RICE

HARC

Policy Options for Clean Air and Sustainable Energy in Texas

January 2009

Texas Business for Clean Air

Prepared by:

Daniel Cohan
Birnur Buzcu-Guven
Daniel Hodges-Copple
Rice University

Dan Bullock
Ross Tomlin
Houston Advanced Research Center

Prepared for:
Texas Business for Clean Air

Acknowledgements

The authors thankfully acknowledge the valuable contributions of Mr. Oviea Akpotaire.

This page intentionally left blank.

Table of Contents

List of Tables

List of Figures

Policy Options for Clean Air and Sustainable Energy in Texas:

Executive Summary

The need for cleaner air and a sustainable supply of electricity represent crucial, interconnected challenges facing Texas today. High rates of electricity consumption and reliance on fossil fuel generation have contributed to unhealthful levels of air pollution and high electricity costs for ratepayers. This report shows that sensible policies and technologies for energy efficiency and renewable energy can help clean the air while ensuring sufficient and affordable electricity supply in Texas for decades to come.

Texas must improve its air quality to protect public health, attain federal standards, and bolster the state's attractiveness to new businesses and workers. Ozone is a powerful oxidant that triggers respiratory illness and increases mortality rates. Despite years of costly control efforts, the state's two largest regions—Houston and Dallas-Fort Worth—continue to violate existing federal standards for ozone by significant margins (Figure 1). Four other Texas regions—Beaumont, San Antonio, Austin, and El Paso—currently exceed more stringent ozone standards recently adopted by the U.S. Environmental Protection Agency (EPA). Fine particulate matter ($PM_{2.5}$) imposes additional risks to human health, triggering cardiovascular and respiratory diseases and premature death even at levels that meet federal standards. $PM_{2.5}$ levels in parts of the Houston and Dallas-Fort Worth regions now hover near the EPA standard, even as concentrations have fallen in much of the rest of the country. Beyond ozone and PM, high mercury levels have triggered fish consumption advisories for some Texas watersheds, and Texas emits more climate-warming carbon dioxide (CO_2) than any other state.

Power plant emissions play an important and controllable role in these air quality challenges (Figure 2). For ozone-forming nitrogen oxides (NO_x), power plants play a major but secondary role relative to vehicle emissions. Power plants emit the majority of sulfur dioxide (SO_2) that forms sulfate particles, which constitute about 35-45% of $PM_{2.5}$ in Texas, and also directly release additional $PM_{2.5}$ to the air. Power plants are also responsible for the majority of mercury emissions in Texas, and for a third of the state's CO_2 emissions.

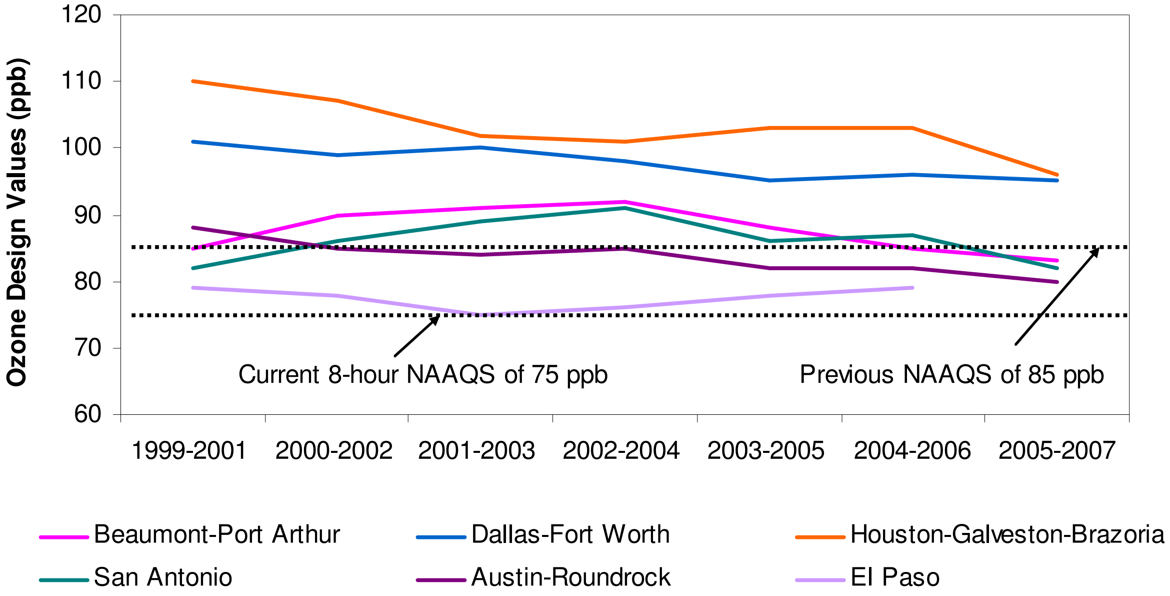


Figure 1. Trends in 8-hour ozone design values in Texas (EPA AQS).

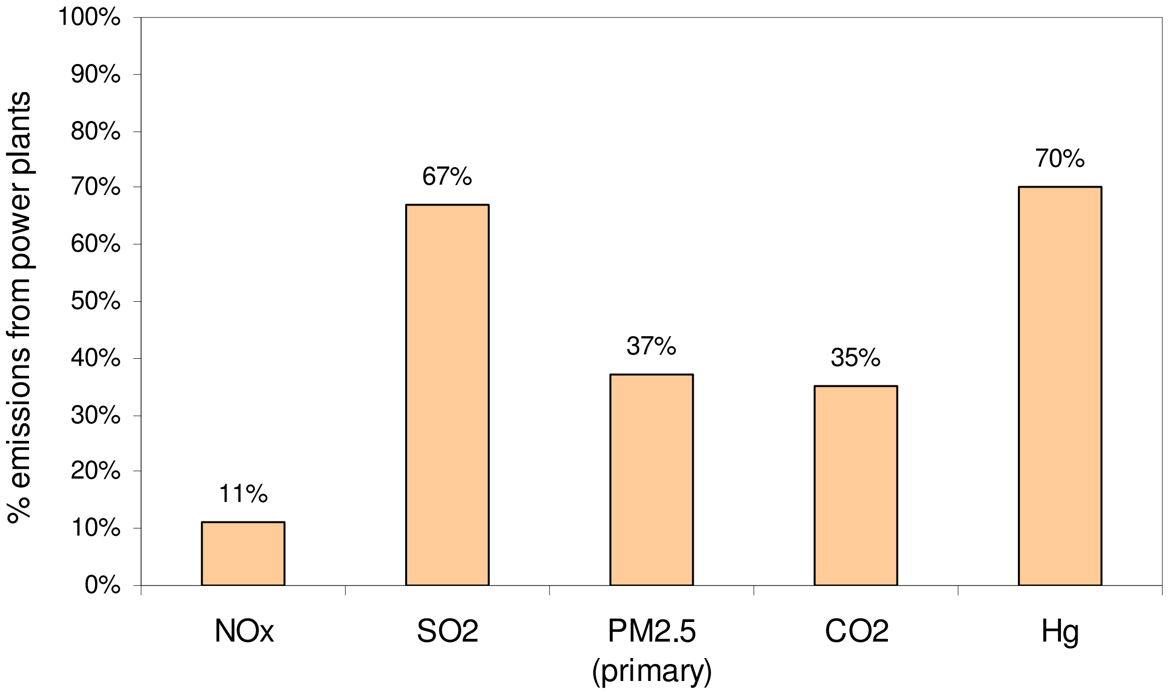


Figure 2. Share of Texas emissions contributed by power plants. (NO_x and SO_2 data from [2]; Hg from [3]; CO_2 from [4]).

Most Texas electric sector emissions come from 1970's-early 1990's vintage coal-fired power plants that have yet to install the most effective control technologies. The "grandfathered" regulatory status of high-emitting power plants, whose capital costs are largely paid for, has given them a strong competitive advantage to provide the cheapest generation in electricity markets. Meeting even the most basic emission standards required of new facilities would entail existing Texas coal-fired power plants to reduce their emissions by about 40% for NO_x, 80% for SO_2, and 70% for primary PM (Table 1). While some progress is underway (e.g., Luminant is undertaking $1 billion in voluntary emissions reductions at its facilities), many Texas coal power plants have yet to install the most effective control technologies that could dramatically reduce their emissions.

Table 1. Emissions reductions if existing Texas coal-fired power plants were hypothetically required to meet federal new source performance standards. (Baseline NO_x and SO_2 from US EPA Clean Air Markets Division for 2007; baseline PM from NETL for 2004).

	NOx	SO2	PM
Annual emissions from Texas coal-fired power plants (tons)	125,481	500,676	33,972
Reduction to meet the federal new source standards (tons)	-53,000	-392,893	-23,408

Beyond air quality, the Texas electricity system confronts important additional challenges. Simply put, Texas consumes too much electricity, at too high of a cost to consumers and to the environment. Texas consumes more electricity than any other state, and its residential electricity consumption exceeds the national average by a significant margin, indicating a strong untapped potential for energy efficiency to provide significant savings. The high consumption rates come at an especially high price to consumers, because Texas electricity prices significantly exceed the national average. Texas generates half of its electricity from natural gas, which is cleaner burning than coal but whose price has been highly volatile in recent years. The heavy reliance on natural gas also competes with other uses of this scarce resource, and leaves consumers vulnerable to volatility in electricity prices.

Electricity consumption in Texas has grown significantly over the past decade, and is projected to undergo further growth as the population and economy continue to grow (Figure 3). However, contrary to conventional wisdom, there is not a dire immediate risk of a shortfall between supply and demand that might threaten electrical reliability in Texas. ERCOT now projects that its system, which covers most of Texas, has sufficient resources to meet peak demand with an adequate reserve margin (>12.5%)

at least through 2012. Although the reserve margin is forecast to dip below the 12.5% target in 2013, that margin does not include: (1) reductions in demand resulting from energy efficiency measures already enacted in the federal Energy Independence and Security Act of 2007 and the state legislature; (2) further growth in wind and solar generation; (3) mothballed capacity; and (4) units in the final phase of interconnection that are awaiting an air permit or interconnection agreement. Our analysis shows that cost-effective efforts to promote energy efficiency, renewable energy and demand response could offset virtually all projected growth in peak demand through the year 2023 and beyond.

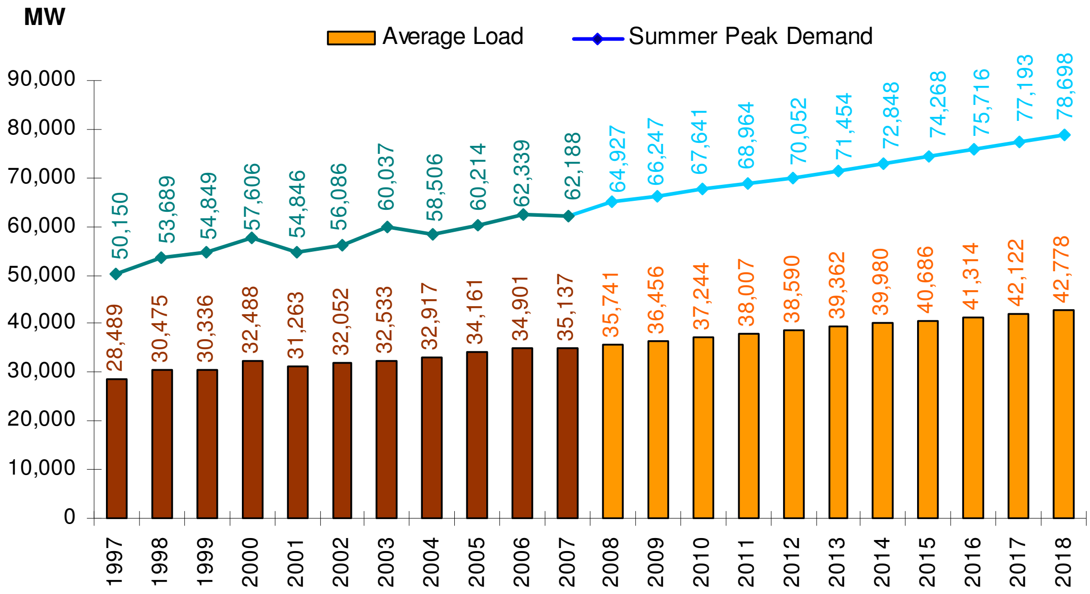


Figure 3. ERCOT historical (1997-2007) and forecast (2008-2018) average load and peak demand. Source: [6]

Energy efficiency and renewable energy may provide substantial benefits to the Texas economy. Levelized cost comparisons show that it is far more affordable to balance supply and demand by investing in energy efficiency than constructing new generation capacity (Figure 4). Wind power is already cost-competitive with other options for new power generation, and solar thermal energy is approaching cost-competitive status. Furthermore, because facilities constructed today will generate electricity for decades to come, prudent planning requires consideration of potential changes in fuel prices or federal policy that could affect generating costs. Wind and solar costs are not susceptible to volatile natural gas prices or to potential cap-and-trade markets that might place an effective price on CO_2 emissions. Our analysis shows that, under CO_2 prices projected for a climate bill narrowly defeated in the last U.S. Congress, coal-fired power plants could actually entail higher costs than renewable options, even as they emit high levels of pollution to the air and consume non-renewable resources (Figure 4).

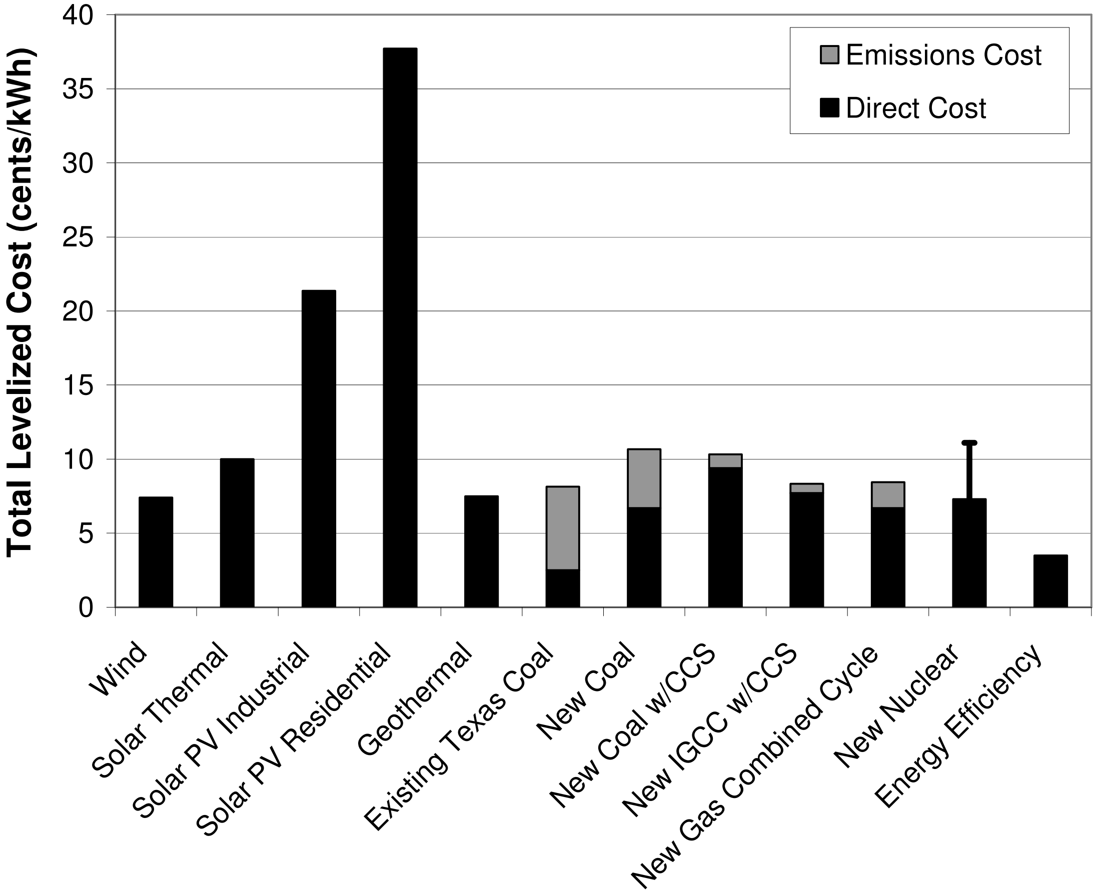


Figure 4. Levelized costs of various electricity options, with and without a hypothetical $43/ton cost of CO_2 emissions under a cap-and-trade market. (See Chapter 3, Table 1 footnotes for assumptions used in calculations).

A challenge to greater adoption of renewable energy is the intermittency of wind and solar power, and the tendency of winds to stagnate during peak summer afternoons. However, Texas is ideally suited for greater integration of these resources. Texas possesses outstanding resources for solar and wind electricity generation and already leads the nation in wind power. In addition, the state's high level of existing natural gas-fired generating capacity represents a flexible, dispatchable source of electricity well-suited for adjusting to changing conditions. Other nations without such favorable circumstances have already integrated renewable energy to levels beyond 20% while maintaining strong reliability and performance. As wind has achieved cost parity with other options, the greatest challenge it faces is securing sufficient transmission capacity to transmit energy from the best wind resources to cities and factories. The Texas Public Utility Commission's (PUC) approval of substantial transmission investments to service Competitive Renewable Energy Zones represents an innovative effort toward addressing that challenge.

A review of current Texas policy and success stories from other states and countries highlights opportunities for promoting air quality and sustainable electricity in Texas. Policy options that deserve consideration in Texas include:

1) **Strengthening the Energy Efficiency Portfolio Standard.** Utilities are now required to offset only a small fraction of their demand growth with efficiency measures. Much greater potential is possible for utilities to help their customers reduce energy demand, with energy savings far exceeding program costs.
2) **Building codes.** Opportunities are available for substantial energy savings beyond existing residential and commercial codes. Several Texas cities are already pursuing strong efficiency measures beyond those adopted statewide.
3) **Public buildings.** State and local governments have taken important steps to improve the efficiency of their buildings, but more can be done. LoanSTAR provides low-interest loans to public entities to implement energy efficiency and renewable energy measures, but the program is oversubscribed. Expanding LoanSTAR could enable a greater number of public buildings to achieve energy savings.
4) **Strengthening the Renewable Portfolio Standard.** The Texas RPS, once a national pacesetter, now contains far less ambitious targets than those set by other states. Raising the targets would better reflect the potential for renewable energy supply in Texas and enhance the incentive provided by Renewable Energy Credit markets. Additionally, as wind power has achieved cost-competitiveness, growth in the Texas RPS could be targeted to helping non-wind renewable resources achieve similar status.
5) **Power plant policies.** Existing coal-fired power plants emit far more pollutants than would be allowed for new or significantly modified facilities. Market-based or regulatory approaches could prompt the installation of control technologies that would greatly reduce emissions. Additionally, a rigorous permitting process can ensure that new power plants achieve strong environmental performance.
6) **Transmission.** Ensuring the successful implementation of Texas PUC's plans for transmission capacity expansion, and creating an ongoing process

to review emerging transmission needs, will be vital to capitalizing on the state's outstanding wind and solar resources.

7) **Combined heat and power and demand response.** CHP and demand response both provide powerful tools for reducing energy demand and could be promoted with greater incentives and awareness. These technologies can be highly cost-effective for balancing peak demand and supply.

8) **Distributed generation.** Other states have provided stronger incentives and policies for promoting small-scale generation of renewable energy, which provides important benefits to the electricity system. Incentives and net metering policies could provide important opportunities for bolstering distributed generation.

9) **Promoting research and development.** Texas has already taken tremendous strides toward ensuring that it is not only a national leader in renewable energy deployment, but also capitalizes on investment and employment opportunities in research, development and manufacture of emerging technologies. Additional steps could be taken to bolster Texas' leadership role in these areas and build upon the success of recently established facilities.

Chapter 1

The Air Quality Challenge in Texas

Air quality in Texas is impaired by several key pollutants. This chapter will review four of the challenges confronting the Texas environment: ozone, particulate matter, mercury, and climate change.

1.1 Ozone

1.1.1 Ozone formation

Ground-level ozone, O3, is not emitted directly to the atmosphere but instead forms from a series of chemical reactions involving oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of heat and sunlight. Anthropogenic (man-made) emissions of NO_x and VOC are often grouped into four categories: industrial point sources, area sources, on-road mobile vehicles, and non-road mobile sources (Figure 1). All of these categories contribute significantly to NO_x and VOC emissions in Texas (Figure 1). Among industrial point sources in Texas, 77% of VOC emissions and 48% of NO_x emissions come from petroleum- and chemicals production-related industries. The petrochemical related emissions are especially important to ozone formation in Houston and along the Gulf Coast. Power plants represent 39% of point source NO_x emissions (11% of total NO_x) in Texas but are small contributors to VOC emissions. Emissions of NO_x and VOC have decreased significantly over the past decade, even as the state's population has grown. This has been achieved mostly from more stringent standards for vehicles and fuels, market-based policies such as the Texas Emission Reduction Plan, and the installation of control technologies at point sources (Figure 2).

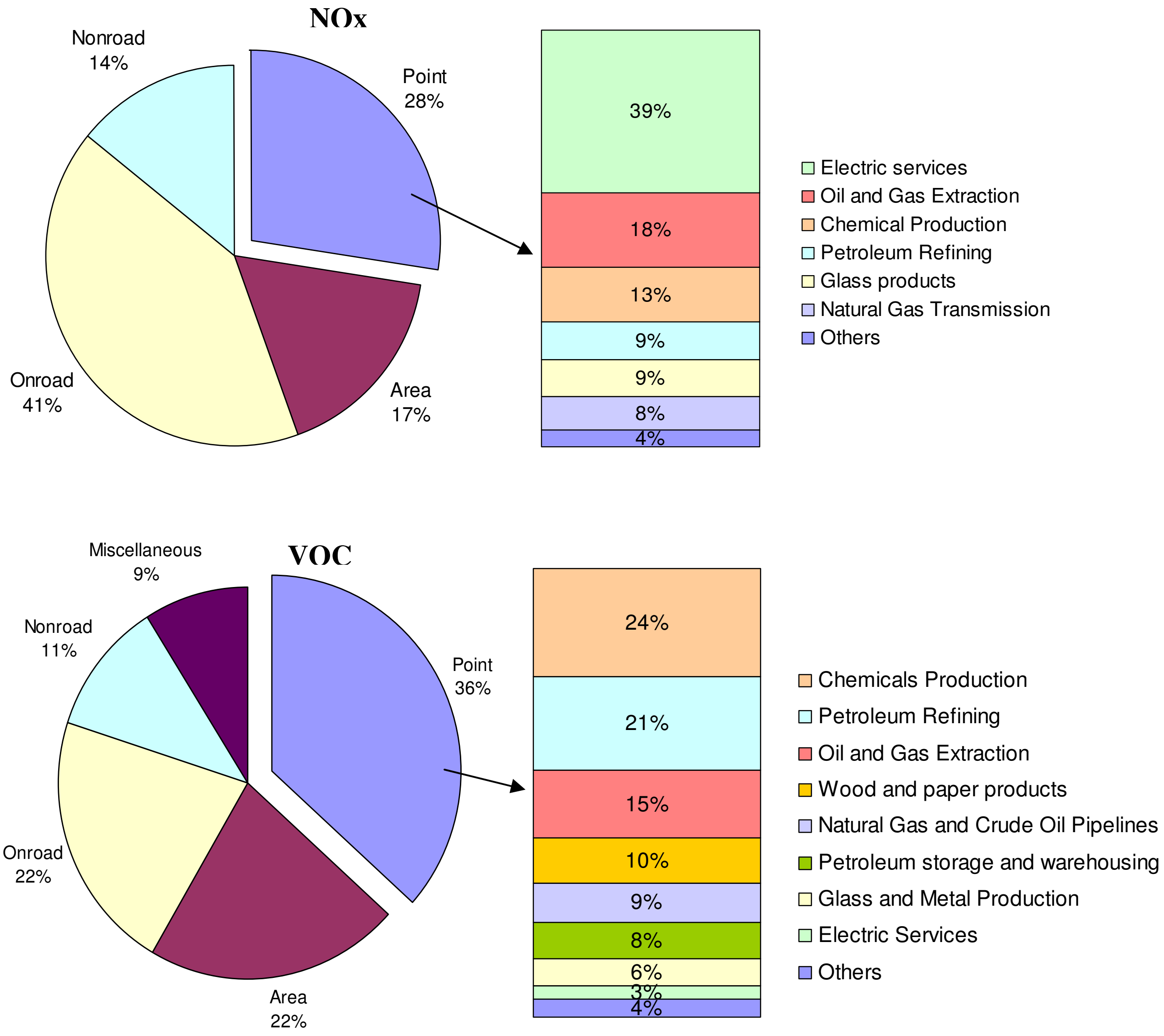


Figure 1 Source categories responsible for NOx (top) and VOC (bottom) emissions in Texas (TCEQ point (2006) and non-point (2005) source emissions inventories).

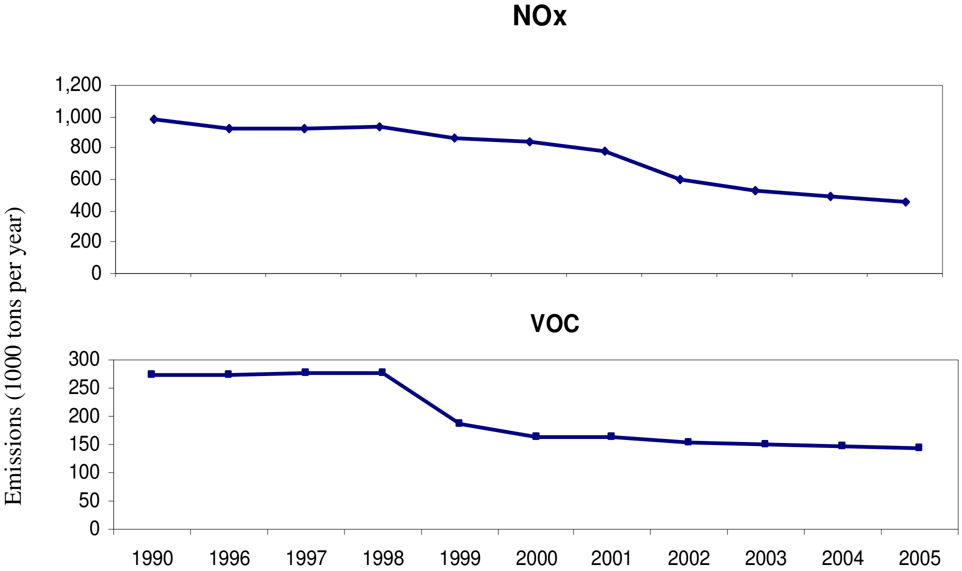


Figure 2. Trends in annual point source emissions of NOx (top) and VOCs (bottom) in Texas. (TCEQ Point Source Emissions Inventory for 2006 and EPA AirData).

