated solution it creates a relatively higher pressure water flow. This water flow can then run through a turbine for generation of electrical power. Current membrane technologies allow a power density for electricity from seawater using PRO in the range of 0.1 to 1.2 W/m^2 of membrane area.[41]

Reverse electrodialysis (RED)

In a reverse electrodialysis (RED) system, an array of alternating cation and anion exchange membranes are stacked between a cathode and anode.[42] The membrane spacing is of the order of 0.1-1 mm with the spaces being alternately filled with a concentrated salt solution and a dilute solution. The solutions continuously flow through the system. The salinity gradient across the membranes creates an electric potential difference (approximately 80 mV for seawater and river water), and the total potential difference of the stack is the sum of the potential across each membrane. The chemical potential difference across the membranes drives the positive ions through the cation exchange membrane toward the cathode and the negative ions through the anion exchange membrane toward the anode. Thus the RED stack operates similarly to a battery where an external circuit can be attached to allow electrons to flow from the anode to the cathode.

The potential difference of the stack and the flow of current in the circuit determine the electrical power obtained from the RED device. Current membrane technologies allow a power density for electricity from seawater using RED near 0.4 W/m^2 of membrane area.[43] If one assumes that a seawater-based RED system has the cross section of a standard shipping container (2.4m x 2.6m), then every kW of capacity would operate at 32 volts and be 40-400 mm in thickness. If the RED system was the length of a twenty-foot (6.1 m) shipping container, its power output would be 15-150 kW.

Saline gradient solar ponds

The following description of SGSPs is from Lu et al., 2002:

> A typical salinity-gradient solar pond has three regions. The top region is called the surface zone, or upper convective zone (UCZ). The middle region is called the main gradient zone (MGZ), or nonconvective zone (NCZ). The lower region is called the storage zone, or lower convective zone (LCZ). The lower zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Above it the NCZ constitutes a thermal-insulating layer that contains a salinity gradient. This means that the water closer to the surface is always less concentrated than the water below it. The surface zone is a homogeneous layer of low-salinity brine or fresh water. If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it.
>
> Because water is transparent to visible light but opaque to infrared radiation, the energy in the form of sunlight that reaches the lower zone and is absorbed there can escape only via conduction. The thermal conductivity of water is moderately low, and if the gradient zone has substantial thickness, heat escapes upward from the lower zone very slowly. The insulating properties of the gradient zone, combined with the high heat capacity of water and large volume of water, make the solar pond both a thermal collector and a long-term storage device.

Each water zone is approximately 1 m in depth, and the operational size of a SGSP would likely be 1-10 acres. The fully operational testing solar pond operated by The University of Texas at El Paso had a surface area of approximately 0.75 acres. The thermal difference between the hot LCZ and the cool UCZ can be used to preheat water for membrane desalination or drive low temperature turbines to generate electricity. Additionally, the heat from the LCZ can be directly used as low grade process heat for aquaculture temperature regulation, industrial heating, and assistance in desalination.

Infrastructure considerations

Hydropower

As new lake construction is considered as part of the Texas Water Development Board State Water Plan or otherwise, Texas can consider including a hydropower facility as part of any dam construction. If the lake project is considered feasible and desirable from an economic and environmental standpoint without a hydropower facility, then the addition of a hydropower facility, assuming technical feasibility, will add little to no further impact while possibly providing a small amount of peak power or pumped storage electric generation capability.

Ocean Power

The considerations for ocean power devices, particularly tidal and wave power systems, are similar to those of the offshore wind and oil and gas industries. They must withstand the harsh corrosive environments of the sea along with the extreme weather of hurricanes. Because the ocean power devices are extracting energy from a much more diffuse resource than fossil fuel reservoirs, to generate appreciable amounts of electricity, they must be deployed over larger distances in arrays that can accumulate ocean energy from a wide area. Shipping and other boat traffic will likely need to be restricted from passing through areas with ocean power systems. Also, transmission lines must connect these systems together like the pipelines necessary for oil and gas wells. Some studies by EPRI have shown that for commercial-sized arrays of wave power devices, the interconnection transmission line to the mainland becomes a negligible cost compared to the power systems themselves.[44]

Salinity Gradients

PRO and RED

The further one is from a river mouth into the bay system of Texas, the higher the saline content of the water becomes until it reaches the salinity of the Gulf. Thus, the gradient from freshwater in rivers to the standard salt concentration of seawater can occur over a distance of a few miles from the brackish estuary at the river mouth out to the open bay. In order to use PRO or RED for electricity generation one must bring the fresh water and seawater into the same location. Therefore, a pipeline might be required to intake bay or ocean water and bring to the river mouth, or vice versa. Either way, this infrastructure would need to be established in environmentally sensitive areas that could prove difficult during a permitting process.

Saline Gradient Solar Ponds

Relatively little infrastructure is required to set up SGSPs. Once the pond reservoir is established, piping and equipment can be brought to the site. The best use of SGSPs would be to find a local demand for the low grade heat energy resource (e.g. industrial or aquaculture). If using SGSPs for electricity generation, the amount of electricity that can be generated from the resource is low and long distance transmission lines should not be a constraint. However, each individual electric-generating SGSP project would need to be connected via small transmission lines.

Economics

Costs

Today, the costs of existing relatively large hydropower facilities are very low because the infrastructure for many of the hydropower facilities has existed for over sixty years. Because the fuel costs are zero, the total power production cost is small (US average being less than 0.9 ¢/kWh[45]) with operation and maintenance being the highest cost.

The costs of ocean power technologies are not well established due to their lack of multiple demonstration projects and essentially no commercial projects. Nonetheless, the Electric Power Research Institute (EPRI) is spearheading several pilot projects along the California and Oregon coast, and the organization estimates energy costs in the range of 9¢ to 14¢ per kWh ($2004) for the first commercial wave farms.[46] Cost estimates from EPRI predict that wave power costs at good sites will be below the costs of wind power at similar cumulative installed capacities for the industry.

The cost of desalinated water from SGSPs using a thermal multi-step flash process can be competitive at $2-$3 ($2002) per 1,000 gallons of distilled water in 1 million to 10 million gallon per day facilities.[47] These facilities can use the reject waters from reverse osmosis desalination. Additionally, the heat provided from SGSPs can reduce the viscosity of the saline water in reverse osmosis making it pass more easily through the semi-permeable membranes[48]. The cost of electricity generation from SGSPs will likely never be cost-competitive with existing and future alternatives unless used in a synergistic way with other applications (e.g. algae production).

Benefits

Because the potential for energy production from water resources in Texas is minimal, there is not a substantial economic benefit that is anticipated for the state. However, some technologies, such as the use of SGSPs for desalination or aquaculture enhancement, could prove beneficial to specific projects and locales.

Subsidies

There are no Texas-specific subsidies to promote hydropower, ocean power, or saline gradient power technologies. The federal Production Tax Credit (PTC) does apply to new efficiency improvements or capacity additions to existing hydropower facilities as well as new generating devices at dams without existing generation capacity.[49] For hydropower facilities, the PTC is only half of the credit allowed for other renewables. Thus, as of Summer 2008, new hydropower capacity would receive approximately 1 cent per kWh generated for 10 years after the installation or improvement was completed as opposed to a new wind power facility receiving 2 cents per kWh.

The federal PTC subsidy has only recently become applicable to renewable energy from the ocean as it was previously not included in the Energy Policy Act of 2005 or the Energy Independence and Security Act of 2007.[50] On October 3, 2008 the U.S. Congress passed and the President signed the Energy Improvement and Extension Act (EIEA) of 2008, which was part of the bill that included the Emergency Economic Stabilization Act of 2008.[51] The EIEA of 2008 makes the full PTC available for "marine and hydrokinetic renewable energy" derived from waves, tides, ocean currents, free flowing water in streams and canals, and differentials in ocean temperature (ocean thermal energy conversion). The marine renewable system must have a capacity over 150 kW and be placed in service before January 1, 2012. The EIEA also extended the Clean Renewable Energy Bond (CREB) program until the end of 2009. The CREB is the equivalent of an interest free loan for financing renewable energy projects that creates an incentive comparable to the PTC for municipal utilities and electric cooperatives that are ineligible for the PTC.

Key Issues

Hydropower

Most good hydropower generation sites in Texas have already been developed. There are numerous sites for new hydroelectric facilities with some having a potential of greater than 10 MW, but the hurdles related to siting and flooding of land will prevent most of them from development. Other in-stream sites for run-of-river applications may take place on a sporadic basis, but they will only provide significant electrical generation for the local system owner and operator.

Ocean Power

Texas has poor prospects for producing energy from ocean-based renewable energy either from tides or waves. The tidal and wave energy resources are well below the quality of other regions, where significant testing and pilots studies have only commenced in the last five years. Ocean thermal energy conversion would have to occur so far offshore from Texas, that it could no longer effectively be considered a Texas-based resource. Other resource areas of the world that have much more favorable conditions would have to implement commercially viable ocean power projects before one could think of engaging in Texas-based ocean power projects.

Salinity Gradients

The key issue for pressure retarded osmosis and reverse electrodialysis is the cost of the membranes. The demand for increased volumes of freshwater, essentially by running PRO and RED systems in reverse, might promote the large scale manufacture of semi-permeable membranes and subsequently reduce their cost for electric generation purposes.

There are no major issues with the development of saline gradient solar ponds as their prospects have been well-studied and documented by the research performed at the University of Texas at El Paso over the last two decades. If there becomes a substantial need for freshwater in the western region of Texas, then SGSPs could prove to be a beneficial energy resource for adding energy as heat to desalination processes.[52]

Information Sources

Hydropower

Idaho National Laboratory Hydropower Website
http://hydropower.inl.gov/prospector/index.shtml
http://hydropower.inl.gov/resourceassessment/pdfs/states/tx.pdf

Energy Information Administration
http://www.eia.doe.gov/fuelelectric.html
http://www.eia.doe.gov/cneaf/electricity/st_profiles/sept05tx.xls

Texas Water Development Board, *2007 State Water Plan*
(http://www.twdb.state.tx.us/wrpi/swp/swp.htm)

Ocean Power

The European Marine Energy Centre
http://www.emec.org.uk

US Army Corps of Engineers (wave hindcast data)
http://www.frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html

Wave data source (NOAA)
http://www.ndbc.noaa.gov/hmd.shtml (National Data Bouy Center)

US DOE Energy Efficiency and Renewable Energy office
http://www.eere.energy.gov/consumer/renewable_energy/ocean

NOAA Tides and Currents
http://tidesonline.nos.noaa.gov
http://tidesandcurrents.noaa.gov

Texas Coastal Ocean Observation Network (TCOON) of Texas A&M – Corpus Christi
http://lighthouse.tamucc.edu/TCOON/HomePage

World Energy Council Survey of Energy Resources 2007
http://www.worldenergy.org/publications/survey_of_energy_resources_2007

Salinity Gradients

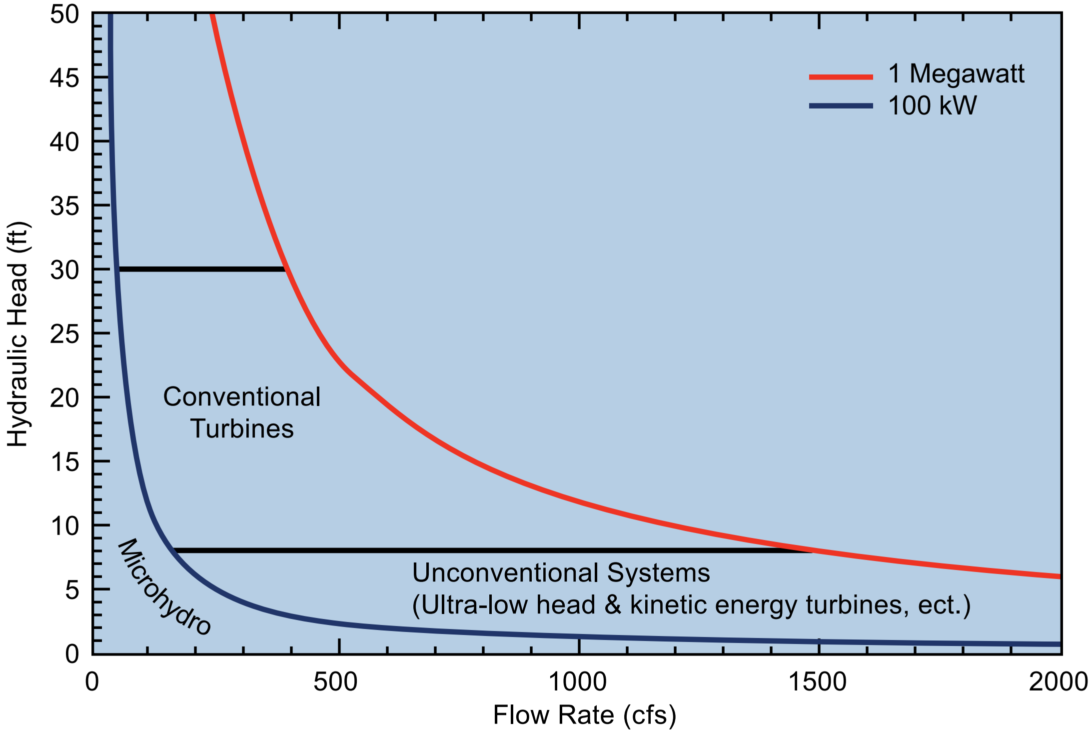
University of Texas at El Paso and El Paso Solar Pond station
http://www.solarpond.utep.edu/

Definition of Small Hydro for Idaho National Laboratory Hydropower Assessment

For the class of turbines defined as "low power", conventional and unconventional systems generate between 100 kWa and 1 MWa of power. Microhydro systems are defined as generating < 100 kWa. Recall that the "small hydro" class (not shown in **Exhibit 6-A**) is defined as generating between 1 MWa and 30 MWa.

Recall that MWa refers to the feasible average power generation that can be expected at the potential hydropower site, not the installed nameplate capacity of the hydropower system.

Exhibit 6-A For the class of hydropower turbines defined as "low power", there are three classes of systems, defined by this figure, that can convert the energy of the water resource into electricity: conventional turbines, unconventional turbines, and microhydro turbines.[53]



02-GA50396-01a

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[1] King, Carey; Duncan, Ian; and Webber, Michael. 2008. Water Demand Projections for Power Generation in Texas. Report to the Texas Water Development Board. August, 2008.

[2] Capacity factor: the ratio of annual electricity generated (due to physical resource or other limitations) compared to the amount generated if the electric generation facility operated at full power 100 percent of the time (e.g. all day every day of the year).

[3] Cruz, João. *Ocean Wave Energy: Current Status and Future Prespectives*. Springer-Verlag, Berlin. 2008. ISBN: 978-3-540-74894-6.

[4] Griffin, O. M. “Power from the Oceans’ Thermal Gradients.” Ocean Energy Resources. New York : ASME, 1977, p. 1.

[5] Trenka, A., Vadus, J.R., Matsuzaki, C. and Yuen, P. “OTEC/DOWA Activities in the United States.” Proceedings: International OTEC/DOWA Association 94 Symposium (Oceanology International Conference 94). Brighton, England: March, 1994.

[6] Energy Information Administration. Annual Electric Utility Data, form EIA-906/920. Available 4-20-08 at: http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.

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CHAPTER 7

GEOTHERMAL ENERGY

Introduction

Texas has the ability to be a U.S. leader in reducing the environmental impact of fossil fuel electrical generation by using renewable geothermal resources that range from just below the Earth's surface to deep within the Earth. This geothermal resource is important because its production inside the Earth is constant and independent of the many natural, changing surface conditions that affect other renewable energy resources. Multiple studies of Texas geothermal resources have been completed. The Department of Energy funded geothermal research projects in the 1970s and 1980s as part of a geopressured-geothermal resources study for the Gulf Coast region. There are many reports on Texas geopressured-geothermal resources available at http://www.osti.gov. On a statewide scale, the Texas geothermal resource was initially investigated and mapped by Charles Woodruff, et al. (1982). The map they produced is still available through the University of Texas, Bureau of Economic Geology. As part of the Texas Renewable Energy Resource Assessment in 1995, Janet Valenza completed the Geothermal Assessment, Chapter 8. In 2006 the Massachusetts Institute of Technology (MIT) Report: The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems for the 21st Century was published describing all of the United States' geothermal resources, including specific tables on resources for Texas. Recently, the Texas Comptroller of Public Accounts released a report on energy in Texas, including a section on geothermal resources (May 2008). This chapter is an extension of these reports with the goal to update and augment the knowledge base of geothermal resources specifically in Texas.

Significance of Resource: Historical, Present and Future Uses

Geothermal energy can be defined by splitting it into its components, *geo* meaning 'Earth' and *thermal* meaning 'heat', making geothermal the heat within the Earth. Geothermal energy represents the natural, internal heat of the Earth that is stored within the rock and fluid. In this chapter, the "geothermal resource" is the energy from inside the Earth that is accessible for humans to use.

Most of the heat inside the Earth originates from the natural decay of radioactive elements. Through various thermal processes, this heat is slowly transferred to the surface of the Earth where it can be accessed to provide for various human needs. The Geo-Heat Center at the Oregon Institute of Technology (http://geoheat.oit.edu) devised a simplified geothermal classification system based on the temperature of the resource (**Exhibit 7-1**). This classification system defines geothermal energy in terms of temperature (low, moderate, and high temperature resources) and how the geothermal heat can be utilized. As **Exhibit 7-1** indicates, geothermal energy has many uses besides the most well-known applications—electrical power production and geothermal heat pumps. For the purposes of this chapter, geothermal resources are divided into three main categories: Geothermal HVAC systems, Direct Use of heated water, and electrical power production.

Exhibit 7-1 Temperature-Based Classification of Geothermal Energy

Resource Temperature	Best Applications For Geothermal Heat*
Surface Temperature (40°F to 80°F)	Geothermal HVAC systems for homes and buildings
Low Temperature (70°F to 165°F)	Direct Use: agriculture and greenhouses, aquaculture (fish farming), mineral water spas and bath facilities, district water heating, soil warming, fruit & vegetable drying, concrete curing, food processing
Moderate Temperature (165°F to 300°F)	Binary fluid generators for electrical production; Direct Use: absorption chillers, fabric dyeing, pulp and paper processing, lumber and cement drying, sugar evaporation
High Temperature (>300°F)	Electricity production, minerals recovery, hydrogen production, ethanol and biofuels production

*Uses of geothermal energy adapted from the Geothermal Education Office materials.

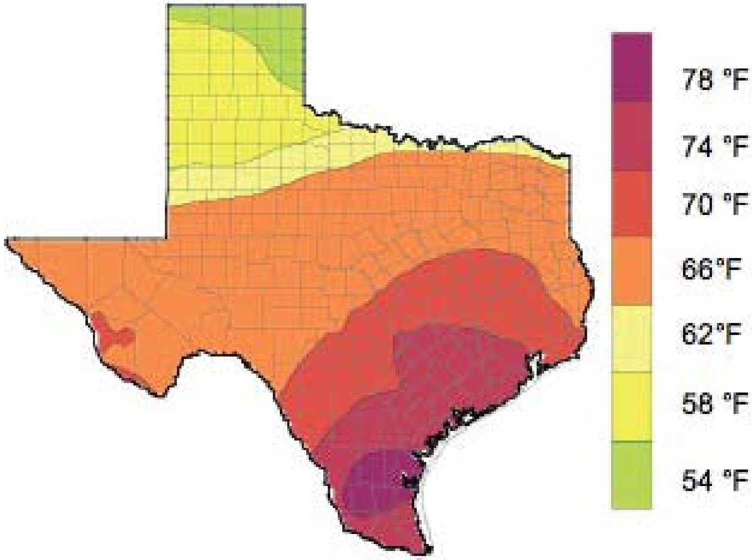
Geothermal HVAC Systems. One of the simplest ways to make use of the geothermal resource is through Geothermal Heating, Ventilation and Air Conditioning (HVAC) systems for homes and buildings. It is also known as geothermal heat pumps (GHP), ground source or ground coupled heat pumps (GSHP or GCHP), or geoexchange systems. This application of geothermal resources in Texas can be used by anyone from the average homeowner to the large commercial developer for the heating and cooling of buildings. According to the U.S. Environmental Protection Agency (EPA), geothermal heat pumps are the most energy-efficient, environmentally clean, and cost-effective systems for temperature control.[2, 5] From 2002 to 2006 there was a 71 percent increase in Geothermal HVAC system installations for residential applications in the United States.[4]

There are three components to a Geothermal HVAC system: 1) the local soil and geological environment; 2) the thermal transfer exchange system, or "loop field;" and 3) the mechanical system or heat pump and the ventilation ducts inside the building. Most installations are done by small to medium sized mechanical engineering or HVAC companies who coordinate with the building contractor. Project coordination includes design of the loop system, a bore-hole drilling contractor, pump installation inside the building, and a ventilation contractor for the building. These systems have reduced maintenance costs because the equipment is typically inside the building and loops are below ground so they are not susceptible to vandalism or extremes in weather conditions.

Once considered primarily a technology for the colder climates, geothermal heat pumps have advanced with improved system designs that are sized for both air conditioning and heating needs. These can work anywhere in Texas if the system is properly designed for the local climate. The geothermal heat pump uses a fluid loop to exchange the excess heat or cold inside the building with the upper few hundred feet of the Earth. Anyone who has gone underground into a natural cavern has experienced the constant temperature that exists within the subsurface. The temperature of the ground and/or groundwater from 10 to 50 feet (3–15 m) beneath the Earth's surface remains relatively constant year round and is able to stabilize the inside air temperature changes from outside weather. In this depth range, the ground temperature in the Panhandle is as low as 54°F ± 2°F (12°C) and in South Texas it is as high as 78°F ± 2°F (25°C) (**Exhibit 7-2**).[6]

By using the constant ground temperature as a starting point for additional cooling or heating of a building, less energy is used when compared to a conventional HVAC system which relies on heat transfer from outside air temperatures. Various studies by the Geothermal Heat Pump Consortium have shown that approximately 70 percent of the efficiency is derived by the Geothermal HVAC system through the ground loop fluids exchanging with the Earth.[5] These systems are referred to as an "offset" technology because of the reduction in electrical power production resulting from their installation. This can reduce monthly cooling and heating energy usage by 40 to 70 percent depending on the heat pump unit, energy efficiency of the building, and the local climate.[5] In addition to reduction in expenses for cooling and heating, excess heat may also be used to heat hot water tanks and swimming pools.

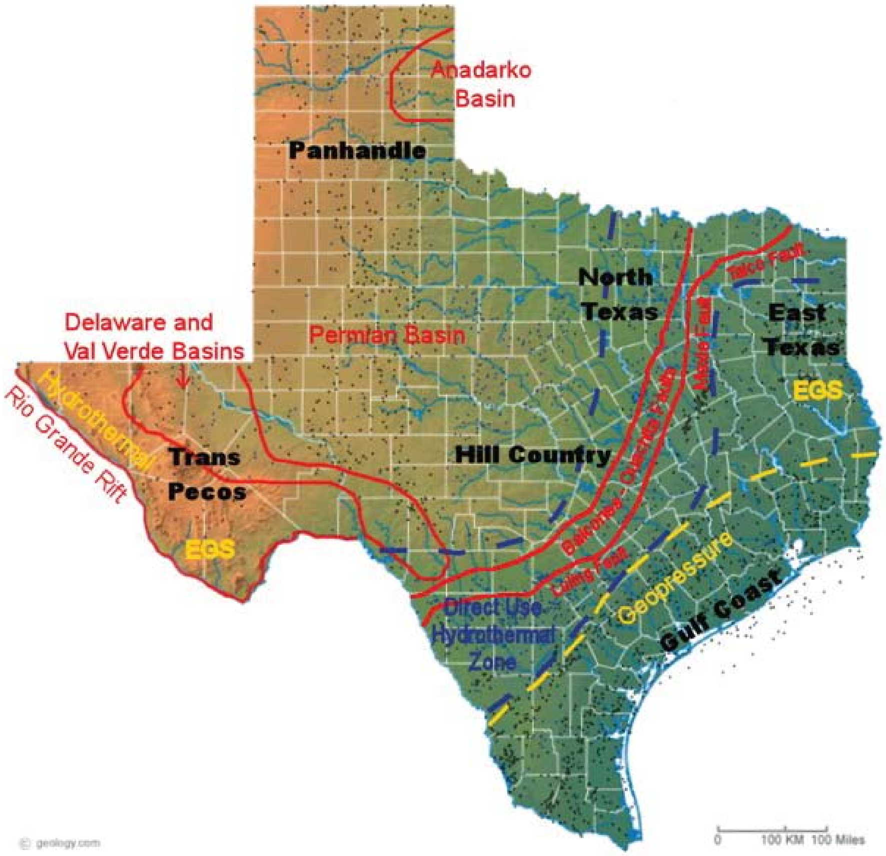
Exhibit 7-2 Average Texas Surface Groundwater Temperatures, a subset of the U.S. map by Gasss, 1982.[6]



Direct Use of Geothermal Resources. The Geo-Heat Center at the Oregon Institute of Technology identified 271 cities and communities in the United States with access to water for Direct Use geothermal applications. Forty three of these communities are in Texas.[10] The geothermal resources in the low to moderate temperature range (shown in **Exhibit 7-1** and **Exhibit 7-3**—Central Texas Hydrothermal Zone) can be extracted from subsurface warm water and used in various industrial and commercial processes including commercial spa health facilities and therapy pools, greenhouses, aquaculture, various food processing facilities, and a host of other applications (**Exhibit 7-1**). Spent fluids from geothermal electric plants can also be collected and used again for other industrial applications in a "cascading" process.

Developing the direct use of geothermal energy typically involves a production facility, a well and pump to bring the warm water to the surface, a mechanical system (piping, heat exchanger, controls, etc.) to deliver the heat to the processing space, and a disposal system in the form of an injection well or storage pond that receives the cooled geothermal fluid.

Exhibit 7-3 Generalized geographic and geothermal location map. Wells locations shown by blue dots (less than 4000 feet) and black dots (greater than 4000 feet). High temperature resources are shown in yellow text and low to intermediate temperatures are in blue. Geologic features are highlighted in red. Map produced by the SMU Geothermal Laboratory.



The following are types of Direct Use applications to focus on in Texas for development.

Community District Systems During the 19th century, hot water began to be used for local space heating applications in the United States. However, it wasn't until the 20th century that more widespread use of geothermal heat became popular. District geothermal systems distribute hydrothermal water from one or more geothermal wells through a series of pipes to several houses and buildings, or to blocks of buildings. District heating can save consumers 30 to 50 percent of the cost of heating compared with natural gas.[7] The geothermal production well and distribution piping replace the fossil-fuel burning heat source of the traditional heating system.

Spa Health Facilities and Therapy Pools Warm water from hot mineral springs or shallow geothermal wells have been used by humans for bathing, soaking and recreation throughout history. Today's spa facilities and therapy pools use warm water with methods similar to those used in ancient times as the primary means of health care and restorative recreation.

This past decade has seen a revival in the spa industry with 1 in 4 Americans having visited a spa and over 32 million active spa-goers worldwide. In 2006 there were 110 million spa visits generating $9.4 billion of revenue in the U.S. with an increase of 16 percent from 2005 to 2006.[8] Spa facilities and pools range from multi-million dollar resorts with luxury spas to reasonably priced public bathhouses and natural pools. The economic impact to communities is largely due to the draw of visitors into the area, with related expenses for food, lodging, and recreation needs as well as employment and housing for staff of the facilities.[9] Currently there are approximately 200,000 people employed in the U.S. Spa industry. In West Texas for example, at Chianti Hot Springs there are over 80,000 visitors annually.[8]

Agribusiness Industry Direct use of geothermal resources has been well received within the agribusiness industry, with the two primary uses being greenhouses and aquaculture (fish farming). Geothermal water (100°F/38°C and above) has been used in at least 40 greenhouses since the late 1970s, in the western states.[10] Many of these facilities cover several acres, raising vegetables, flowers, houseplants, and tree seedlings. The DOE Energy Efficiency and Renewable Energy program reports that greenhouse operators using geothermal resources estimate energy savings of about 80 percent compared to fuel costs for traditional energy sources.[7] Aquaculture ponds and ground heating to extend the growing season for specialty crops (85°F water and above) exist in 12 states. These Direct Use applications are usually in relatively rural settings due to the need for large amounts of land and can stimulate the economy for a rural area..

Geothermal Electric Generation Application. Electric power generation development using geothermal energy has been very active worldwide, with systems in the United States developed since the 1960s. Most of the focus and knowledge are on geological locations that are tectonically active, such as volcanoes, geyser fields, and hot springs in the western United States. These are areas where heat from within the Earth has reached sufficiently shallow depths to make the economics of heat recovery feasible for large scale power production. As of 2008, geothermal electricity is produced in California, Nevada, Utah, Idaho, Hawaii, Alaska, New Mexico, and Wyoming, with projects currently under development in Oregon. With increased research on Enhanced Geothermal Systems (EGS) by the U.S. Department of Energy and private companies, many other states, including Texas, are being considered for the development of geothermal energy production.

Depending on the technology used and the location, geothermal electric power can be generated using temperatures as low as 165°F (74°C) in Alaska, to approximately 200°F (93°C) in the Texas Gulf Coast region. The variation in useable temperatures is primarily due to the temperature differential needed between the surface cooling cycle and the hot fluid temperatures in the binary fluid turbine. These binary systems use a secondary fluid in a closed loop for the working fluid, which flashes to steam and turns a turbine. This allows the geothermal fluid that is lower than the boiling point of water to be used for heat extraction before being injected back into the ground.

Much of Texas has geothermal resources that are accessible for geothermal electrical production. The three primary resource areas are shown in Figure 8.2 as the conventional hydrothermal and Enhanced Geothermal Systems (EGS) of West Texas, the geopressured formations along the Gulf Coast, and the EGS of East to South Texas.

Development Issues for Texas: Special Considerations for Large-Scale Use

Each of the different types of geothermal development has preferred implementation areas in Texas. Geothermal HVAC systems have the most widely distributed potential for installation, with all regions of Texas being included. The most expensive places for installation are those with basement rock at the surface, such as the Hill Country and parts of North Texas due to the increased cost related to drilling boreholes instead of installing a horizontal loop field. The most immediate Direct Use application of geothermal resources is limited to the Balcones—Ouachita, Luling—Mexia—Talco Fault structures which form the northern and western boundary of the Texas Coastal Plain. Here the heated water is less than 4,000 ft (1.2 km) below the surface and is in certain places already being produced for community water supplies.[17, 18] Use of this water can be as general as preheating of hot water for commercial buildings, or as focused as use in high-end spas. The concern about widespread development is the ability of the aquifers to sustain long term high flow rates. Since community water systems use these aquifers for drinking water, a constant supply is necessary. One way to reduce stress due to over development of the aquifers is to allow the thermal energy to be extracted initially then cascade the cooler water into a community water supply. This procedure would eliminate the existing need for cooling towers.

Generating electricity from Texas' geothermal energy has increased the value of the resource because of the widespread potential for development and its minimal environmental impact. Geothermal power plants have additional considerations compared to the other geothermal resource categories because of size and resource demands. Below is a list of concerns that can be expected to be raised during project development, along with appropriate solutions.

The most common concern about geothermal power development relates to water: availability, quality, and disposal. Geothermal energy production requires large volumes of water (thousands of barrels per day) at temperatures in the range of 200°F (93°C) and above. Billions of barrels of water are currently being produced across Texas from oil and gas wells. This water is typically high in minerals and salt, and thus would contaminate surface waters and soil if disposed of at the surface, because of this the water is injected back into the subsurface. Similarly developed geothermal fields are a closed loop, where water is produced from one well, its heat extracted using a binary electrical unit, and then injected back into the ground. In this case the purpose is three fold: 1) reducing the potential for surface impacts, 2) extracting more heat from the system, and 3) preventing drawdown of fluids in the system. Thus reinjection prevents overproduction of the reservoir and extends the life of the power plant.

The surface environmental impact on an area with a geothermal power plant is limited to the plant, wells, and pipelines with the common concern being noise levels around the wellhead. Most of the areas favorable for geothermal electricity production have an existing infrastructure already built by the oil and gas industry; therefore, only limited additional impact is expected on-site.

Geothermal binary fluid turbines produce little to no air contaminants because of the closed loop working fluid design. In flash steam plants (not likely to be used in Texas) trace amounts of hydrogen sulfide, nitrous oxide, sulfur dioxide, and carbon dioxide may be emitted but only at levels less than present air emission standards.[16] Projects incorporating co-production or geopressure wells could produce small amounts of hydrocarbon condensates, which require appropriate handling when these resources are extracted from the fluid as regulated by the Texas Railroad Commission. The extracted hydrocarbons can be collected and sold or used as part of a preheating system.

Binary geothermal power plants can be air or water cooled. In areas with limited access to surface water, such as lakes or rivers, a forced air cooling tower is the recommended method for the cooling cycle of the binary system. Forced air cooled plants use no fresh water.[16]

Geothermal resources have a competitive edge compared to some other renewable energy resources. Unlike electricity from wind and solar, geothermal is considered baseload capacity and is competitive with other baseload technologies such as coal and natural gas plants. Geothermal power projects can be located in major population centers or in rural communities and scaled to meet existing needs. For the oil and gas industry, it enhances the economics and increases the longevity of their oil and gas fields by decreasing the cost of water production.

Texas Geothermal Resources

The Texas geothermal resource is as extensive as the state is big. The entire state has geothermal resources that can be used by individuals, businesses, schools, and the government. The accessibility of the geothermal resource varies by geographic region and in some instances by county. One aspect of the geothermal resource that is fairly consistent throughout Texas is the Geothermal HVAC system resources. Although the ground level geologic setting will not be covered in this section, these systems are an important part of the geothermal economic package because they can reduce overall energy consumption in Texas by thousands of MW. The following section will detail the resources for Direct Use applications and electrical production from geothermal resources.

Texas Geothermal Resource Details

For a geothermal resource to be commercially viable, heat must be removed from the ground at a rate and a cost that returns a reasonable profit. The economics associated with accomplishing this depend on: 1) the quality of the resource, principally its temperature, depth, and fluid characteristics; and 2) the ease and rate with which geofluids can be extracted and then reinjected. These factors are a function of geology, i.e., rock type and layer thickness, porosity and permeability, and thermal history. First the resources related to Direct Use applications are discussed, then the deeper resources for geothermal electrical production.

Direct Use Geothermal Resources

Low to moderate temperature wells and springs have been in use in Texas for decades.[17, 18] Shown in **Exhibit 7-3**, Texas has multiple major hydrothermal regions with the two most prominent ones discussed below—the Central Texas fault zones and Trans-Pecos region of far West Texas.

Central Texas. Central Texas has had a history of geothermal activity from springs and mineral waters which has supported over 50 spas since the late 1800s through today. The faults in the area allow for deep circulation of fluids that upwell along fractures bringing the heat to an accessible depth. They contain waters with acceptable temperatures, salinities, quantities, and drilling depths for many Direct Use geothermal projects (**Exhibit 7-1**). Springs such as San Pedro Springs, Comal Springs, San Marcos Springs, Barton Springs, and Salado Springs are found along the Balcones—Ouachita fault trend. Shallow aquifers (4,000 feet or less) along the Balcones—Ouachita structural trend have elevated temperatures reaching as high as 153°F (67.2°C) in Marlin. Some areas have artesian flow. Waco used to be named "Geyser City" because of this feature, although today with increased water consumption the water table has dropped and wells are no longer artesian. Beyond the main Balcones—Ouachita faults are other warm zones. To the east and north are the Luling—Mexia—Talco Faults which bring warm water to Bryan (117°F (47°C) at 3,000 ft (915 m)) and as far north as Paris (115°F (46°C) at 3,400 ft (1030 m)). On the western side of the Hill Country the Hickory aquifer, (with water of 130°F (54°C) from approximately 4,000 ft (1220 m)) is used for municipal water for communities such as Eden. In the Dallas County area the drinking water wells ranged in temperature from 106°F (41°C) at 2,600 ft to 135°F (57°C) at 4,000 ft and reported to be cooled before using. These areas are considered prime locations for geothermal Direct Use applications. The total resource stretches in a band from Val Verde County to Red River County and includes many of Texas' major cities that currently spend resources to cool the water rather than using the excess heat (**Exhibits 7-2** and 7-3).[17, 18]

Trans-Pecos, West Texas. Another area with significant geothermal potential is the tectonically active area of the Rio Grande Rift, an extensional zone that runs from Colorado to New Mexico and into Texas, near El Paso, and continues along the Rio Grande for over 300 miles to the Big Bend region (**Exhibit 7-3**). Igneous and sedimentary rocks both at the surface and deep within the structure have elevated the regional temperatures.[11, 20, 21] Along the Rio Grande floodplain are Indian Hot Springs, located in Hudspeth County, where geothermal fluids surface from a series of springs, the hottest is 117°F (47°C). Other springs are the Boquillas Hot Springs in Big Bend National Park and in the Chianti Mountains of West Texas; the Chianti Hot Springs has 110°F (43°C) geothermal waters. The area is known for its recharging ground water that circulates to a depth of over 3,400 ft (1030 m) creating known geothermal resources in the Presidio Bolson, Hueco Bolson, and the Big Bend area. This represents the best potential for conventional hydrothermal geothermal development in Texas and includes El Paso, Culberson, Hudspeth, Jeff Davis, Presidio, and Brewster Counties.[20, 21]

Geothermal Resources for Electrical Production

Geopressured Resources

A geopressured resource consists of highly pressurized hot brine, due to water trapped during the burial process. These resources often are saturated with methane and found in large, deep aquifers. Wells drilled into this resource flow pressurized to the surface. Water temperature can range from 190 to over 400°F (90—200°C). Three forms of energy are useable in geopressured wells: 1) *thermal* from the high temperatures, 2) *hydraulic* from the high fluid flow pressure, and 3) *chemical* from the dissolved methane in the fluids.

There are two parallel geopressured bands of very thick sand deposits that follow the Texas Gulf Coast line (**Exhibit 7-3**). These are in fact, layers or lenses of sands that were deposited by ancient delta systems, cut off from other water sources by subsidence and rapid burial. The weight of the impervious rock above the entrapped sand pockets, coupled with the decomposition of ancient organic matter into methane, resulted in high pressure zones. These are considered the most important resource of its type in the U.S. These rocks can be up to 50,000 feet thick (15 km), but more commonly are drilled to depths of 8,500 to 18,000 ft (2.6 to 6 km).[15]

Because of their thickness and lateral extent, huge geopressured brine reservoirs exist within the deep, porous rocks of the Gulf Coast. Thick sandstone units within the Frio and Wilcox Formations contain prospective geothermal resource areas called fairways, with their large brine reservoirs.[22, 23] Sands in the fairways can be several hundred feet thick with temperatures over 300°F (150°C) and relatively high permeability. In these geopressured zones, thermal gradients averaging 18°F/1,000 ft (30°C/km), coincide with geopressure gradients that approach 1 psi per foot (more than twice the hydrostatic gradient resulting from water pressure alone).[22]

A U.S. Department of Energy (DOE) program that spanned from the 1970s to the mid 1990s culminated in a geopressure power plant in Brazoria County at Pleasant Bayou between 1989–1990 that produced one MW of electricity.[24] The production well was 16,500 ft (5 km) deep and sustained flow rates of 20,000 to 23,000 barrels of brine per day, with an average wellhead temperature of 268°F

(131°C) and a gas content of 29 cubic feet per barrel. At this production rate (600 Mcf/day) the natural gas produced with the geopressured brine is roughly two and a half times higher than the average (230 Mcf/day) natural gas well in Texas.[25] The five-year geopressure well test revealed a large sandstone aquifer estimated to contain enough fluid for a three MW power plant to operate at least 10 years.[26]

Other wells used in the DOE "Wells-of-Opportunity" program (oil and gas wells drilled by industry and used for short-term tests) revealed that the brine in Gulf Coast deposits contained natural gas in quantities close to saturation. Results showed that it is feasible to produce brine at rates of thousands of barrels per day and to inject the spent brine into relatively shallow saline aquifers for disposal without adverse environmental impact.[26]

The temperatures prevailing within this large geopressure reservoir represent a significant amount of heat. It has been estimated that over 5,100 EJ are contained within the Texas sandstone deposits.[37, 28] Uncertainties remain about the reservoir mechanics, particularly the capability of these aquifers to produce brine for extended periods of time, and the amount of energy recoverable. Models of conventional reservoir dynamics must be modified to account for the pressures prevailing in geopressurized zones and the system interconnectivity through faults. The hot brine temperatures (200 to 400°F (93—204°C) could be best used for binary cycle conversion power plants.