Depending on a variety of conditions, ozone may be more responsive to controls of NO_x, VOC, or a combination of the two [8]. Most studies show high ozone concentrations in Texas to be primarily responsive to NO_x controls, although in some NO_x-rich centers of urban regions, VOC controls would also reduce ozone levels. Ozone and its precursors can be transported in the atmosphere over a period of hours or days, so ozone in an urban region may respond to both local and regional emissions controls [9].

In the Houston-Galveston-Brazoria (HGB) region, transient episodes of especially high ozone concentrations result from rapid and efficient ozone formation in relatively narrow, intense plumes of highly reactive VOCs (HRVOC) and NO_x co-emitted from petrochemical facilities [10]. HRVOC emissions from a single facility can jump to 10-1000 times its annual average during occasional upset conditions [10, 11]. Winds carry these plumes through the urban area and mix them with NO_x emissions, primarily from on-road and non-road mobile sources. Apart from the petrochemical plumes, significant levels of ozone can form on hot and stagnant days from Houston's mix of mobile and other NO_x and VOC emissions.

The Dallas-Fort Worth (DFW) region does not contain major petrochemical facilities, and its ozone concentrations do not spike to the brief high levels occasionally experienced by Houston [10]. Point sources account for only about one-eighth of the region's NO_x inventory. However, ozone in the region still exceeds federal standards on many days, and on an 8-hour basis Dallas ozone levels are nearly as high as Houston.

The majority of NO_x and VOC in the region comes from onroad mobile (cars and trucks) and nonroad mobile (construction equipment, aircraft and locomotives, among other) sources, with area sources contributing large amounts of VOC. Significant amounts of ozone are also transported into the region as NO_x from point sources (e.g. power plants and cement kilns) interacts with biogenic VOCs. The Texas Air Quality Study-II estimated that on high ozone days, about half of the region's ozone originates from local emissions and half results from transport from other regions, including eastern Texas, Houston, and interstate sources [10].

The Beaumont-Port Arthur (BPA) area is significantly impacted by the emissions of NO_x and VOCs from the industrial point sources in the Ship Channel region. The effect of mobile and area sources on peak ozone levels is less significant than that of point sources. Ozone precursors are also transported from Louisiana, which form a significant ozone plume near the area.

1.1.2 Impacts of Ozone

Ground-level ozone is a powerful oxidant and respiratory irritant. Short-term exposure to ozone has long been linked to a variety of respiratory symptoms such as cough, respiratory irritation, shortness of breath, and asthma episodes in vulnerable populations. Epidemiological evidence has also indicated that long-term ozone exposure may increase the likelihood of children to develop asthma. More recently, several epidemiological studies have more clearly linked high levels of ozone with increases in daily mortality rates [12, 13]. For example, Bell et al. (2004) found that a 10-ppb increase in the previous week's ozone was associated with a 0.52% increase in daily mortality and a 0.64% increase in cardiovascular and respiratory mortality. A recent study suggests that exposure to ozone very early in life during respiratory tract development may have profound effects on airway functioning, and therefore young children may be especially susceptible to adverse effects of ozone [14]. The results of an 18-year study in California indicated that the current ozone levels contribute to an increased risk of hospitalization for children with respiratory problems [15].

Beyond its harmful effects on human health, the oxidizing effects of ozone also damage plants, impairing their growth rates, reproduction and overall health [16-18]. Ozone reduces yields for timber and many economically important crops such as soybeans, wheat, and cotton. Plants respond to ozone by closing their stomata, impairing the ability of trees to sequester carbon dioxide from the atmosphere and thus contributing to global warming [19]. Ground-level ozone also directly contributes to global warming by acting as a powerful greenhouse gas. Global concentrations of ozone have risen by around 30% since the pre-industrial era, making ozone the third most important contributor to climate change after CO_2 and methane [20].

1.1.3 Ozone Non-attainment, Controls, and Consequences

The Clean Air Act tasks the U.S. Environmental Protection Agency (EPA) with setting ambient air quality standards for ozone and other "criteria" air pollutants. The agency must periodically review the latest findings of epidemiology and toxicology to ensure that the standards are sufficiently stringent to protect public health with an "adequate margin of safety." EPA initially regulated ozone based on the maximum 1-hour ozone concentration each day, setting a limit of 125 parts per billion (ppb). After scientific evidence demonstrated health impacts from extended exposure to ozone, in 1997 the standard was strengthened to 85 ppb over an 8-hour period. With subsequent studies demonstrating health impacts at even lower levels of ozone, EPA in March 2008 lowered the 8-hour ozone standard to 75 ppb. Its scientific advisory board has recommended that an even more stringent standard is necessary to protect public health.

Ozone concentrations throughout Texas have fallen significantly over the past decade (Figure 3) as a result of federal, state, and local efforts to reduce NO_x and VOC emissions. Texas efforts to attain the ozone standards have included:

- Incentives for the retrofit and replacement of diesel engines through the Texas Emission Reduction Plan (TERP)
- Texas Low Emission Diesel fuel standards
- Vehicle Inspection and Maintenance
- Transportation control measures
- Emissions limits for power plants, cement kilns, and other major point sources (TCEQ SIP revisions of 1999 (DFW) and 2003 (DFW and HGB)).
- Emissions cap and trade markets

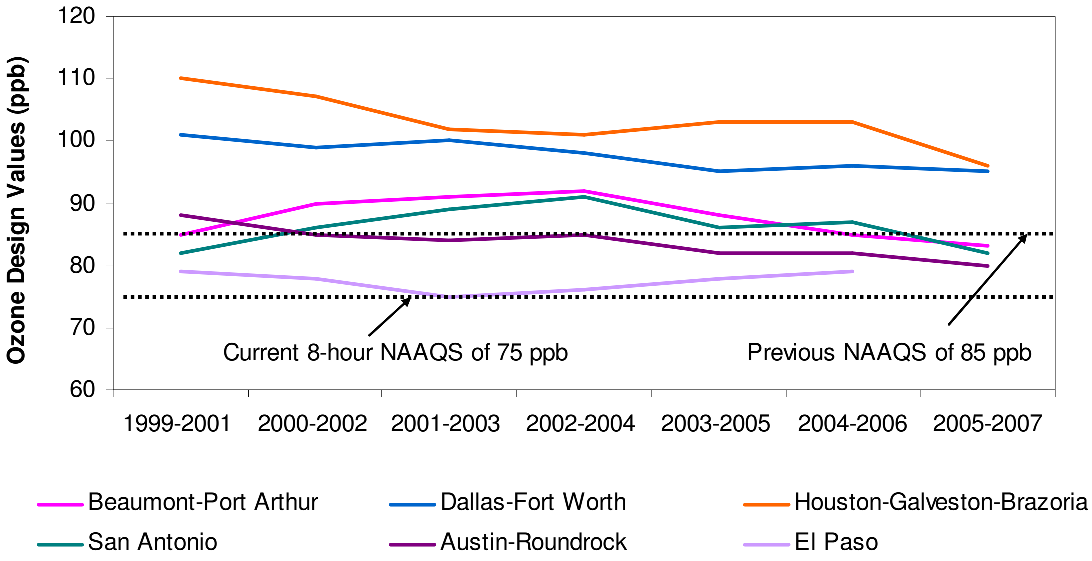


Figure 3. Temporal trends of 8-hour O3 design values in Texas regions (EPA AQS).

Despite these efforts and observed improvements, ozone levels in all major Texas urban regions exceed the new 75 ppb standard (Table 1). If those levels persist, the state may face non-attainment status and the need to develop air quality plans for more regions than in the past.

Table 1. Most recent 8-hour ozone design values for Texas regions (TCEQ presentation on Revision to the Ozone NAAQS, 2008).

Region	Ozone Design Value (2005-2007) (ppb)	Current 8-hour NAAQS (ppb)	Required Reduction (ppb)
Houston-Galveston-Brazoria	96	75	21
Dallas-Fort Worth	95	75	20
Tyler-Longview-Marshall	84	75	9
Beaumont-Port Arthur	83	75	8
San Antonio	82	75	7
Austin	80	75	5
El Paso	79	75	4

The HGB and DFW regions continue to exceed the older 85 ppb standard by significant margins (Table 1) and thus face an especially pressing need to meet this standard. Both Houston and DFW were originally classified as "moderate" non-attainment regions for the 85 ppb standard, obligating them to attain the standard by 2010. For Houston, Governor Rick Perry in 2007 requested that EPA reclassify Houston as a "severe" non-attainment region and extend its attainment deadline to 2019. The Texas Commission on Environmental Quality (TCEQ) has yet to propose a plan for attaining the ozone standard in the Houston region on this extended deadline. Thus, high ozone levels are likely to persist in the Houston region for years to come.

For DFW, TCEQ has submitted to EPA a State Implementation Plan (SIP) revision detailing its plans for attaining the 85 ppb standard by 2010 [21]. On July 1, 2008, the EPA proposed conditional approval of the SIP, which imposes NO_x limits on power plants, cement kilns, gas-fired reciprocating internal combustion engines, and other emissions sources. For mobile sources, major emission reductions are expected to result from fleet turnover as federal vehicle and fuel standards have been tightened. The plan would achieve additional mobile source emission reductions through voluntary transportation control measures and efforts to reduce diesel freight idling. The latest DFW ozone design value[i] for 2005-2007 remains 10 ppb above the standard (Table 1), so sharp improvement would be needed to meet the standard by the deadline. Attainment plans must contain contingency measures that would be imposed in case attainment is not actually achieved by the deadline. However, the proposed contingency plan contains only a few minor measures for additional VOC reductions, plus an accounting device to take credit for emissions reductions from fleet turnover already expected to occur.

Continued non-attainment of previous and new federal ozone standards has important consequences for Texas. Non-attainment regions are subject to transportation conformity[ii], which hinders their ability to obtain federal funds for transportation projects. EPA imposes stringent and sometimes costly new source review requirements on facilities operating in non-attainment areas, which can discourage businesses from expanding in or relocating to these regions. In terms of human health, non-attainment signifies that millions of Texans continue to be exposed to excessive levels of a pollutant associated with respiratory illness, asthma attacks, and premature mortality. These

---

[i] EPA determines attainment of the ozone standard based on a "design value," representing a 3-year average of each year's 4th highest 8-hour ozone concentrations. Attainment for June 2010 will be based on observed ozone levels in 2007-2009.

[ii] Transportation conformity, which is required by the CAA, ensures that highway and transit projects that are consistent with the air quality goals receive federal funding and approval, and that these projects will not cause new air quality violations, worsen existing violations, or delay attainment of the NAAQS (USEPA).

health impacts impose an economic cost through increased medical bills and missed work days. Non-attainment poses other economic costs on Texans as well. In addition, non-attainment impairs perceptions of the quality of life and environmental health of a region, making it more difficult to attract new businesses and highly-skilled professionals.

1.2 Particulate Matter

1.2.1 Particulate Matter (PM) Composition and Source Apportionment in Texas

Particulate matter (PM) is a complex mixture of microscopic particles and liquid droplets in the air. Particles smaller than 2.5 micrometers in diameter, are known as $PM_{2.5}$ or “fine particles”; particles larger than 2.5 micrometers and smaller than 10 micrometer are called “inhalable coarse particles”, or PM_{10}. Some particles, known as primary particles are emitted directly to the atmosphere from a source, such as power plants, diesel vehicles, fires, and windblown dust. Others, known as secondary particles, form in chemical reactions in the atmosphere from emissions of NOx, SO_2, and ammonia, and include sulfate, nitrate, and ammonium. Organic carbon PM occurs as both primary particles and secondary particles formed from hydrocarbon emissions.

A typical chemical composition of $PM_{2.5}$ mass in Houston area is presented in Figure 4. In Southeast Texas, organic carbon (30–40%), sulfate ion (40–50%), and ammonium ion (9-12%) comprise the majority of the $PM_{2.5}$ mass (Figure 4) [22, 23].

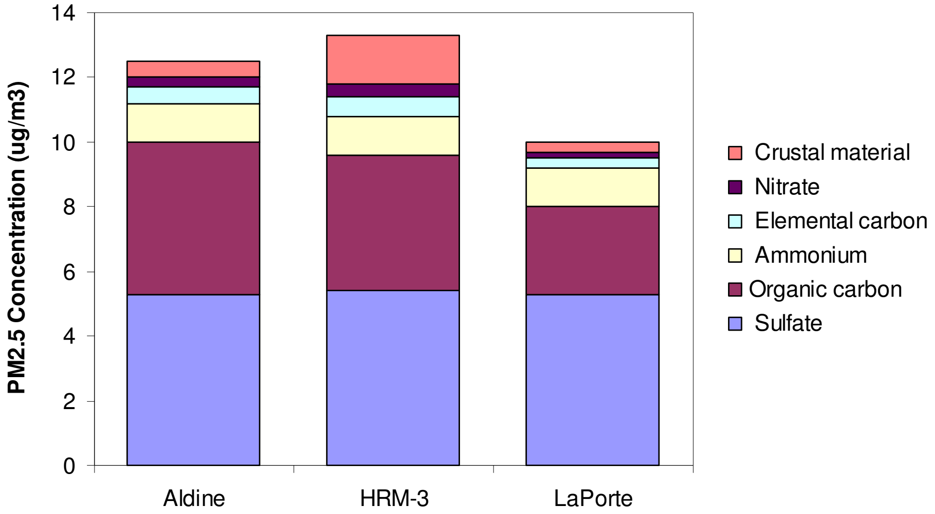


Figure 4. PM2.5 chemical composition at three Houston area sites [22].

Because of the diverse nature of $PM_{2.5}$, it is important to conduct scientific analyses to determine how various emissions sources contribute to $PM_{2.5}$. Among the conclusions of various source apportionment studies of Houston $PM_{2.5}$ are the following:

- Sulfate ammonium makes up approximately 35-45% of the $PM_{2.5}$ in southeast Texas. The sulfate forms from SO_2 emissions from Texas, 71% of which is from power plants (Figure 6), and neighboring regions.
- Mobile-source emissions are responsible for about 30-40% of $PM_{2.5}$ (Figure 5).
- Meat cooking and wood combustion, including fires, provide small but measurable contributions to $PM_{2.5}$.

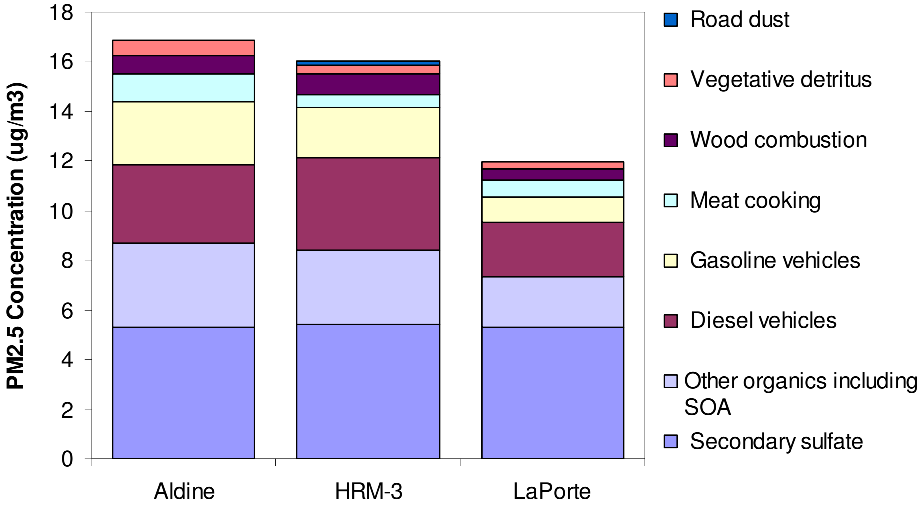


Figure 5. PM2.5 source apportionment for Houston area sites [22].

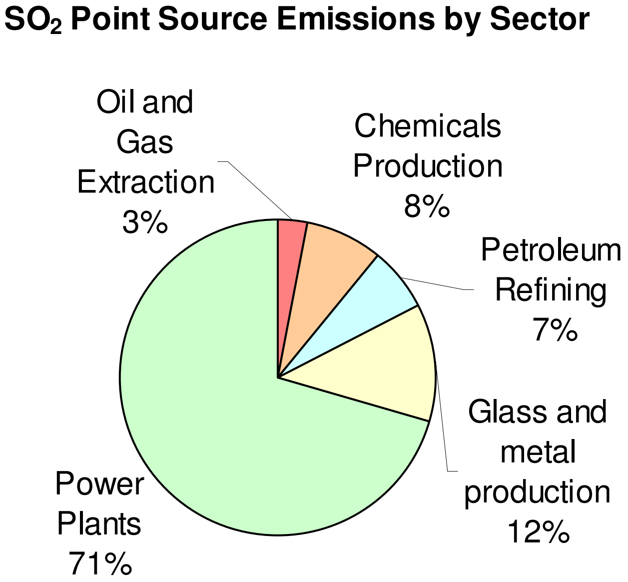


Figure 6. Point source of SO2 emissions (2006) in Texas (TCEQ Point Source Emissions Inventory for 2006).

1.2.2 Impacts of Particulate Matter

$PM_{2.5}$ is especially harmful to human health because it can penetrate deeply into the lungs [24]. Coarse particles also cause important health effects [25]. Population-based studies in hundreds of cities around the world have demonstrated a strong link between PM and premature deaths, respiratory and cardiovascular diseases, and hospital admissions [26-29]. Long-term studies of children's health have demonstrated that particle pollution may significantly reduce lung function and growth in children [30, 31]. California Air Resources Board recently released an estimate of 14,000 to 24,000 premature deaths linked to exposures to ambient PM statewide annually [32].

Fine particles also form a haze that impairs visibility. In many parts of the country, especially in the national parks, the visibility has been reduced by 70% from natural conditions [33]. Fine particles can remain suspended in the air and travel long distances, impairing visibility even in areas far from major emission sources. For example, under some meteorological conditions, power plant and urban emissions from eastern Texas can be major contributors to visible haze in Big Bend National Park [34]. Under the Regional Haze Rule, state and federal agencies are working to control haze levels in pristine wilderness and national park areas. Those efforts will require substantial reductions in $PM_{2.5}$ levels.

1.2.3 PM Trends and Potential Reductions

Nationally, annual $PM_{2.5}$ concentrations declined by 14% between 2000 and 2006 (EPA, 2008). At the same time, 16 out of 33 sites in Texas had increasing $PM_{2.5}$ concentration trends. Two sites of concern are the Houston Aldine (18% increase to 14.6 micrograms per cubic meter ($\mu g/m^3$) from 2001 to 2006) and Houston Clinton site (33% increase to 16 $\mu g/m^3$ from 2001 to 2006). Figure 7 shows the design value trends for critical Texas sites.

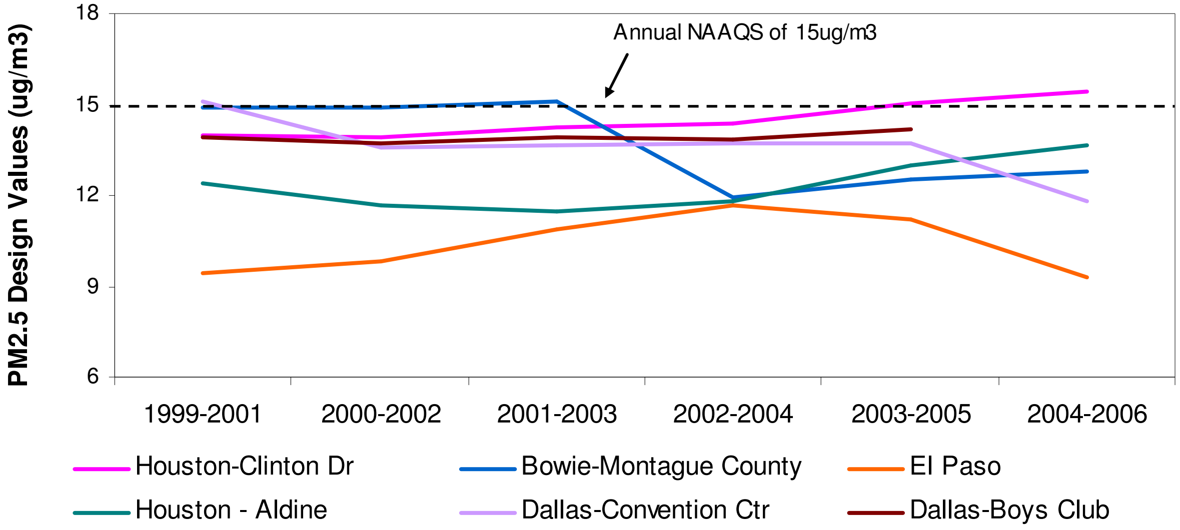


Figure 7. Design values for annual PM2.5 at selected Texas monitors (Data from TCEQ, EPA AQS, and [1]).

Since all of Texas has been designated in attainment of $PM_{2.5}$ standards so far, the state has not directly targeted $PM_{2.5}$ emissions in its control plans. The state has also conducted far less modeling and analysis for $PM_{2.5}$ than for ozone. Yet there are strong reasons to attempt to reduce $PM_{2.5}$ levels in Texas. Many health studies have found significant impacts of $PM_{2.5}$, including increased mortality rates, even at levels below the 15 ug/m^3 threshold. Texas should also take a proactive approach to assure continued attainment of federal standards, given that future tightening is possible. Even without further tightening, several Texas monitors are very close to the federal standards and would benefit from greater reductions.

The levels at the Houston monitors put the region very close to violating the federal $PM_{2.5}$ annual standard. The Clinton monitor exceeds the annual limit of 15 ug/m^3, but has not yet triggered a non-attainment designation because it was attaining the standard when designations were being considered in 2004. This monitor, located near the Ship Channel, may be influenced by atypical local conditions such as an unpaved lot trafficked by heavy machinery. However, it remains unclear whether controlling those local conditions will reduce PM levels sufficiently to meet the standard or how EPA will classify the region in the next round of designations if these levels persist.

EPA has so far chosen to not tighten the annual standard, in spite of recommendations from its science advisory board that tightening is needed to protect public health. EPA is however significantly lowering the 24-hour standard, from 65 μg/m^3 to 35 μg/m^3. This change will put some Dallas, Houston, and northeast Texas monitors very close to violating the standard. As of 2006, six counties in Texas had $PM_{2.5}$ 24-hour design values between 30-33 μg/m^3 [35].

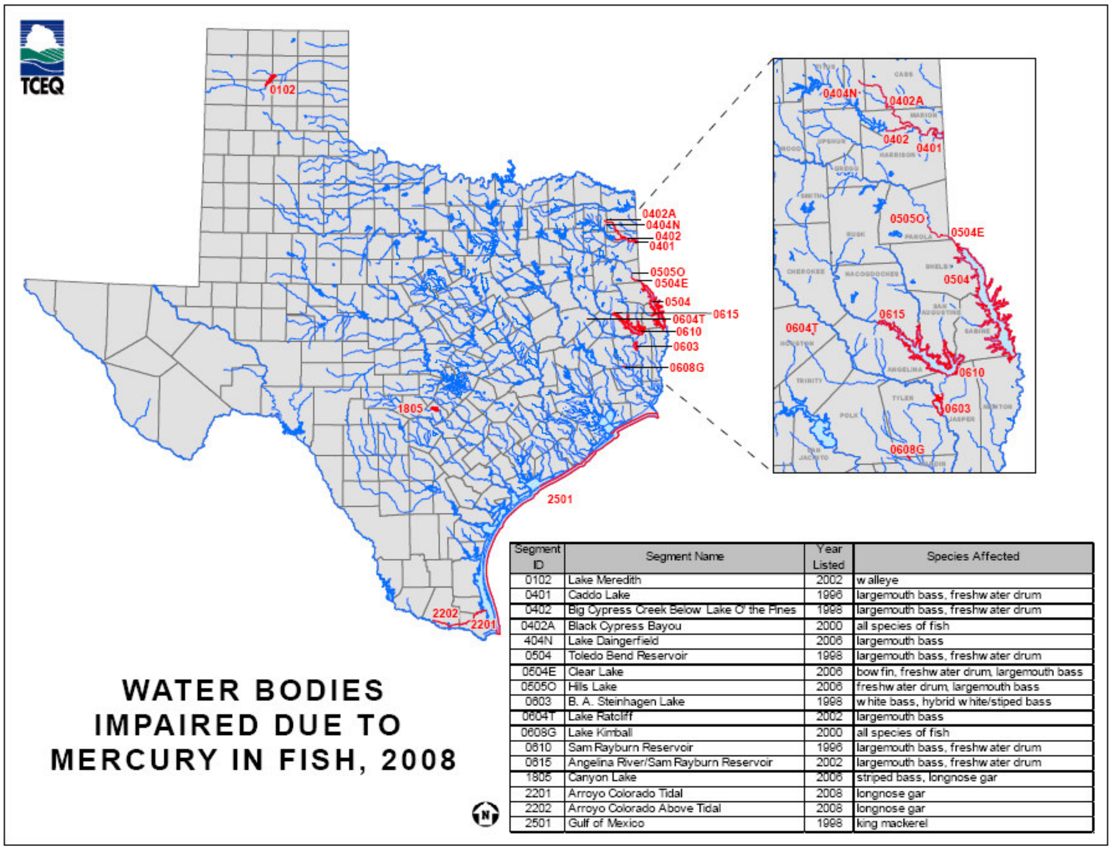
Based on the source apportionment studies, reductions in power plant emissions of SO_2 and vehicle and other direct emissions of PM will be especially critical to reducing $PM_{2.5}$ concentrations in the Houston region. Although SO_2 emissions in Texas have been reduced by about 20% over the past 15 years, far greater reductions are possible through power plant controls as will be discussed in Chapter 2. The Clean Air Interstate Rule would have resulted in dramatic reductions in power plant SO_2 emissions in Texas and throughout the eastern U.S., but that rule has now been vacated in federal court.

1.3 Mercury

1.3.1 Concentrations of mercury in Texas watersheds and fish

Mercury is emitted from combustion processes primarily in three forms: gaseous elemental form (Hg^o), divalent reactive gaseous mercury (RGM), and particulate mercury (Hg(p)). Two forms of mercury (RGM and Hg (p)) have much shorter lifetimes in the atmosphere, and as a result, tend to be deposited in water bodies close to the major sources [36-38]. Atmospheric deposition of mercury through rainfall or dry deposition to the water bodies is considered the primary way to enter aquatic living organisms [39]. In water bodies, mercury can be converted to the organic form, methylmercury (MeHg) and then bioaccumulate in organisms within the food chain. Predatory fish at the top of the food chain accumulate the highest levels of mercury, posing a consumption risk to wildlife and humans eating those fish. Fish consumption is the primary source of methylmercury exposure in humans.

The Texas Department of State Health Services issues mercury advisories if a mercury concentration in a water body is 0.7 mg/kg or greater. Seventeen water bodies are listed as impaired due to high mercury concentrations in fish (Figure 8). Twelve of these water bodies are located in East Texas and for more than 10 years, fish consumption advisories has been in place in five of them. Not surprisingly, the state's 18 coal power plants are concentrated in the eastern part of the state. In fact, the Monticello and the Martin Lake power plants, which are in close proximity to the mercury impaired water bodies, lead the state and the nation for power plant mercury pollution (see Chapter 2). However, Luminant announced the plans to install activated carbon injection – a sorbent injection system technology in all of its new and existing plants to reduce mercury emissions (Luminant news release, Feb 2008).



Segment ID	Segment Name	Year Listed	Species Affected
0102	Lake Meredith	2002	walleye
0401	Caddo Lake	1996	largemouth bass, freshwater drum
0402	Big Cypress Creek Below Lake O' the Pines	1998	largemouth bass, freshwater drum
0402A	Black Cypress Bayou	2000	all species of fish
404N	Lake Daingerfield	2006	largemouth bass
0504	Toledo Bend Reservoir	1998	largemouth bass, freshwater drum
0504E	Clear Lake	2006	bowfin, freshwater drum, largemouth bass
0505O	Hills Lake	2006	freshwater drum, largemouth bass
0603	B. A. Steinhagen Lake	1998	white bass, hybrid white/stiped bass
0604T	Lake Ratcliff	2002	largemouth bass
0608G	Lake Kimball	2000	all species of fish
0610	Sam Rayburn Reservoir	1996	largemouth bass, freshwater drum
0615	Angelina River/Sam Rayburn Reservoir	2002	largemouth bass, freshwater drum
1805	Canyon Lake	2006	striped bass, longnose gar
2201	Arroyo Colorado Tidal	2008	longnose gar
2202	Arroyo Colorado Above Tidal	2008	longnose gar
2501	Gulf of Mexico	1998	king mackerel

Figure 8. Texas water bodies impaired due to mercury in fish [40].

1.3.2 Emissions and transport of mercury - role of power plants

Mercury is emitted into the atmosphere through both natural and man-made processes. Major anthropogenic sources of mercury emissions into the atmosphere include fossil fuel combustion, waste incineration, iron-steel production, coke and lime production, non-ferrous metal smelting, petroleum refining, and mercury cell chlor-alkali plants [3].

Figure 9 shows that power plants accounted for approximately 31% of mercury emissions from man-made sources in the United States in 1999 [3]. Figure 9 shows that power plants (Electric Generating Units or EGUs) accounted for about 70% of the mercury emissions in Texas in 2003, excluding mobile sources [3].

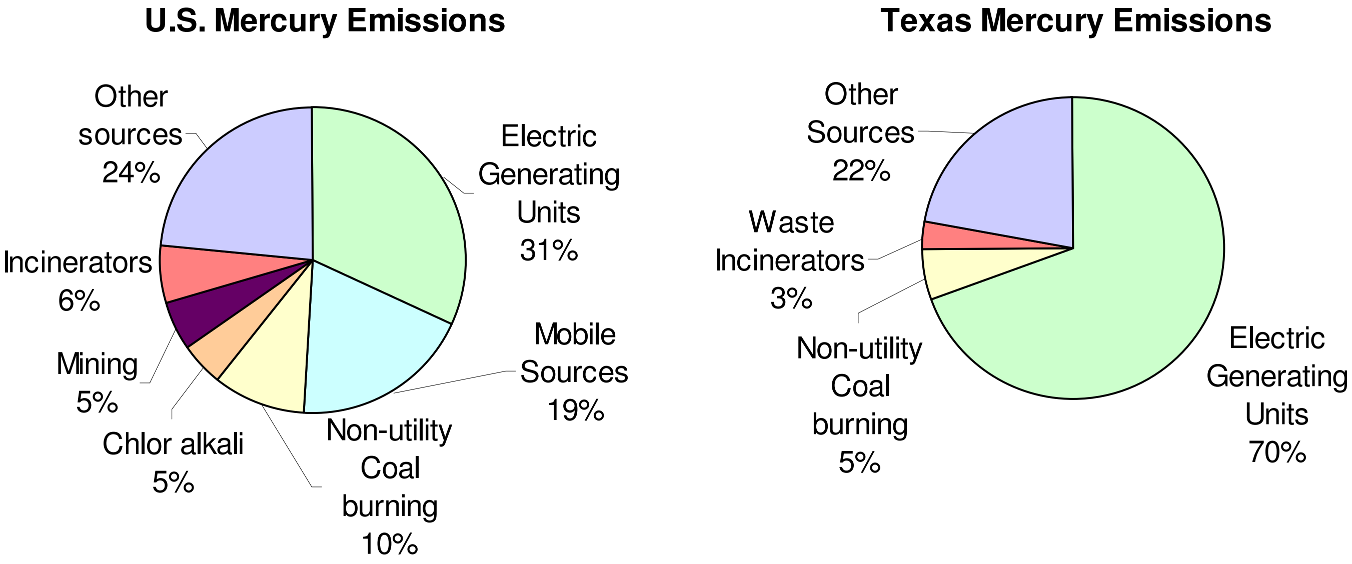


Figure 9. Man-made emissions of mercury in the US (1999) and in Texas (2003).

1.3.3 Impacts of Mercury

Mercury (Hg) is a neurotoxin that can significantly impact human health and child and fetal development even at very low levels. The most widely documented impact of mercury is the damage to neurological development in children exposed to mercury in utero or in infancy, resulting in impairment to IQ and attention and motor skills [41]. Trasande et al. (2005) found that 315,000-635,000 children are born each year in the U.S. with cord blood mercury levels associated with loss of IQ [42]. They estimated that this results in lost productivity of $8.7 billion per year, $1.3 billion of which they attributed to mercury emissions from U.S. coal power plants. EPA attributed lower monetized impacts to IQ impairment from mercury [43].

Other health effects of mercury may be important as well. There is recent evidence that links the environmental exposure to mercury to increased autism rates, and the autism risk decreases with the distance from the mercury pollution source [44-49]. Some studies have also linked blood mercury levels to cardiovascular disease [50]. Carcinogenic effects have been noted at high doses in animals.

Mercury contamination of fish could also have economic impacts beyond the health effect by impairing the recreational and economic value of fishing. The elevated levels of mercury could lead to more stringent emissions standards for coal mining industry and coal fired power plants, which in turn could have a negative impact on Texas' economy [3].

1.3.4 Current efforts to control mercury emissions

EPA's efforts to regulate mercury emissions from coal- and oil-fired power plants started in December 2000 with the introduction of section 112 of the Clean Air Act. In 2005, EPA removed these electric generating units from the section 112 list of sources of hazardous air pollutants (HAP). Subsequently, it enacted Clean Air Mercury Rule (CAMR) under section 111., which would permanently cap and reduce mercury emissions from new and existing coal-fired utility units. The 79th Texas Legislature passed HB 2481, which requires Texas to adopt the CAMR rule, and to participate in the nationwide cap-and-trade program [51]. On February 8, 2008, however, the D.C. Circuit vacated both the CAMR and the EPA's rule for the removal of the power plants from the CAA section 112 list (US Court of Appeals, 2008). EPA is currently in the process of reviewing the Court's recent decisions.

If still effective, under CAMR, a statewide cap of 4.6 tons per year would become effective in 2010 and a final cap of 1.8 tons per year in 2018. Texas mercury emissions in 2003 were estimated as 7.2 tons per year, excluding the emissions from mobile sources [3]. In Texas, power plants are currently regulated for NOx and SO_2 and will also be regulated under the Clean Air Interstate Rule (CAIR), which has an additional benefit of reducing RGM [3]. However these controls must be supplemented with mercury-specific controls, such as activated carbon injection as a mercury sorbent in order to achieve further reductions.

1.4 Climate Change

1.4.1 Expected impacts of climate change in Texas

Global climate models (GCM) available from the Intergovernmental Panel on Climate Change project that temperatures in the US could rise by 3.2^{o}F to 7.2^{o}F depending on different emission scenarios [20]. The GCM results also suggest a warmer Gulf Coast region by 2050, with the greatest increase in temperature occurring in summer and lowest increases in winter. The average temperature could increase by at least 2.7F ± 1.8F in the Gulf Coast region [52]. Along with the average temperatures, the frequency of extreme high temperature days will also increase. Global climate models do not reach an agreement on the impacts of climate change on precipitation amount, some predict declines, some indicate increases for the Gulf Coast region [52].

Climate change may also have an effect on the outdoor air pollutant concentrations, especially ozone [53]. Ozone formation in the atmosphere is highly dependent on temperature. Ozone concentrations in the atmosphere show an increase in warm summer months, especially in the afternoons, when the temperatures are the highest [54]. At cooler temperatures, ozone precursors, NOx, react to form peroxyacetyl nitrates

(PANs) instead of catalyzing ozone formation. Moreover, biogenic emissions of volatile organic compounds, which are also precursors to ozone, increase with the temperature [55]. Therefore, control of ozone formation becomes more challenging. Bell et al (2007) showed that the largest increases in ozone levels are predicted to occur in cities that already have high pollution levels, such as Houston [56].

Other potential impacts of climate change in Texas include the sea level rise, loss of coastal wetlands, erosion of beaches, saltwater contamination of drinking water, and decreased longevity of low-lying roads, causeways, and bridges. Relative sea level in the Gulf Coast is likely to rise at least 0.3 meter (1 foot) across the region and possibly as much as 1.6 meters (5.5 feet) in some parts of the region (in Galveston 0.7 -1.3 meter increase is projected). Relative sea level rise takes into account the combined effect of the sea level rise due to increases in temperature and melting of ice, and the changes in land surface elevation due to subsidence [52]. Sea level rise could increase the vulnerability of coastal areas to storms and associated flooding. Climate change is also related to certain health outcomes associated with heat, air pollution (see previous sections on health impacts of air pollutants), water contamination, and diseases carried by insects such as malaria, dengue fever, and Lyme disease [57].

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Changes in stream flow tend to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes. Because evaporation is likely to increase with warmer climate, it could result in lower river flow and lower lake levels, particularly in the summer. If stream flow and lake levels drop, groundwater levels could also be reduced. Global climate models project moderate to extreme drought conditions throughout Texas by the end of the 21st century. On the other hand, more intense precipitation could increase flooding [52].

1.4.2 Texas contribution to climate change

Carbon dioxide is the leading anthropogenic contributor to global warming [20]. It is also a difficult gas to control because it is ubiquitously emitted proportional to the amount of fossil fuel and biomass combusted and is not captured by traditional control technologies. Thus, control of CO_2 requires reducing the amount of fuel used (i.e., efficiency and conservation) or capture and storage of the CO_2, which is not yet in widespread commercial use (see Chapter 3). Carbon dioxide lasts for years in the atmosphere, so CO_2 emitted in one location can contribute to climate change worldwide.

Texas leads the nation in total CO_2 emissions with 652 million metric tons of CO_2, representing 11% of CO_2 emissions nationwide [4]. If Texas were a country, it would rank seventh ahead of Canada and United Kingdom in total CO_2 emissions. Total CO_2

emissions in Texas have increased 26% from 1980 to 2004. Most of this increase is attributed to the electric generation and transportation sectors, as industrial emissions have been relatively flat (Figure 10). Total CO_2 emissions from electric power generation in 2004 was 225 million metric tons [4], which correspond to the CO2 emissions from 1 x 10^{12} midsize cars per km traveled (World Resources Institute)**.**

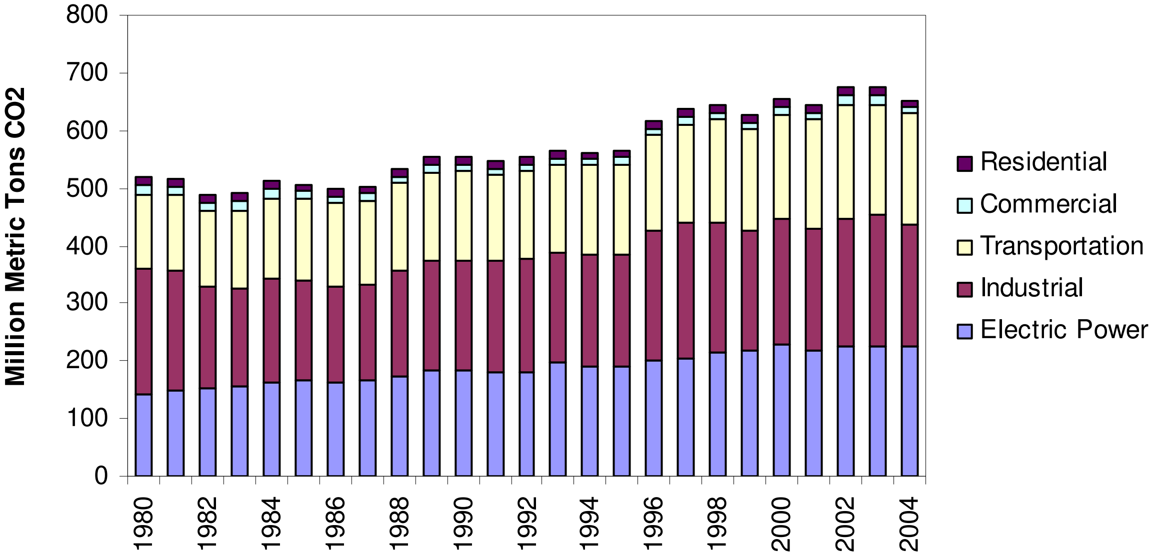


Figure 10. Texas CO_2 emissions from fossil fuel consumption by sector (1980 -2004) [4].

Chapter 2

The Electricity Challenge in Texas

Before options for improvement can be identified, the status of the electricity system in Texas and its key challenges must first be explored. This chapter will review key features of electricity generation and consumption in Texas and the impacts of electricity generation on the economy and the environment. We will conclude that: Texas consumes too much electricity, at too high of a cost to consumers and to the environment.

2.1 Electricity Consumption in Texas

Texas leads the nation in total electricity consumption, with 343 TWh of electricity sales in 2006 [5]. On a per-capita basis, Texans consume more electricity than the national average (Figure 11) and more than twice the rate of some other states, such as NY, HI and CA [5]. Widespread use of air conditioning and a relatively heavy reliance on electricity for residential energy needs contribute to the high consumption levels [5], and to date Texas has not pursued significant energy efficiency measures as aggressively as some other states. Texas also has a high percentage of large energy-intensive industries, including petroleum refining and petrochemical production, aluminum and glass manufacturing, and paper and wood industry. Residential and commercial electricity consumption have both been increasing in recent years as the Texas population and economy have grown (Figure 12). Even on a per capita basis, residential electricity consumption increased 38% between 1981 and 2006 [5]. Industrial consumption has shown little growth, fluctuating year to year due to economic conditions, energy prices and efficiency improvements (Figure 12).

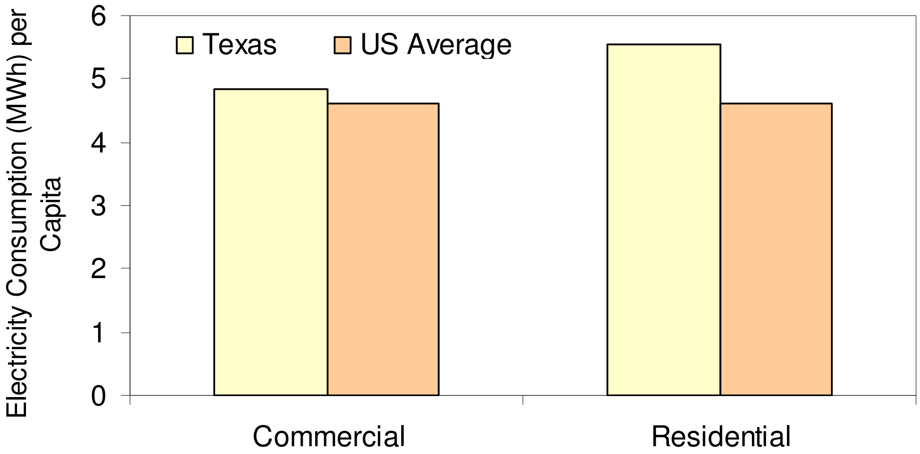


Figure 11. Residential and commercial electricity consumption per capita [5].

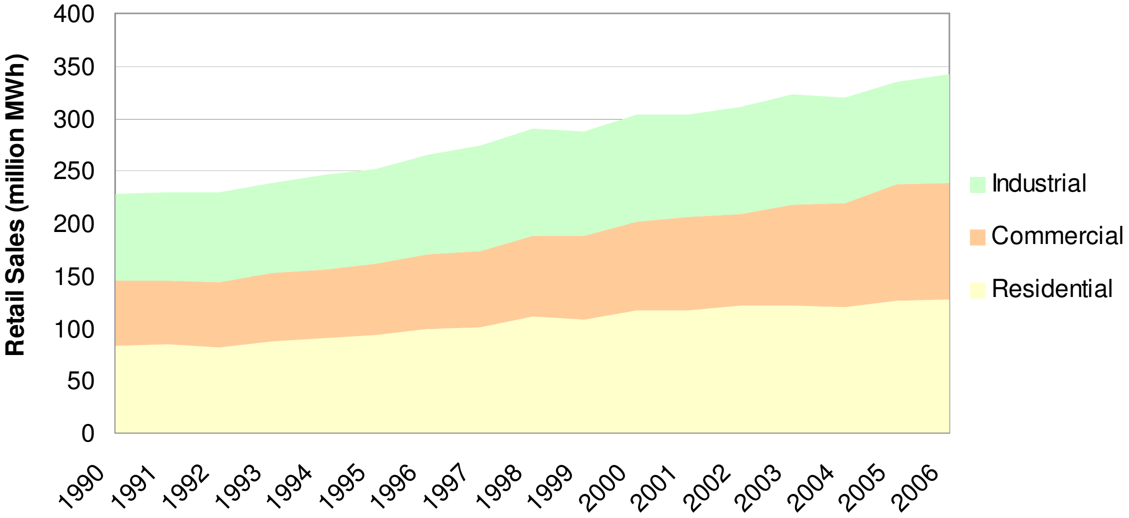


Figure 12. Retail sales of electricity by sector (1990-2006) (Increase in residential use is 54%, commercial 79% and industrial 25%) [58].

Residential and commercial sectors have peak hours when the electricity demand is the highest. Baseload demand is lower in other times; however power companies need to have sufficient capacity to meet the peak demand. Increased levels of electricity consumption in residential and commercial sectors therefore lead to inefficient use of the electricity, which is reflected as higher prices to consumers. Average retail electricity prices in Texas were 10.15 cents/kWh overall through 2007, 16% above the national average [59]. Texas residential customers have paid even higher rates, averaging 12.29 cents/kWh through 2007 [59]. The combination of high consumption and high prices has led Texas households to have the second-highest average electricity bills in the country.

2.2 Electricity Supply in Texas

Natural gas and coal are the leading sources of electricity in Texas, with important contributions from nuclear and other sources. Approximately 71% of electricity *capacity* in Texas consists of natural gas-fired generators, with coal, nuclear and wind power comprising most of the remainder (Figure 13). However, many of the natural gas facilities operate only during times of high power demand, so their share of overall *generation* is only 49%. Most coal and nuclear plants operate at high levels throughout most of the year to provide baseload power, and provided 36.5% and 10.3% of overall generation in 2006, respectively (Figure 13).

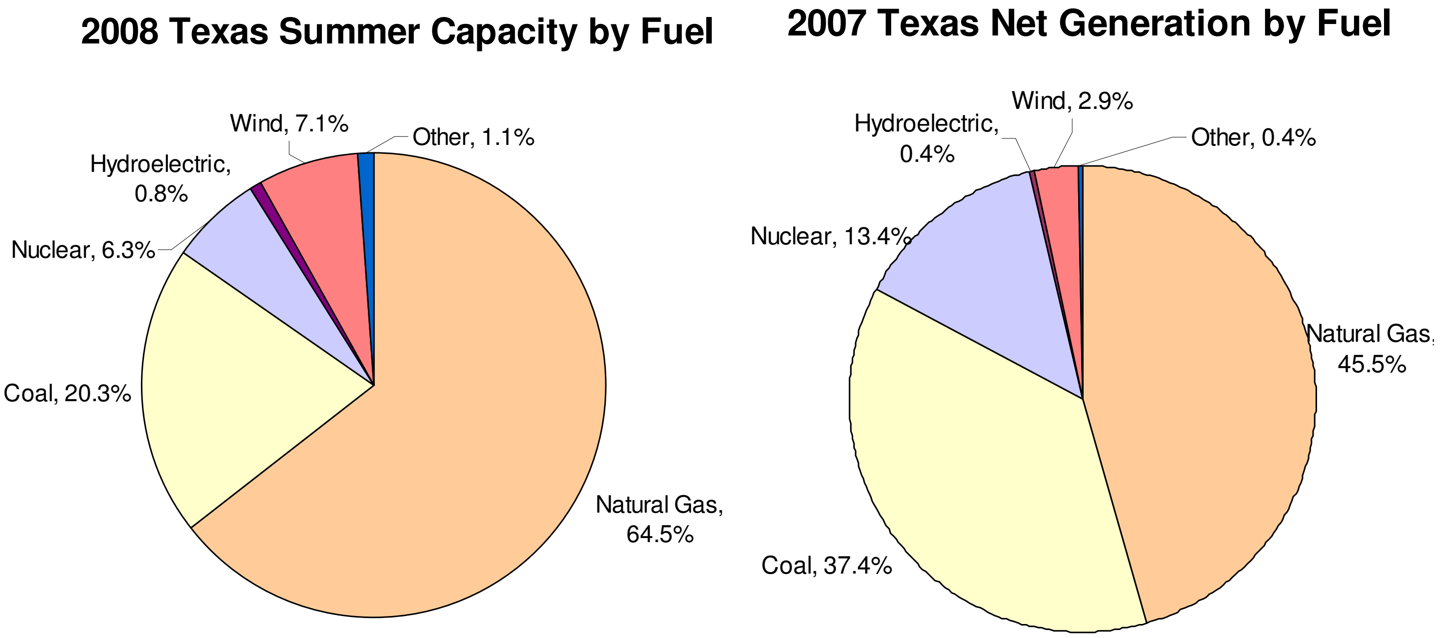


Figure 13. Electricity generating capacity in 2008 (left) and net electricity generation by fuel in Texas in 2007 [60].

Most of the recent growth in the state's generating capacity has come from natural gas power plants and wind turbines, as no new coal or nuclear power plants came online in Texas since 1992, although a few new coal units are close to completion (see section 2.4.2) (Figure 14). Much of the growth in natural gas capacity was planned in the late 1990's when natural gas prices were low. The subsequent rise in natural gas prices prompted some natural gas capacity to be mothballed. Texas wind capacity grew 57% in 2007 to a nation-leading 4,300 MW [61]. Although wind has grown to more than 4% of the state's capacity, it provides only about 3% of electricity generation because wind speeds are variable. Hydropower contributes only 1% (640 MW) of the state's electrical generating capacity and less than 0.5% of the energy produced. An additional

1,000 MW of undeveloped hydropower potential was identified by a 1993 study [62], but there are no major plans to develop that potential and doing so might entail significant regulatory, cost, and environmental hurdles.

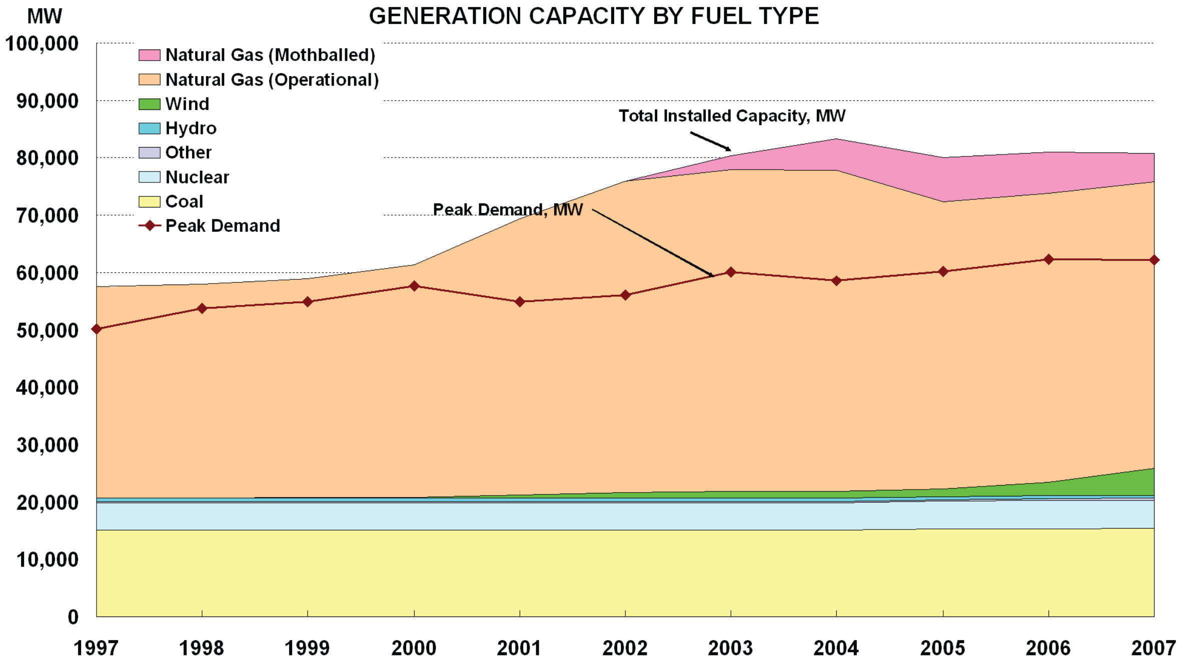


Figure 14. Trends in electricity generation capacity by fuel type (1997-2007) [63].