There are other, less studied geopressured reservoirs in Texas. The geopressured Delaware Basin of West Texas (**Exhibit 7-3**) extends from 8,000 ft to a depth of nearly 30,000 ft (2.4—9 km), with pressures of 0.65 to 0.94 psi/ft and temperatures from 140 to 400°F (60—200°C).[31, 32] Recent funding by the DOE and SECO assisted in expanding existing data to over 5,000 wells and over 8,000 temperature-depth points for analysis as part of an investigation of the Delaware and part of the Val Verde Basins.[31, 32] The counties included in this study are Ward, Loving, Winkler, Reeves, Pecos, Terrell, Crockett and Hudspeth. Analysis of the temperature data suggests there is complex variability in the thermal gradient throughout the region. Numerous strata from the Devonian 31 formation through the Ordovician Ellenberger formation show porosity and permeability sufficient for heat extraction for absorption chillers and electrical power generation.

A small fraction of the Anadarko Basin extends into the Panhandle of Texas from Oklahoma (**Exhibit 7-3**). The basin contains between 6,000 to 30,000 ft of sediment and has a fluid-pressure range of 0.52 to 0.85 psi/ft, and a temperature range from 140 to 425°F (60—220°C).[32] A recent geothermal investigation of South—Central U.S., including this basin, has been conducted by Negraru, Blackwell, and Erkan, (2008).[49]

Coproduced and Stranded Resources

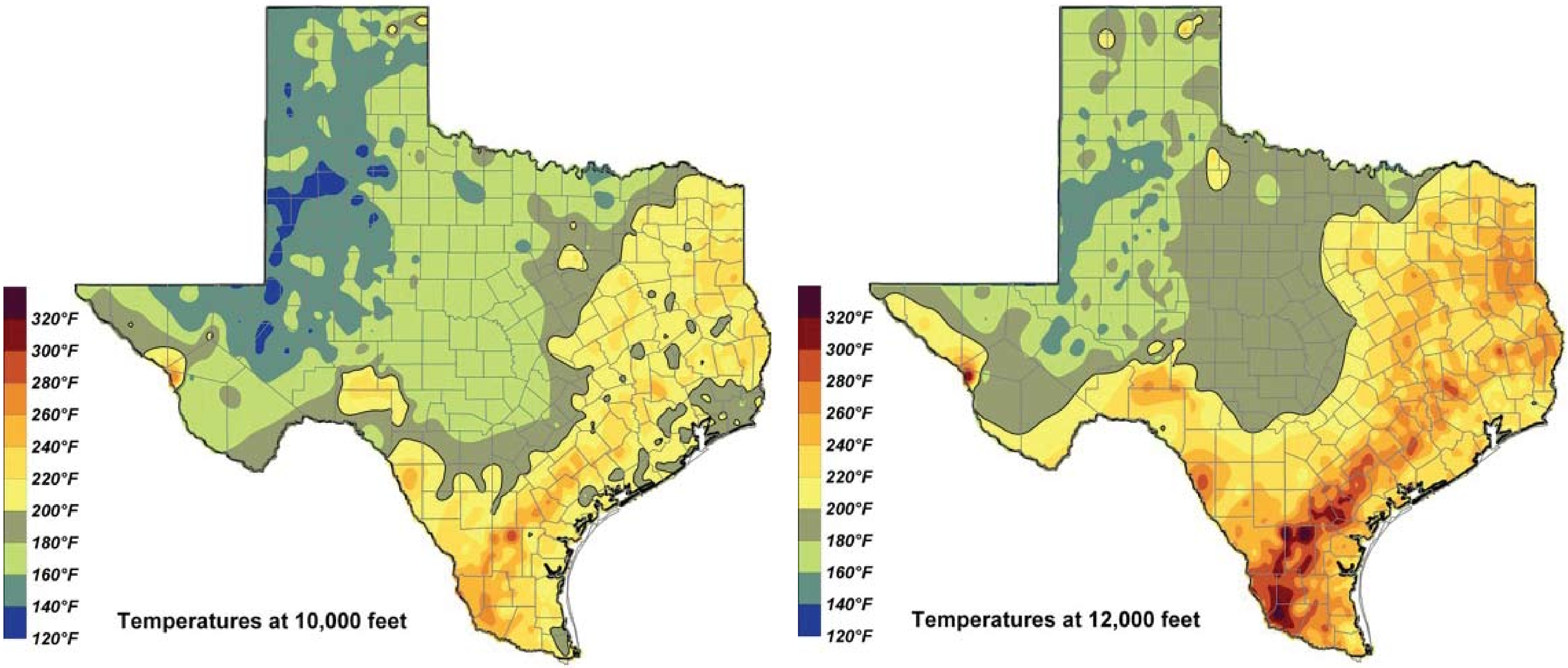
Within sedimentary basins, two distinct geothermal resource categories are found: coproduced and stranded.[31, 32] Stranded geothermal resources are geothermal fluids left in an oil and gas field after the extraction of hydrocarbons is completed. Oil and gas companies try to avoid water production due to the additional expenses for separation and disposal. This resource estimate is included in the overall geopressure and Enhanced Geothermal Systems (EGS) estimates, but is unique in that it is a resource known in detail from drilling, but currently being avoided by oil and gas companies rather than developed. The use of horizontally drilled wells are specifically of interest in developing Texas geothermal resources, since their large intercepted area makes them good heat exchangers for EGS designs.

Coproduced fluids occur when oil and/or gas is pumped from a well along with hot water and economically extracting all of them at the same time. In these cases the well produces adequate hydrocarbon volumes for the well to remain economical with the additional expense of water disposal. In other instances, a well is drilled primarily for gas but the reservoir is water wet and the gas is dissolved in the water. Production of the gas results in excessive amounts of water. If the water is sufficiently hot (~200°F/93°C or more) and the flow volume is suitably high, then electric power can be produced. By developing electrical energy from these fluids, it extends the life of the well through the value added of the electricity.

Temperatures at 10,000 to 12,000 ft (3 to 3.7 km) have been calculated using uncorrected bottom-hole temperatures from oil and gas well logs (**Exhibit 7-4**). Actual temperatures in the ground are normally higher than the well log bottom-hole temperature because the circulation of drilling fluids cools the deep formations. The Permian Basin is the coldest region with temperatures starting at 120°F (49°C) at 10,000 feet (3 km). South Texas has the highest temperatures at 10,000 ft, reaching 282°F (138°C) (Figure 8.3).[36] At 12,000 ft (3.6 km) the South Texas uncorrected temperatures reach 318°F (159°C). The areas shown in yellow to brown are zones with the highest initial potential for stranded and coproduced geothermal resources.

McKenna et al. (2005)[34] point out that numerous states produce substantial amounts of water in conjunction with hydrocarbon production. In Texas, approximately 12 billion barrels of water (1 barrel equals 42 gallons) are produced and injected each year. If this coproduced water has temperatures of 212°F (100°C), then over 1,099 MW of electrical power could be generated from the heat extraction before the water is reinjected into the ground.[39] This is enough energy to power at least 275,000 homes.

Exhibit 7-4 Uncorrected temperatures of formations at 10,000 and 12,000 feet depth from oil and gas well logs. The maps were produced by the SMU Geothermal Laboratory.



Enhanced Geothermal Systems Resource

The Enhanced Geothermal Systems (EGS), category represents geologic formations with limited quantities of water but with high temperatures that can be produced if a fluid is injected into the rock to act as a carrier for the heat. In the previous Texas Assessment (1994) Hot Dry Rock was discussed. This is now considered one aspect of EGS development. This resource is huge in comparison to other categories in Texas because it can utilize deeper resources and could be produced anywhere. The minimum EGS resource temperature usually starts at about 300°F (150°C) to be economically viable (**Exhibit 7-4**, Table 8.3).[39]

The geothermal resource suitable for sustaining EGS technology is inferred from subsurface temperatures and rock types. Because of heat conducting from the Earth's interior, subsurface temperatures increase with depth. Depending upon the conductivity of rock types, the composition of the Earth's crust (conductivity and radioactivity), and the mantle heat flow, the temperatures at depth will vary (**Exhibit 7-4**). The basement rock of East Texas is considered the area with the highest heat flow in Texas (Blackwell and Richards, 2004).[12] Here the potential for EGS is the greatest, especially if combined with coproduction of oil and gas. The calculated temperatures of the basement rock in East Texas are 400°F (200°C) at 20,000 ft (6 km) (Negraru et al., 2008).[49]

Oil and gas well drilling temperature records were used to calibrate the the available heat models for the most accessible EGS resources—300°F (150°C) to 480°F (250°C) between 10,000 and 20,000 ft (3 to 6 km) in Texas. Even at just these depths the Texas EGS resource is immense reaching 90,000 EJ. The resource is listed as thermal energy because the conversion factor to electric energy varies with technology. To give perspective though of how much energy is available, using an average binary turbine conversion rate of 10% from thermal energy to electrical, and a very conservative availability rate of 0.2% there is still over 100 times more power capacity than the total Texas yearly electrical consumption.[1, 39, 49] Even modest utilization of this EGS resource could supply a large portion of the State's energy and most likely do so on a permanent basis.

Exhibit 7-5 Geothermal Resource Base for Texas. The amount of heat is based entirely on temperature. Each depth shows the amount of thermal energy available for extraction from different temperature levels. Based on Table 3 of Negraru, Blackwell, and Erkan, 2008.[49]

Geothermal Resource Base for Texas

Exajoules, EJ (10^18J)

		°F	212	300	390	480	575	
		°C	100	150	200	250	300	
Feet	KM							
10,000	3.0		24,246	14				
13,000	4.0		40,939	1,147				
16,000	5.0		47,596	37,521	36			
20,000	6.0		50,194	48,788	2,509			
23,000	7.0		34,753	61,997	34,701	38		
26,000	8.0		22,029	68,170	61,945	2,086		
30,000	9.0			83,462	68,030	26,402	278	
33,000	10.0			76,176	68,656	57,743	1,929	
Energy (EJ)			219,757	376,975	235,877	86,269	2,207	
Total Thermal Energy (EJ)								921,085

Table 7-6 Texas Geothermal Resources by category.

	Total Resource (EJ)	Accessible Resource (EJ)	Percent Available	Depth Range (ft)
Hydrothermal (<180°F or 82°C)	84	84	100	< 5000
Geopressured*	5,100	3,570	70	8000—18,000
EGS (> 300°F)	700,000	90,000	13	12,000—33,000
Coproduced/Stranded (212°F or 100°C)	220,000	55,000	25	7000—26,000
Total Geothermal Energy Resource	925,184	148,654		

*Geopressured resource includes the dissolved methane content. This number is only for extraction from the sandstone formations, not the shale formations.

Quantification of Resource Base

The thermal energy potential of each of the geothermal resources described above is summarized in **Exhibit 7-6**. These numbers represent the total thermal energy reserve of hydrothermal, geopressured, and EGS resources. The Texas geothermal resource values of **Exhibit 7-6** are computed as the total thermal energy contained within the depth range of the resource as described above. In addition, accessible resource values are achieved by assuming an appropriate fraction of the total resource base according to technology, geologic setting, and current economic threshold. The following fractions are assumed: hydrothermal is 100 percent accessible, geopressured is 70 percent accessible, EGS uses the mid-range MIT value of 13 percent accessible,[38] and coproduced is about 25 percent accessible based on drilling records.[36]

The use of sedimentary basins and geopressured formations are the highlight for Texas electrical production. Developing existing oil and gas fields into geothermal electrical production areas has the greatest potential for tapping into the 925×10^{21}J of thermal energy stored under Texas.[39, 49] Using information from previously drilled oil and gas wells, tens of thousands of temperature data points can be used as an exploration tool for defining the most accessible resources. The use of geopressured geothermal resources for thermally enhanced oil recovery seems especially viable in South Texas because of the collocation of resources below heavy-oil reservoirs. Geopressured-geothermal resources can also be used for other applications such as absorption chillers, desalination, agriculture, and aquaculture projects.

The economical viability of the East and South Texas EGS potential has yet to be determined. There are wells drilled to 20,000 feet (6 km) but unlike the geopressure areas, the wells have limited natural flow capacity. As EGS projects are completed in Australia and Europe, the likelihood of project development in Texas increases. The 2006 MIT Future of Geothermal Report, suggests EGS could be a sustainable source of energy.[39]

Space heating and agribusiness applications using water in the 100°F to 170°F temperature range represent the largest potential use of low to moderate temperature hydrothermal energy in Texas. This is based on successful applications in New Mexico and Idaho. In small projects, the resource can last decades if proper management procedures are followed, i.e., the geothermal water is injected back into the reservoir or pumping does not exceed the natural recharge rate. With the addition of a heat exchanger to wells that have already been drilled, many Central Texas municipalities could take advantage of the currently wasted heat from the water they pump for various purposes.

Geothermal Resource Variability

To its advantage, geothermal resource utilization is not dependent upon intermittent forces, such as wind and solar energy. Rather it is available 24 hours a day, 365 days a year, and is considered baseload energy technology. Heat from within the Earth does not vary with day or season, but instead, on geologic time scales of millions of years. While long-term variations in climate can impact aquifer recharge rates, which in turn may change the availability of producing fluids, water already in the subsurface is usually reinjected into a connected reservoir to be reheated for eventual multiple production runs. As long as a balance is maintained between heat extraction and recharge, the resource has an infinite lifespan, thus being truly sustainable.

Geothermal Energy Utilization

Geothermal resources have been used in Texas for over a century. From the use of warm water for recreation and health spas to cooling and heating homes around the state, this is not a new resource. It is certainly under-developed when considering the possibility of 925×10^{21}J as the starting resource base for Texas.[39, 49] Education of the public and businesses is needed to accelerate the transfer of new technology and increase project funding for the use of geothermal resources in Texas.

Current Geothermal Resource Use in Texas

Geothermal HVAC Systems

The Crawford Ranch of President George W. Bush is the most prominent Geothermal HVAC system in Texas. Based on geothermal heat pump sales in Texas for the past decade, there are approximately 10,000 residential systems installed. This equates to only a 0.004 percent energy offset (reduced electrical production) for Texas from Geothermal HVAC systems; for comparison, Florida's offset is 0.23 percent.[3] With a 30 to 70 percent energy savings, there is much potential for future energy savings from Geothermal HVAC systems. Most Texas systems have been installed since the 1980s, yet as shown by homeowners in the McAllen area residential systems have been installed for over 50 years and are still working.[40] Although it is rare, there are systems that have been installed upfront by developers for entire neighborhoods, for example in the Valley Ranch subdivision in Irving, Texas in the 1980s.[41] It is difficult to determine how many total systems have been installed since there is no single organization keeping records. There are some records for commercial buildings with Geothermal HVAC systems from engineering firms who installed the system, but this information is collected on a company by company basis. Older installations are usually not recorded or the company no longer exists. With the prestige of LEED certification, installing Geothermal HVAC systems is becoming increasingly common. Under the LEED criteria a Geothermal HVAC system can add up to 19 points and be the difference between Silver, Gold or Platinum LEED Certification. Completed in 2006, the McKinney Green Building (McKinney, Texas) is an example of the first Platinum commercial office structure in Texas, and it uses a Geothermal HVAC system. School districts are likely to use the SECO LoanSTAR program for Geothermal HVAC systems. Because of the LoanSTAR program there is more available information on schools with installations. Cotulla High School is the first Texas school to use geothermal for heating of its 10 campus buildings, and the Austin Independent School District was the first heating and cooling installation in the state of Texas. At present there are at least 34 school districts and 140 schools in Texas with Geothermal HVAC systems installed.

Direct Use Applications

Geothermal Direct Use applications are often considered the "buried treasure" since many of the uses are in private ownership or only locally known. Usually the only person who knows that a geothermal resource is in use is the mechanical staff. The best known example in Texas is a project that started in the 1970s as geothermal well developed in Marlin, Texas for heating the Falls Community Hospital & Clinic.[42] This project was funded by the U.S. Department of Energy, Natural Resources Advisory Council and the Farmers Home Administration with the objective to demonstrate the technical feasibility of using a geothermal resource to meet the hospital's space heating and water heating needs. Since 1982, the facility has used the 3,900 ft (1.2 km) deep well, yielding 600 gallons of water per minute from the Hosston Sands aquifer, with temperatures from 140 to 155°F (60—68°C). The water is used directly in the summer for the hot water needs and in the winter months to heat the hospital with a secondary use of preheating the hot water.

One of the more common applications of Direct Use wells in Texas has been for spa facilities. Spa facilities can range from hi-end destination locations to user-friendly community bath house facilities. Although there have been tens of geothermal wells and mineral springs used for such purposes in Texas, currently the only existing hot springs destination is in West Texas at Chianti Hot Springs with over 80,000 visitors annually.[8]

In the past geothermal artesian wells flow steadily from sources in Marlin, Ottine, and San Antonio, Texas. Marlin received over 500,000 visitors to their spas from the early 1900s through 1950s with well water temperatures at 130°F (54°C).

Ottine was the site of a children's polio treatment center but moved away from mineral water therapy with the advent of the sulfa drug. The active well has a temp of 102°F (39°C). Hot Wells Resort in San Antonio was an active mineral water site through 1925 when a fire destroyed the hotel. The bath house remains with its artesian well flowing at 103°F (39°C) water; private owners are considering restoring the bath facilities after the San Antonio River Authority completes the river improvement projects.[43] A simple application based on a warm well (98°F/37°C) is Stacy Pool in Austin. This Austin recreation pool well has been flowing since the 1930s.

According to the Oregon Institute of Technology, Texas has 43 communities with access to water for Direct Use applications which could be attracting businesses to use this resource. Wells providing water from 100 to 140°F (38—60°C) are currently available for use in the following communities: Eden, Marlin, Taylor, Austin, Ottine, San Antonio, and Kennedy.

Geothermal Electrical Power

Commercial electrical production from geothermal resources is still in the development stage in Texas. The DOE geopressured-geothermal demonstration in 1989-90 of a one MW power plant at Pleasant Bayou, Brazoria County, is bringing much renewed interest with rising energy prices and the desire for renewable energy. This project showed that geothermal electrical power generation can be accomplished in Texas.

Conversion Technology

The geothermal power industry is in the process of undergoing a paradigm shift. Until 2006 there was no technology or energy pricing that would cause consideration of fluids less than 250°F (121°C) for geothermal electrical production. Then in 2006, the project in Chena Hot Springs, Alaska produced electricity with 165°F (74°C) water and the geothermal world took a new look at many previously ignored resources, such as the sedimentary basins in the Gulf Coast and the West Texas. New interest in project development from existing oil and gas fields has spurred new technology from binary fluid designs to gas compressors. An increased need for micropower plants (30 kW to 500 kW) as part of distributed power development has resulted in companies designing new systems for geothermal energy production. Examples of companies today with existing or demonstrating power plant technology for electrical generation in Texas are ORMAT Technologies, UTC Power, ElectraTherm, Inc, and Deluge, Inc.

Another technology that can use the geothermal fluids is absorption chillers. Large commercial applications can use the heated fluids directly for air conditioning, increasing the energy efficiency of the system. This is currently being done in Chena Hot Springs, Alaska, using their hot water to keep an ice hotel frozen throughout the summer.

Each year Geothermal HVAC companies improve their products for residential and commercial applications. The highest rated systems are currently at 30 SEER, which is the highest efficiency level of the Energy Star government ratings for home applications. A list of companies manufacturing geothermal heat pumps can be found on the U.S. Government Energy Star website: http://www.energystar.gov/.