The state's 18 coal and two nuclear power plants are concentrated in the eastern part of the state, while most wind generation occurs in the Panhandle and western part of the state (Figure 15). The largest electricity generating power plants in Texas use coal and nuclear power as the fuel source (Figure 16). The South Texas Project has two nuclear reactors with a combined capacity of 2,700 MW, while Luminant's Comanche Peak facility has two reactors with a combined capacity of 2,430 MW. The W.A. Parish Electric Generation Station in Fort Bend County is the largest coal- fired power facility in Texas with 3,969-MW capacity.

The Horse Hollow Wind Energy Center in west-central Texas is the largest wind farm in the world with a total capacity of 735 MW and is located in Taylor and Nolan counties on approximately 47,000 acres of land. The Sweetwater wind farm recently doubled its capacity to 585 MW, while the Buffalo Gap wind facility expanded its capacity to 353 MW. The Capricorn Ridge wind facility in Coke County began operation in July of 2007 and can produce 364 MW of electricity. The Roscoe Wind Farm in Abilene, which is the largest new facility with 209 MW power capacity is located about 50 miles southwest of Abilene [61].

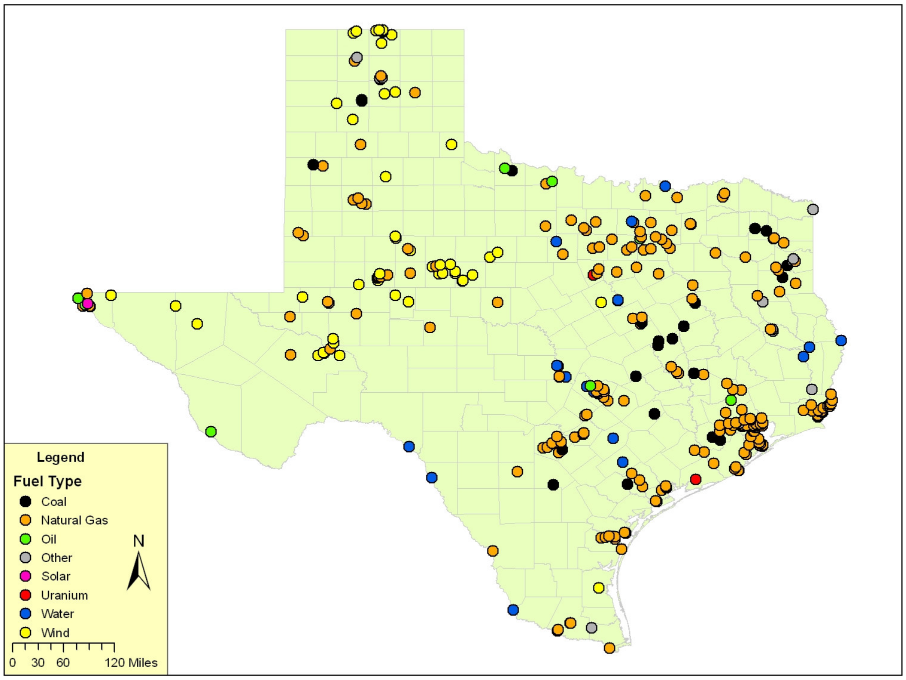


Figure 15. Texas power plants by fuel type. Source: Platts GIS Geospatial Mapping Data, 2006

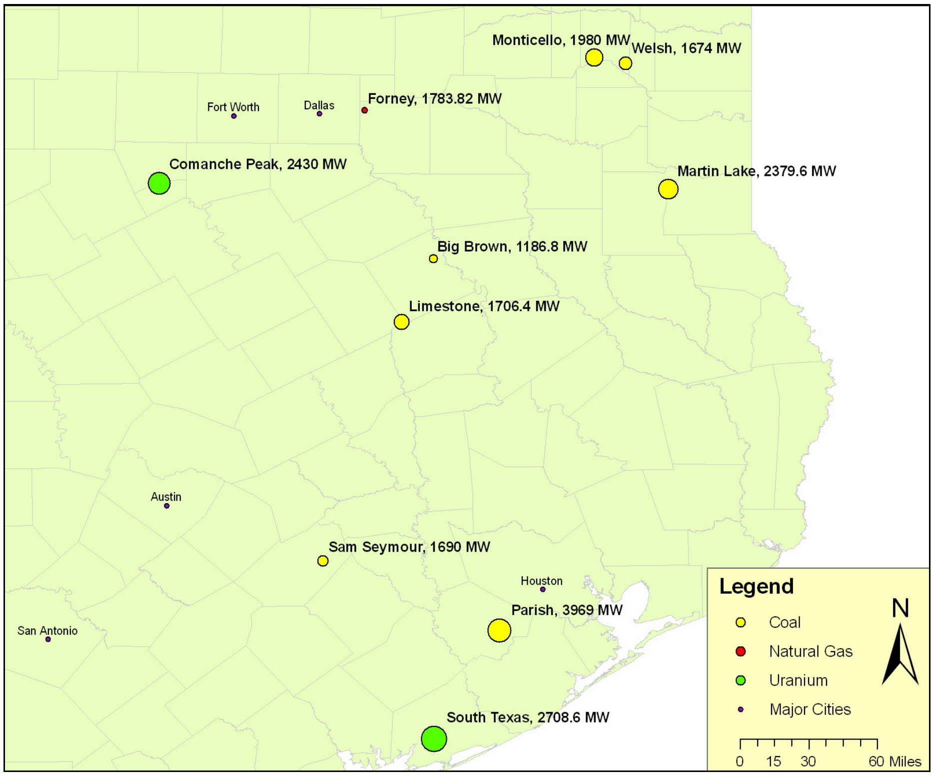


Figure 16. Largest generating plants in Texas in 2006 by capacity. Source: Platts GIS Geospatial Mapping Data, 2006.

Heavy reliance on natural gas, coal and nuclear power for electricity generation has important consequences for Texas. Natural gas offers important advantages for electricity generation, including its suitability for flexibly providing peaking load and its lower emissions than coal. However, price volatility for natural gas generally exceeds volatility in other energy markets, given the seasonal nature of demand and the lack of overseas trade. Natural gas prices have more than quadrupled since 2002 and can swing widely from month to month (Figure 17). The cost of electricity generated from natural gas is also more sensitive to fuel price fluctuations than other types of electricity, since fuel is the largest share of cost for natural gas electricity but a smaller share for capital-intensive generation like coal and nuclear.

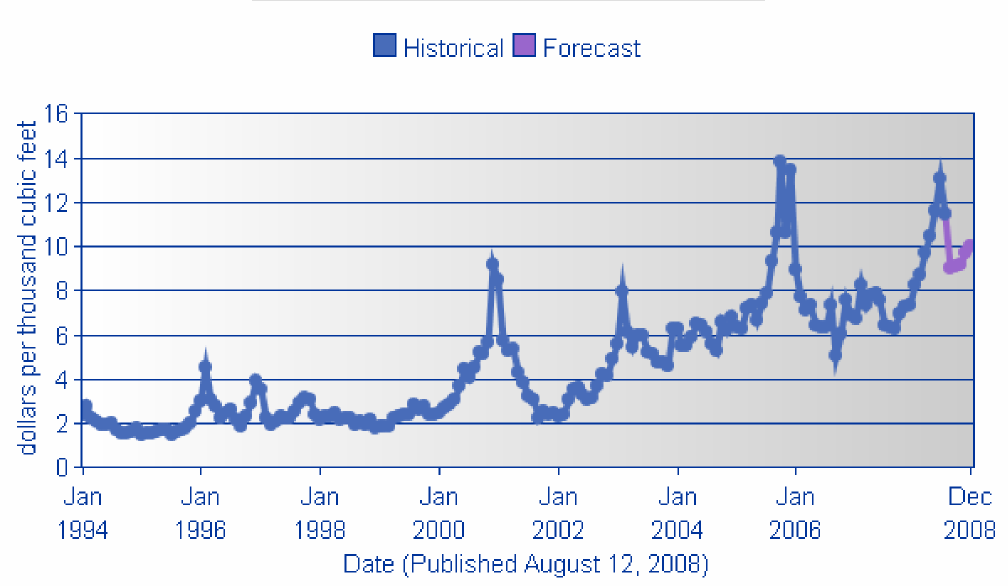


Figure 17. Monthly natural gas Henry Hub spot price [64].

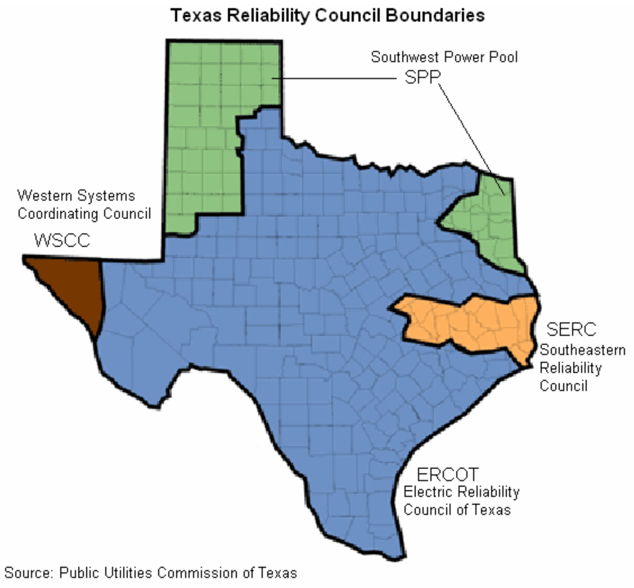
Resource scarcity is another drawback to using natural gas in electricity generation. Texas is the nation's leading producer of natural gas, but is also its leading natural gas consumer. Despite the existence of large gas reserves such as the Barnett Shale field in Northeast Texas, the state's new gas wells have been experiencing decline rates of more than 55% in early years, and these high decline rates suggest a decrease in Texas' production capacity in the near future [65]. North America contains less than 3% of the world's proved reserves of natural gas [66]. Some in the chemical industry have argued that natural gas is too valuable to burn and that natural gas combustion for electricity generation adds to the scarcity and cost faced by other natural gas consumers. T. Boone Pickens argues that natural gas should not be used for energy generation, instead should be conserved to be used for powering vehicles as an alternative to imported oil.

Coal provides a cheaper source of electricity that is less subject to price volatility, and a reliable source of baseload power. However, output from coal power plants cannot readily be adjusted to respond to changes in electricity demand load. The greatest drawback to coal generation is its heavy impact on air quality and the environment. The emissions impacts of coal electricity generation will be discussed in the next section. Those emissions may also significantly raise the future cost of electricity from coal if federal market-based policies are enacted to associate a price with emissions.

Nuclear power is another baseload source of electricity, with lower emissions of air pollutants and no direct greenhouse gas emissions. Nuclear power has achieved a solid safety record in the U.S. for the past three decades. However, nuclear power has critical drawbacks such as high and uncertain capital costs, heavy consumption of water, reliance on uranium mining, and a lack of long-term facilities for radioactive waste disposal.

2.2.1 Transmission and Distribution

A unique feature of Texas electricity markets is the Electric Reliability Council of Texas (ERCOT) system (Figure 18), the only entirely intrastate grid in the continental U.S. By contrast, other parts of the U.S. are served by regions connected through the Western Interconnect and Eastern Interconnect power grids. ERCOT manages the electricity market and brings electric power to 21 million customers in Texas, which account for 85% of the state's electric load and 75% of the Texas land area [63]. The relatively isolated nature of the ERCOT grid has the important consequence that electricity demand in Texas must primarily be satisfied by electricity generated within the state.



Source: Public Utilities Commission of Texas

Figure 18. Texas electricity grids

Within four electric grids serving in Texas, transmission and distribution service providers are responsible for the transmission of electricity to local retail electric providers (Figure 19). The transmission system has struggled with congestion for electricity flowing into certain urban regions, and lacks sufficient capacity for transmitting electricity from parts of the state with the greatest wind resources. Plans to expand transmission capacity to enable more wind generation will be discussed in Chapter 4.

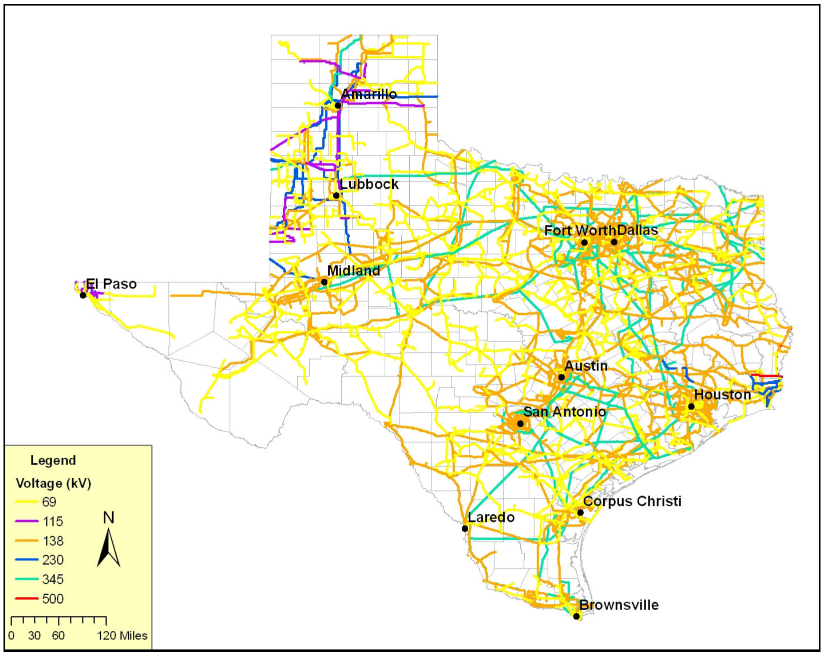


Figure 19. Texas transmission lines. Source: Platts GIS Geospatial Mapping Data, 2006.

2.3 Air Pollution from Electric Generation

2.3.1 Power plant emissions

As detailed in Chapter 1, electric generation causes the majority of SO_2 and Hg emissions in Texas and a significant share of PM2.5, NO_x and CO_2 (Figure 20).

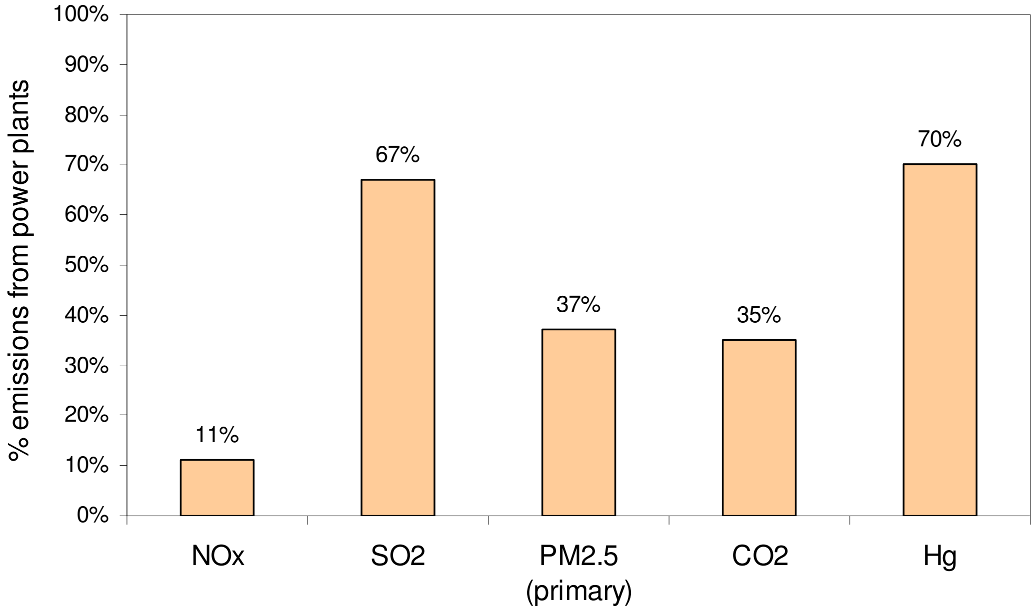


Figure 20. Share of Texas emissions contributed by power plants. (NO_x and SO_2 data [2, 67]; Hg [3]; CO_2 [4]).

Coal power plants are responsible for virtually the entire electric sector SO_2 and Hg emissions, and much of the sector's NO_x and CO_2 emissions (Table 2). Natural gas causes far fewer emissions per unit of electricity than coal.

Table 2. Texas electricity generation and emissions in 2006 [60].

Texas 2006 Generation and Emissions by Fuel Type

Fuel Type		Petroleum	Coal	Natural Gas	All Other Resources	Total Fuel Resources
Generation (TWh)		2	146	197	56	401
Emissions (1000 tons)	NOx	9	132	120	25	287
	SO2	32	577	1	6	615
	CO2	3163	165994	114743	0	283900
Emissions (lbs/ MWh)	NOx	10	1.8	1.2	0.9	1.43
	SO2	36.2	7.9	0.01	0.2	3.07
	CO2	3581	2268	1168	0	1417

Figures 21-24 show emissions levels from the major coal plants in Texas. Luminant's Martin Lake and the Monticello power plants in East Texas led the state and the nation in power plants mercury pollution in 2004, emitting 1,367 and 2,400 pounds, respectively [68]. They are also the state's largest emitters of NO_x and SO_2 and CO_2 [69]. However, they are being outfitted with new pollution controls as detailed in the following section (Luminant news release, Feb 2008).

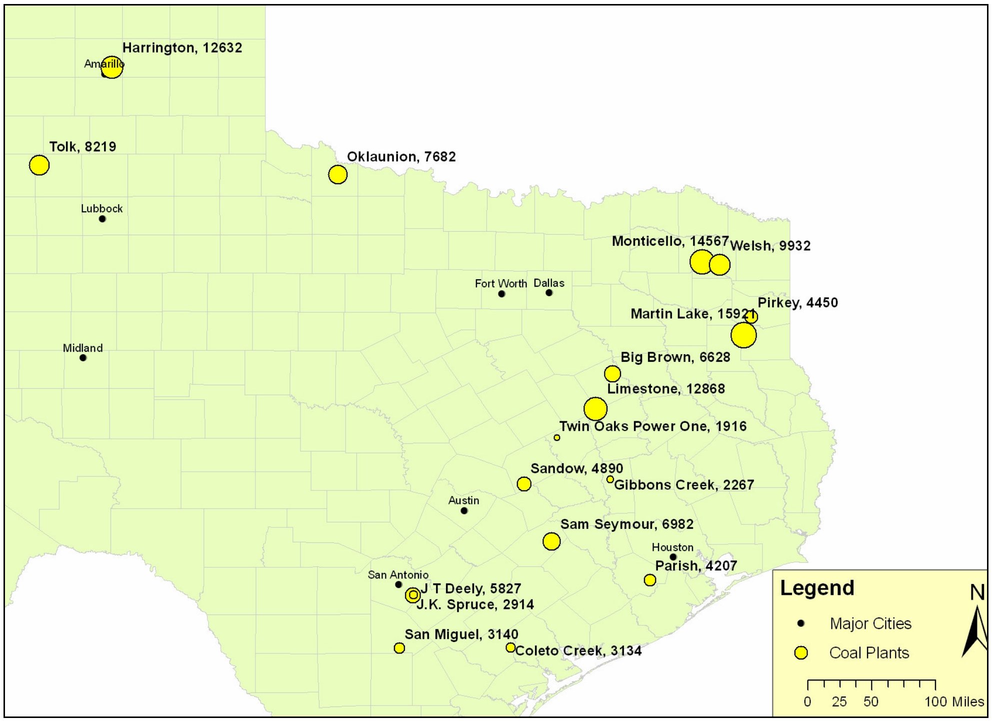


Figure 21. Largest NOx emitting power plants in Texas (emissions in tons). Source: EPA Clean Air Markets, 2007 data

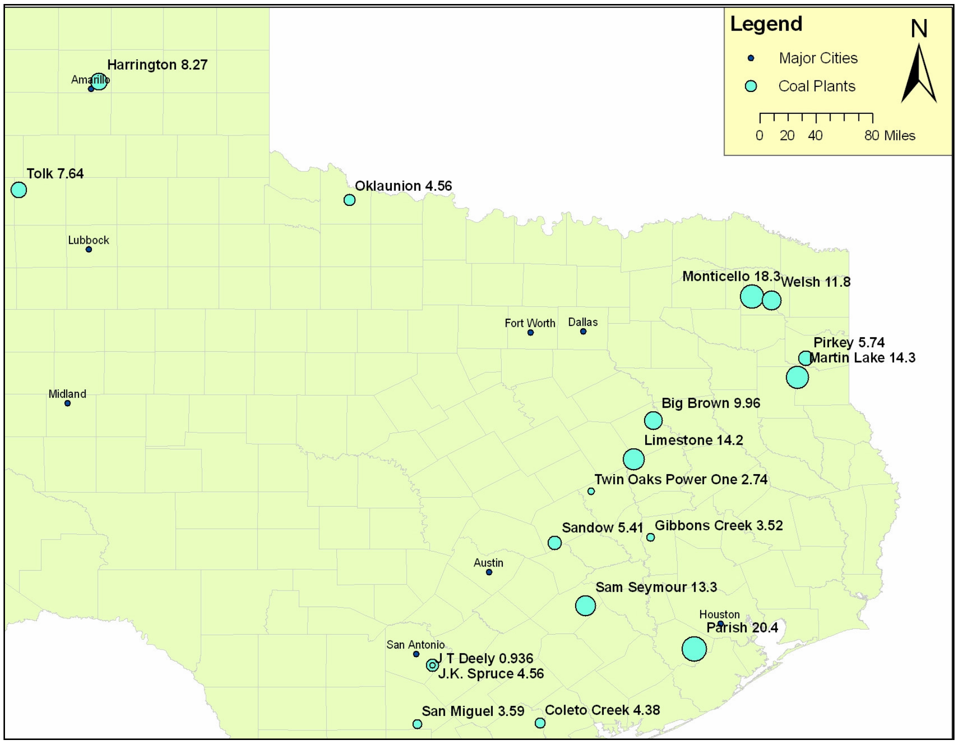


Figure 22. Largest CO_2 emitting power plants in Texas (emissions in millions of tons) Source: EPA Clean Air Markets, 2007 data.

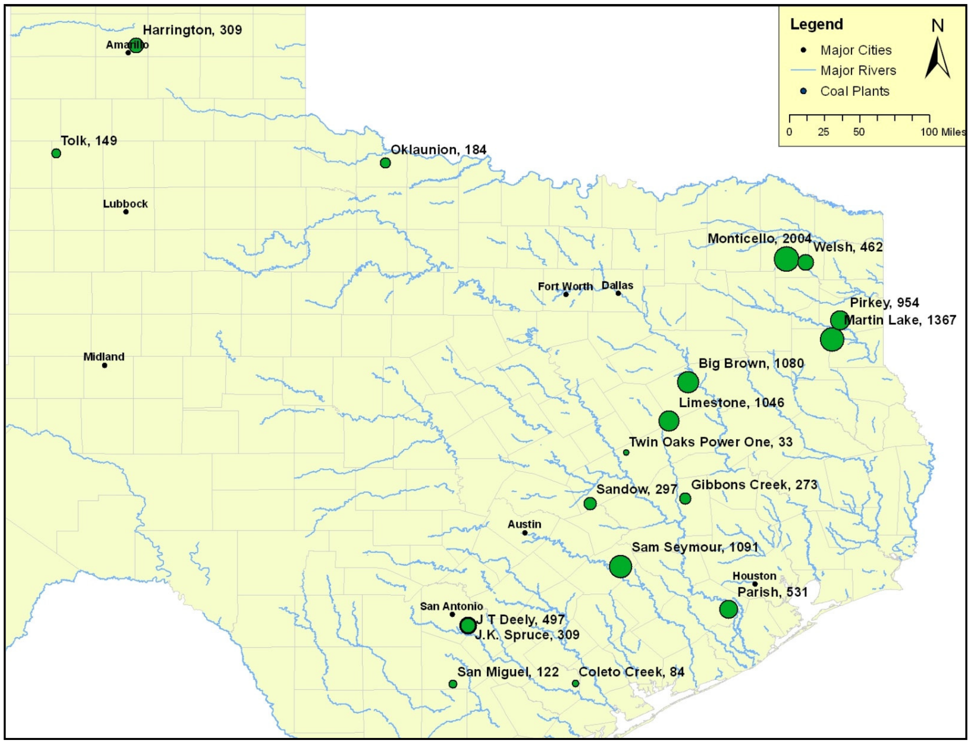


Figure 23. Largest Hg emitting power plants in Texas (emissions in lbs). Source: eGRID 2006, data from 2004.

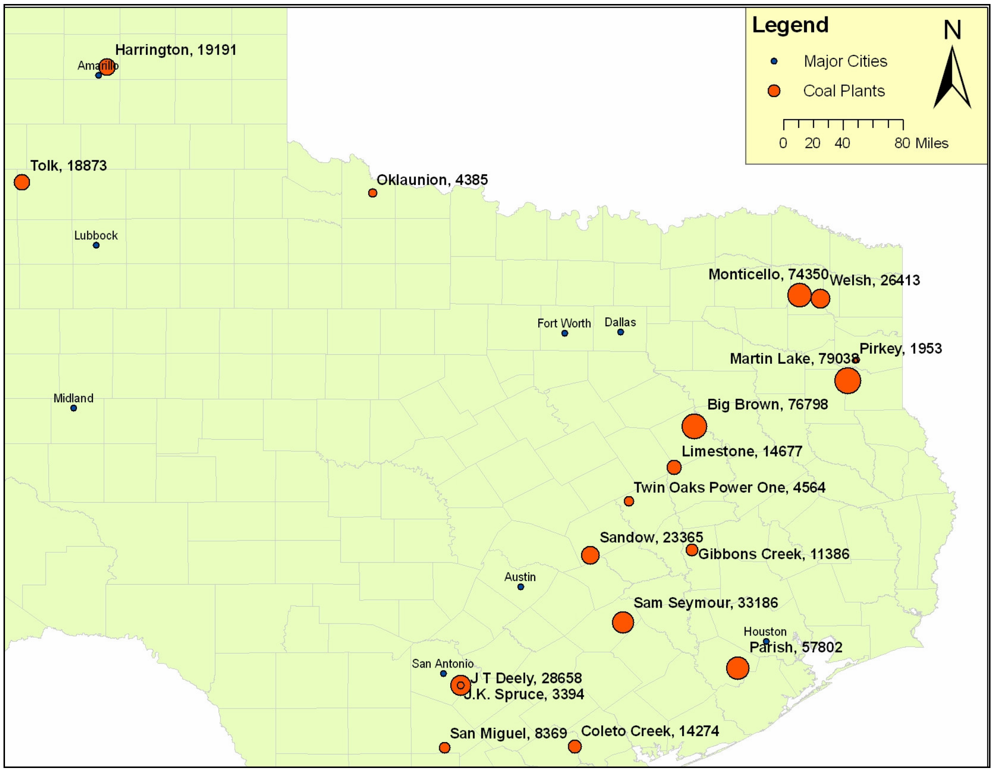


Figure 24. Largest SO2 emitting power plants in Texas (emissions in tons). Source: EPA Clean Air Markets, 2007 data

2.3.2 Emission control technologies

All of the state's 36 coal-fired boilers came on-line between 1971 and 1992, before the most effective emissions control technologies were widely available and before emissions regulations had been tightened. Since then, only the four boilers at the W.A. Parish Plant have been retrofit with the most effective control technology for NO_x, selective catalytic reduction (SCR). Luminant in early 2008 announced a $1 billion voluntary emissions reduction plan that includes SCR at Martin Lake and Sandow and selective non-catalytic reduction (SNCR) at Monticello and Big Brown for NO_x reduction, and activated carbon injection for mercury control system-wide [70]. Most other facilities use low NO_x burners, over-fire air, or a combination of the two, resulting in less effective NO_x control. Many facilities do not use effective controls for PM, SO_2, and mercury emissions either.

An analysis was performed to investigate the amount of emission reduction that could be achieved by these power plants if they were to meet current standards. The U.S. EPA issued standards in 2006 dictating the maximum levels of NO_x, SO_2, and PM emissions from any new or significantly modified power plant [71]. Table 3 compares the current emissions of Texas coal-fired power plants with the possible reductions that could have been achieved by (1) meeting the new unit emission standards, (2) meeting the reconstructed or modified unit emission standards, and (3) achieving the NO_x emission rates of the W.A. Parish Plant with SCRs. For CO_2, we compute the impact of achieving the heat rate[iii] (i.e., efficiency) that EPA expects new coal plants to achieve.

Table 3. Potential emissions reductions under different scenarios (Baseline NO_x, SO_2, and CO_2 emissions data from US EPA Clean Air Markets Division for 2007; for PM, the data is from NETL for 2004)

		NOx	SO2	PM	CO2
	Annual Emissions from Coal Power Plants	125,481	500,676	33,972	169,557,039
Possible Emissions Reductions (tons)	Reduction to meet the new unit standard	-53,000	-392,893	-23,408	
	Reduction to meet the modified unit standard	-20,133	-382,946	-23,408	
	Reduction to match performance of Parish SCRs	-93,414			
	Impact of a heat rate of 9,300 BTU/kWh on CO2 emissions				-15,685,571

The analysis clearly demonstrates that existing Texas coal power plants are emitting far more pollutants than would be permitted from new or modified units. Most Texas coal power plants are now emitting several times above the EPA limits but have been "grandfathered" because of their age. Requiring all existing plants to comply with those limits could reduce SO_2 emissions by nearly 80% and yield significant reductions in NO_x and PM. Although mercury is not considered in Table 3, control technologies are available to reduce mercury emissions by more than 90% [72]. The numbers in Table 3 may even understate the differences, because most proposals for new power plants anticipate emission rates far below the EPA maximal limits. With their capital costs already paid and their grandfathered status from environmental regulations, the old facilities enjoy enormous competitive advantages relative to other facilities, perpetuating their high emission rates. Because the emissions limits apply only if significant modifications are made, the plants face a significant disincentive to installing improvements that would trigger new source review. The voluntary emissions reduction plan by Luminant will provide important progress toward the potential identified by Table 3, but still leaves many coal power plants statewide that are not employing the best available control technologies.

[iii] Heat rate is a measure of the efficiency of converting a unit of fuel (MMBtu) into a unit of electricity (MWh); lower heat rates implies higher efficiency. CO2 emissions are proportional to heat rate.

2.4 Projected supply and demand

2.4.1 ERCOT projections for demand and supply

Texas has rapidly grown, with a population growth rate of 1.8% a year and economic growth of 3% a year from 2000 to 2006. The population is expected to grow at a rate of 1.7% a year through 2023 and the economy is projected to grow at 3.2% a year [73]. The demand for electricity in Texas has grown significantly as a result of this rapid growth. Over the past 10 years (1997-2007), ERCOT's average hourly load grew 2.3% a year and the system peak demand grew 2.4%. ERCOT projects average load growth of 1.97%/year and peak demand growth of 1.95%/year over the next decade (Figure 25) [6]. The growth rates are slightly lower than previous estimates due to less optimistic projections of economic growth and a small increase (10% per year) in efficiency. The demand projections do not account for federal energy efficiency measures already enacted by the Energy Independence and Security Act of 2007, or for potential additional steps to reduce demand.

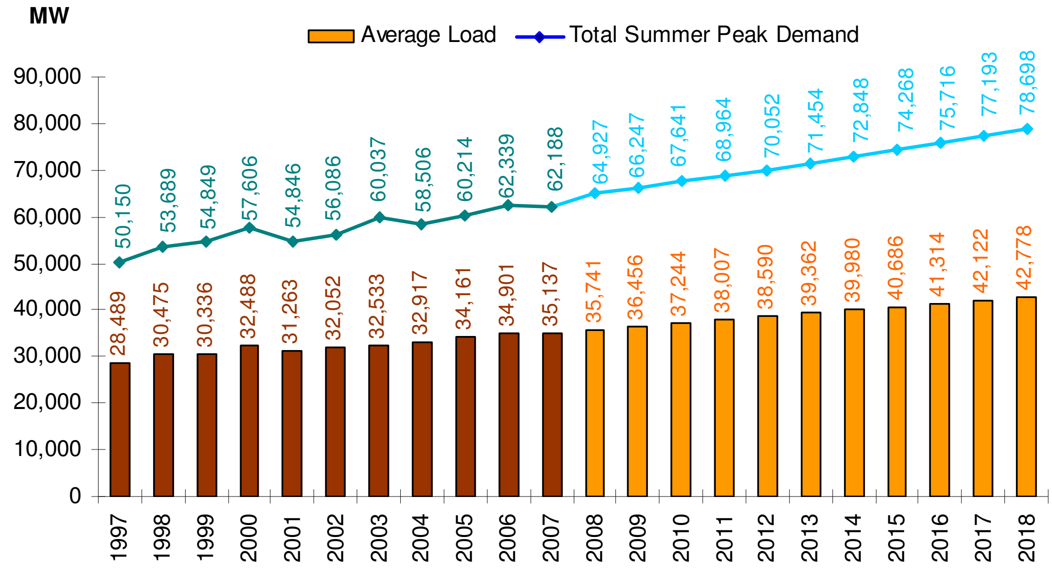


Figure 25. ERCOT historical (1997-2007) and forecast (2008-2018) average load system peak demand [6] .

As demand grows, it is important to ensure that there are sufficient resources to satisfy peak demand with an adequate reserve margin (12.5%) to ensure reliability. ERCOT projects that available generating resources will be more than sufficient to satisfy peak demand through 2012 [74] (Table 4). Although the reserve margin is forecast to dip below the 12.5% target in 2013, that margin does not include: (1) reductions in demand resulting from energy efficiency measures already enacted in the federal Energy Independence and Security Act of 2007 and the state legislature; (2) further growth in wind and solar generation; (3) mothballed capacity; and (4) units in the final phase of interconnection that are awaiting an air permit or interconnection agreement. Including the renewables capacity and the projections of the American Council for an Energy-Efficient Economy for additional demand response and energy efficiency programs would result in a reserve margin far above the targeted level and offset virtually all projected growth in peak demand in Texas through the year 2023 (Table 4).

NOx emission reduction benefits of these recommended energy efficiency measures were approximated by multiplying the annual electricity savings estimations from ACEEE report, and overall NOx emission rate of Texas electricity generation, which is 1.43 lb per MWh (Table 2). NOx emissions to be saved by implementing these energy efficiency measures were also presented in Table 4.

2.4.2 Planned Electricity Generation Capacity in Texas

In 2006 TXU proposed to build 11 coal-fired power plants. One year later, when TXU was bought to become Luminant, it cancelled plans to build eight of the 11 units.

As of July 3, 2008, eleven coal-fired boilers (totaling 4,566 MW) and 5,345 MW of natural gas capacity are already permitted and under construction. In addition, seven coal-fired (3,250 MW) and 54 gas-fired plants (13,622 MW) are seeking permits to start construction, and six nuclear units (8,940 MW) plans to apply for a permit by the end of this year (Tables 5 and 6).

The permitted and pending coal plants are expected to emit up to about 21,100 tons per year of NO_x, compared to the 287,000 tons emitted by all Texas power plants in 2006 (Tables 2 and 6). The plants will use SCR or SNCR to bring their NO_x rates to 0.05-0.10 lb/mmBtu (SCR facilities toward lower end of range, SNCR toward higher end), compared to an average 0.16 lb/mmBtu for existing Texas coal plants. The permitted and pending plants will have SO_2 emissions up to 42,100 tons, compared to the 615,000 tons from 2006, and per-MMBtu rates several times below existing coal plants. However, none of the proposed plants would implement carbon capture and storage to control CO_2.

As for renewable resources, at least 1,708 MW of installed wind projects came on line in West Texas in 2007, with an additional 3,290 MW will come online in 2009 [75]. In addition, T. Boone Pickens proposes to build a 4,000-MW wind energy facility on 200,000 acres in five counties Texas Panhandle and to sell the electricity produced into the ERCOT grid. Ineo USA has applied for a permit to add two solar units (30-MW total) to its facility in Brazoria County. Fort Bliss built a 1.5 MW solar photovoltaic power plant in 2006 and a 20-MW unit in 2007. They plan to extend the facility in 2008 and 2009 to generate 1,000 MW solar power [76]. The City of Austin is planning to build a 30-MW solar plant by 2009 and, a much larger solar plant in West Texas of 100 or 200 MW by 2020 [77].

Table 4. Electricity resources and demand in the ERCOT region.

Units in MW	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Total Resources [1]	75,749	77,894	77,918	78,843	78,843	78,843	78,843	78,843	78,843	78,843	78,843	78,843	78,843	78,843	78,843
Total Demand with Reserve (12.5%) [1]	73,157	74,724	76,213	77,437	79,015	80,555	82,126	83,728	85,360	85,360	88,722	90,452	92,216	94,014	95,847
Difference	2,593	3,170	1,705	1,406	-172	-1,712	-3,283	-4,885	-6,517	-6,517	-9,879	-11,609	-13,373	-15,171	-17,004
Energy Efficiency [2]															
Appliance Stds [2]															
Old	112	167	203	238	264	290	316	341	368	393	419	445	460	475	490
Proposed	37	56	68	79	88	97	105	114	122	131	140	148	153	158	163
Building Codes [2]	166	334	476	622	754	899	1,054	1,177	1,282	1,394	1,498	1,754	1,932	2,148	2,362
CHP [2]	238	463	677	881	1,075	1,258	1,433	1,599	1,756	1,906	2,048	2,183	2,312	2,434	3,750
Expand LoneSTAR [2]	85	170	257	344	433	523	616	704	796	888	988	1,088	1,188	1,292	1,398
EEPS [2]	254	528	859	1,188	1,514	1,836	2,156	2,472	2,794	3,112	3,430	3,746	4,060	4,374	4,686
Total Energy Efficiency Savings	**892**	**1,718**	**2,539**	**3,352**	**4,128**	**4,903**	**5,680**	**6,407**	**7,118**	**7,824**	**8,523**	**9,364**	**10,105**	**10,881**	**12,849**
Projected Gap [3]	3,485	4,888	4,244	4,758	3,956	3,191	2,397	1,522	601	1,307	-1,356	-2,245	-3,268	-4,290	-4,155
Renewables (Solar and Wind) [4]	784	789	1,063	813	1,313	1,813	2,313	2,313	2,313	2,813	2,813	3,313	3,813	3,813	3,813
Demand Response [2]	1,130	1,595	2,148	2,775	3,463	4,209	4,955	5,766	6,566	7,573	8,650	9,735	10,858	12,050	13,241
Total [5]	**5,399**	**7,272**	**7,454**	**8,346**	**8,731**	**9,213**	**9,665**	**9,601**	**9,480**	**11,693**	**10,107**	**10,803**	**11,403**	**11,573**	**12,899**
Tons of NOx saved per year [6]	3,059	5,821	8,675	11,441	14,111	16,772	19,515	22,300	24,846	27,466	29,908	32,669	35,264	37,854	40,406

[1] Total resources and demand are from ERCOT's 2008 report [6]. Total demand up to 2013 was projected and reported by ERCOT; total demand from 2013 to 2023 was calculated using a 1.95% load growth rate.

[2] Energy efficiency and demand response projections are from ACEEE report [73].

[3] Projected gap = (total resources + the energy efficiency savings) - total demand with reserve.

[4] "Renewables" include solar and wind. Capacities of wind projects are included at 8.7%. ERCOT counts 8.7% of the installed wind capability as dependable capacity during peak demand periods.

[5] Total = total resources+ energy efficiency savings+ demand response+ renewables capacity- total demand with reserve. These numbers assume the adoption of TBCA's legislative agenda in totality.

[6] These values were calculated based on the overall NOx emission rate of Texas electricity, which is 1.43 lb/MWh (Table 2), and multiplying that by the annual electricity savings (in MWh) for each energy efficiency policy as reported in [73].

Table 5. Capacity of proposed power plants (permitted or awaiting permit) by July 3, 2008. Source: TCEQ, [75]. (see Table 8 for detail of coal-fired units.)

Fuel Type	Permit Status	Total Number of Units	Capacity (MW)
Gas	Pending	54	13,622
	Permitted since 2005	25	5,345
Coal	Pending	7	3,250
	Permitted since 2005	11	4,566
Nuclear	application expected by 9/2008	6	8,940
	Permitted in 2007	2	2,700
Wind	online in 2009		3,291
	online in 2010		60
	online in 2011		270
Solar	pending	2	30
Biomass	under construction		100

Table 6. Proposed coal plants (permitted or awaiting permit) by July 3, 2008. Source: TCEQ

Applicant Name	County	Date application received	Date permited	Fuel	# of New Boilers	Capacity (MW)	Control Technologies	NOx (TPY)	SO2 (TPY)	PM (TPY)	Hg (TPY)
City Public Service J.K. Spruce	Bexar	11/24/2003	12/28/2005	Subbituminous	1	750	SCR, LNB, Wet FGD, FF	1752	2102	771	0.07
Sandy Creek Energy Associates	McClennan	1/9/2004	1/9/2004	Subbituminous	1	800	SCR, LNB, OFA, Dry FGD, FF	1804	3585	1490	0.075
Formosa Plastics Corporation, Texas	Calhoun	5/31/2005	5/31/2005	Petroleum Coke, Subbituminous	2	300	SNCR, Limestone Injection, FF	920	2608	544	0.04
Nacodoches Power LLC	Nacogdoches	12/22/2005	3/1/2007	Wood Refuse Biomass, Natural gas	2	430	SCR, LNB, Wet FGD, FF	759	171.6	96.6	NA
Oak Grove Management Company LLC	Robertson	7/27/2005	6/13/2007	Lignite	2	1600	SCR, LNB, OFA, Wet FGD, FF	6286	15085	3144	0.72
Calhoun County Navigation District - E.S. Joslin Power Station	Calhoun	7/11/2005	8/20/2007	Petroleum Coke	1	300	SNCR, Limestone Injection, FF	813	2071	597	0.035
Sandow Power Company LLC	Milam		12/27/2007	Lignite	2	564	SNCR, Limestone Injection, FF				
Total of Permitted					**11**	**4744**		**12334**	**25622.6**	**6642.6**	**0.94**
NRG Texas Power, LLC-Limestone Electric Generating Station	Limestone	6/12/2006	Pending	Subbituminous, Bituminous, Petroleum Coke	1	800	SCR, LNB, Wet FGD, FF	1752	2102	1226	0.07
Coleto Creek LLC	Goliad	1/4/2008	Pending	Subbituminous, Bituminous	1	650	SCR, LNB, OFA, Dry FGD, FF	1461	1753	935	0.07
Tenaska Trailblazer Partners LLC	Nolan	2/19/2008	Pending	Subbituminous	1	600		1819	2183	1092	0.2
Las Brisas Energy Center, LLC	Nueces	5/19/2008	Pending	Petroleum Coke	4	1200	SNCR, Limestone Injection, FF	3776	10480	2808	0.16
Total of Pending					**7**	**3250**		**8808**	**16518**	**6061**	**0.5**

SCR=Selective Catalytic Reduction, LNB=Low Nox burner, OFA=Over fire air, FGD=Flue Gas Sulfurization, FF=Fabric Filter

Chapter 3

Technologies for Addressing the Energy-Air Quality Challenge

The previous two chapters illustrated the challenges of assuring sufficient, reliable, and affordable supplies of electricity while reducing the impacts of electricity generation on air quality in Texas. To address those challenges, it will be necessary to reduce power plant emissions, reduce electricity consumption, and replace some of the need for fossil fuel generation. A variety of renewable energy, energy efficiency, and emissions control technologies all have the potential to help meet those objectives. This chapter will critically review the current status of each option, its current and potential level of use in Texas, and its potential for helping to balance electricity demand and supply and reduce air pollutant and greenhouse gas emissions. It will also present analyses comparing the cost-effectiveness and potential impacts of each option for increasing electricity supply, reducing electricity demand, or reducing air pollutant emissions.

3.1 Energy efficiency and conservation

Energy conservation means reducing the amount of energy consumed, either by energy efficiency measures (using less energy to achieve the same or higher performance) or by decreasing the use of energy consuming services. Energy efficiency and conservation could offset a significant portion of Texas' future energy demand growth. The residential sector accounts for the largest amount of potential efficiency savings, followed by the commercial sector and then industrial uses. Energy efficiency options associated with residential and commercial buildings include improvements in lighting, HVAC (Heat-ventilation air conditioning) equipment and building shells, electronic equipment, appliances and water heaters. The American Council for an Energy Efficient Economy has estimated that energy efficiency could reduce peak demand by 17% and total electricity consumption by 11% in Texas (Figures 26 and 27) [73]. In these figures, the rising top line reflects "business as usual" before enacting additional energy efficiency or other measures. Opportunities for efficiency will continue to increase as improved technologies emerge in the future. For example, the U.S. DOE Zero-Net Energy Commercial Buildings Initiative aims to develop economically viable buildings that offset all their electricity use through energy efficiency and renewable energy technologies.

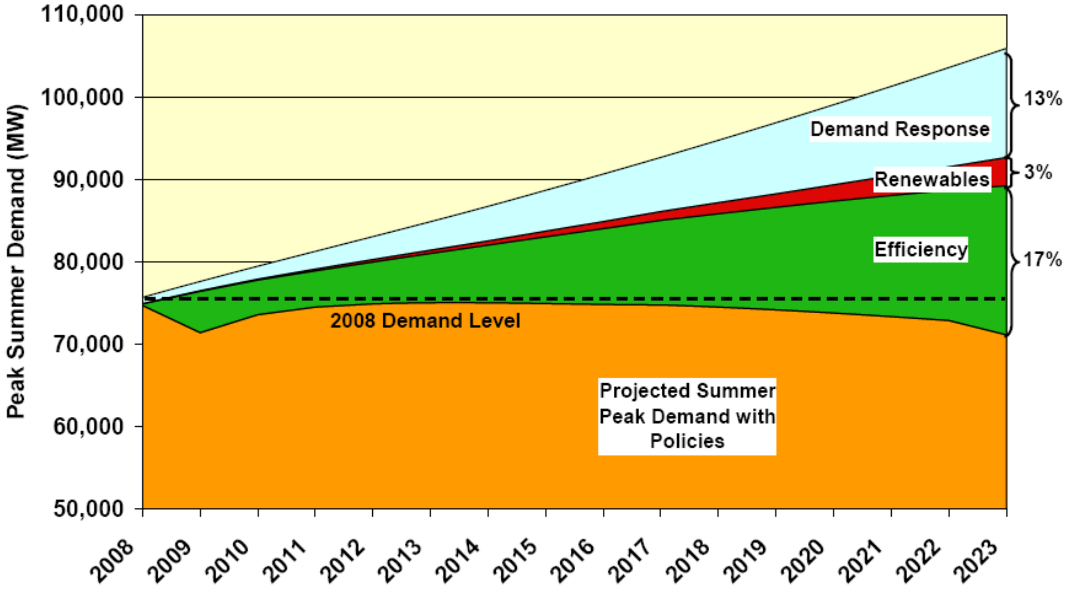


Figure 26. Fraction of summer peak demand that can be met with demand response, efficiency, and renewable resources [73].

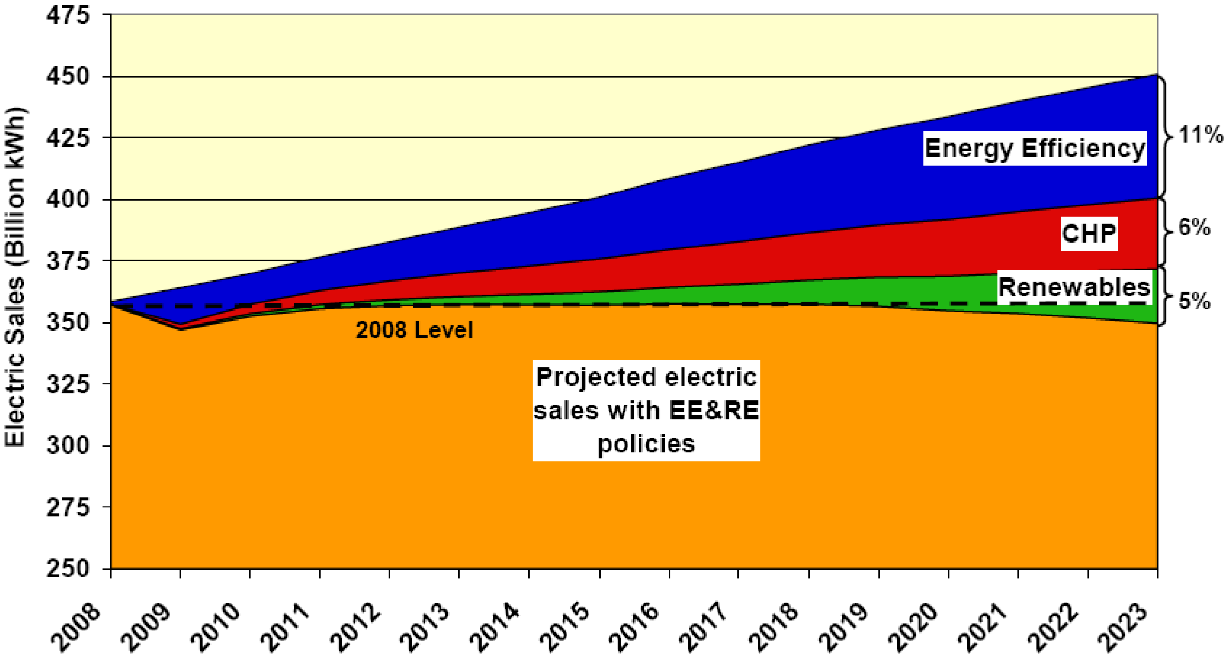


Figure 27 Share of future electricity consumption that can be met with efficiency and renewables resources [73]. (Figure produced before HB3693 enacted at state level)

Technologies for improving energy efficiency include the following:

Lighting: A report by McKinsey found that lighting offers the most cost-effective energy efficiency improvement potential [73]. ACEEE found improved lighting efficiency to have the greatest potential for reducing commercial sector electricity use in Texas [73]. The reductions can be achieved by using higher efficiency lighting, such as compact fluorescent lights (CFLs) and light emitting diode (LED). To produce the same amount of light, a CFL uses an approximately 30% and an LED uses 12% of the power of an incandescent bulb, and they last 8 and 40 times longer, respectively. Long lifetime and efficiency overcome higher upfront costs to yield significant net savings [78].

***HVAC Equipment and Building Shells*:** Texas A&M ESL has found that both new residential and commercial buildings could achieve at least 15% energy savings beyond building codes [79, 80]. Better insulated windows and doors, leak proof ducting, additional attic and wall insulation and other measures could greatly reduce heating and cooling needs for residential buildings. Existing homes can also be made more efficient by improvements to the building shell, such as increased attic insulation [78]. ACEEE reported that improved building shells together with more efficient HVAC equipment could reduce Texas residential electricity consumption by 38,000 GWh in 2023, the largest potential residential electricity savings identified by the report [81]. For commercial buildings, McKinsey report suggested that use of programmable thermostats, insulation, reflective roof coatings, and other measures may improve heating and cooling efficiency by additional 15 to 20% [78].