Infrastructure Considerations

Electrical production from geothermal energy will most likely be situated along with existing oil and gas field wells. Field equipment needs electricity and could be the first major use of geothermal electricity. Baseload or peak power contracts for the excess energy could be offered into ERCOT's wholesale market or sold directly to load serving entities and transmitted using existing transmission lines. Lines with insufficient carrying capacity would need to be upgraded from the generation location to the major line. Most of the geothermal resources available for immediate electrical development projects are near existing population centers, so transmission lines are already in place. The Trans-Pecos region has a limited transmission grid and oil and gas fields often utilize diesel fuel for generating electricity in rural areas. In these instances, the onsite need for the produced electricity is even greater. As large fields are converted to geothermal electrical production in West Texas, working with the other renewable industries to ensure the transmission of the electricity will be important.

The largest expense for a Geothermal HVAC system is the ground loop field. The ground loop depth varies according to local geology and ground water movement in the area; if there is 10 feet of soil below the surface, then a horizontal loop can be installed. More typically a vertical loop is installed and includes between 200 to 300 ft (61—91 m) per borehole per ton of air exchange. Vertical systems have increased upfront costs but are shown to improve system efficiency compared to horizontal designs.[5, 7] The payback period is about two to ten years, depending on the heat pump and energy efficiency of the building. The loop field materials are usually guaranteed to last at least 50 years. Since much of the expense is in the ground loop, with a guaranteed time frame, one consideration would be for ground loops to be paid for by municipalities, rural electric cooperatives, or even neighborhood associations, who could then lease them back to homeowners in order to spread the expense over the life of the system.

Economics

Costs

Residential Geothermal HVAC systems cost approximately $3,000 to $5,000 per ton of air conditioning capacity.

Geothermal power plants have not yet been installed in Texas. Therefore the Return on Investment (ROI) is an estimate based on current technology, drilling expenses, and the cost of existing western U.S. geothermal power plants.[50] Using a binary fluid turbine for the power plant and basic transmission line hook-up, the estimated cost to build a power plant is:

$750,000 to $1,500,000 for a 250 kW system

$2,500,000 to $5,000,000 for a 1MW system

Benefits

1. Geothermal energy is a geologically sourced renewable resource that is basically constant in a human timeframe.
2. Geothermal energy is versatile. It can cool and heat through Geothermal HVAC systems, it can produce direct heat for various industries, and it can generate electrical power in Texas.
3. Geothermal energy is considered pollution free and does not contribute to greenhouse heating. Some of the newest binary power plants have no emissions while others emit only 0.3 lb of carbon (CO2) per MWh of electricity generated. This figure compares with 282 lb/MWh of carbon for a natural gas plant and 497 lb/MWh of carbon for a bituminous coal plant (this does not include 'clean coal' approach). Nitrogen oxide emissions, which can combine with hydrocarbon vapors to produce ground-level ozone, are at or close to zero in geothermal power plants and are much lower than fossil fueled power plants.[16]
4. Geothermal power plants have a smaller surface footprint than many conventional power plants, and therefore have less of an impact on the surrounding environment. Other land uses are possible with little interference.
5. Geothermal power plants have a high capacity factor, running 98% of the time, with routine maintenance constituting the primary downtime. They supply baseload electrical power.
6. Geothermal power generation is capable of being a distributed source. Over 600,000 oil and gas wells have been drilled in Texas and are scattered over much of the state, but with distinct high density regions. The advent of smaller (50 kW to 250 kW) binary power plants provides the opportunity for using many of these wells for a distributed system of power generation.
7. Geothermal energy is its own source. No outside sources of energy are necessary to maintain power output, thus making the expenses for the life of the power plant stable regardless of the market demands for the resource as in natural gas and coal.
8. Geothermal energy can be an economic boom for rural areas when oil and gas fields are converted to geothermal electrical power production since similar oil and gas well-related jobs are still needed. Also, by using geothermal waters for Direct Use applications, new businesses are brought into a community as well as tourism with spas and therapy pools.
9. Geothermal HVAC systems typically have lower maintenance than conventional systems, as all of the equipment is installed inside the building or underground. Unoccupied parts of a building can easily be shut down due to the more modular nature of this system.
10. Although the Geothermal HVAC system infrastructure costs are slightly higher, the payback is better in the long run. They have lower operating costs and are far more energy efficient than conventional systems, and the money saved on energy bills usually covers the initial investment in two to ten years.

Key Issues

The price of electricity needs to stay high (over 8 cents per kWh) for geothermal electricity production in Texas to be economically competitive. As it becomes a normal business practice for oil and gas wells with fluid temperatures over 200°F to switch to geothermal electrical production, rather than be plugged and abandoned, then the pricing is expected to decrease along with new technology becoming available. A future carbon tax is a concern for hydrocarbon related companies and they are looking at geothermal as an offset mechanism. Also the ability to use CO2 as a working fluid for heat extraction is currently being researched because of its reduced surface friction and increased heat capacity over water.[44] This would create a geothermal power plant that is carbon negative.

Geothermal electrical power production projects have a different business structure than the oil and gas companies. Oil and gas companies operate on a short-term, quick turnaround time for investment. Geothermal power projects are high in upfront investment and they have long-term paybacks of 10 to 30 years. Another difference is that oil and gas wells often have many leaseholders on a well and even at different depths. Geothermal power companies usually limit the number of investors and mineral right holders because of the long-term structure of the business plan.[50] Therefore, using certain existing oil and gas wells may initially be challenging. In Texas, the Railroad Commission lists geothermal as a separate mineral from oil and gas creating a new royalty for the mineral right owner.

Increased education and marketing concerning geothermal resources for Direct Use and Geothermal HVAC systems are both important in order to give potential users the knowledge that the technologies even exist. Geothermal resources are not easily seen or felt and thus are not a widely known resource. This gives geothermal a disadvantage compared to other resources such as wind, biomass, and solar. As for electricity production, once there are a few geothermal power plants online in Texas producing baseload electricity, the important advantages of geothermal will be enjoyed by both producers and consumers.

Information Sources

Fundamental Data Collection

Few Texas aquifers have been measured specifically to assess their thermal characteristics. Bottom hole temperature measurements have been logged for most oil and gas wells and included on the well headers from the more than 600,000 wells drilled in the state. Although only a small portion of those wells have been examined for current reports, the data is available for others to access if interested in site specific locations. Coupled with the oil and gas data is water well drilling information for community wells, which includes temperature and fluid chemistry. The geopressure studies from the 1970s and 1980s along the Gulf Coast also include data. The resulting geothermal resource evaluation given in this chapter is a summary of all of this information. With the ability to access much data online, only key reports, organizations, and maps have been listed below.

Information Sources

Data Bases and Organizations

In Texas, the Railroad Commission regulates the exploration, development, and production of geothermal energy on public and private land and accordingly keeps files on each geothermal and oil and gas well in the state. The public may access these files which include such forms as the production test and completion report and log, the producer's monthly report of geothermal wells, the monthly geothermal gatherer's report, the producer's certification of compliance and the authority to transport geothermal energy, and the application to inject fluid into reservoirs. (http://www.rrc.state.tx.us).

The SMU Geothermal Laboratory has conducted United States regional and Texas geothermal resource assessments coordinated by David Blackwell and Maria Richards. Both raw data and maps are available online at http://www.smu.edu/geothermal. The Geothermal Resource Assessment for the I35 Corridor East to the state boarder includes new oil and gas data and resource maps available on the SMU Geothermal Lab website and the SECO website.

Research efforts by Swift and Erdlac at the West Texas Earth Resources Institute (WTERI), and later continued by Erdlac at The University of Texas of the Permian Basin Center for Energy and Economic Diversification (UTPB-CEED), produced a 5,000+ well database of over 8,000 temperature-depth points from oil and gas well log headers for the Delaware Basin, the northern part of the Val Verde Basin, and parts of the Trans-Pecos region in Texas. This data was uploaded to the DOE Field Office in Golden, CO and a copy of the data along with an additional report was also provided to the SECO office in Austin in 2006.

The Geo-Heat Center at the Oregon Institute of Technology conducts research and provides assistance to potential users (local governments, geothermal developers, pump manufacturers) of the direct-heat resource base of the country. The Center provides technical and development assistance, research to resolve developmental problems, and distributes educational and promotional materials to stimulate development. Requests for assistance have targeted geothermal heat pumps, space and district heating, greenhouses, aquaculture, industrial, and electric power. (http://geoheat.oit.edu).

International Ground Source Heat Pump Association is a non-profit, member driven organization established in 1987 to advance geothermal heat pump technology on local, state, national and international levels. They host a yearly conference and workshops on designing, installing, drilling, regulations, etc. related to Geothermal HVAC systems. (http://www.igshpa.okstate.edu/)

Geothermal Heat Pump Consortium is the national non-profit trade association for the geothermal heat pump industry. They are a member-driven trade association consisting of manufacturers, architects, engineers, heating and cooling businesses, drilling companies and earth loop installers, and others involved with geothermal heat pump technology. They have case studies and an open forum for people to submit questions. (http://www.geoexchange.org/)

US Dept. of Energy Geothermal Resource Division has information on all three types of geothermal resources located on the Energy Efficiency and Renewable Energy (EERE) website under Geothermal Technologies Program. The EERE works in partnership with the U.S. industry to establish geothermal energy as an economically competitive contributor to the U.S. energy supply. There are reports for many states, including Texas, on their individual resource base. Also basic information shown through animated examples of how geothermal energy is developed, grants, and current news related to geothermal energy. http://www1.eere.energy.gov/geothermal/

The Geothermal Resources Council is an international, non-profit educational association which has yearly meetings, publications and an on-line information system containing material from a variety of sources including a) the Geothermal Power Plant Data Base that covers most geothermal power plants worldwide, b) a U.S. Vendors Data Base which lists companies and contractors who supply goods and services, and c) the Geothermal Resources Council Bulletins dating back to the 1970s. (http://www.geothermal.org)

The Geothermal Education Office (GEO) produces and distributes educational materials about geothermal energy to schools, energy/environmental educators, libraries, industry, and the public. GEO collaborates frequently with education and energy organizations with common goals, and, through its website, responds to requests and questions from around the world. (http://www.geothermal.marin.org).

Information on Texas' Geopressured Resources is available online at http://www.otsi.gov. There are volumes of reports with detailed geology and economics for resource development projects.

The American Association of Petroleum Geologists (AAPG) geothermal database covers North America. This database contains 28,744 bottom hole temperature recordings from oil and gas well log headers covering the United States, Canada, and Mexico collected from 1969 to 1972. The AAPG Bookstore sells a cd-rom with the data titled: DP—AAPG DataRom (CSDE, COSUNA, GSNA), ISBN: 1588611884. They also sell the Geothermal Map of North America (2004) ISBN: 0791815722. (www.aapg.org).

Summary Documents

The list below contains a short set of documents that characterize the geothermal resources of Texas.

The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems on the United States in the 21st Century, Tester, Jefferson, 2006 MIT Report.[39] The report was prepared by an MIT-led interdisciplinary panel, was released to the public January 22, 2007. The report suggests that 100,000 MWe of electrical generation capacity can be met through EGS within 50 years with a modest investment in R&D. There is a table in Chapter 2 with state by state geothermal resource information for various depths. (http://geothermal.inel.gov/)

A Resource Assessment of Geothermal Energy Resources for Converting Deep Gas Wells in Carbonate Strata into Geothermal Extraction Wells: A Permian Basin Evaluation, Erdlac, et al., 2006.[31] This report was the first year of a proposed 3-year study to evaluate the Delaware Basin portion of the larger Permian Basin for its geothermal power generation potential. Project built off of previously conducted investigations and was funded for one year by DOE.

Geopowering Texas: A Report to the Texas State Energy Conservation Office on Developing the Geothermal Energy Resource of Texas, Erdlac, 2006.[32] This report was conducted in tandem with the DOE investigation of the deep Delaware Basin and looked at all aspects of geothermal energy development: Geothermal HVAC, direct use, and power generation. Project was funded by Texas SECO.

West Texas Renewable Energy Strategies: Natural and Human Resources, Erdlac, 2006.[48] This report was funded by the Department of Commerce Economic Development Administration (DOC-EDA) to discuss geothermal, solar, and wind energy in West Texas. The report was designed for the general public to read and included information on how the public could use these resources more directly, the strengths and weaknesses of the resources, and how they might be nested together for mutual benefit.

Factors Affecting Costs of Geothermal Power Development, Hance, 2005.[50] This report discusses in detail the various costs of developing a geothermal power plant. From the beginning steps in exploration to the financing of the long term loan after a power purchase agreement has been set, it gives details and equations to help individuals work through what is needed for development.

Geothermal Resource Assessment for the State of Texas, Woodruff, et al. 1982.[18] From well data and remotely sensed lineaments, this report analyzed and interpreted the hydrothermal/geothermal data to the year 1980.

Geothermal Resource of Texas (Map), Woodruff, 1982.[19] A concise but thorough summary of Texas hydrothermal and geopressured resources on a single full color map (scale 1:1,000,000).

Geopressured Geothermal Energy: Proceedings of the Sixth U.S. Gulf Coast Geopressured Geothermal Energy Conference, Dorfman and Morton, 1985.[14] This compendium of papers presented to a 1985 geopressured/geothermal conference held in Austin, Texas, included topics on the production characteristics of design wells, the deformation history of geopressured sediments, the detection of microseismic events, the anomalous occurrences of liquid hydrocarbons in geothermal brines, and the transfer of technology to improve recovery from gas reservoirs.

Texas: Basic Data for Thermal Springs and Wells as Recorded in Geotherm, Bliss, 1983.[46] This compilation of the information stored in the database geotherm includes thermal wells and springs by county, location by latitude and longitude, well depth, water temperature, and aquifer. This is available on the SMU Geothermal Lab website.

Assessment of Geothermal Resources of the United States—1978, Geological Survey Circular 790, Muffler, 1979.[45] This circular is the most comprehensive assessment performed by the USGS in evaluating the nation's geothermal resources.

Low-Temperature Geothermal Resources in the Western United States, Mariner, 1983.[47] This article identified the resources of the Western U.S., including the Rio Grande Rift province of West Texas.

The Xerolithic Geothermal ("Hot Dry Rock") Energy Resource of the United States: An Update, Nunz, 1993.[38] This report presents revised estimates, based on the most current geothermal gradient data, of the hot dry rock energy resources of the United States. A tabulation of the Texas HDR resource is included in the state-by-state listings. The report also includes a color contour map of mean geothermal gradient for the United States.

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Chapter 8

END-USE ENERGY EFFICIENCY

Executive Summary

Energy efficiency can be viewed as an energy resource, since the need for supply-side energy resources can be displaced by the adoption of more efficient equipment at homes and businesses or through changes in energy consumption patterns or practices.

Avoiding the consumption of energy through energy efficiency measures provides a clean energy resource that is immediately available. There is abundant energy savings potential available at a low cost through energy efficiency measures in all economic sectors in Texas.

Some energy efficiency will arise naturally in response to high fuel prices and concerns about air pollution and climate change. Further energy efficiency can be realized through public education efforts, commitments to sustainable development and climate change mitigation by businesses and other organizations, more stringent building codes, accelerated research and deployment of new technologies, utility demand-side management programs, and equipment efficiency standards.

Introduction

Definitions vary, but energy efficiency tends to be associated with the concept of using less energy to perform the same task through technology-based measures. By using more efficient equipment, the same output may often be obtained with fewer energy inputs. Whether behavioral or operational changes may be regarded as a form of energy efficiency is sometimes debated.

While we shall adhere to the more common engineering definition of energy efficiency in this chapter, it may be noted that economists tend to define energy efficiency much differently — as the level of energy usage associated with performing a task at a minimum cost.[1] Under this definition, technologies that use more physical units of energy (e.g., British thermal units, barrels of oil equivalent, etc.) may nonetheless be regarded as energy efficient if they are less expensive. For example, the substitution of electrical microwave drying equipment for natural gas-fueled product drying equipment at a manufacturing facility might require greater energy inputs (either in terms of BTUs or cost), but — under the economists' definition — might nonetheless be regarded as an energy efficient process if it performed the drying function at a lower total cost, by speeding the drying process, improving the quality of the product, and/or reducing product defects.

Conservation, demand response, and demand-side management are related concepts. Energy conservation tends to refer to simply using less energy. Demand response refers to changes in the temporal pattern of energy use through pricing programs (e.g., real-time pricing, interruptible tariffs, and time-of-use pricing) and load control programs (e.g., direct control of air conditioning equipment or the installation of under-frequency relays on industrial facilities). Demand response programs do not necessarily lower the overall consumption of energy. When energy efficiency, conservation, and demand response initiatives are undertaken by electric or natural gas distribution or retail utilities, such programs are often referred to as demand-side management.

Unlike renewable energy, energy efficiency is not a source of energy supply. However, it may provide similar benefits or may be regarded as an alternative to greater supply. Both renewable energy and energy efficiency are seen as ways to address the economic, national security, and environmental challenges associated with meeting the growing world demand for energy resources. Further, the combination of the two can be combined into a robust and effective sustainable energy strategy due to their complementary temporal, economic, and geographic characteristics.[2] The relationship is close enough that the small-scale generation of energy supplies through renewable energy technologies on the customer side of the meter (e.g., photovoltaic systems and solar water heaters) qualifies as an energy efficiency measure under the rules of the Public Utility Commission of Texas (PUCT) and is promoted through utility energy efficiency programs.

In the aftermath of the oil price shocks of the 1970s, federal and state policies to promote energy efficiency were devised. National programs (e.g., the Weatherization Assistance Program) were launched by the U.S. Department of Energy (DOE) to reduce wasteful energy consumption in homes and other buildings. Corporate Average Fuel Economy (CAFE) standards were established for automobiles. National research laboratories turned their attention to resolving the nation's energy crisis. Utilities were required to establish demand-side management programs to promote the adoption of energy efficient technologies and practices. Through the integrated resource planning (IRP) rules adopted in many states, utilities were required to treat demand-side resources on the same basis as supply-side resources in their resource plans. Solicitations were conducted for the procurement of demand-side resources from energy services companies.

While interest in energy efficiency faded in the 1980s and early 1990s as a result of lower energy prices and confusion over which entities might be responsible for continuing demand-side management programs, as retail electricity markets have become more competitive, interest in energy efficiency has climbed to new heights. The prices of some traditional energy resources are now at record levels. The use and production of fossil fuel energy resources has been linked to climate change. America's imports of crude oil remain at high levels.

In July 2006, the DOE and Environmental Protection Agency (EPA) jointly released a National Action Plan for Energy Efficiency, with the goal of "creat[ing] a sustainable, aggressive national commitment to energy efficiency." The action plan embodies the notion of treating increased efficiency as an energy resource; indeed, the first recommendation in the plan is for the U.S. to "recognize energy efficiency as a high-priority energy resource."[3] A long list of recent federal and state policy initiatives have sought to promote energy efficiency.

Market imperfections are thought to be responsible for the failure of consumers to achieve an optimal level of energy efficiency. Such failures may include a lack of information about cost-effective energy efficiency opportunities and new technologies, and a divergence in interests among various parties to economic transactions. For example, the economic interests of homebuilders and future homeowners may not be well aligned. Builders may have an interest to focus on minimizing the cost of construction, and grant inadequate attention to the comfort and energy costs of future residents. Similarly, landlords may pay inadequate attention to tenants' utility bills. If appropriate regulatory mechanisms are not put in place, utilities have little financial interest to reduce their sales and revenues through energy efficiency programs. Consequently, policies and programs to promote energy efficiency tend to focus on financial subsidies to offset the higher initial cost of energy efficient equipment, regulatory reforms to ensure that interests are better aligned, educational campaigns, the transformation of markets for energy-intensive equipment, building construction codes, and equipment efficiency standards.