***Electronic Equipment*:** Energy use could be substantially reduced by establishing or raising performance standards and reducing stand-by losses in PCs, office equipment, TVs, audio systems, and other devices. Many electronic devices continue to draw power when not functioning or apparently turned off, such as a DVD player on but not playing or a microwave not in use, but its clock is on. Energy use due to these standby losses can be reduced by simply unplugging the device when not in use.

Industrial Sector: Options for reducing industrial electricity use include upgrading electric motors and improving end-use-specific systems to increase efficiency [78]. ACEEE identified a wide array of options for reducing industrial electricity use in Texas at costs of less than 3¢/kWh, including sensor and controls; electric supply improvements; motor management; fans; and pumps. [81]. The largest potential reductions identified by ACEEE were in the petrochemical industries.

3.2 Wind Power

3.2.1 Status of Technology

Wind power generates electricity with virtually no direct emissions and minimal use of water and other resources. It can provide significant environmental benefits by offsetting the need for other energy sources. While some bird and bat fatalities have been attributed to wind turbines, properly sited wind facilities are not thought to cause significant damage to bird and bat populations [82].

Wind power is generated when wind rotates the rotors of a turbine, operating a generator that creates electricity. Virtually all modern turbines for utility scale power are horizontal-axis turbines featuring rotating blades similar to those of an airplane propeller [83]. The typical modern wind turbine has a three-blade rotor with a diameter of 230-260 ft. mounted on a tower measuring 200-260 ft. in height. Utility-scale wind turbines are grouped together to form wind farms containing 30-150 turbines averaging an output of 1.6 MW of electrical power per turbine [84].

Wind turbines can produce power at a minimum wind speed of about 12 miles per hour and reach their maximum power output at 30 mph [84]. The amount of energy available to a wind turbine also increases in proportion to the cube of the wind speed, making a doubling in wind speed equivalent to an eight-fold increase in energy potential. Wind speed increases with height, leading to modern turbines with much taller towers and larger rotors. Wind turbines can be located on land or off-shore. Off-shore wind farms take advantage of higher average wind speeds over water, but are much more expensive to build and maintain than land-based farms.

Since wind does not blow all the time, the power generated by a turbine compared to the possible power generated if the turbine operated at full capacity all the time is an important indicator of wind power performance. This is measured by a capacity factor. Higher capacity factors increase the amount of electricity generated per turbine and reduce the cost per kilowatt-hour. Modern turbines have average capacity factors of about 34 percent. In Texas, capacity factors had reached an average of 35 percent by 2005 [85]. Many new wind power projects in prime locations boast capacity factors of about 40 percent. Capacity factors of about 40 percent can be expected for many of the new wind farms being built in West Texas and the Panhandle [86].

Capacity factors could improve further in the future. Increasing the size and height of turbines could improve their performance, and would require the use of lighter materials to minimize weight. New rotor-blade shapes, lighter, more efficient gearboxes and integrated control systems can also increase capacity factors and reduce costs [84]. According to an NREL study on potential technological improvements for wind turbines, improvements to the rotor alone could increase capacity factors by 10-35 percent [87].

The intermittency problem of the wind power could be solved using energy storage technologies, including compressed air storage, flywheels, and flow batteries. The wind energy could be stored during the night and could be released in the morning when the power demand is rising. Although there is no current wind farm with already installed storage systems, compressed air energy storage technique is being evaluated for installation in McCamey wind farm in Texas and in Iowa Stored Energy Park ([88], www.isepa.com)

3.2.2 Cost

The use of wind power is growing rapidly, both in Texas and around the world. During the last decade, wind energy growth rates worldwide averaged about 30% annually and nearly 50% annually in Texas [83]. While high production rates have resulted in price declines of about 80% since the late 1990's [83], high demand for wind power and commodities generally in the last few years have resulted in rising materials prices, while the falling value of the U.S. dollar has raised the cost of turbines imported from Europe.

Unlike many traditional electricity generating technologies, the cost of wind energy is highly correlated with the quality of wind resource at the development site and the type of wind turbine technology employed to capture the resource. Because energy production from wind turbines increases in proportion to the cube of the wind speed, the cost of energy from a wind turbine will decrease eight-fold by a doubling in wind speed. As a result, turbine manufacturers are quickly providing larger turbines on taller towers to reach greater wind speeds existing hundreds of feet above ground. The cost of wind energy is also highly dependent on whether the facility is located on or off-shore. While off-shore wind farms take advantage of higher average wind speeds over water, they are much more expensive to build and maintain than land-based farms. The actual cost of energy produced by wind turbines is a complex calculation comparing anticipated energy production with site-specific capital and development costs.

Several recent attempts have been made to estimate the cost of wind energy. For example, the U.S. EIA Annual Energy Outlook 2008 estimates levelized costs[iv] of 7.4 cents per kWh for new wind turbines coming on line by 2015 [89] (Figure 28). This does not account for the federal production tax credit of 2 cents per kWh, which was set to

---

[iv] The present value of the total cost of building and operating a generating plant over its economic life. Costs are levelized in real dollars (i.e., adjusted to remove the impact of inflation).

expire in December 2008 but was extended until the end of 2010. The 2008 analysis by Lazard Ltd estimates the cost of wind power to be 4.4-9.1 cents/kWh, including the 2 cent production tax credit [90]. In Texas, the cost of wind energy is believed to be on the low end of the cost scale, due to high quality wind resources existing in the state and due to lower development and installations costs [83]. While the current unsubsidized cost estimates for wind are slightly higher than for traditional electricity technologies using fossil fuels, full consideration of energy costs, including the value of environmental benefits, actually causes wind to be one of the most cost-effective energy options as will be seen later in this chapter. Wind also avoids the risk of future rises in fuel costs that can be problematic for some other electricity sources.

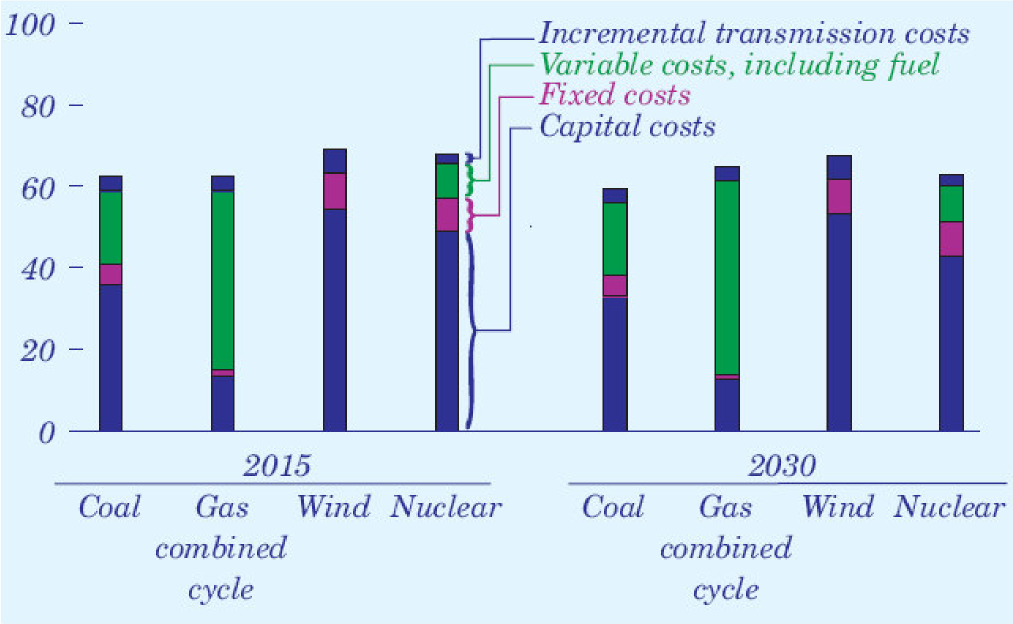


Figure 28. Levelized electricity costs for new power plants, in mills per kWh, predicted by U.S. Department of Energy in Annual Energy Outlook 2008 [89]. A mill is a tenth of a cent. Note: Other sources estimate much higher costs for nuclear power (see Table 7, footnote q).

3.2.3 Wind power potential in Texas

Texas already leads the nation in installed wind generation capacity, and also contains the largest land-based wind farm in the world (Figure 29) [83]. Wind power development in Texas has seen a four-fold increase since the establishment of Renewable Portfolio Standard 1999 [91]. In 2007, Texas increased its capacity by 57 percent, going from 2,739 MW of installed capacity to 4,296 MW. The nation as a whole increased capacity by 43 percent over the same time period [92]. 1,708 MW of installed wind projects came on line in West Texas in 2007, with an additional 3,290 MW will come online in 2009, and this total does not include the 4,000-MW wind farm that is being built by T. Boone Pickens in Pampa, TX (see section 2.4.2).

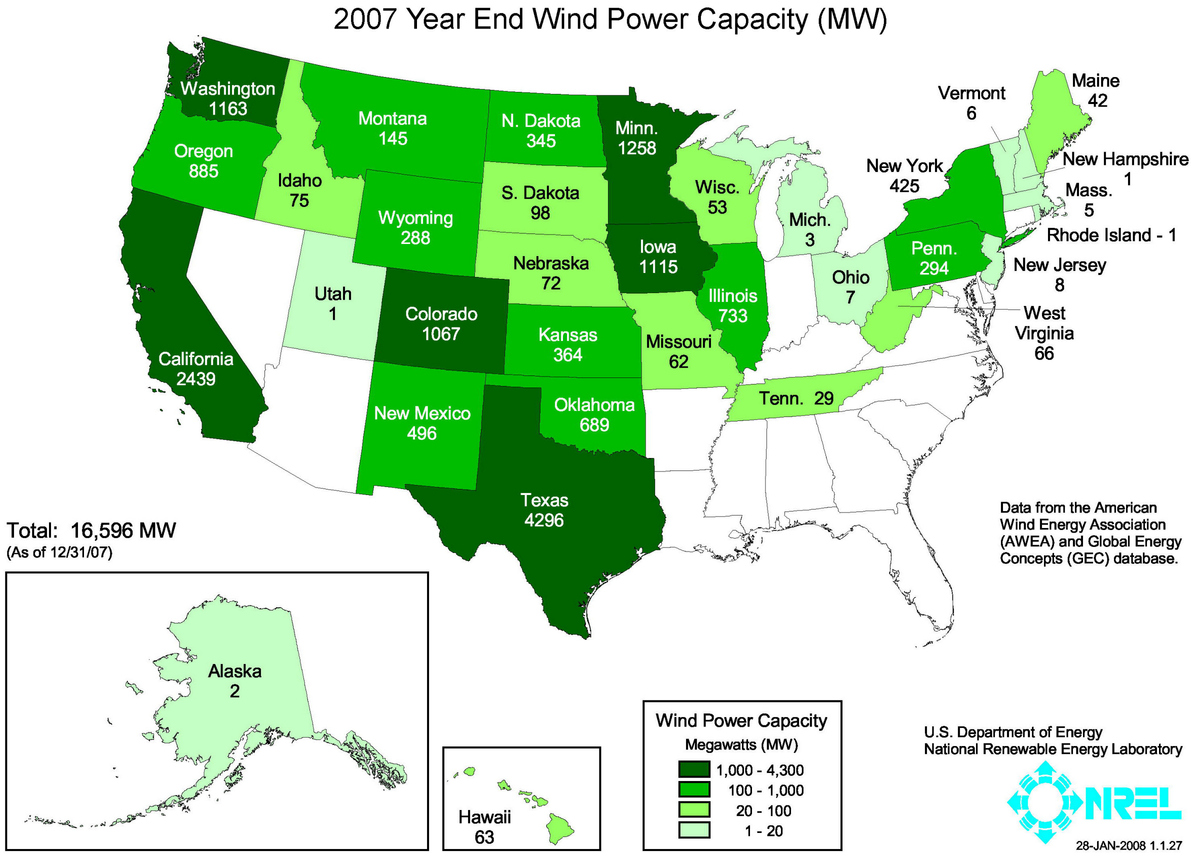


Figure 29. Wind power capacity by state, 2007. [92]

The Panhandle and West Texas mesas have excellent conditions for the generation of wind power. Parts of central Texas and the Gulf Coast south of Galveston also have good wind conditions (Figure 30). The McCamey area, south of Odessa and Midland, are the first wind development sites in the state. West-Central Texas, encompassing the Sweetwater/Abilene area, has the state's largest concentration of wind development, including three of the nation's largest wind projects [93]. The area hosts the world's largest wind farm, FPL Energy's 735 MW Horse Hollow site, with 428 wind turbines in Nolan and Taylor counties [94]. The most promising wind-generation locations in Texas are expected to achieve capacity factors ranging from 38 to 43 percent [86].

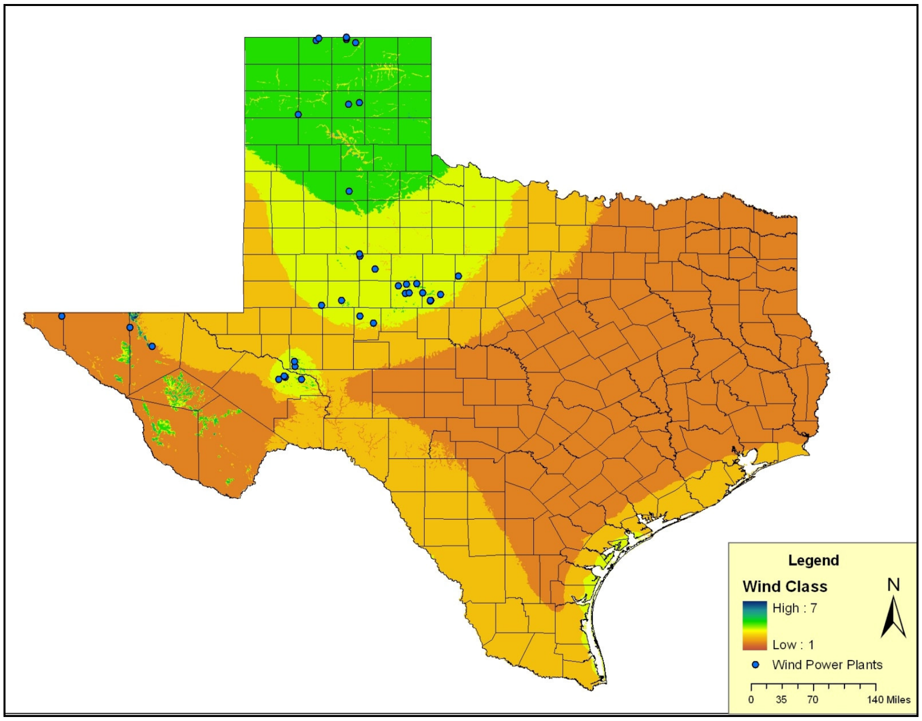


Figure 30. Wind potential (*West Texas A&M. Alternative Energy Institute*) and wind power plants (*Platts GIS Geospatial Mapping Data, 2006*) in Texas.

Intermittency poses a major hurdle to expanded reliance on wind power in Texas, but one that can be addressed. Wind speeds vary and are difficult to predict, creating a challenge for grid operators in balancing supply and demand. For example, on February 26th 2008, ERCOT's wind production dropped 82 percent in three hours and ERCOT was required to reduce power to industrial customers when back-up sources were unable to provide enough reserve power [83]. Winds often stagnate during hot summer days when electricity needs in Texas are at their highest [86]. For these reasons, there are concerns about wind's ability to provide a reliable source of electricity, especially during periods of peak demand. However, Germany, Spain and Denmark have all successfully integrated high levels of renewable energy generation into their electric grids while maintaining energy reliability [95]. With proper planning and adoption of best practices, wind penetration of at least 20% can be effectively accommodated in electric grids [96, 97]. Texas is especially well suited for handling intermittency, because it contains a large amount of natural gas facilities that provide flexible amounts of power, and because its wind resources are in diverse locations to smooth out conditions on each day.

The final major challenge to wind power growth is transmission. Wind power is often produced far from urban areas where electricity demand is greatest. Construction of new transmission lines from wind farms to load centers is expensive and time-consuming. Nonetheless, Texas has recently taken a major step toward providing new transmission capacity to support large-scale growth in the wind sector.

On July 17th, 2008, the Texas Public Utilities Commission approved a plan to construct 18,456 new megawatts of transmission capacity linking wind farms in the Panhandle and West Texas to urban areas of the state. The new capacity could power 3.7 million homes on a hot summer day, or 11 million in milder weather, and is estimated to cost $4.93 billion [98]. The plan is by far the largest transmission capacity addition for renewable energy ever approved in the United States. With the timely approval of this plan, Texas became the first state having a power grid area to deal with providing transmission capacity for renewable energy. The quick and easy approval of this plan is one of the benefits of ERCOT, being independent of other power grids.

3.3 Solar Power

3.3.1 Status of Technology

Like wind power, solar power has the potential to yield enormous environmental benefits by offsetting the need for polluting forms of energy. Solar power can be classified into two forms, solar thermal and solar photovoltaics. Solar thermal is used in concentrated utility-scale facilities, while photovoltaics can be applied at utility scales or at small scales by homes and businesses.

Solar Thermal

Solar thermal technology involves the conversion of solar radiation to heat energy which can then be used to produce electricity. Solar thermal power can be generated in a variety of different ways, including parabolic troughs (mirrored troughs to focus the sun’s rays on fluid-filled tubes to operate a heat engine), power towers (arrays of mirrors that focus sunlight on a central tower), dish systems (mirrored dish focuses sunlight on a heat engine), and Fresnel reflectors (linear series of flat or slightly curved mirrors that focus sunlight on one or more overhead receiver tubes). All of these technologies are currently in, or scheduled for, commercial use in one or more locations worldwide. Parabolic trough and power tower designs have been in use longest and more data is therefore available on their performance and cost-effectiveness.

Photovoltaics

Photovoltaic solar refers to solar power generated by photovoltaic (PV) cells that convert sunlight directly into electricity. Since PV cells do not require a heat engine or heat transfer fluid, they can be placed extremely close to, or on top of, the object to which they provide electricity. This distributed form of generation has several advantages, including lack of transmission lines, ability to provide power in remote areas, and, when connected to a normal electric grid, the opportunity to sell electricity back to the grid provider, especially during peak daytime hours.

Solar photovoltaic cells can also be concentrated to form a solar photovoltaic plant. Electricity is then transmitted to consumers through transmission lines similar to solar thermal plants or fossil fuel power plants. Concentrated photovoltaic plants can take advantage of areas of high solar insolation, like deserts, and also of policy or tax incentives that favor large-scale, concentrated solar energy production. Two solar PV facilities are being built in California with total capacity of 800 MW, twelve times the size of the current largest plant [99].

Photovoltaic cells contain two layers of oppositely charged semiconducting material. Sunlight striking the cell creates a flow of electrons through a circuit, generating electricity. Typically, silicon is used as the semiconductor, although new "thin-film" technology promises to greatly reduce or eliminate the need for silicon, reducing costs considerably. Nanotechnology also holds great potential for increasing the efficiency and reducing the cost of PV cells.

3.3.2 Cost

Solar Thermal

Although solar power remains more expensive than fossil fuels and wind, solar generation peaks on summer afternoons when electricity demand and wholesale prices tend to be highest. Solar energy provides an especially good complement to wind, as it peaks on summer afternoons when winds are often relatively light. Centrally generated solar thermal electricity is currently the most cost-effective means of providing electricity from solar power. It is still, however, more expensive than producing electricity from fossil fuels. A 2003 study for the National Renewable Energy Laboratory (NREL) found that electricity generated by parabolic-trough plants had a levelized energy cost of around 10 ¢/kWh [100]. By 2020, the authors expect that the price will fall to around 5¢/kWh. The NREL study found power tower-generated electricity cost roughly 12.5¢/kWh and projected it would fall to around 4.5 ¢/kWh by 2020. Lazard Ltd. in 2008 estimated the levelized cost of solar thermal at 8.7-12.4 ¢/kWh, including the benefit of federal incentives such as a 30% investment tax credit [90].

Photovoltaics

Electricity from photovoltaic cells currently costs more than electricity from solar thermal plants. The Solar Price Index (www.solarbuzz.com/SolarPrices.htm) estimates that solar PV costs 21.4¢/kWh for industrial applications and 37.7¢/kWh for residential, as of August 2008. However, including federal tax incentives, Lazard estimates photovoltaic cells have a levelized cost of 9.6-15.4¢/kWh [90]. The U.S. DOE Solar America Initiative aims to reduce PV costs to 9¢/kWh by 2015. Despite their higher cost per kilowatt-hour, solar photovoltaics not only produce greatest output during peak summer periods but also can be used by homes and businesses to offset retail purchases of electricity. Thus, solar panels may become cost-effective even before they can compete on a wholesale price basis.

3.3.3 Solar Potential for Texas

There is a wide range of evidence showing that Texas has the potential to be a national leader in solar power. A study by Environment Texas found that solar thermal power plants covering a 30 x 30-mile area in west Texas could power the entire state. Similarly, NREL estimated that Texas has sufficient solar potential to produce, under optimal conditions, 127,000 MW of electricity on 0.04 percent of its land [101], more than the state's current total generation capacity. The study also classifies 39,000 acres in West Texas as having "premium" solar insolation levels receiving 7.0 kWh/m^2/day or more (Figure 31). By comparison, solar insolation levels in the Mojave Desert, site of the new Solar One solar thermal plant, are 7.4 kWh/m^2/day [102]. The premium solar insolation area in West Texas is located inside the ERCOT grid area, making connection with the rest of Texas easier. In order for concentrated solar power plants in West Texas to supply consumers in the eastern part of the state, however, large transmissions lines would need to be constructed. The construction of new transmission capacity planned by the Texas PUC may help address some of that need.

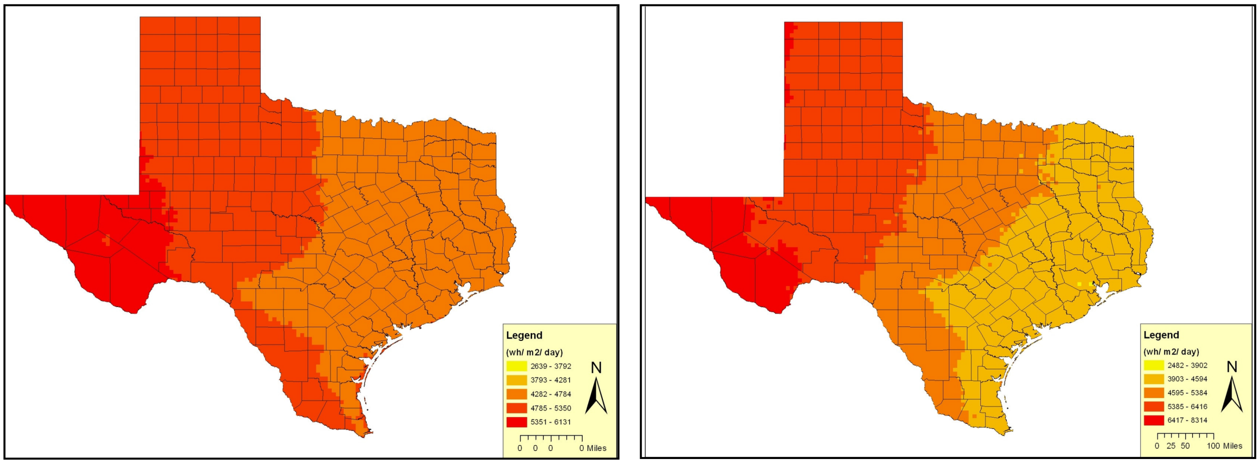


Figure 31. Solar potential of photovoltaic panels (left) and concentrated solar power (right) in Texas (*Platts energy data*).

Decentralized photovoltaics also present an attractive opportunity for Texas, both as a means of electricity generation and as a nascent high-tech industry. Almost all of

Texas has average solar insolation values greater than 5 kWh/m^2/day, compared to a maximum insolation of less than 4 kWh/m^2/day in Germany, the world's largest producer of solar electricity [103]. If the cost of PV electricity continues to fall as predicted and retail electricity rates in Texas stay higher than the national average, PV could achieve price-parity in the state within the next 5 to 10 years.

Texas also has the potential to become a leader in photovoltaic manufacturing. According to *The Energy Report* from the Texas Comptroller of Public Accounts, Texas stands to gain 5,567 new jobs and $4.5 billion of investment from the PV industry by 2015 [83]. This represents 13 percent of all new U.S. solar jobs and investment, second only to California. Texas' large semi-conductor and chemical manufacturing industries and strong solar resources make it well suited to attract PV jobs and investment.

If solar power becomes cost-competitive in Texas, it has the potential to generate a significant portion of the state's energy while producing next to zero harmful pollutants or CO_2 emissions. In addition, the solar industry could create high-tech jobs and bring billions of investment dollars to Texas, stimulating the state's economy.

3.4 Other renewable energy sources

3.4.1 Geothermal Power

Current status

Geothermal is a reliable form of renewable base load power, and the U.S. is a leader in geothermal electric generation capacity with 2,850 MW [104]. Emerging technologies such as "engineered reservoirs" (creating cracks in heated rock for water to circulate in); geopressured geothermal (using high-pressured brine trapped in sedimentary layers); "co-produced fluids" (water mixed with fossil fuels in oil and gas fields); as well as low-quality, or low-temperature, conventional geothermal methods have been increasingly popular to make use of the geothermal potential [83]. In Texas, electricity generation from geothermal energy is still in research phase, and there is no planned geothermal power plant development.

Potential for Texas

The high-temperature geothermal resources required for electricity generation by conventional geothermal technologies should be close to the surface. These types of geothermal resources are only found in a few states in the US (California, Hawaii, Nevada, Wyoming (Yellowstone area) and Utah). However, emerging technologies could enable seven more states, including Texas, to develop geothermal projects, according to the Geothermal Energy Association.