Energy efficiency efforts since the 1970s have had an effect. The U.S. economy has grown significantly more energy-efficient. A recent report from the American Council for an Energy-Efficient Economy (ACEEE) notes that, by the end of 2008, U.S. energy consumption (as measured per dollar of economic output) will have been slashed to half of what it was in 1970 (from 18,000 Btus to about 8,900 Btus[4]), although changes in the structure of the American economy accounts for some of this decline. A recent study has concluded that states with aggressive energy efficiency efforts have reduced their rate of growth in electricity demand by about 60 percent, relative to the growth that would have occurred absent such programs.[5] Another recent study found evidence that states with strong commitments to energy efficiency successfully reduced commercial and industrial electricity intensity, although gains in the residential sector were not apparent.[6] Efficiency gains in transportation have been impressive. The National Academy of Sciences and the U.S. Department of Transportation concluded that CAFE standards "clearly contributed to increased fuel economy of the nation's light-duty vehicle fleet," and that in their absence, gasoline use would have been "about 2.8 million barrels per day greater than it is" [in 2001].[7] A new index from the DOE suggests that energy intensity in the U.S. dropped by 10 percent from 1985 to 2004, with the greatest gains occurring in the industrial sector.[8] However, there is some evidence that these figures may overstate energy efficiency achievements.[9]

Over the past few decades, Texas has been developing the policies, rules, programs, and infrastructure to more effectively exploit the state's vast potential for additional energy efficiency. Statewide building construction energy codes have been adopted. Goals for peak demand reduction from energy efficiency programs administered by the state's investor-owned electric utilities have been established and achieved. Goals for energy efficiency have been established for political subdivisions (e.g., government facilities) in the areas of the state that are in "non-attainment" or "near-non-attainment" status relative to federal air quality standards. Research at our state's universities has resulted in significant advances in energy efficiency. New firms have been established to develop, manufacture, and market the latest lighting, window, and energy storage technologies. An infrastructure for rating the energy efficiency of new homes and for conducting energy audits has also been developed.

Despite our state's achievements, there remains a vast untapped potential for energy efficiency in Texas. This chapter characterizes the state's energy efficiency resource base, describes existing programs and policies, delineates some key issues, and suggests means of advancing the efficient use of energy in Texas, the nation's largest energy consumer.

Resource

The quantification of energy efficiency potential is typically performed by comparing the actual level of energy consumption to the level that would result if all consumers adopted more efficient technologies.[10] "Technical potential" represents the savings that are possible regardless of the cost of energy efficiency measures. This may be calculated on an instantaneous (assuming that all equipment is immediately replaced with more efficient equipment) or phase-in basis (assuming that equipment is replaced with the most efficient equipment readily available in the marketplace at the end of the useful life or "burnout" of the existing equipment). "Economic potential" refers to the share of the technical potential that can be achieved under reasonable economic payback periods. Estimates of economic potential are sensitive to assumptions made about consumer payback periods or discount rates. Conservation supply curves may be used to depict economic potential. Finally, the "market potential" provides an estimate of the energy efficiency savings that can reasonably be expected from utility programs and other types of voluntary programs and policies.

Eleven studies examined by researchers at the ACEEE suggest that very substantial technical, economic, and achievable energy efficiency potential remains available in the U.S.[11] Across all sectors, these studies show a median technical potential of 33 percent for electricity (i.e., electricity usage could be reduced by one-third) and 40 percent for natural gas. Median economic potentials for electricity and gas are 20 percent and 22 percent respectively. The median achievable potential is 24 percent for electricity (an average of 1.2% per year) and 9 percent for gas (an average of 0.5% per year).

The Western Governors Association Energy Efficiency Task Force concluded that it is feasible to reduce electricity use in the western U.S. by 20 percent from projected levels by 2030 through best practices and programs.[12] McKinsey Global Institute suggests that the global growth in energy demand could be cut in half over the next 15 years from energy efficiency projects with an internal rate of return of 10 percent or more.[13]

The American Solar Energy Society (ASES) has sought to estimate the size of the energy efficiency industry in the U.S. This is a challenging task, since it is difficult to assign the portion of housing costs, appliance costs, jobs, and business activities that are clearly devoted exclusively to promoting energy efficiency. By ASES' count, the energy efficiency industry was responsible for $932.6 billion in revenues and 3.5 million jobs in the U.S. in 2006. These numbers reflect a wide variety of business, non-profit, and government-related activities. The vast majority of revenue and jobs created were through private industries, predominantly manufacturing and recycling related businesses.[14]

Achievable energy efficiency potential might best be gauged by examining the accomplishments of aggressive programs and policies across the country, although differences in climate, building stock, industrial base, and energy prices must be taken into consideration when considering the savings that might be achievable in a particular region. The National Action Plan for Energy Efficiency reports that energy efficiency programs are realizing significant energy savings in California and parts of the northeast U.S. Savings "on the order of 1 percent of electricity and natural gas sales" are "helping to offset 20 to 50 percent of expected growth in energy demand in some areas."[15]

Where are these opportunities to reduce energy use without lowering our standard of living? Our homes and commercial buildings can be constructed with materials that reduce air infiltration. Higher efficiency motors, air conditioners, and appliances can be used. Industrial processes can be redesigned to reuse what would otherwise be waste heat. Greater attention could be paid to energy costs when considering operating and maintenance practices. Some examples of energy efficiency opportunities are listed in **Exhibit 8-1**.

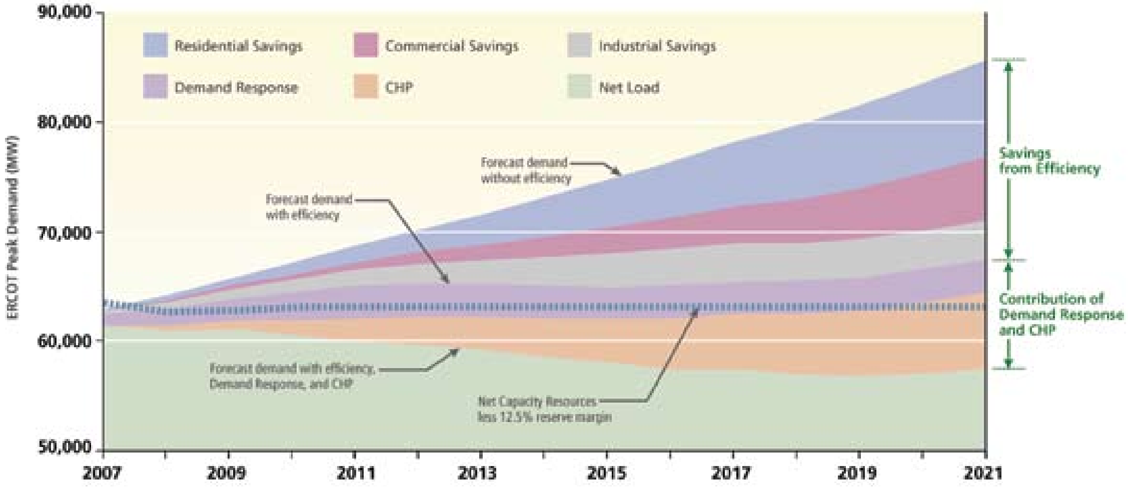
Two reports were sponsored by environmental groups in 2007 in an attempt to quantify the demand for energy that can be offset by implementation of advanced energy efficiency measures in Texas. The first, entitled *Power to Save: An Alternative Path to Meet Electric Needs in Texas*,[16] was prepared by Optimal Energy for the nonprofit groups National Resources Defense Council and Ceres. In this report, Optimal Energy reviewed the opportunities for implementing programs targeting residential and commercial customers with subsidies to participate in centralized demand reduction strategies, and posits that "ambitious energy efficiency actions can, over the next 15 years, eliminate over 80% of forecasted electric load growth at costs substantially cheaper than new electric supply." *Power to Save* also pointed to a vast (20,000 MW) potential for combined heat and power (CHP) in Texas, indicating that industrial users could use this method to generate both electricity and useful heat energy for use at their own facilities, thereby reducing their need to purchase power from a utility.[17]

Exhibit 8-1 Some Common Energy Efficiency Measures (Residential, Industrial, and Commercial)

RESIDENTIAL	
End Use or Category	Description
Weatherization	Apply caulk and weatherstripping.
HVAC and Geothermal Heat Pumps (GHPs)	Install more efficient air conditioning and space cooling equipment
Lighting	Install compact fluorescent or light emitting diode bulbs in lieu of incandescent bulbs
Appliances	Install Energy Star rated appliances in lieu of standard efficiency equipment
New Home Construction	Build new homes to Energy Star levels of efficiency
Envelope	Install spectrally-selective low-emissivity windows, reflective roofing, radiant barriers
Green Building	Adopt green building principles, leading to lower energy costs, lower water consumption, better indoor air quality, and other benefits
Photovoltaic Cells and Solar Water Heating	Reduce some electricity purchases with on-site electricity generation or water heating from solar technologies

INDUSTRIAL	
End Use or Category	Description
Pumps	Install more-efficient pumps and ensure that pumps are properly sized
Compressed Air Leaks	Eliminate leaks in compressed air equipment
Motors	Install high efficiency motors and use variable speed drives, where applicable
HVAC	Install more efficient air conditioning and space cooling equipment
Lighting	Upgrade lighting systems
Process Optimization	Ensure that the overall industrial process is designed and operated in an efficient manner
Pinch Technology	Ensure that sources and uses of heat in an industrial process are properly matched
Combined Heat and Power	Use waste heat from an industrial process for electricity generation, where applicable
Transportation	
Hybrid and Plug-in Hybrids	
Electric and Fuel Cell Vehicles	

EXHIBIT 8-2 Effect of Efficiency, Demand Response and CHP on Demand Forecasts



Source: Natural Resources Defense Council and Ceres, *Power to Save: An Alternative Path to Meet Electric Needs in Texas*, by Optimal Energy, Inc. (January 2007), http://www.ceres.org/pub/docs/Ceres_texas_power.pdf (Last visited July 18, 2007.)

COMMERCIAL	
End Use or Category	Description
HVAC and GHPs	Install more efficient air conditioning and space cooling equipment
Envelope	Install spectrally-selective low-emissivity windows, reflective roofing, radiant barriers
Lighting	Upgrade lighting systems
Office Equipment	Purchase Energy Star rated office equipment
Commissioning and Retrocommissioning	Use energy control systems more effectively
Photovoltaic Cells	Reduce some electricity purchases with on-site electricity generation from solar technologies

The second report, published by the American Council for an Energy-Efficient Economy (ACEEE) in March of 2007, is entitled, *Potential for Energy Efficiency, Demand Response, and Onsite Renewable Energy to Meet Texas' Growing Electricity Needs*.[18]

The ACEEE study proposed a series of nine "effective and politically viable" policies, two-thirds of them concerning energy efficiency, to reduce energy consumption and demand growth over the next 15 years. Some of these proposals echo and expand upon the recommendations in *Power to Save*, such as expanding utility energy efficiency programs; setting additional standards for electric appliances and equipment; and drafting more stringent building codes. In addition, the report proposes initiating an additional energy efficiency program for homes and commercial buildings; a state and municipal buildings efficiency program; and a market transformation initiative consisting of a series of short-term programs to educate the public on energy efficiency and offer rebates on energy efficient products.

ACEEE asserted that if its policies (including those concerning demand response, CHP and on-site renewable energy) are implemented, "Texas can meet its summer peak demand needs without any additional coal-fired power plants or other conventional generation resources." ACEEE also asserts that its energy-saving policies "would meet 8% of Texas's electricity consumption in 2013 and 22% in 2023." Thirty percent of the projected energy savings would come from utility efficiency programs; 30 percent from improved CHP policies; 22 percent from appliance standards and building-related programs; and the remainder from on-site renewable energy projects.[19]

Under the requirements of HB 3693 (2007 legislative session), the PUCT is presently commissioning a more in-depth assessment of the state's energy efficiency potential. The results of this study are expected to be released by the end of 2008.

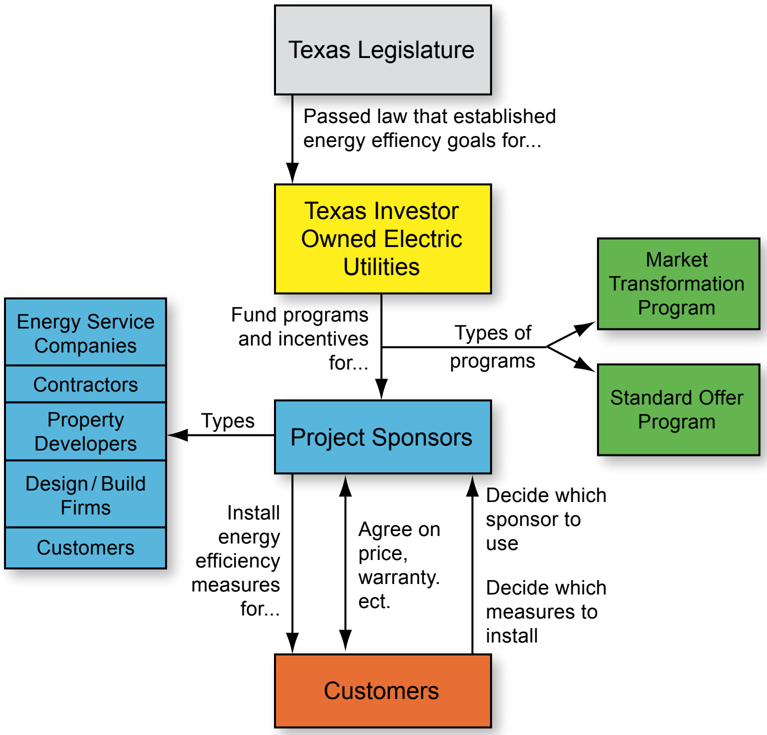
Exhibit 8-3 Examples of Energy Efficiency Strategies for Exploiting Energy Efficiency Opportunities

Opportunity	Strategies and Examples
New Home Construction	More stringent building construction code. Voluntary programs for home builders: • Austin Energy's Green Building program • Energy Star New Home program developed by the US EPA and implemented by many of the Texas' investor-owned electric utilities
Improve Performance of existing residential dwellings	Standard Offer programs: • Programs administered by the state's investor-owned electric utilities to provide financial subsidies to energy services companies and other organizations who perform weatherization activities. Energy audits Proposed programs to provide homebuyers with greater information about the energy performance of homes being sold. For low-income families, the federal Weatherization Assistance Program and its implementation through the Texas Department of Housing and Community Affairs
HVAC	Rebate programs (e.g., Austin Energy's program) Improve installation practices of equipment installers (e.g., Oncor's AC Installer Training program). Education about GHPs, programs of municipal community purchase and leasing of ground loops. Encourage AC distributors to stock more efficient equipment (e.g., Oncor's AC Distributor market transformation program).
Lighting	Buy down programs for compact fluorescent (CFL) bulbs The Mayors' Challenge program (organized by Environmental Defense and involving the mayors of the state's four largest cities). CFL give-away programs in lower-income neighborhoods (e.g., Houston in summer 2008).
Photovoltaic Cells	Federal tax credits. Rebate programs (e.g., Austin Energy) Net metering policies that permit consumers to receive a payment or credit for solar power injected into the grid. PV installer training programs.
Hybrid, Plug-in Hybrid, and electric vehicles	Federal tax credits. Greater access to HOV lanes on highways.

Utilization of the Resource

Utilization of Texas' energy efficiency resource involves tapping into the state's vast potential for energy efficiency improvements through utility energy efficiency programs, policy actions, government programs, university research, and innovations from the private sector. Policies and programs to promote energy efficiency may employ a variety of strategies. Financial rebates or tax credits may be offered to encourage consumers to purchase more energy efficient equipment. Building energy codes or appliance efficiency standards may be imposed by governments. Educational campaigns or training programs may be offered. Interventions may be undertaken at different levels of the supply chain for products and services. Some example strategies are outlined in **Exhibit 8-3**.

Exhibit 8-4 Overview of Texas Energy Efficiency Programs



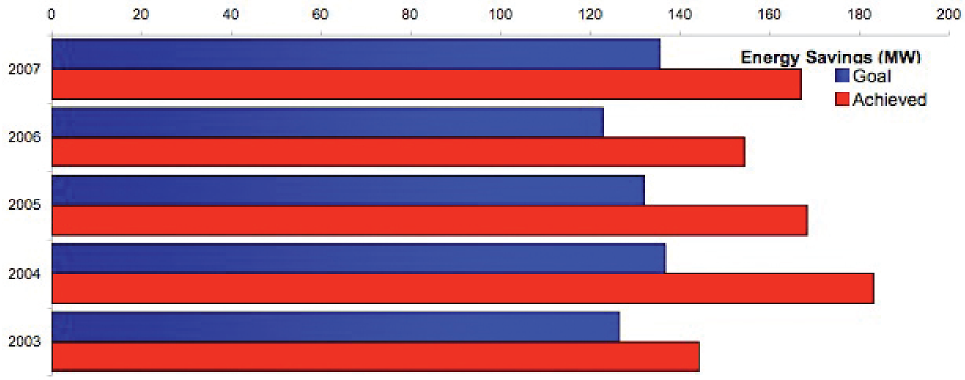
Source: Frontier Associates LLC. *Energy Efficiency Accomplishments of Texas Investor Owned Utilities*. June 16, 2008.

The energy efficiency programs administered by the state's investor-owned utilities have proven to be a particularly effective source of energy efficiency improvements. A goal for energy efficiency in Texas was initially established by legislation that opened portions of the state to retail competition for electricity – Senate Bill 7 in 1999. Under Section 39.905 of the Public Utility Regulatory Act, investor-owned utilities in Texas are responsible for administering various energy efficiency programs, while the competitive market for energy services works directly with energy consumers to implement qualifying energy efficiency measures. "Project sponsors" may include energy services companies, homebuilders, and consulting firms. The program structure is depicted in **Exhibit 8-4**. On a statewide basis, these programs have consistently exceeded their goals of meeting 10 percent of the projected growth in electrical demand through energy efficiency, as noted in **Exhibit 8-5**. Program goals for energy efficiency were changed through HB 3693 during the 2007 legislative session.

The state's larger municipal utility systems (e.g., Austin Energy and CPS in San Antonio) also offer a variety of innovative energy efficiency programs.

A number of successful public sector energy efficiency projects conducted outside of utility programs have demonstrated the potential savings that can be achieved through building commissioning, which involves the optimization of building systems including the HVAC system. One noteworthy example of a successful project is the Energy Conservation Program at Texas A&M University.

Exhibit 8-5 Total Energy Savings by IOUs, 2003-2007



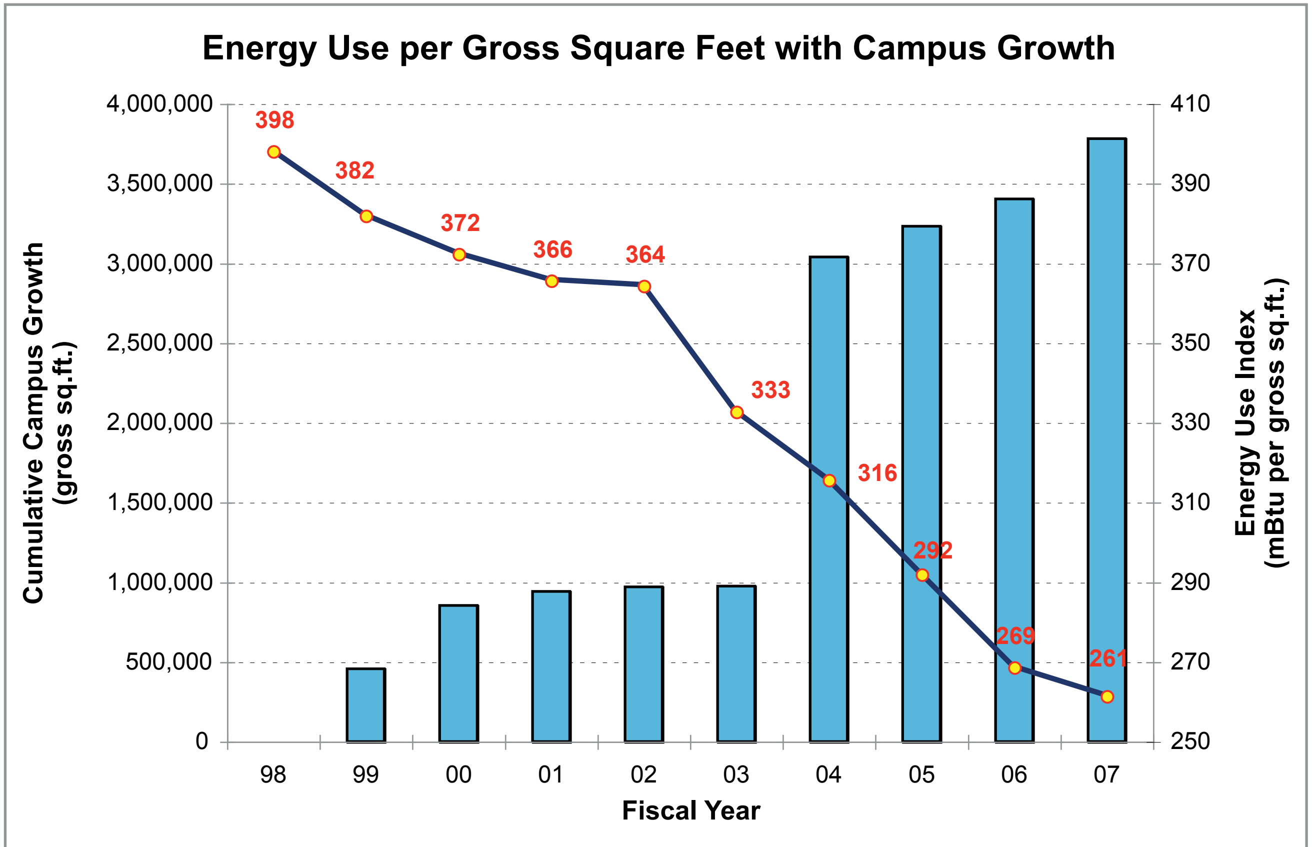
Source: Frontier Associates LLC. *Energy Efficiency Accomplishments of Texas Investor Owned Utilities*. June 16, 2008.

Texas A&M University – College Station, Texas

Total Area Covered to date	**8,100,000 sq.ft.**
Project Cost to date	**$ 8,300,000**
Total Measured Savings to date	**$ 53,700,000**
Average Annual Savings	**$ 4,500,000**

With over 46,000 students, Texas A&M University has one of the largest student bodies in the United States. The main campus covers over one square mile, and is densely packed with buildings. The newer West Campus also has a large area but fewer buildings. With over 190 large buildings and over 18 million square feet of conditioned facilities, utility cost represented a major expense to the university in the 1990s. The Physical Plant Department spearheaded the Energy Conservation program, which was developed to fully manage resources from the Energy Systems Lab (ESL) of Texas Engineering Experiment Station (TEES) to help control these large utility costs.

Exhibit 8-6 Energy Use per Gross Square Feet with Campus Growth



Note: EUI in mBtu per GSF is based on Source (rather than Site) consumption, with a heat rate of 8,100 Btu per kWh.

Exhibit 8-7 Energy Conservation Standards

Name	Description
ASHRAE *Advanced Energy Design Guides* (AEDG)[1]	A series of publications designed to provide recommendations for achieving energy savings over the minimum code requirements of ASHRAE Standard 90.1-1999 Initial series of guides have an energy savings target of 30% which is the first step in the process toward achieving a net zero energy building Each 30% Guide addresses a specific building type
ASHRAE Standard 90.1-1999[2]	Energy Conservation Standard, established in 1999 Provides the fixed reference point for all of the 30% Guides in the Design Guide series Maintains a consistent baseline and scale for all of the 30% AEDG series documents
ASHRAE Standard 90.1-2010[3]	Incorporates goal to achieve 30% energy savings in the 2010 standard compared to ASHRAE Standard 90.1-2004 Savings obtained are part of ASHRAE's goal to achieve market-viable net-zero energy buildings by 2030
ASHRAE Standard 189P: Sustainable Buildings Standard to Define Green Buildings[4]	Proposed new standard that will provide minimum guidelines for green building. Addresses energy efficiency, a building's impact on the atmosphere, sustainable sites, water use efficiency, materials and resources, and indoor environmental quality for commercial buildings and major renovation projects Compilation of criteria that must be met in order for local building code officials to provide a Certificate of Occupancy for a facility Goal is to achieve a minimum of 30% reduction in energy cost (and carbon dioxide equivalent) over that in ASHRAE Standard 90.1-2007 First such green building standard in the United States

The state-of-the-art Continuous Commissioning® (CC®) process developed by the Energy Systems Laboratory has been applied as part of the campus program. CC® emerged from a program of implementing operational and maintenance improvements. CC® identifies and implements optimal operating strategies for buildings as they are actually being used rather than as the design intended. The DDC (Direct Digital Control) system and network on the TAMU campus, together with CC®, have become a powerful and effective tool for reducing energy use.

As of December 31, 2007, the CC® process has been applied to more than 80 buildings and all five central utilities plants on the Texas A&M campus resulting in substantial improvements to the operation of the buildings and plants. Dedicated CC® teams carry out daily operational optimization measures on the central chilled water and hot water distribution loops, the central plants and the campus buildings. Thus far, cumulative measured chilled water, hot water, and electricity savings achieved from Continuous Commissioning® on the Texas A&M campus have exceeded $50 million. CC® costs to date have been approximately $8.3 million.

The Texas LoanSTAR (loans to **S**ave **T**axes **A**nd **R**esources) Program is a highly successful energy efficiency program established by the State to help fund energy retrofits for public buildings. LoneSTAR uses a revolving loan mechanism which will allow it to continue indefinitely and benefit generations of future Texans. The program was initiated by the Texas Energy Office in 1988 and approved by the DOE as a statewide energy efficiency demonstration program. The quality control on all phases of LoanSTAR has made it one of the most successful and best-documented building energy efficiency programs, state or federal, in the United States. As of November 2007, LoanSTAR has funded a total of 191 loans totaling over $240 million dollars. As a result of these loans, the LoanSTAR Program has achieved total cumulative energy savings of over $212 million dollars, which result in direct savings to Texas taxpayers.[20]

The source of funding for LoanSTAR is petroleum violation escrow funds (PVE) received from the federal government. LoanSTAR is unique in a number of ways (including the acronym for its name, since its origins are in the Lone Star State). The size, $98.6 million, makes it the largest state-run building energy conservation program in the United States. The loans are targeted for public buildings, including state agencies, school districts, higher education, local governments and hospitals.[21]

The state's adoption of minimum building energy codes in 2001 pursuant to Senate Bill 5 was a key step toward improving the energy performance of new homes and commercial buildings. The International Energy Conservation Code was adopted for residential construction, while the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-1999 was adopted for new commercial structures. SB 5 has produced total annual electricity savings (2006) of 498,582 MWh/yr which includes 393,069 MWh/yr (78.8%) for single-family residential; 15,956 MWh/yr (3.2%) for multi-family residential; and 89,557 MWh/yr (18.0%) for new commercial buildings. Natural gas savings were calculated to be 576,680 MBtu for new residential and commercial construction.

Several organizations have joined forces to develop a series of reports providing information on how to obtain energy savings beyond the minimum codes adopted by the state. **Exhibit 8-7** provides a brief description of these design guides and lists new and proposed energy conservation standards.

Some areas of Texas (e.g., the City of Frisco) have adopted building codes that exceed the minimum standards adopted by the state. The cities of Houston and Dallas are actively considering stronger codes. Austin is home to the nation's oldest and largest voluntary "green building" program, which seeks to promote energy efficiency in addition to water conservation, the utilization of recycled building materials, improved indoor air quality, and other goals.

A new program developed by Texas Home Energy Raters Organization (Texas HERO) seeks to identify savings opportunities in existing residential dwellings through energy audits. The Center for the Commercialization of Electric Technologies seeks to commercialize a variety of advanced electric technologies to improve energy efficiency, grid security, economic development, and other goals.

The Energy Systems Laboratory at Texas A&M University has developed recommendations for achieving "15 percent above code" energy performance for single-family residences and commercial office buildings complying with ASHRAE Standard 90.1-1999 based on studies investigating the best mixture of measures to produce maximum energy reductions. For residential homes, the study found that for an electric/gas house, solar domestic hot water (DHW) systems and tankless water heaters resulted in 15.2 percent and 9.3 percent energy savings respectively, followed by 8.5 percent savings from moving HVAC units and ductwork into the conditioned space. Similarly, for an all-electric house, solar DHW systems resulted in 10.9 percent energy savings, followed by 8.7 percent savings from moving HVAC units and ductwork into the conditioned space.[22] For commercial buildings, results showed that reducing lighting loads and implementing occupancy sensors were the most effective individual measures for both electric/gas and all-electric buildings. Combining lowering the glazing U factor and lighting loads proved to be the two most effective strategies for the electric/gas building with savings of up to 20 percent. For the all-electric building, the combination of implementing occupancy sensors and resetting the cold deck from a constant to a variable setting (55F to 60:55F; 55:85F) to improve the performance of the cooling system proved to be most effective with savings up to 20 percent.[23]

Energy efficiency programs have also been established by private organizations and the government (at federal, state, and local levels) in an attempt to conserve energy, reduce greenhouse gas emissions and save money through a combination of efficiency measures. The 2030 Challenge, the Western Governors' Association Clean and Diversified Energy Initiative, and the Energy Independence and Security Act of 2007 are three relatively new initiatives that incorporate efficiency measures as a means to achieve energy saving goals. In addition, the State of Maryland and the City of Austin, Texas have enacted progressive measures to decrease their energy usage over the next few decades, with other states and regions following suit. **Exhibit 8-8** lists these programs, denoting the players involved, overall objectives, and the energy efficiency strategies identified to meet specified goals.

Exhibit 8-8 Energy Efficiency Initiatives

PROGRAMS		
Name	Parties Involved	Goal
2030 Challenge[5]	Architecture 2030 (non-profit organization and creator of program). As of May 2008, 17 organizations/companies have joined in Texas alone. • Numerous organizations and individuals including: The American Institute of Architects (AIA), US Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED), American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), State of New Mexico, etc.	Overall objective: To have “all new buildings and major renovations reduce their fossil-fuel GHG-emitting consumption by 50% by 2010, incrementally increasing the reduction for new buildings to carbon neutral by 2030”. To accomplish this, Architecture 2030 has issued **The 2030 Challenge** asking the global architecture and building community to adopt the following targets: • New construction must meet a fossil fuel, GHG-emitting, energy consumption performance standard of 50% of the regional average annual energy use for the specific building type and an equal amount of existing areas should be renovated in the same manner annually • The fossil fuel reduction standard for all new buildings shall be increased by 10% each year through 2025, ultimately being carbon-neutral by 2030
Clean and Diversified Energy Initiative (CDEi)[6]	Western Governors’ Association	Overall goal to encourage Western regions to “move toward a cleaner more diverse energy future” by identifying changes in state and local policies to achieve: • A 20% increase in energy efficiency by 2020 • Adequate transmission capacity for the region over the next 25 years • 30,000 megawatts of new clean and diverse energy generation by 2015 Specific energy efficiency measures include implementing electricity energy efficiency programs, more stringent building codes, and minimum efficiency standards for appliances. In addition, it encourages the use of financial subsidies and pricing policies to encourage a reduction in energy use, thereby increasing efficiency.
Energy Independence and Security Act of 2007[7]	Federal Government (Executive Order)	Includes provisions to improve energy efficiency in lighting and appliances, as well as requirements for federal agency efficiency and renewable energy use that will help reduce greenhouse gas emissions. Specific efficiency measures include: • Requiring all general purpose lighting in federal buildings to use Energy Star® products or products designated under the Energy Department’s Federal Energy Management Program (FEMP) by the end of FY 2013. • Establishing new appliance efficiency standards • Creating an Office of High-Performance Green Buildings

STATE/CITY INITIATIVES		
Name	Responsible Agency	Goals
EmPOWER Maryland[8]	Maryland Energy Administration	Reduce energy consumption by 15% by the year 2015. Plan to accomplish this through the implementation of seven steps: 1. Improve building operations 2. Expand use of energy performance contracting 3. Increase state agency loan program 4. Require energy efficient buildings 5. Purchase Energy Star products 6. Expand community energy loan program 7. Ensure accountability
Austin Climate Protection Plan (Texas)[9]	City of Austin	Aggressive plan to reduce greenhouse gas emissions through the implementation of 5 distinct plans including utility and building plans that directly incorporate the following efficiency measures: **Utility Plan:** • Save 700 MW of energy through conservation/efficiency measures by 2020 **Homes and Buildings Plan:** Build all single-family homes to be zero net-energy capable by 2015 • Increase efficiency in all other new construction by 75% by 2015

Residential: Jim Sargent's Zero-Energy Home

Jim Sargent of Anderson-Sargent Custom Builder is leading the way in energy efficient homes for the North Texas area. In 2004 he joined forces with Building America to build a "first-of-its-kind Zero Energy Home" at Lone Star Ranch in Frisco, Texas. With a goal of building a home that consumes less energy than it can produce through renewable energy systems, Sargent and team constructed an energy efficient design plan that addressed durability, indoor environmental quality, water efficiency, and occupant comfort.[24]

All major systems of the house are integrated in order to maximize energy efficiency. The architectural design integrates function without sacrificing the aesthetic beauty of the home. Strategically placed windows and overhangs help the house stay cool in the summer and warm in the winter, foam insulation in the floor prevents heat loss, and the vented, reflective metal roof all work together to make the home as efficient as possible. Appliances and lighting are another key aspect of the house; energy efficient clothes washers and dishwashers save both energy (42% and 25%, respectively) and water (59% and 44%, respectively) compared to standard appliances, and the fluorescent lighting installed throughout the home helps reduce overall energy consumption. In addition, photovoltaics installed on the roof along with a solar water heater provide the renewable energy the house requires to maintain its zero-energy status. Together the integrated systems work seamlessly, reducing overall annual energy consumption by 45 percent compared to a conventional home of similar size. The zero-energy home comes with a price tag of about $1 million dollars; although this is not feasible in many circumstances, Sargent and team hope the project will provide an example of what houses could be like, and help people to integrate some of the energy efficiency measures into their own homes.[25]

Exhibit 8-9 Robert E. Johnson building designed to be a sustainable project with numerous Energy Conservation Design Measures (ECDMs)

Source: Suwon Song "Development of New Methodologies for Evaluating the Energy Performance of New Commercial Buildings", Department of Architecture, Now Research Professor, Yonsei University, South Korea.

Commercial: Robert E. Johnson Building

The Robert E. Johnson building is one of the first State of Texas office buildings built with an emphasis on high performance. It is a six-story, 303,389 ft^2 office building for State legislative support staff, which includes a large print shop and data processing center. The building was designed to be a sustainable project with numerous Energy Conservation Design Measures (ECDMs) designed to make the building more efficient than prevailing building code (i.e., ASHRAE Standard 90.1-1989). The building contains over 50 percent windows in the façade consisting of two types of low-e glazing. Deciduous live oak trees shade a significant portion of the south façade up to approximately the 3rd floor. Calibrated simulation was used to show that the building was 20.79% more efficient than the prevailing building codes due to its high efficiency windows, efficient heating and cooling systems (i.e., chillers, boilers, air handling units, pumps and cooling towers).[26],[27]

Economics

When exploring the economics of energy efficiency measures or programs, it is quite common to consider the costs and benefits from a variety of perspectives, including the consumer's, the utility's (if the measure might be promoted through a utility program), and the impacts of the measure on energy rates (if the measure could potentially affect the utility's revenues and consequently its cost and rate structure).[28] A total resource cost test seeks to combine each of these perspectives. A societal test might be employed if externalities, or other indirect costs, and benefits are thought to be worthy of consideration. Since programs to foster energy efficiency often involve subsidies, developing an awareness of the distributional impacts of the costs and benefits of a program may be important.

Because the range of energy efficiency measures and strategies has no limit, it is not feasible to fully characterize all of their costs and payback periods.

Key Issues

As noted earlier, there may be a variety of impediments to achieving an optimal level of energy efficiency. The availability of energy efficient products may be limited. Consumers may be unaware of opportunities to reduce their energy consumption and cost. Lower-income families may lack the capital to purchase premium-priced energy efficient products. Consumers may be unaware of the attractive payback periods associated with energy efficiency investments. The interests of landlords and tenants may diverge with respect to energy efficiency investments. Similarly, homebuilders and homeowners may have divergent interests. The environmental costs associated with energy use may not be adequately reflected in energy prices, leading to over-consumption of energy resources. In order to promote energy efficiency, policies and programs must be designed to effectively overcome these impediments.

A number of studies suggest that the direct effects of energy efficiency programs may become diminished due to rebound effects.[29] By reducing consumer energy costs, consumers will have more disposable income to spend on energy-using goods. A more efficient air conditioner might tempt a consumer to set it to a lower temperature. Consumers might be less concerned about turning out lights when leaving a home if their home is lit with compact fluorescent bulbs or LED lighting. Improvements in fuel efficiency appear to lead to a small increase in the use of automobiles.[30]

Energy efficiency efforts should be strategically targeted to consumers who would not otherwise undertake the energy efficiency measure. Free ridership, along with rebound effects and allegedly biased reporting, may contribute to some over-reporting of the savings associated with various energy efficiency programs.[31]

Information Sources

US Department of Energy: Energy Efficiency and Renewable Energy
http://www.eere.energy.gov/

R & D at Texas A & M Energy Systems Laboratory
http://esl.eslwin.tamu.edu

American Council for an energy Efficient Economy
http://aceee.org/

Energy Efficiency Programs administered by the State's Investor-Owned Electric Utilities:
www.texasefficiency.com

Exhibit Endnotes

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Chapter 9

SUMMARY AND CONCLUSIONS

Texas' vast size, abundant resources, favorable business and political climates, and innovative, hard working citizens have helped to make Texas a national and international leader when it comes to energy. Texas leads all other states in both the production and consumption of energy. Its leads the states in both oil and gas production[2] and is the nation's leading refining state with more than one fourth of U.S. oil refining capacity. The Texas power grid, which serves most of the State, is one of only three power grids in the continental United States and has served as a national and international model for transitioning to a competitive retail environment.

To a large extent, Texas' native energy resources and the success of industries built around them fueled Texas' population and economic growth for the past hundred years. They have enabled the state to play a large role in shaping national and even international energy policies, in part because Texas is disproportionately impacted by the effects of those policies.

As with fossil fuels, Texas is fortunate to contain a large and disproportionate share of the nation's renewable energy resources. Among the contiguous 48 states, Texas has the highest potential for generating renewable energy from its solar, wind, biomass and geothermal resources.[3] Furthermore, these available renewable energy resources are almost entirely untapped.

As of September 2008, Texas had 5,871 MW of installed wind capacity;[1] more than double that of California, the state with the next highest level of installed capacity. But Texas' installed wind capacity comprises only about 4 percent of the state's estimated developable wind capacity, so there is plenty of potential for additional growth.[4] The same is true for Texas' other renewable energy resources including solar, biomass, and geothermal. Of the state's enormous developable solar and geothermal capacity, Texas has only begun to scratch the surface with large-scale and small-scale, distributed projects developed to date.

Texas possesses current energy demand and future growth rates that suggest the need to encourage development of the state's renewable energy resources. This fact is significant as new energy facilities, renewable or otherwise, will be constructed most rapidly in the context of declining fossil fuel production and a large, growing economy.

Looking ahead, renewable energy represents a real opportunity for Texas to leverage its hard-earned energy knowledge, leadership, and proven track record well into the next century, to meet its own – and the nation's – energy needs, and to maintain its leadership role in shaping the energy policies of the future.

But this will not happen automatically. Capitalizing on the opportunities presented by Texas' renewable energy resources will require careful consideration of the technical, political, economic and regulatory landscapes on which all energy development projects depend. It will require consideration of long-term strategies, formulation of shorter-term priorities, and identification and removal of barriers to development, all of which have the potential to affect the eventual outcome.

Renewable Energy has many advantages, but cannot and will not solve all of Texas', our country's, or the world's energy problems on its own. Certainly, renewable resources have an important role to play within the context of a diverse, stable energy supply, which includes consideration of all available fuels and of the benefits, costs and consequences of each. All in all, however, renewable energy resources are certain to play a LARGE AND growing role in the next century, a role in which Texas is well-positioned to lead.