Although there is no geothermal power plant development in Texas, the state has a competitive advantage over other states. Texas' vast amount of already drilled oil and gas wells, skilled drilling work force, and extensive data and knowledge regarding those wells could save the state a significant amount of money and resources. Nevertheless, new research is still needed for Texas to utilize the high potential geothermal resources. The above-mentioned "engineered reservoir" technique also could have some potential for Texas, primarily because this technique is similar to some processes used to extract natural gas from the Barnett Shale in North-Central Texas. The researchers in Southern Methodist University estimate that Texas has a potential geothermal capacity of 400 to 10,000 MW with 2,000 MW realistic in the near term [93].

Geothermal power also has the potential of bringing environmental and economic benefits to the state. According to Good Company, a typical geothermal power plant (30 MW) releases 1-4% of the amount of CO_2 emitted by traditional coal power plants, and represents a $60 million investment in Texas. To make use of 1,000 MW of the geothermal capacity of Texas, approximately 33 power plants would need to be built, which would create 8,500 jobs for the state, and would bring $1.9 billion investment.

Cost

Electricity generated using conventional geothermal power in other parts of the country costs five cents to eight cents per kWh. The Good Company report estimates the potential geothermal power prices to be 20 to 25% higher than the average wholesale price or similar to a clean coal plant price in Texas. The Lazard analysis estimates geothermal has a levelized cost of 4.2-6.9¢/kWh, including the benefit of a 2¢/kWh production tax credit [90].

3.4.2 Energy from Biomass

Current status

Energy generated from biomass is the nation's largest source of renewable energy, accounting for 48% percent of the total in 2006. Currently, biomass energy accounts for less than one percent of electrical power production in Texas [83]. Texas has 17 operational landfill gas projects generating electricity, with a total capacity of 74 MW [105]. Texas has no wood biomass power plants in operation, but two new plants are in development [93].

Potential for Texas

Texas has many resources to generate energy from biomass, such as massive agricultural and forest industries. If utilized, the available biomass supply could produce 20% of Texas' energy needs [106]. East Texas has an estimated 3.1 million tons (before drying) of logging residue, which has the potential to produce sufficient electricity to power 300,000 homes [107]. A recent report estimated that Texas agricultural wastes have the potential to produce 419 MW of electricity, or enough to power over 250,000 homes [108]. According to the EPA, Texas has 55 landfill sites with a potential for electricity production [105]. The largest landfills in Texas have the potential to produce 200 MW of electricity, sufficient to power more than 100,000 homes in the state [106]. Wood-fired power plants do produce some air pollutant emissions, including ash, VOC, SO_2 and NOx, although the amount of these pollutants emitted by these plants is considerably lower than the amount emitted by coal-fired power plants [109]. However, landfill gas use can reduce the release of methane, a greenhouse gas.

Cost

Prices for electricity generated from wood-fired power plants tend to range from 5 cents to 7¢/kWh, with a national average cost of about 6 cents [83].

3.5 Demand Response

Demand response refers to efforts to curtail electricity use specifically at times of peak power demand or high power prices, either by reducing consumption or shifting it to off-peak periods. Demand response can be achieved by asking customers to turn off equipment, by asking customers to turn on on-site generators, or by using thermal storage technologies, which allow building air conditioning needs to be met with stored chilled water produced by electric chillers operating at night. Demand response can be a powerful way to ensure system reliability and performance and can minimize the need for costly new generation facilities. ACEEE has estimated that enhanced demand response efforts could reduce peak demand in Texas by 13% (Figure 26) [81].

Advanced electric meters (or smart meters) can enable real-time pricing and communication with the utility, reducing waste and improving peak-load management. Real-time metering and pricing help consumers monitor and modify their behavior during peak hours: conservation when prices are high is rewarded. Smart electricity grids are currently limited in scope in the U.S. although utility companies are beginning to explore investment opportunities in this regard. Texas utility Oncor, for instance, has contracted Swiss smart-meter company Landis + Gyr to produce 3 million advanced meters by 2012. The $690 million cost of the project will initially be paid for by customers but over time will pay for itself through electricity savings and a reduced need to build new power plants, mitigating emissions in the process.[v] In addition to reduced peak demand, supplier savings would also include: reductions in maintenance

---

[v] Oncor press release, May 22 2008 (http://www.oncor.com/news/newsrel/detail.aspx?prid=1135).

costs through self-diagnostics, better forecasting to improve efficiency of wholesale purchases, and reduced meter-reading costs.[vi]

3.6 Combined Heat and Power/Cogeneration

In Texas today, electricity generation is provided predominantly by large (> 500 MW), remotely-located power plants – the so called "central station utility model." The model relies on long transmission lines to connect these power plants to load centers requiring electricity. The model allows for economies of scale in construction, fuel procurement, and operations and maintenance, which historically has resulted in low electricity prices. However, the remote location of central station power plants necessitates that heat, which is a normal output of the power generating process, be discarded unused into the environment. As a result, the central station model results in the loss of about two thirds of the energy existing in the raw fuel.

Combined Heat and Power (CHP), or cogeneration, refers to a form of distributed generation where naturally occurring thermal energy is captured and used productively for heating and cooling needs. To allow this, CHP systems must be located nearby a facility with a suitable thermal (heating or cooling) load. CHP can be used any place that heating or cooling is needed. The systems can be very large to serve a petrochemical complex, or small to match the heat load of a building, hospital, university campus, or school. In most cases, CHP uses conventional power generating equipment, but that equipment is sized consistent with the scale of the host facility's energy needs [110]. The primary goal of CHP is to meet the energy needs of a specific host building or facility, rather than to provide electricity to the wholesale market. By using the thermal energy available from the power generating process, CHP plants can have overall energy efficiency between 75-80%, which is at least double the efficiency attained using the central station model [20]. As a result, CHP systems provide impressive environmental benefits and enhance the wise utilization of our energy resources. Because CHP systems are located at the point of energy use, they do not require expensive upgrades to the transmission and distribution infrastructure to support broad implementation and hence reduce the losses that would occur during the transmission [110]. Due to the ability to "island" the CHP system during grid outages, CHP systems improve the security of energy supplies of their site hosts. For many adopters, CHP will reduce their overall energy costs. A number of CHP equipment suppliers operate in Texas today, providing thousands of jobs in the process.

3.6.1 Technology

Although any fuel (coal, diesel, biomass, and municipal waste) is usable in CHP plants, natural gas is most widely used. Some CHP facilities can use multiple fuel types

---

[vi] energywatch.org, *Get Smart: Bringing meters into the 21st century* (2005): 8-9 (http://www.energywatch.org.uk/uploads/Smart_meters.pdf).

to have the flexibility to switch in case of a price increase or resource scarcity. About 90% of all CHP systems in Texas are fueled with natural gas. As natural gas prices are expected to continue to rise, the high energy efficiency of CHP systems increases the economic value of natural gas. A small fraction of CHP in Texas is powered by renewable fuels such as wood wastes and landfill gas, although the potential exists for much more. Renewable fuels can be converted in biogas through the use of anaerobic digesters or gasification, or simply combusted to generate high pressure steam. Untapped sources of biomass fuel include urban wood waste, land clearing wastes, agriculture wastes, forestry wastes, and wastes from lumber mills and paper mills. A recent study by HARC concluded that 400-1,000 MW of CHP could be fueled with Texas agricultural wastes alone [108].

3.6.2 Current and potential use of CHP in Texas

Texas has been very successful in CHP development, and currently is the nation's leader in CHP output. Texas' CHP capacity of 16,000 MW represents 20% of total generating capacity in the state and 23% of the nation's CHP capacity [111].

The vast majority of CHP in Texas is operating at industrial sites along the Gulf Coast. Because these host facilities have large energy needs, these CHP plants are also extremely large. Today, only a small fraction of the existing CHP capacity is provided by plants with a capacity of less than 100 MW. The implication is that a large number of highly sophisticated energy managers running the region's chemical plants and petroleum refineries have found that CHP is cost-effective and beneficial to their facilities.

CHP technologies have the potential to bring clean and cost-effective electricity generation opportunities to the state. A recent report by HARC estimated a potential to add 20,000 MW of CHP in Texas at industrial plant sites, commercial buildings, institutional facilities and campuses, and agricultural operations [110].

3.6.3 Impacts on Energy and Environment

CHP technologies are efficient, consume less fuel (about 40% less than the conventional single systems), conserve energy, and thus significantly reduce energy costs. As an example, a newly built CHP capacity of 5,000 MW would save 185 BCF of natural gas or 34 million barrels of oil each year [111].

CHP systems reduce power demand by allowing on-site power generation and by using the heat from electricity generation, for operating cooling, heating and/or humidity control equipment. CHP achieves large reductions in electric energy cost by avoiding electric energy purchases during peak period, during which the charge for electric energy usage is the highest [110]. The American Council for an Energy Efficient

Economy has estimated that combined heat and power could reduce total electricity consumption by 11% in 2023 in Texas (Figure 32) [73].

By using only one fuel for both heat and electricity generation, CHP produces fewer emissions than traditional power generation techniques. CHP reduces the emissions of toxic air pollutants and greenhouse gases. CHP units reduce mercury emissions by 100% and NOx emissions by 84% compared to the average power plant emissions in Texas. CO2 is reduced by 51%, and SOx emissions are completely eliminated [112].

3.7 Air Pollutant Emission Controls

As noted in Chapter 2, existing coal-fired power plants in Texas are emitting far more NO_x, SO_2, and mercury than would be allowed for new or modified facilities. A variety of technologies are available to control these emissions.

For NO_x, the most effective control technology is selective catalytic reduction (SCR) [113]. In SCRs, injected ammonia reacts with flue gas NO_x in the presence of a catalyst to reduce NO_x emissions by 80-95% [113]. Based on EPA costing methodology [114], an SCR for a 600 MW boiler (close to the average size in Texas) would have a capital cost of about $52 million and, including Operation& Maintenance (O&M), would add a little over 0.2 cents/kWh to its cost of electricity. Other technologies, such as low NO_x burners and overfire air, are less costly but do not yield as much NO_x reduction. In Texas, all proposed new coal plants would use SCR, or the somewhat less effective selective non-catalytic reduction (SNCR), but among existing plants only W.A. Parish has installed SCR and Luminant is installing SCR and SNCR on some boilers (see Chapter 2). The NO_x emissions per MWh from Parish with SCR are about 80% lower than at plants which use other NO_x control technologies. SNCR reduces NOx emissions by 30-40%, and an SNCR for a 600-MW unit would have a capital cost of $5.5 to 15 million.

For SO_2, flue gas desulfurization (FGD), also known as “scrubbers,” can reduce emissions by about 95% [115]. A variety of wet and dry technologies have been developed for removing SO_2. For a 600 MW boiler, the capital cost of a wet scrubber would be roughly $75 million, adding roughly 0.3 cents/kWh to electricity costs [116]. In Texas, all proposed new coal plants would use FGD technology to achieve emissions well below EPA limits, but existing plants emit an average of four times those limits.

For mercury, two approaches can be taken to yield significant reductions. Using SCR and FGD in combination not only dramatically reduces NO_x and SO_2 but also reduces mercury emissions by about 90% [72]. That is because SCRs convert mercury into a form that can be readily captured by the FGD device. For plants that do not have these costly devices, injection of activated carbon can in some cases reduce mercury emissions by more than 90% at costs of less than 0.1 cents/kWh [72].

In sum, SCR and FGD can together achieve maximal control of NO_x, SO_2, and mercury from coal-fired power plants at a cost of roughly one-half cent per kWh.

3.8 Carbon Capture and Storage

Carbon dioxide (CO_2) capture and storage (CCS) is an emerging technology to capture concentrated CO_2 emissions from industrial and electricity generating units at the point of generation and to store them for a long time, isolated from the atmosphere. CCS is still in its early state of development, and has not yet been proven at a commercial scale for electric utilities.

Current status of CCS technology

There are different types of CO_2 capture systems: post-combustion, pre-combustion and oxyfuel combustion. Post-combustion capture of CO_2 in power plants is economically feasible under specific conditions. The technology required for pre-combustion capture is widely applied in fertilizer manufacturing and in hydrogen production. Although the initial fuel conversion steps of pre-combustion are more complicated and costly, the higher concentrations of CO_2 in the gas stream and the higher pressure make the separation easier. Oxyfuel combustion is still in demonstration stage and needs the usage of high purity oxygen. This results in high CO2 concentrations in the gas stream and, thus, in easier separation of CO_2 and in increased energy requirements in the separation of oxygen from air [78].

For the transport of large amounts of CO_2 to distances up to 1,000 km, pipelines are the most common method used. Pipeline transport of CO_2 is a well applied technology in the US (in the USA, over 2,500 km of pipelines transport more than 40 $MtCO_2$ per year) [117].

The technologies used for the storage of CO_2 in deep, onshore or offshore geological formations are very similar to the technologies that have been developed for oil and gas industry needs; however their economic feasibility has not yet been proven for storage in unminable coal beds. The combination of CO_2 storage with Enhanced Oil Recovery (EOR) could lead to additional benefits from the oil or gas recovery. Ocean storage of CO_2 is still in the research stage. CO_2 could be injected or dissolved into the water column (below 1,000 meters) using a fixed pipeline or a moving ship, or deposited using a fixed pipeline or offshore platform to depths below 3,000 m [117].

Costs and the technical and economic potential of CCS

In most CCS systems, the cost of capture is the largest cost constituent. Over the next decade, the cost of capture could be reduced by 20–30%, and more cost reductions could be achieved by emerging technologies that are still in the research or demonstration phase. It is estimated that the combination of low-cost capture options (in gas processing and in hydrogen and ammonia manufacture, where separation of CO_2 is already performed regularly), short transport distances (less than 50 km) and profitable storage options (EOR) can lead to the limited storage of CO_2 (up to 360 Megatons of CO_2 per year) [117].

McKinsey has estimated the generic cost of building a CCS equipped power plant as approximately $2800 per KW capacity. CCS retrofits have lower overall efficiencies and higher costs than newly built plants with capture [78]. IPCC predicts that CCS would increase electricity production costs by $0.01–0.05 per kWh, depending on the fuel, the CCS technology used, and the location [117]. Using EOR as the storage option would reduce additional costs by around $0.01–0.02 per kWh.

3.9 Comparison of Options

Analyses were conducted to compare the relative cost-effectiveness of renewable energy, energy efficiency, and emissions control technologies for achieving three objectives: (1) providing overall electricity generation, (2) helping to balance supply and demand during peak periods, and (3) reducing power plant emissions. The following sections discuss those analyses.

3.9.1 Cost-effectiveness for electricity generation

To compare the costs of power generation that may be operating for decades to come, it is important to compare not only the direct costs of generation but also how those costs might be affected by future environmental policies. Levelized direct costs, the traditional way for comparing energy options, account for the annualized capital, operating & maintenance, and fuel costs of power generation, and divide the aggregate costs by the amount of electricity generated. Market-based policies for emissions, such as a federal cap-and-trade system or emissions tax, can place a significant monetary value on emissions and influence the price of electricity for utilities and consumers. Proper risk management for long-term energy planning should account not only for current costs but also for the possible impacts of future policies and conditions.

Considering only direct costs, existing coal power plants provide the cheapest electricity, since they are assumed to have already paid off their capital costs (Table 7, Figure 32). Energy efficiency is also very cost-effective for offsetting the need for power generation. The net cost of energy efficiency is actually negative, as the direct costs are less than the energy bill savings that would result. Among new power generation options, wind is estimated to be slightly more expensive than coal, but would be the most cost-effective option if the federal production tax credit (PTC) of 2¢/kWh is included. Solar thermal and PV are more expensive than other options, not accounting for the federal PTC and a favorable temporal profile (high production when demand and prices are greatest) that could enable solar to garner higher market prices. The U.S. DOE Solar America Initiative aims to reduce PV costs to 9¢/kWh by 2015, and NREL estimated that solar thermal costs could reach 5¢/kWh by 2020 [100]. The cost of new nuclear power is highly uncertain as discussed in Table 7, footnote q.

Including the potential monetary value of emissions dramatically changes the comparison. NO_x, SO_2, and mercury emissions all had marketable values under CAIR and CAMR, and may become subject to new market-based emission policies or mandates for control. While Texas power plants can currently emit CO_2 for free, Congress has been considering legislation that would create taxes or cap-and-trade markets for CO_2. Since power plants built today will be in operation for decades to come, even purely economic self-interest must consider how these policy developments could impact the total costs of generation. Potential future emissions prices were estimated for NO_x ($2071/ton), SO_2 ($1682/ton) and mercury ($78 million/ton) based on EPA CAIR and CAMR Regulatory Impact Analyses, which predicted the marginal price of emissions allowances in 2020 if CAIR and CAMR had proceeded. For CO_2, we considered the average estimate ($43/ton) of the price that would have resulted by 2020 if the bipartisan Lieberman-Warner Climate Security Act had been enacted [118, 119].

Including these monetized costs of emissions, the cost of generation from existing coal plants would more than triple, as these plants would have to spend large amounts of money to buy emissions allowances or pay emissions taxes. Wind power becomes the most affordable new generation options, and solar thermal becomes cost-competitive with coal on this basis. Thus, the power generation options that are best for air quality could also be the most affordable for consumers. Carbon capture and storage becomes a cost-effective option for coal plants with the inclusion of potential CO_2 costs, which represent the majority of emissions costs in this analysis. The monetized costs do not include the impact of water withdrawals on the environment and water supply. Thermoelectric power plants are responsible for 39% of all freshwater withdrawals in the U.S. [120]. Nuclear, coal, and solar thermal plants are heavy users of water. The table also does not account for upstream environmental impacts of fossil fuel and nuclear power, such as coal and uranium mining, natural gas drilling, and emissions from fuel transport.

Table 7. Levelized costs and environmental impacts of various electricity options. Reductions in renewable energy costs through incentives or future improvements in technology are not included.

		Emissions (lbs/MWh)					
	Direct Costs (¢/kWh)	**NO_x**	**SO_2**	**Hg (lb/GWh)**	**CO_2**	**Water Withdrawal (gal/MWh)[n]**	**Total Costs Including Monetized Emissions[o] (¢/kWh)**
Land-based Wind	**7.4[a]**						**7.4**
Solar Thermal	**10.0[b]**					750-930	**10.0**
Solar PV Industrial	**21.4[c]**						**21.4**
Solar PV Residential	**37.7[c]**						**37.7**
Geothermal	**7.5[p]**						**7.5**
Existing Texas Coal	**2.5[d]**	1.6[h]	6.38[h]	0.074[i]	2160[h]	300-600	**8.1**
New Coal	**6.7[a]**	0.54[j]	0.59[j]	0.066[k]	1676[m]	300-600	**10.7**
New Coal w/CCS	**9.4[e]**	0.71[j]	0.77[j]	0.066[k]	246[m]	300-600	**10.3**
New IGCC w/CCS	**7.7[f]**	0.33[j]	0.09[j]	0.020[k]	238[m]	250-400	**8.3**
New Gas Combined Cycle	**6.7[a]**	0.07[l]	0.01[l]		807[m]	230-240	**8.4**
New Nuclear	**7.3-11.1[a,q]**					500-1100	**7.3-11.1**
Energy Efficiency	**3.5[g]**						**3.5**

Note: CCS = carbon capture and storage

[a] Expected levelized costs for new generation coming on-line in 2015, from Annual Energy Outlook 2008 [89].

[b] Estimate from NREL, 2003 [100].

[c] August 2008 Solar Price Index, from www.solarbuzz.com/SolarPrices.htm.

[d] Calculated based on fuel and O&M costs from [89], assuming zero capital costs (plant already paid for) and using the average heat rates of existing Texas coal-fired power plants.

[e] Costs from [89], plus an extra 2.7¢/kWh for carbon capture and storage based on IPCC 2005 [117]

[f] Calculated based on capital, O&M and fuel costs from [89], assuming capital charge rate of 13.9%/year

[g] Average levelized cost of energy efficiency options for Texas, from [81]

[h] US EPA CAMD emissions data for Texas coal-fired power plants, 2007

[i] US EPA EGRID data for Texas coal-fired power plants, 2004

[j] Based on US EPA (2006) [121]. For pulverized coal plants with CCS, higher NOx and SO2 are assumed to account for 31% increase in coal needed per MWh [117].

[k] US EPA New Source Performance Standards for pulverized coal (assumes sub-bituminous) and IGCC.

[l] Estimates from US EPA IPM model.

[m] Expected CO_2 emission rates for future pulverized coal power plants, from IPCC 2005 [117]

[n] U.S. DOE (2006) estimates assuming closed-loop cooling systems [120].

[o] Sum of direct costs plus monetized value of emissions. Emissions prices for NO_x ($2071/ton), SO_2 ($1682/ton) and mercury ($78 million/ton) are based on EPA CAIR and CAMR Regulatory Impact Analyses, which predicted the marginal price of emissions allowances in 2020 if CAIR and CAMR had proceeded. CO_2 cost estimate ($43/ton) is average of estimates by EPA [118] and the Congressional Budget Office [119] for year 2020 price of CO_2 allowances under legislation under consideration in Congress. The value of water withdrawals is not monetized.

[p] Average of Lazard estimate range, excluding benefit of production tax credit.

[q] Costs for nuclear are highly uncertain since no new facilities have been built in U.S. for 3 decades. U.S. EIA (2008) estimates 7.3¢/kWh; MIT (2003) estimates 7.7-9.1 ¢/kWh [122]; Keystone Group (2007) estimates 8.3-11.1 ¢/kWh [123]. As discussed by Lovins and Sheikh (2008), actual nuclear costs may exceed even the high end estimate [124].

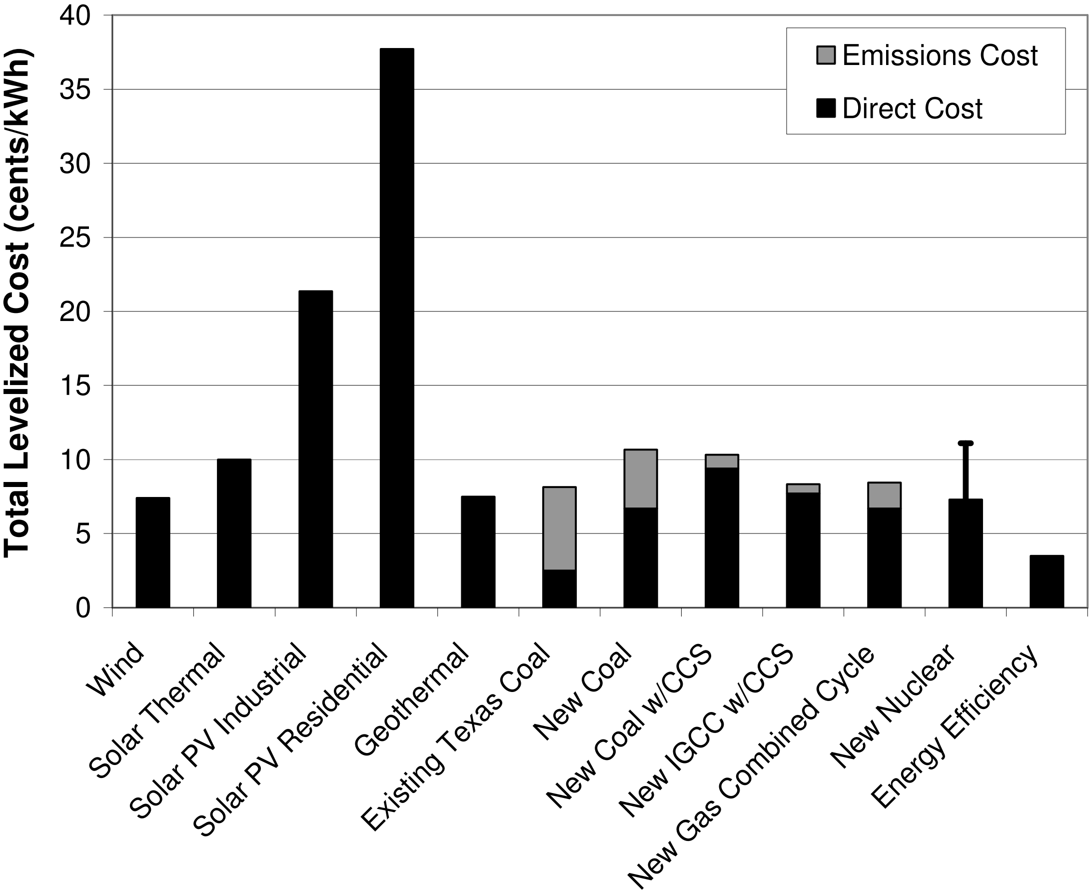


Figure 32. Costs of various electricity options, including monetized value of emissions under possible future policies. The majority of emissions costs are for CO_2, based on a hypothetical $43/ton cost under federal climate legislation (See Table 7 footnotes). Reductions in renewable energy costs through incentives or future improvements in technology are not included.

3.9.2 Cost-effectiveness for peak power

Peak power conditions pose a unique set of challenges in assuring that peak supply is sufficient to balance peak demand. Peak periods also correspond with some of the highest electricity prices on spot markets. Balancing peak supply and demand with an adequate margin of safety is crucial to ensuring the reliability of the electricity system.

The peak power analysis compares the upfront investment costs (i.e., capital costs) of various options for providing an additional 1 MW of peak power capacity, or of reducing peak demand by 1 MW (Figure 33). Each option for electricity supply was evaluated by comparing the new facility capital cost estimates from U.S. DOE Annual Energy Outlook 2008 [89]. The investment costs for demand response and energy efficiency were taken from the ACEEE report for Texas [81]. Winds are often light during times of peak demand, so the costs for wind were scaled up to account for the fact that more than 1 MW of wind capacity must be built to supply 1 MW of peak power. Two assumptions were used for wind: (1) a 17% capacity factor, which is the average empirical performance of Texas wind turbines during peak periods [125], and (2) a 8.7% capacity factor, which is what ERCOT assumes for wind during peak periods to assure a sufficient margin of safety. Other energy sources were assumed to have 100% capacity factor at peak times.