Other chapters of this report have presented detailed information about Texas' renewable energy resources – solar, wind, biomass, geothermal, water, and efficiency – and have presented specific recommendations pertaining to those resources. This chapter synthesizes common themes and presents additional contextual information applicable to all resource types. It is structured around these main themes:

- Accommodating Intermittency
- Delivering Renewable Energy to Markets
- Valuing Distributed Generation
- Incorporating Energy Storage
- Economics of Renewable Energy Investments
- How Carbon Changes the Picture
- Government Subsidies
- Jobs and Economic Development
- Resource Allocation Consequences and Tradeoffs

Accommodating Intermittency

Resource intermittency is a significant issue for some renewable energy resources more than others. Texas' geothermal energy resource is generally stable and available year-round. Much of the state's biomass and water resources are created seasonally or intermittently, but their intermittentcy is not problematic since they can largely be stored for use when needed. Wind and solar resources are intermittent over short time periods and generally cannot be economically stored, so their intermittency poses unique challenges for integrating them into the electricity system at a large scale. Wind generation has achieved sufficient penetration on the Texas power grid that intermittency is beginning to emerge as an operational issue.

In February 2008, ERCOT cut service to several large customers in the Houston area after losing about 1,400 MW of wind power over the previous three hours. The drop coincided with rising electricity demand in the early evening hours and with a weather front pushing colder weather into the state. In response, ERCOT activated an emergency plan to curtail power to interruptible customers and shaved 1,100 MW within 10 minutes. No other customers lost power during the declared emergency and the affected interruptible customers were fully restored after about 90 minutes.[5] This provided a reminder that the intermittency associated with some forms of renewable energy can create some challenges. Fortunately, these operational risks can be managed.

Strategies for Accommodating Intermittent Resources

- **Forecasting**. Generators and Grid Operators may anticipate Intermittency through development and utilization of better short-term resource forecasting models.

- **Diversification**. The effects of intermittency may be alleviated by diversifying generation among intermittent resources and by obtaining intermittent generation from diverse locations. For example, the combined intermittency of wind and solar generation in west Texas may be less extreme than the intermittency of either resource alone, and the combined intermittency of distributed solar generators installed over a wide area may be less extreme than that of a single large solar power plant.

- **Demand Response, Storage, and Backup Generation**. Options for responding to resource intermittency include relying upon demand response (such as ERCOT's curtailment of interruptible customers), or drawing on energy storage or other rapidly-available generation resources. In addition to other benefits, "smart meters" may enable customers to respond to intermittency by shedding loads in real-time. On the supply side, if other energy resources are available or can be made available within a short period of time, they may be used to "back up" the intermittent resource.

Delivering Renewable Energy to Markets

Some renewable energy resources are located far from major energy markets, posing unique challenges in delivering renewable energy to customers. Wind energy is a prime example, with most Texas wind energy development to date occurring in west Texas while the largest retail energy markets are in the Dallas/Fort Worth, Houston, San Antonio and Austin metropolitan areas. Concentrating solar power plants face a similar electricity transmission challenge, since the state's best direct solar resource exists in far west Texas. Biomass is typically transported to processing facilities for the production of liquid fuels, which in turn are transported by pipeline networks and public highways to retail outlets.

The degree to which renewable energy sources must be transported has a large influence on the economics and energy return of utilization.

Energy transmission is an intra-state as well as an inter-state issue. Given Texas' abundance of renewable energy resources, it is just as important to consider how to export Texas renewable energy to other states and regions.

Strategies for Delivering Renewable Energy to Markets

- **Intra-state transmission.** Texas' efforts to develop electric transmission infrastructure to connect renewable energy resource-rich areas of the state with load centers through the designation of Competitive Renewable Energy Zones (CREZ) has the potential to stimulate development of these resources. In August 2008, the Texas PUC approved a nearly $5 billion plan to construct 2,400 miles of transmission lines that will accommodate over 18 GW of wind capacity, just 1,000 MW shy of the current installed wind capacity in the United States. While the CREZ transmission projects were developd primarily with wind energy in mind, they may also benefit new non-wind RENEWABLE and (delete traditional) fossil power plants as well.

- **Interstate transmission.** Some proposals for large wind farms in the Texas panhandle and throughout the upper Midwest call for wind energy to be transmitted to load centers on the east and west coasts via new high-capacity electric transmission lines. Development of new transmission projects tend to be guided by regional transmission authorities, and few pathways currently exist for review, approval and development of transmission infrastructure which would cover the distances necessary to make these transactions possible. New transmission planning structures are needed to enable such development.

- **Non-transmission solutions to transmission problems**. Transmission network upgrades are typically paid for by ratepayers through regulated processes. But network upgrades aren't the only measures which can help resolve transmission problems. Other measures, such as energy storage, demand response, efficiency and distributed generation, can perform similar functions as transmission and alleviate the need for, and cost of, new transmission and distribution infrastructure improvements. Changes are required to ensure these technologies have access to the same ratepayer-backed funding mechanisms available to traditional transmission upgrades.

Valuing Distributed Generation

Small renewable energy generation systems located at the point of use capture the benefits of renewable energy while reducing utility costs. One study identified 19 key values of distributed generation, including values associated with energy generation, available capacity, transmission and distribution cost deferrals, reduction in system losses, reactive power, improved system resiliency, increased reliability, electricity price protection, and pollutant and greenhouse gas emission reductions.[6]

Examples of distributed renewable generation include rooftop solar water heaters and solar electric systems, small wind energy generating systems, and ground-source heat pumping systems. Most distributed generation systems produce enough energy to meet a portion of a home's or business' energy needs, reducing the amount of electricity purchased from the utility. Such reductions are equivalent to reductions in consumption derived from efficiency or conservation measures. Some technologies at times produce more than enough energy to meet a home's or business' energy needs, and during those periods export electricity to the grid. Capacity, exported energy and other key values provided by distributed generation should earn the generation owner compensation at a fair value. If efficient, transparent markets are efficient, transparent markets are unavailable or impractical to enable distributed generation owners to be compensated for the value they create, then that value should be made available.

Strategies for Valuing Distributed Generation

- **Incentive programs**. Policies and programs supporting adoption of distributed renewable generation, including the efficiency programs offered by Texas electric utilities, should recognize and account for the total value of distributed renewable energy delivered to the utility and its ratepayers.

- **Interconnection policies**. Policy makers should encourage adoptions of consistent interconnection requirements and processes by all Texas electric utilities.

- **Net metering**. All customers with distributed renewable generation should have the opportunity to earn a fair price for energy outflows without having to switch retail electric providers or renegotiate the terms of existing retail energy purchase contracts.

Incorporating Energy Storage

Energy storage refers to wide range of technologies which can be used to store energy and release it later to perform some useful task. Like distributed generation, energy storage is another example of an energy service which does not fit neatly into the traditional electricity system model consisting of generation, transmission, distribution, and retail sales. From a grid operator's perspective, storage can act like load (when it is being charged), generation (when it is releasing energy), and can be used to improve utilization of transmission assets. Development of economical storage is useful to intermittent energy resources, in particular, because it enables intermittent resources to comprise a larger portion of available capacity without compromising grid operations.

Texas has a number of mature oil fields that could be used for compressed-air energy storage (air is pumped in during off-peak periods when power prices are low and extracted for extra power generation during peak periods when power prices are high), and market participants are exploring other options for compressed air storage or large-scale batteries.[7] Solar thermal power plants often make use of thermal storage which can smooth and shift output to capture higher energy values later in the afternoon and evening. Distributed storage concepts have been proposed, including dispatching of energy stored in the batteries of plug-in hybrid vehicles during peak demand periods or as back-up power during emergencies.

Strategies for Incorporating Energy Storage

- The Governor's Competitiveness Council recommended in July 2008 that the state "establish an innovation prize or prizes, funded with private-public revenue, for the commercialization of large-scale energy storage."

- The PUC and ERCOT should consider energy storage, demand-response, and distributed generation in conjunction with transmission planning and authorize rate recovery for all cost-effective solutions.

Economics of Renewable Energy Investments

All energy generation projects are capital intensive. Most renewable energy projects tend to be even more so, in part because they lack ongoing fuel costs. As a result, financial returns on capital investments in renewable energy tend to be highly stable and predictable over the life of the project. This stands in sharp contrast to the fuel price volatility associated with some fossil fuel generation, which can result in highly volatile energy prices for consumers. The stability and predictability of renewable energy investments creates value which can be passed on to consumers of renewable energy through long-term, fixed price energy sales contracts. Similarly, investments in energy efficiency and conservation act as buffers against fuel price volatility.

In the case of distributed renewable generation, the high initial cost and long payback term does not always align with the interests of home- and building-owners who may not plan to own the home or building long enough to reap the financial reward from an investment in a distributed renewable generation system. Additionally, for many commercial projects, the developer and building owner are not responsible for energy costs, and therefore have no incentive to invest in efficient design and construction. These misalignments mean some cost-effective distributed renewable generation and efficiency projects will not be built absent some kind of intervention, such as up-front rebates offered through efficiency programs.

Conclusions relating to the Economics of Renewable Energy Investments

- **Long-term economic predictability**. For many renewable energy generation projects, "fuel" costs are non-existent, making financial returns on capital investment highly stable, predictable, and non-volatile. This stability has a value which can and should be recognized in energy markets.

- **High initial investment and owner/operator mismatch**. Due to misalignment of interests, some cost-effective distributed renewable energy and energy efficiency projects may not proceed without policy intervention. Up-front incentive payments, policies to promote energy efficient building construction, and financing mechanisms tied to the property rather than the owner, can encourage customers to make otherwise cost-effective capital investments.

How Carbon Changes the Picture

Regulation of greenhouse gases such as carbon dioxide (CO_2) by the federal government could have a pronounced impact on Texas' energy future. The Kyoto Protocol, an international agreement between more than 170 countries, first formalized a mechanism for establishing a maximum amount of greenhouse gases which could be emitted by participating countries, and for tracking and trading greenhouse gases through the use of carbon credits and offsets. The mechanism functions by creating a market for carbon credits, which provide their owners with permission to emit a fixed amount of CO_2 into the atmosphere. The additional cost of obtaining credits increases the cost of emitting CO_2, thereby increasing the cost of fossil fuel-derived energy. Since 2005, the Kyoto mechanism has been adopted by all countries within the European Union.

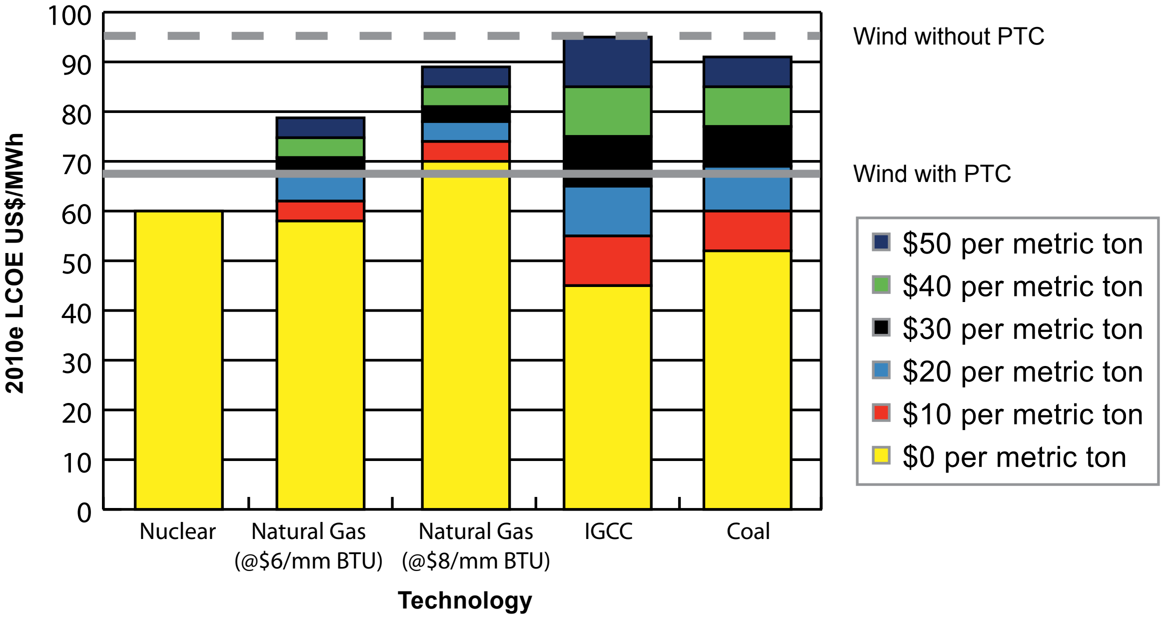
In the U.S., mandatory carbon regulation has been considered but not adopted by the federal government. Some voluntary and regional efforts have taken hold, however. The Chicago Climate Exchange has been operating as North America's only voluntary, legally-binding greenhouse gas reduction and trading system for emission and offset projects since 2003. The Regional Greenhouse Gas Initiative (RGGI), a mandatory, cooperative effort between 10 northeastern states with the goal of stabilizing and then reducing CO_2 emissions from power plants by 10 percent by 2018, held its first carbon credit auction in September 2008.[8]

By increasing the cost of fossil fuel-derived energy, carbon regulation can make non-carbon emitting energy resources, such as many renewable energy resources, more cost-competitive. A recent evaluation illustrated how different market prices for CO_2 could affect the competitiveness of wind energy under RGGI regulation in the northeast (**Exhibit 9-1**).

Conclusions Relating to Potential Carbon Regulation

- **Disproportionate Effect**. Federal regulation of carbon dioxide and other greenhouse gases will have a large and disproportionate effect on Texas, due to the state's abundance of fossil fuel resources and the industries which have developed around them.
- **Opportunity for Texas Renewables**. Texas' abundance of renewable energy resources means the state has a natural hedge against potential carbon regulation. Texas can profit from and maintain its leading position in development and integration of renewable energy resources and policy.

Exhibit 9-1 Effects of CO_2 Prices on Wind and Fossil Energy Costs in the Northeastern U.S.



Source: Ernst & Young, Presentation: United States renewable energy attractiveness indices: Q2 2008; Impact of the Regional Greenhouse Gas Initiative and IRS Notice 2008-60 on renewable energy, September 23, 2008.

Government Subsidies

All energy resources, renewable and non-renewable, benefit from subsidies and are subject to policy and regulatory frameworks that promote or impede each resource's competitiveness in the Texas, U.S. and global energy marketplaces. Unraveling the complex interrelationships between energy utilization and government policy can make comparing the true economic costs and benefits of each energy resource, and quantifying the extent to which each resource is economically advantaged or disadvantaged by government, a formidable task. Nonetheless, a number of conclusions can be reliably drawn by investigating direct and indirect incentives provided at the federal and state/local levels.

Energy subsidies may be either "direct" or "indirect." Direct subsidies include payments from the government directly to producers or consumers, and tax expenditures. Indirect subsidies include government actions that do not involve direct payments to producers or consumers but which affect the cost of consumption or production of some form of energy.

Federal Subsidies

According to the Energy Report released by the Texas Comptroller in May 2008, at the federal level, direct financial subsidies attributable to specific renewable energy sources totaled about $6.2 billion in 2006 and comprised about 45 percent of all direct federal energy subsidies. More than three quarters of federal renewable energy subsidies, about $4.7 billion, went to ethanol production alone, mostly for use as a gasoline additive. Wind, solar, hydroelectric and biomass technologies comprised a second tier of federal subsidies, together receiving another $1.3 billion. Biodiesel and geothermal together received smaller amounts.

Another way of looking at direct financial subsidies is to compare the amount of subsidies to the total amount of consumer spending on energy. From this viewpoint, federal subsidies as a percent of total consumer spending on energy amounted to just 1.4 percent overall, but comprised a greater share of spending, 4.5 percent, on renewable energy resources than for non-renewable sources. This average is not consistent among all fuels, however. Federal subsidies are highest for ethanol (26.5%) and nuclear power (20.9%), while solar (12.3%), wind (11.6%), biodiesel (9.9%) and coal (6.9%) comprise a second tier. Hydroelectricity, biomass, and geothermal resources join oil and gas as the least subsidized fuels from this perspective. **Exhibit 9-2** presents an overview of federal energy subsidies.

Federal direct financial subsidies critical to renewable energy markets in Texas include the production tax credit (PTC) for wind, the investment tax credit (ITC) for solar, and the ethanol blender tax credit. In October 2008, Congress extended the wind PTC through 2009 and the solar ITC through 2016.

State and Local Subsidies

At the state and local level, Texas provided approximately $1.4 billion in direct financial subsidies to renewable and non-renewable energy sources in 2006, almost all of which, 99.6 percent, went to oil and gas production. The remaining 0.4 percent, or about $6.2 million, went to solar, biodiesel, wind, and geothermal. It should be noted that of the $2.5 million listed for solar, over $2 million was a local subsidy provided by the City of Austin through its municipal electric utility, Austin Energy.

When viewed as a percent of total spending on energy, Texas state and local subsidies for non-renewable sources are on average more than seven times higher than those for renewable energy sources. Texas state and local subsidies comprised about 1.5 percent of consumer spending on energy from non-renewable resources, and about 0.2 percent of spending on renewable resources. Of renewable energy sources, solar energy emerges as the resource with the largest combined state and local subsidy, with subsidies comprising 9.2 percent of total spending in Texas (the state share of this solar subsidy is about 1.8% of total spending, near the state's 1.5% subsidy of oil and gas, but lower than the state's 3.1% subsidy of biodiesel energy). Texas also subsidizes geothermal and wind power of about 0.2% of consumer spending. **Exhibit 9-2** summarizes Texas state and local energy incentives.

Indirect Subsidies

Of course, direct subsidies represent only part of the complex environment in which energy resources compete. Other policies, market structures, and regulatory frameworks also affect the economic viability of individual energy resources but are not counted as direct subsidies. An example of an indirect energy subsidy at the federal level is the limitation on liability afforded to owners of nuclear power facilities, which effectively reduces the cost of nuclear-derived energy by eliminating the need to insure nuclear facilities against losses associated with nuclear accidents.

Exhibit 9-2 Estimated Federal Government Taxpayer Subsidies as a Share of Total Spending on Energy Sources in 2006*

Energy Source	Federal Taxpayer Subsidies	Total Energy U.S. Consumer Spending	Total Spending on Energy Source	Federal Taxpayer Subsidies as a Percent of Total Spending
Oil and Gas**	$3,502,732,143	$772,404,554,400	$775,907,286,543	0.5%
Coal	$2,754,908,000	$37,228,867,200	$39,983,775,200	6.9%
Nuclear	$1,187,426,000	$4,506,192,000	$5,693,618,000	20.9%
Subtotal Nonrenewable	**$7,445,066,143**	**$814,139,613,600**	**$821,584,679,743**	**0.9%**
Ethanol	$4,708,277,549	$13,082,400,000	$17,790,677,549	26.5%
Biodiesel	$92,315,835	$840,350,000	$932,665,835	9.9%
Wind	$457,924,289	$3,502,105,629	$3,960,029,918	11.6%
Solar	$382,756,318	$2,731,644,481	$3,114,400,799	12.3%
Hydroelectric power	$295,234,608	$56,123,748,494	$56,418,983,102	0.5%
Biomass	$209,641,875	$50,421,528,417	$50,631,170,292	0.4%
Geothermal	$29,158,534	$5,825,057,818	$5,854,216,352	0.5%
Subtotal Renewables	**$6,175,309,008**	**$132,526,834,839**	**$138,702,143,847**	**4.5%**
Total Subsidies	**$13,620,375,151**	**$946,666,448,439**	**$960,286,823,590**	**1.4%**

*Federal fiscal years run from October 1 to September 30.
**'Oil and gas' includes natural gas production, crude oil production and natural gas plant liquids production.

Source: U.S. Energy Information Agency and Texas Comptroller of Public Accounts.

Exhibit 9-3 Estimated Texas State and Local Taxpayer Subsidies as a Share of Total Texas Energy Consumer Spending in 2006

Energy Source	Texas State and Local Subsidies	Total Texas State and Local Consumer Spending	Total Spending on Energy Source	Texas State and Local Subsidies as a Percent of Total Texas Spending on Energy
Oil and Gas	$1,417,434,337	$93,326,324,400	$94,743,758,737	1.5%
Coal	n/a	$2,207,721,600	$2,207,721,600	0.0%
Nuclear	n/a	$197,251,200	$197,251,200	0.0%
Subtotal Nonrenewable	**$1,417,434,337**	**$95,731,297,200**	**$97,148,731,537**	**1.5%**
Ethanol	n/a	$93,539,160	$93,539,160	0.0%
Biodiesel	$2,107,420	$65,967,475	$68,074,895	3.1%
Wind	$1,508,800	$833,501,140	$835,009,940	0.2%
Solar	$2,574,101*	$25,458,927	$28,033,028	9.2%
Hydroelectric power	n/a	$276,128,843	$276,128,843	0.0%
Biomass	n/a	$1,401,718,490	$1,401,718,490	0.0%
Geothermal	$45,400	$18,698,436	$18,743,836	0.2%
Subtotal Renewables	**$6,235,721**	**$2,715,012,471**	**$2,721,248,192**	**0.2%**
Total Subsidies	**$1,423,670,058**	**$98,446,309,671**	**$99,869,979,729**	**1.4%**

n/a: not applicable
*$2,074,101 of this total comes from Austin Energy utility company.

Source: U.S. Energy Information Agency and Texas Comptroller of Public Accounts.

At the state level, the Renewable Portfolio Standard (RPS) and the construction of transmission to Competitive Renewable Energy Zones (CREZ) may improve the economics of renewable energy, while market structures in non-competitive areas may present barriers to the installation of customer-sited, distributed renewable generation. None of these policies shows up in a tabulation of direct financial subsidies.

Conclusions Relating to Government Subsidies

- Subsidies should be quantified and aligned with Texas' strategic priorities for energy.
- Texas provided $1.4 billion in direct financial subsidies to energy in 2006:
    - $1.394 billion (99.6%) went to oil and gas production;
    - $6.2 million (0.4%), went to solar, biodiesel, wind, and geothermal. Of this $6.2 million, over $2 million was a local subsidy provided by the City of Austin through its municipal electric utility, Austin Energy.
- Out of every dollar Texas consumers spend on energy, direct state and local subsidies made up 1.5 cents for fossil fuel-derived energy but only 0.2 cents for renewable energy in 2006.

Jobs and Economic Development

Expanding the use of renewable energy in Texas may have a significant positive impact on employment. Research has shown that renewable energy creates more jobs in the construction and manufacturing sectors, per megawatt of installed power capacity, than does fossil fuel generation.[9] This reflects the facts that renewable energy resources tend to be more diffuse and, therefore, more labor intensive to capture, and that development of renewable energy resources tends to be up-front capital- rather than fuel cost-dependent, compared with fossil fuel generation. And because of the fact that renewable energy resources are dispersed throughout the state, developing renewable energy can create new economic opportunities in rural areas of Texas.

One study addressed potential job growth in Texas under differing national energy policies and estimated that Texas, under a scenario of "climate protection strategies," would gain 123,000 net jobs by 2020, the majority in the construction and services sector.[10] Another study considered the economic development impacts of investing in 100 MW of solar energy by 2020 in Austin, and found that the local economy would receive the benefits of a $952 million net increase in gross regional product, 293 net new jobs, $283 million in increased earnings, $8.8 million in net sales tax revenue, and $0.6 million in net property tax revenue.[11] 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.[12]

Renewable energy jobs are diverse and involve manufacturing, sales, construction, maintenance, service, and other skills. In order to meet the anticipated demand for installers the renewable energy industry has worked to create accreditation and certification standards. One such standard is the Institute for Sustainable Power Quality Standard (ISPQ 01021). The Interstate Renewable Energy Council provides third-party assessment of workforce training programs, such as the ISQP 01021 North American licensee, including accreditation for training programs, accreditation for continuing education providers, certification for independent master trainers, certifications for affiliated master trainers, and certification for instructors. The North American Board of Certified Energy Practitioners (NABCEP) has developed an entry-level solar certification program that is currently offered in Texas through Austin Community College. ACC's program is a 48-hour course that was offered for the first time January 2006.[13] NABCEP also offers professional certification for installers of solar electric and solar thermal systems, and is working on a certification for installers of small wind energy systems.

Conclusions Relating to Jobs and Economic Development

- **Rural economic development**. Renewable energy can provide jobs and economic development opportunities for Texas, especially in rural areas.
- **Manufacturing jobs**. Utilization of renewable energy can provide economic stability in the manufacturing and service sectors.
- **Workforce development**. Workforce development is needed to prepare Texans for jobs in the renewable energy sector.

Resource Allocation Consequences and Tradeoffs

Utilization of all energy sources presents differing impacts on air and water quality, land and water use, and wildlife, and requires decisions concerning competing uses of associated land and water resources. Many energy production technologies require vast amounts of water for use in steam turbines. Allocation of water between competing energy, agricultural, industrial, commercial and domestic demands will become a more important issue as each of these demands continues to increase. Certain distributed renewable energy generation technologies, such as wind, solar, and geothermal systems, can help reduce water consumption by water-consuming power plants, freeing those water resources for other uses. Wind facilities require small dedicated footprints over large land areas and can coexist with and minimally disrupt agricultural and ranching land uses, while solar facilities typically cannot.

Renewable energy resources are no different than fossil resources in this respect – whether "from wells to wheels," or "from winds to wall sockets," utilization of all energy resources requires careful consideration of resource allocation consequences and tradeoffs.

Conclusions Relating to Resource Allocation

- **Competing uses**. Large-scale implementation of renewable energy technologies will require decisions concerning competing uses of associated land and water resources.

Additional Barriers to Development

In September 2006, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy reviewed recent literature discussing the "non-technical barriers" to renewable energy use.[14] While the study focused on solar, its conclusions are applicable to a broad range of renewable energy technologies. The study identified marketing, institutional, and policy impediments that are holding back the acceptance of renewable energy technologies. These key barriers are listed here, from most frequently cited to least:

- **Lack of government policy support**. This includes the lack of policies and regulations supporting development of renewable energy technologies and the presence of policies and regulations hindering renewable energy development and supporting conventional energy development. Examples include fossil-fuel subsidies, insufficient consumer-based renewable energy incentives, government underwriting for nuclear power plant accidents, and difficult zoning and permitting processes for renewable energy.

- **Lack of information dissemination and consumer awareness.** Utilization of renewable energy and energy efficiency can be increased through educating consumers concerning the availability, economics, and other benefits of these technologies.

- **High up-front capital cost.** Renewable energy technologies tend to have a higher up-front cost compared with conventional energy technologies.

- **Difficulty overcoming established energy systems.** This includes difficulty introducing innovative energy systems, particularly for distributed generation such as photovoltaics, because of technological lock-in, electricity markets designed for centralized power plants, and market control by established generators.

- **Inadequate financing options.** Private markets may not have developed mature financing models applicable to small- and mid-scale renewable energy projects.

- **Failure to account for all costs and benefits of energy choices.** This includes failure to internalize all costs of conventional energy (e.g., effects of air pollution, risk of supply disruption) and failure to internalize all benefits of renewable energy (e.g., cleaner air, energy security).

- **Inadequate workforce skills and training.** This includes lack in the workforce of adequate scientific, technical, and manufacturing skills required for renewable energy development; lack of reliable installation, maintenance, and inspection services; and failure of the educational system to provide adequate training in new technologies.

- **Lack of adequate codes, standards, and interconnection and net-metering guidelines.** In Texas, interconnection and net metering standards are consistent within ERCOT and for investor-owned utilities outside ERCOT, but no standards, voluntary or mandatory, exist for municipal utilities or rural electric cooperatives.

- **Poor perception by the public of renewable energy system aesthetics.** Some neighborhood associations prohibit the installation of solar panels on rooftops; some communities object to the siting of wind turbines or other energy facilities nearby.

- **Lack of stakeholder/community participation in energy choices and renewable energy projects.** Energy consumers often feel they have little say over what kind of generation is built and integrated into the retail energy product they purchase.

Closing

The U.S. is one of the world's major energy producers and consumers, and Texas is at the epicenter of U.S. renewable energy development. Texas' success in developing its wind resource, coupled with its enormous solar, geothermal and biomass potential, lead one study to conclude in mid-2008 that Texas was the most attractive U.S. state for long-term renewable energy development, ranking first among the states in wind and infrastructure, second in solar, and third in biomass and geothermal (**Exhibit 9-4**).[15]

As renewable energy sources emerge as a dominant contributor to future energy supplies, benefits will accrue to those regions with abundant renewable energy resources and policies that successfully encourage their development. With the right focus, Texas can be well-situated to benefit from its renewable energy resources and to maintain and expand its leadership role in energy well into the next century.

Exhibit 9-4 United States Renewable Energy Attractiveness Index

Ranking*	State	All Renewables Index	Long-Term Wind Index	Long-Term Solar Index**	Biomass Index	Geothermal Index	Infrastructure Index***
1 (1)	Texas	81	85	75	67	69	81
2 (2)	California	71	68	80	76	78	74
3 (3)	New Mexico	70	71	73	56	67	74
4 (3)	Colorado	69	71	72	53	66	67
5 (5)	Oregon	67	68	63	67	66	68
6 (6)	Montana	66	69	61	58	67	70
6 (9)	Washington	66	69	55	64	60	66
8 (6)	New York	65	68	59	61	57	57
8 (9)	Iowa	65	68	57	65	53	60
8 (9)	Massachusetts	65	65	62	67	66	73
8 (12)	Pennsylvania	65	67	59	63	62	70

* Ranking in prior quarter in brackets
* Solar Index represents the index scores for both large- and small-scale solar
*** Combins with each set of technology factors to generate the individual technology indices

Source: Ernst & Young, United States renewable energy attractiveness indices, Q2 2008.

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[1] Steven M. Wiese is the founder and Principal Consultant of Clean Energy Associates, LLC, a Texas-based renewable energy consulting and services company.

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GLOSSARY

Glossary definitions appear under the heading of the resource to which they are applicable. Energy terminology common to all resources is defined in the last section labeled "Energy."

SOLAR [1, 2]

Concentrator—Lens (refractor) or mirror (reflector) which directs the intercepted solar radiation onto an absorber area that is smaller than the aperature.

Diffuse insolation—Portion of the global insolation reaching a collector or building surface after scattering from clouds, atmospheric particles or any other materials (i.e., that portion whose direction is not from the sun).

Direct radiation, Direct insolation—That portion of the insolation that comes directly from the sun without scattering by the atmosphere or clouds.

Global insolation—The insolation striking a surface from all directions, including the diffuse plus the beam insolation.

Insolation—Amount of solar energy reaching a surface per unit of time, typically over a day (kWh/m2-day).

Solar spectrum—Distribution of the sun's energy with wavelength. About 40 percent of solar energy is in the visible wavelengths, with most of the remainder in the long-wavelength (infrared) portion of the spectrum and a small fraction in the ultraviolet portion.

Spectral distribution—Distribution of some quantity (such as solar energy, emissivity, or absorptivity) with wavelength.

WIND

Anemometer—device for measuring wind speed; cup, propeller, or vanes.

GIS—geographic information system; computerized mapping/analytical tool.

Rayleigh distribution—probability determined mathematically from the average wind speed.

Net metering—method of measuring the energy produced and consumed at a business or residence that has its own renewable energy generator such as solar panels or wind turbines.[9]

Wind power class—range of wind power, scale defined by Pacific Northwest Laboratory, small numbers correspind to low wind power, high numbers correspond to higher wind power.

Wind power plant—number of wind turbines at one location for generation of electricity, connected to the utility grid; also called wind farm or wind park.

Wind shear—change in wind speed with height above the ground, commonly modeled with a power law.

Wind turbine—machine for converting wind energy into other forms, primarily mechanical and electrical.

BIOMASS

The following terms, phrases, and abbreviations are commonly used in the fields of ecology and biomass energy. Definitions were adapted from several sources (3, 4, 5, 6, 7)

Aerobic—living or active only in the presence of free oxygen.

Anaerobic—living or active in an environment with no air or free oxygen.

Anaerobic digestion—degradation of organic materials by microbes in the absence of oxygen to produce biogas (carbon dioxide and methane).

Bagasse—residue remaining after extraction of sugar from sugar cane.

Biodiesel—a diesel fuel consisting of methyl or ethyl esters of the energy storage lipids of plants and animals.

Bioenergy—energy derived from the conversion of biomass.

Biofuel—solid, liquid, or gaseous fuels derived from the conversion of biomass.

Biogas—a gaseous mixture of carbon dioxide and methane yielded by the anaerobic digestion of organic matter.

Biomass—plant or animal matter; strictly, a quantitative estimate of the total mass of organisms (plants and animals) within a given area, measured in units of mass, volume, or energy.

Carbohydrate—any of a group of organic compounds having the approximate formula of $(CH_2O)n$ and including, in order of increasing complexity, sugars, starches, hemi-cellulose and cellulose.

Cellulose—a complex polymeric carbohydrate that is the chief structural component of plant tissue, found in cell walls or fibers.

Char—the solid, carbonaceous residue resulting from incomplete combustion of organic materials.

Cultivar—a variety of a plant species in cultivation.

Dedicated energy crop—a crop grown specifically for its ability to generate energy.

Ethanol—ethyl alcohol (“grain” alcohol) produced by fermentation and distillation; chemically, C_2H_5OH.

Fermentation—the decomposition of complex organic compounds into relatively simpler ones under the action of a ferment—typically a yeast, bacteria, or other micro-organism.

Hemicellulose—a class of non-cellulosic polysaccharides of cell walls that are more readily hydrolyzed than cellulose to yield simple sugars; includes xylan.

Landfill gas—naturally occurring biogas produced from the decay of organic materials in landfills.

Lignin—the non-carbohydrate, structural constituent of wood and some other plant tissues that encrusts cell walls and cements cells together.

Lignocellulose—plant materials made up primarily of lignin, cellulose, and hemi-cellulose that form the structural portion of plants.

Methanol—methyl alcohol (“wood” alcohol) usually manufactured by steam reforming of natural gas, but also by the destructive distillation of wood; chemically, CH_3OH.

Moisture content—the amount of water contained in biomass, expressed as a percentage of the total mass of dried material (dry basis) or of the original wet material (wet basis).

Oils—triglycerides that are liquid at room temperature, owing to a comparatively lower proportion of saturated fatty acids than in fats.

Phytomass—plant biomass.

Pulp—a mixture of ground-up, moistened cellulosic material obtained from a variety of mechanical, chemical, and thermal treatments and used to make paper.

Sludge—a non-pumpable mixture of solids and liquids, frequently referring to the residue of sewage treatment.

Stover—mature stalks of cured corn used as livestock feed.[2]

WATER

Conventional hydropower plants—hydropower plants that use water from a lake, river, or reservoir in a single pass through turbines.

Ocean Thermal Energy Conversion (OTEC)—energy from ocean temperature differentials.

Pumped storage plants—Hydropower plants that take advantage of the difference in cost of electricity between peak and off-peak consumption times to economically recycle water between two reservoirs for multiple turbine passes (do not produce new power; rather, they merely act in analogous fashion as batteries for storing power generated by other means).

Salinity Gradient—a change in salinity between bodies of water or layers within a body of water.

Tidal range—The vertical distance between the high and low tide tidal barrage. The dam-like structure used to enclose a natural bay or estuary to form a basin.

GEOTHERMAL [8]

Accessible fluid resource base—energy in geopressured water in sandstones and shales reachable by production drilling without regard to the amount recoverable or cost of recovery.

Accessible resource base (HDR)—that part of the resource base at temperatures above 25°C down to current routinely drillable depth (approximately 7 km) or the depth at which the critical temperature of water (374°C) is reached, whichever is less.

Accessible resource base (hydrothermal)—limited to permeable reservoirs that can produce water to a maximum depth of 3.2 km to bring thermal energy to the surface.

Aquifer—subsurface rock unit from which water is produced.

Basin—segment of the crust that has been downwarped. Sediments in basin increase in thickness toward the center.

Bolson—a basin with no drainage outlet.

Binary cycle technology—the preferred alternative for developing liquid-dominated reservoirs.

Brine—a highly saline solution.

Drawdown—the reduction in temperature of an HDR unit due to extraction of its heat energy at a rate greater than its natural reheating.

Fault—a plane of weakness within a rock body along which separation and differential movement occurs.

Geopressured—type of geothermal resource occurring in deep basins in which fluid is under high pressure.

Hydrothermal—hot water. The systems can be either a hydrothermal convection system in which upward circulation of water transports thermal energy to reservoirs at shallow depths or to the surface or a conduction-dominated system involving the existence of high vertical temperature gradients in rocks that include aquifers of significant lateral extent.

Injection well—well into which water or gas is pumped to promote secondary recovery of fluids or to maintain subsurface pressure.

Methane—a major component of natural gas.

Potentially useful resource base (for HDR assessments)—that part of the accessible resource base that could potentially be used for either electricity generation or direct heat applications, assuming a minimum process rejection temperature of 40°C.

Recoverable Resource (hydrothermal)—that part of accessible resource base that is producible at the wellhead under reasonable assumptions of future economics and technology.

Reservoir—natural underground container of liquids, such as oil, water or gas. May be formed by local deformation of strata, by faulting, by intrusions, and by changes of porosity.

Resource—fraction of accessible fluid resource base that can be extracted for use at costs competitive with other forms of energy at a foreseeable time, under reasonable assumptions of technological improvement and economic favorability.

Rio Grande Rift—a province extending from New Mexico into Texas has a high heat flow and thermal springs.

Seismic activity—the likelihood of an area being subject to earthquakes.

Subsidence—movement in the earth's crust in which surface material is displaced vertically downward with little or no horizontal component.

Total resource base (for HDR assessments)[10]—all the heat energy contained in the rock units underlying the specified area or region (exclusive of hydrothermal and geopressured systems) to a depth of 10 km at temperatures above a reference of 15°C.

ENERGY

British thermal unit (BTU)—a unit of energy equal to the amount of heat required to raise the temperature of one pound of water 1˚F.

Capacity—the maximum power that a machine such as an electrical generator or a system such as a transmission line can safely produce or handle.

Capacity factor—the amount of energy a facility generates in one year divided by the total amount it could generate if it ran at full capacity. A capacity factor of unity implies that the system ran at full capacity the entire year; a typical wind farm will operate at 0.25 capacity factor, or 25%.

Heat rate—the amount of chemical energy required by a given fossil-fueled power plant to produce 1 kWh of electricity, expressed in Btu's. Heat rate is actually the inverse of the plant's thermal efficiency but expressed in inconsistent units (both Btu's and kWh are energy units).

Heating value, higher and lower—the potential combustion energy of any material, referred to as higher heating value (HHV) when water in the combustion products is condensed into liquid, and lower heating value (LHV) when the water remains a vapor.

Joule (J)—a standard international unit of energy; 1055 Joules is equal to 1 BTU.

Kilowatt (kW)—one thousand Watts; the power requirement of ten 100 W light bulbs or about that of a hair dryer.

Kilowatt-hour (kWh)—a unit of energy equal to one kW applied for one hour; running a 1 kW hair dryer for one hour would dissipate one 1 kWh of electrical energy as heat.

Megawatt (MW)—one million Watts; a modern coal plant will have a capacity of about 1000 MW.

Megajoule (MJ)—one million Joules.

Quad—a very large unit of energy equal to one quadrillion (1015) BTU.

Thermal efficiency—the ratio of the useful work out to the energy in for a given thermodynamic process. Efficiencies are less than one or may be expressed as a percent.

Watt (W)—a standard unit of power defined as one Joule of energy transferred or dissipated in one second.

POLICY

Competitive Renewable Energy Zones (CREZ)—areas of the state identified as having the best renewable energy resources.[11]

Renewable Energy Credit (REC)—a credit equal to one megawatt-hour of qualified renewable energy generated and metered in Texas that can be used or traded by utility companies.[12]

Renewable Portfolio Standard (RPS)—mandate created by the Texas Legislature through Senate Bill 7 (1999) to construct a specified amount of renewable energy. The first RPS mandated that electricity providers generate a total of 2,000 MW of additional renewable energy by 2009. The current RPS is at 5,880 MW by 2015 with a target of 10,000 MW by 2025.[13]

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