Demand response provides by far the cheapest way to reduce peak demand, costing only $46,000 per MW, since its impacts are directly targeted at peak periods. However, it would not significantly reduce energy needs or emissions at other times. Energy efficiency and natural gas combined cycle plants also provide attractive options for balancing peak supply and demand. Although wind was one of the most cost-effective options for overall power generation, it is the most expensive option for balancing peak energy needs because of its low capacity factors during peak periods. This points to the attractiveness of a comprehensive portfolio approach that utilizes wind for overall power generation together with natural gas and efficiency measures to ensure that peak periods are reliably handled.

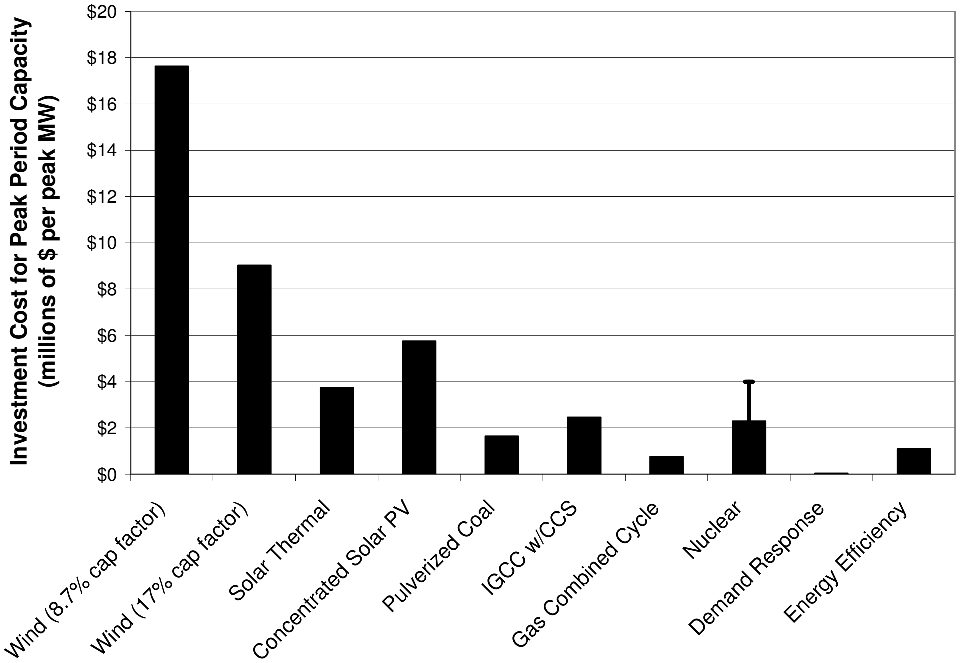


Figure 33 Upfront investment cost to add 1 MW of peak capacity, or to reduce peak demand by 1 MW. The nuclear cost reflects the range of capital cost estimates from U.S. EIA ($2292/kW) and McKinsey ($3500-$4000/kW).

3.9.3 Cost-effectiveness for emissions reductions

Energy efficiency and renewable energy can offset power plant emissions to the extent that they replace the need for fossil fuel generation. For this analysis, we credit renewable generation or demand reduction for offseting the average emission rate of Texas facilities in 2006 (1.43, 3.07, and 1417 lb/MWh for NO_x, SO_2, and CO_2 respectively; see Chapter 2, Table 2). More sophisticated analyses have considered the specific power plants that are offset by specific wind farms [126], but such an approach is beyond the scope of this study.

The cost-effectiveness of energy efficiency and renewable energy for emissions reductions depends completely on how costs are considered. Based on the 3.5 cent/kWh average cost of energy efficiency measures from the ACEEE report, the corresponding cost-effectiveness for emissions reductions would be $49,000 per ton of NO_x, $23,000 per ton of SO_2, and $49 per ton of CO_2. This is far higher than most emission control options for NO_x and SO_2, and comparable to the cost of carbon capture & storage for CO_2 [117]. For example, TCEQ estimates that TERP diesel controls achieve NO_x reductions for an average cost of $4,400 per ton. The net cost of energy efficiency is actually negative, since energy savings would more than offset the costs. Including those savings, energy efficiency is an ideal, "no regrets" approach to emissions reduction. Likewise, since wind was shown to be cost-competitive with other generation options on a per kWh basis, it can also be an effective way to reduce emissions and can complement other control strategies.

Chapter 4

Policy Options for Addressing the Energy – Air Quality Challenge

Texas has been a recognized leader in applying market-oriented approaches to promote renewable energy and air quality. That role has been exemplified by the Texas Emission Reduction Program and by policies such as renewable portfolio standards that have catapulted Texas into the top position for wind energy generation nationwide. Even so, Texas continues to use more electricity and fossil fuels and generate more CO_2 emissions than any other state or some major countries in the world. On a per household basis, Texas has the seventh highest residential electricity consumption – and second highest monthly electricity bills – of any state [60]. This chapter will examine the policy approaches of select states and countries by which aggressive, coordinated efforts on both the supply and demand sides can lead to reduced energy consumption, enhanced renewable energy production, and cleaner air. We will then examine policy options that could be enacted in a realistic and cost-effective manner in Texas, focusing on measures that could be enacted in the upcoming 2009 Legislative Session. We note many areas of success in existing innovative policies in Texas, and also highlight areas for improvement that could be addressed by carefully crafted policies.

4.1 How could Texas better promote energy efficiency?

Texas has been ranked 11th among the states for its efforts to promote energy efficiency [127]. Stronger building codes, product and appliance standards, consumer incentives, and public education all offer the potential to reduce energy consumption.

4.1.1 Energy Efficiency Portfolio Standards

Senate Bill 7 of 1999 established a utility energy efficiency improvement program, also known as an energy efficiency portfolio standard (EEPS). The provision requires investor-owned electricity utilities to meet 10% of their annual growth in demand by energy efficiency measures. With electricity demand growing by about 2% per year, this provision was equivalent to reducing energy demand by about 0.2% annually. Utilities must contract with outside energy efficiency service providers to implement these measures, and may provide incentives to consumers for energy efficiency measures. In 2007, House Bill 3693 increased the energy savings requirement to 20% of annual residential and commercial demand growth but omitted the industrial sector [83].

The energy efficiency measures have proven to be highly successful and to achieve benefits that far outweigh the costs. PUCT found that measures enacted in 2005 alone saved 500,000 MWh of electricity, exceeding the goal by 27%, and that the $78 million spent by utilities that year will result in $290 million in energy cost savings, a return on investment of nearly four-to-one [128]. Measures enacted in the first four years resulted in about 2,700 tons of cumulative NOx reductions [129]. The format of the program ensures that results are verified by independent third parties and creates a market for energy efficiency services and associated jobs.

Given the success of the existing provisions, could the state adopt a more ambitious target for energy efficiency measures? Abundant evidence suggests that much greater energy savings could be achieved by utility programs. The American Council for an Energy-Efficient Economy has estimated that an expanded utility energy efficiency program could offset 40-50% of projected growth in Texas electricity demand [81]. Likewise, the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy estimates that 40-50% of the nation's electricity load growth could be displaced through energy efficiency, pricing reforms, and load management. California and Connecticut each require utility programs to achieve electricity savings of about 1% per year [130], more than double the Texas target. Nationwide, demand-side management programs by utilities achieved 59.9 million MWh of total energy savings in 2005 [131], several times larger than Texas achieved on a per-capita basis.

Raising the requirements of the Texas program would greatly increase energy savings, reduce emissions, and avert some of the need to construct new power plants. More importantly, such a policy would yield savings to consumers that would far exceed its costs. ACEEE recommends expanding the utility targets to 50% of demand growth, resulting in 28.5 billion kWh of annual electricity savings and 9400 MW of peak demand reduction by 2023 compared to a 10% standard [81]. Many of the measures currently funded by utilities to meet their EEPS requirements, such as weatherization of low-income homes, could be greatly expanded if the requirements were strengthened.

Beyond strengthening the energy savings target, other modifications could enhance the program's effectiveness. The energy efficiency mandate currently applies to regulated investor-owned utilities that supply about 80% of Texas electricity sales [81]; the program could be expanded to encourage other electricity providers to participate in the program. The state could also loosen caps on the utility-paid portion of each measure in order to enable a wider array of measures to be implemented. The provisions of HB 3693 could be modified to once again allow industrial users to participate in the EEPS program, opening the door to a broader array of cost-effective efficiency measures.

A challenge to the success of utility-based programs is that utilities profit by selling electricity, and thus face a disincentive to exceed their energy savings targets. Although energy efficiency generally costs less than building new capacity, more could be done to properly align utilities' incentives to implement efficiency measures and exceed their mandated levels. One potential approach would be to establish tradable Energy Efficiency Credits (EECs), akin to the RECs that accompany the state's RPS program. EECs would be provided for measures that reduce energy consumption, and each utility would be responsible for a certain level of EECs based on their electricity sales. A tradable credit system would enable utilities to profit by exceeding their energy savings targets. It would also allow more ambitious energy savings targets to be achieved while minimizing costs because the market-based approach would encourage implementation of the most cost-effective measures needed to achieve the overall goal.

4.1.2 Building codes

The state building codes for commercial and residential construction were last improved in 2001, when Senate Bills 5 and 365 adopted the 2000 International Residential Code (IRC) and the 2000 International Energy Conservation Code (IECC); more stringent codes apply to state-funded buildings. Strengthening the state codes could lead to more widespread energy savings. For state building codes to be enforceable on non-government buildings in Texas, they must be adopted by local jurisdictions [132]. The State Energy Conservation Office (SECO) provides training and education about building codes through video training and its Texas Healthy Homes program. House Bill 3693 in 2007 authorized SECO to lead a review cycle of subsequent releases of the building codes, with analysis and recommendations to be provided by the Texas A&M Energy Systems Lab (ESL). Studies by the ESL have shown that energy use could be reduced by at least an additional 15% in both commercial and residential buildings [79, 80]. Improvements to lighting, electrical equipment, HVAC equipment, building shells, and water heaters can all reduce energy consumption in a cost-effective manner [133]. ACEEE has recommended that the state aim for 15% above-code savings by 2009, and 30% savings by 2020; they estimate that doing so would result in more than 10.5 billion kWh of annual electricity savings (81.2 billion kWh cumulative) and 2360 MW of peak demand reduction by 2023, at a cumulative cost of $5.8 billion.

Other states and cities have adopted more stringent building codes. The City of Dallas recently adopted an ordinance establishing the citywide green building program that will be incorporated into the Dallas City Code. The program will require the City to reduce current building energy use by 50% through new building design efficiency and existing building retrofits. The Houston City Council also recently approved the adoption of a new commercial energy code, which will provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings. The

City of Austin applies stringent green building standards to new residential and commercial buildings, and is in the process of further strengthening those standards. The City of Frisco requires new homes to achieve Energy STAR designation and for new commercial buildings to comply with the Energy STAR Cool Roofs Program. California approved the nation's first statewide green building code in July 2008, requiring all new construction to reduce energy by 15% and water use by 20% [132].

4.1.3 State and Municipal Buildings and Operations

Apart from the energy efficiency standards and building codes that could be applied to buildings and appliances statewide, state and local governments could also take a leadership role in enhancing the energy efficiency of their own buildings and operations. Doing so would not only reduce energy consumption and government expenditures directly, but would also provide a model to encourage wider adoption of energy efficiency and renewable energy.

On a statewide level, Senate Bill 982 in 2005 updated process and design standards for energy conservation in new state buildings. House Bill 3693 in 2007 set a goal for state agencies, universities and school districts to reduce energy consumption by 5% per year for six years [83]. Achieving that goal would result in significant energy savings and should be a priority. Progress toward that goal may be facilitated by expanding the LoanSTAR program, administered by SECO, which provides low-interest loans to public entities to implement energy efficiency and renewable energy measures. However, LoanSTAR's $99 million revolving loan fund is currently oversubscribed, hindering some eligible projects from being conducted. ACEEE has recommended expanding the fund to $300 million, which it estimates would result in 5.9 billion kWh in annual electricity savings and 1400 MW of peak demand reduction by 2023 [81]. They estimate that the cumulative cost to the government to finance the associated bond and administer the program would be $724 million, far less than the energy cost savings.

Many local governments in Texas have taken significant steps to promote energy efficiency and renewable energy in their buildings and operations, which could be emulated by other municipalities or on a statewide basis. The City of Plano has committed to pursuing the highest level of LEED certification possible for its new and remodeled buildings. The City of Houston has issued a request for proposals to improve the energy efficiency of 11 million square feet of its facilities, to be paid for by subsequent energy cost savings. Houston is also retrofitting all of its traffic lights with LED bulbs that result in 80% energy savings and much longer lifetimes between replacements. The City of Houston, City of Dallas, Austin I.S.D, and City of Austin rank #1, 2, 7, and 8 nationwide among the top local government purchasers of green power, purchasing 15-40% of their electricity from wind providers (and biogas in Austin) [134]; Texas A&M ranks #7 among university purchasers of green power.

4.1.4 Appliance and Product Efficiency Standards

In its 2007 report, ACEEE had identified 10 products not covered by federal standards for which adopting efficiency standards from other states would yield feasible and cost-effective energy savings for Texas [135]. Since then, the Energy Independence and Security Act of 2007 adopted standards for many of these products on a federal level. However, there do remain some products not covered by federal standards (e.g., bottle-type water dispensers, pool pumps, portable electric spas, and commercial hot food cabinets) for which Texas could consider adopting the standards established by other states [136].

4.1.5 Education

Public education campaigns on energy conservation have resulted in significant short-term (18-24 months) demand reductions in California by targeting specific, low-effort action items (such as urging consumers to adjust thermostats when away from home and promoting the purchase of compact fluorescent lamps) [81]. Such measures work best using diverse media and have achieved significant short-term reduction without causing lifestyle impacts. ACEEE estimated that extensive public education campaigns in Texas could yield energy savings up to 5% [81].

4.1.6 Incentives

Consumer incentives to promote energy efficiency typically take the form of tax exemptions, rebates, and on-bill financing. Texas lacks a statewide funding program to promote consumer expenditures to improve energy efficiency. However, the state's Energy Efficiency Portfolio Standard (EEPS) has prompted some local utilities to offer low cost loans, rebates, and advice for improving efficiency. Spending by Texas utilities for energy efficiency was only $3.56 per capita in 2004, six times less than the rates of Vermont or Massachusetts [127]. House Bill 3693 in 2007 increased the requirements of the Texas EEPS program and thus may prompt some increase in incentives from utilities, but not to the level of some other states. In Massachusetts, for example, utility companies are now mandated to offer rebates and other incentives for customers to upgrade lighting, air conditioning and industrial equipment to more efficient models, provided that those incentives are less expensive than the cost of powering the older, less-efficient equipment.[vii]

[vii] Massachusetts 2008 Energy Bill (http://www.env-ne.org/public/resources/pdf/MA_Energy_Bill_Summary.pdf).

On-bill financing can help small businesses and homeowners overcome and recoup the typically large up-front investment costs associated with energy efficient improvement projects. SoCalGas and San Diego Gas and Electric, for instance, offer 0% financing up to five years on loans ranging from $5,000 to $50,000 for qualifying natural gas equipment and can be more than offset by energy savings [132]. Loan payments are conveniently consolidated into monthly utility bills. To reduce energy consumption in rental properties, the PAYS System financing concept, originated by the Energy Efficiency Institute, could provide a way for owners and tenants to share in the benefits of installing energy efficiency measures. The concept avoids up-front costs to tenants and owners by paying for efficiency improvements through electric bill surcharges, which would be more than offset by the energy savings. The Texas Public Utility Commission (PUC) would need to authorize such a program.

Electricity providers can be some of the most effective agents for promoting energy efficiency and conservation among consumers. However, utility companies profit from selling electricity, so they can face a disincentive to reduce consumption. Several states with regulated utility markets have created incentive structures to encourage utility companies to promote energy efficiency and conservation, linking rate increases and revenue to the success of those efforts. Oregon's Department of Energy, for instance, has issued more than 12,000 tax credits worth $243 million to businesses and residents that invest in qualifying energy-efficient appliances and equipment, recycling, renewable energy resources, sustainable buildings, and greener transportation – investments that have saved or generated energy worth $215 million a year [137]. Such policies would be challenging to enact in Texas' competitive electricity market, where utility profits would be diminished by reduced demand. However, the state's EEPS, which requires utilities to offset part of their demand growth with energy efficiency measures, could be adjusted to provide market-based incentives for achieving greater levels of energy savings.

4.1.7 Demand response

Peak demand places the greatest strains on electric system reliability, drives the need for costly new power plants, and results in the highest spot market rates under the Texas pricing system. More should be done to curb demands for electricity during peak periods. A fledgling but effective method of controlling electricity consumption during peak load periods takes the form of demand response when peak loads approach critical limits, in which either utility companies or private energy management firms actively engage large customers toward dramatically and immediately reducing electricity consumption or switching to on-site power generation. As a low-cost operational reliability tool, demand response effectively moderates high energy prices or fuel shortages, remedies imbalances between electricity demand and supply (during peak hours, shoulder periods, extreme weather events, generation outages, or erroneous load forecasts), and can address temporary air quality problems. Anticipating ERCOT's short-term power supply challenges in the near future, ACEEE has recommended the following actions to promote demand response:

- The Texas Legislature should require that all new buildings be equipped with smart, programmable meters that permit direct load control (a remote, incentive-based, emergency-oriented mechanism) and that all REPs and utilities meet a Demand Response Portfolio Requirement enforced through tradable Demand Response Credits.

- The PUCT should create direct load control programs (particularly air conditioning management) for both residential and commercial customers to maximize the amount of direct load control.

- Texas's transmissions and distribution utilities should receive incentives and cost recovery for administering demand response programs such as direct load control [81].

Taken together, ACEEE estimates that these measures could reduce peak demand by 13,241 MW by 2023, at a cost of only $427 million.

4.1.8 Smart meters

H.B. 2129 (2005) revised several provisions of the Public Utility Regulatory Act to incent smart metering on both the supply and demand sides. Consistent with H.B. 2129, PUC rule §25.130 permits electric utilities to administer a nonbypassable surcharge to recover costs incurred for deploying advanced metering systems.[viii]

Other states and countries have taken more aggressive measures toward smart metering. Utilities in states such as California, Pennsylvania, and Florida are installing smart meters on large scales. Georgia Power's large customers in Florida were able to reduce electricity demand by 20–30% during peak load, and the utility achieved a 41% reduction in load during peak times.[ix] Italy's dominant utility deployed smart meters to over 27 million customers from 2000-05 with advanced features that include the ability to remotely turn power on or off to a customer, detect service outage more readily, detect unauthorized use of electricity, change the maximum amount of electricity a customer can demand at any time, and remotely change payment methods. The estimated cost was 2.1 billion euros (roughly $3.15 billion), but at a savings rate of 500

[viii] PUCT rulemaking on advanced metering (§25.130) (http://www.puc.state.tx.us/rules/subrules/electric/25.130/25.130.pdf).

[ix] ECOS, "Smart approaches to electricity use" (2007): 12-13 (http://www.publish.csiro.au/?act=view_file&file_id=EC135p12.pdf).

million euros per year, the payback period was only four years. Two regional Australian governments have committed to replacing old meters with smarter versions, and the country's Solar Cities program also mandates installation of small meters in small businesses. Sweden requires monthly readings of all electricity meters by 2009, and electric companies will be required to introduce automatic meter reading for billing electric energy consumption by 2009.[x]

4.2 How could Texas better promote renewable energy?

4.2.1 Incentives for Renewable Energy Deployment

Texas leads the nation in deployment of wind energy generation, resulting in large numbers of jobs, substantial investment, and increased tax revenue for the state. Texas does not provide direct funding to homes or businesses for renewable electricity, but does offer the following tax incentives [137]:

- Businesses engaged solely in manufacturing, selling, and installing solar and wind energy devices are exempt from the state franchise tax.
- Other businesses can receive a franchise tax deduction for the cost of solar and wind energy systems.
- Homeowners and businesses receive a property tax exemption for the appraised value of solar, wind, or biomass energy systems.

In addition, the State Energy Conservation Office administers an Innovative Energy Demonstration Program that provides technical information and education about renewable energy and funds demonstration projects. Austin Energy, Bryan Texas Utilities, and CPS Energy offer rebates for photovoltaic and solar water heating systems.

Many other states offer more extensive incentives for the deployment of renewable energy systems. Common financial incentives to promote renewable energy include grants, tax incentives, loans, and Public Benefit Funds (PBFs). According to DSIRE, 18 states now offer rebates for renewable energy technologies, and 19 states offer personal tax incentives. Over the past three decades, many states have coordinated financial incentives with other state programs; by leveraging utility-based clean energy programs; and by diversifying their programs from grants or loans into a broader set of programs. This diversification has led to portfolios of programs with greater sectoral coverage, a wider array of partnerships with businesses and community groups, and an

---

[x] Ibid.

overall reduced risk associated with programmatic investments in energy efficiency and clean supply options [138]. Massachusetts's recent Green Communities Act requires utility companies to enter into 10- to 15-year contracts with renewable energy companies to help finance renewable energy projects. The New York State Energy Research and Development Authority (NYSERDA) provides a $4.00 to $4.50 per watt rebate for solar PV and will cover up to 60% of the system's total installed cost [138]. Denmark has offered significant subsidies to increase the renewable energy share of domestic electricity generation from 3.1% in 1992 to 25% by 2004, reducing CO_2 output by 10%. The Danish renewables industry is now the world leader in wind turbine manufacturing, creating substantial employment and export revenue [139]. Germany has devoted $9 billion to new onsite renewable power plant construction, such as CHP systems and solar units and $7.4 billion in operation of plants, accounting for 170,000 jobs and helping Germany generate 10% of its electricity from renewables.

Public benefit funds (PBFs), the most common mechanism for supporting ratepayer-funded clean and efficient energy programs, provide pools of resources used by states to invest in clean energy supply projects and are typically created by levying a small charge on customers' electricity bills. PBFs can also lead to job creation through lowering energy costs and stimulating public and private sector investments. Roughly 20 states have established PBFs for clean energy supply although eligible technologies vary. The California PBF generates $135 million per year for clean energy, funding wind and solar rebates and consumer education [138]. The New York Energy $mart Program has been credited with creating 4,700 jobs, increasing labor income by $182 million per year, and increasing economic output by $224 million per year [138].

4.2.2 Promoting renewable energy research, development and manufacturing

Texas' outstanding wind and solar resources, high-caliber research universities, and skilled workforce present an opportunity to expand not only renewable energy deployment but also research and manufacturing of renewable energy products. Doing so could attract investment and highly-skilled jobs to Texas, many of them in rural parts of the state. Additional jobs could be created in the energy efficiency arena to retrofit existing buildings, install energy efficient devices, and research energy-efficient technologies.

Texas leads the nation in deployment of wind energy generation, resulting in large numbers of jobs, substantial investment, and increased tax revenue for the state. Texas is increasingly taking a leadership role in the research and development of renewable power systems as well, attracting highly-skilled jobs to the state. The U.S. Department of Energy selected the Texas Lone Star Wind Alliance, a Texas-led consortium of universities, agencies, and businesses, to create the Texas National Large Wind Turbine

Research and Test Center near Corpus Christi. Texas has pledged $5 million to support the facility, and an additional $5 million may be provided by the Texas Emerging Technology Fund [140]. Vestas, a major Danish wind turbine supplier, plans to open a wind turbine research center in Houston in 2009, eventually employing more than 100 people. Other major research facilities in Texas include the NSF Wind Science and Engineering Research Center at Texas Tech, the Texas A&M Energy Systems Lab, an offshore composite structures research center at the University of Houston, and an offshore technology research center at University of Texas and Texas A&M. The Texas Emerging Technology Fund supports a variety of fields, including research and development of energy efficiency and renewable energy technologies. Continued support of these efforts and additional efforts to expand on that success are crucial to maintaining Texas' leadership role in renewable energy.

Other states have also embarked on ambitious efforts to attract green energy investment and jobs. In August 2008, Florida created the Florida Energy Systems Consortium, providing $50 million of funding to support renewable energy research at its state universities. The New York State Energy Research and Development Authority (NYSERDA) has an extensive history of funding energy research in New York. New Jersey's Renewable Energy and Economic Development program helps promote renewable energy businesses in that state. The Colorado Governor's Energy Office is partnering with four utility companies under the Small Wind Incentive Program and offers rebates for small wind turbine installations.

4.2.3 Renewable Portfolio Standards

Renewable Portfolio Standards (RPS) have received widespread acclaim as an affordable, market-based approach to enhance the diversity of energy supply, provide a market for emerging technologies, spur local development and investment, and reduce emissions, water use and fossil fuel use [141-145]. When Texas first established its RPS program in 1999 [146], it was the largest program of its kind in the nation and the first to track compliance using tradable Renewable Energy Credits (RECs). A national review of RPS programs in 2004 [141] found Texas to have the most successful program in the country, noting the success of the REC trading market and crediting the program for catalyzing the tremendous growth in wind power in the state. Texas achieved its original RPS targets four years ahead of schedule, and in 2005 Senate Bill 20 increased the renewable energy mandate to 5,880 MW by 2015, with a target of 10,000 MW by 2025.

Despite the success and expansion of the Texas RPS, many states have now leapfrogged ahead of Texas to enact more aggressive RPS requirements. Twenty-five states have set RPS mandates to obtain 10-25% of electricity from renewable sources, with target years ranging from 2010-2025 [132]. Six other states have established non-binding state goals of 10-20% to be achieved by 2015-2025. By contrast, the provisions of Senate Bill 20 are equivalent to 4-5% of electricity production by 2015, and a non-binding 8% by 2025 [83]. Once the leader in state RPS programs, Texas now ranks among the least aggressive of states with RPS mandates (Figure 34). The current RPS requirement for 2015 will likely be met by 2008 [83] and is dwarfed by the more than 18,000 of new wind generation that will be enabled by new transmission capacity authorized by the Texas PUC. A low RPS mandate diminishes the value of the tradable RECs that incentivize renewable energy generation and hinders Texas' leadership role in renewable energy generation. The Union of Concerned Scientists estimates that a more aggressive 20% target would lead to billions of dollars in electricity savings, significant job creation, and large reductions in power plant emissions [147].

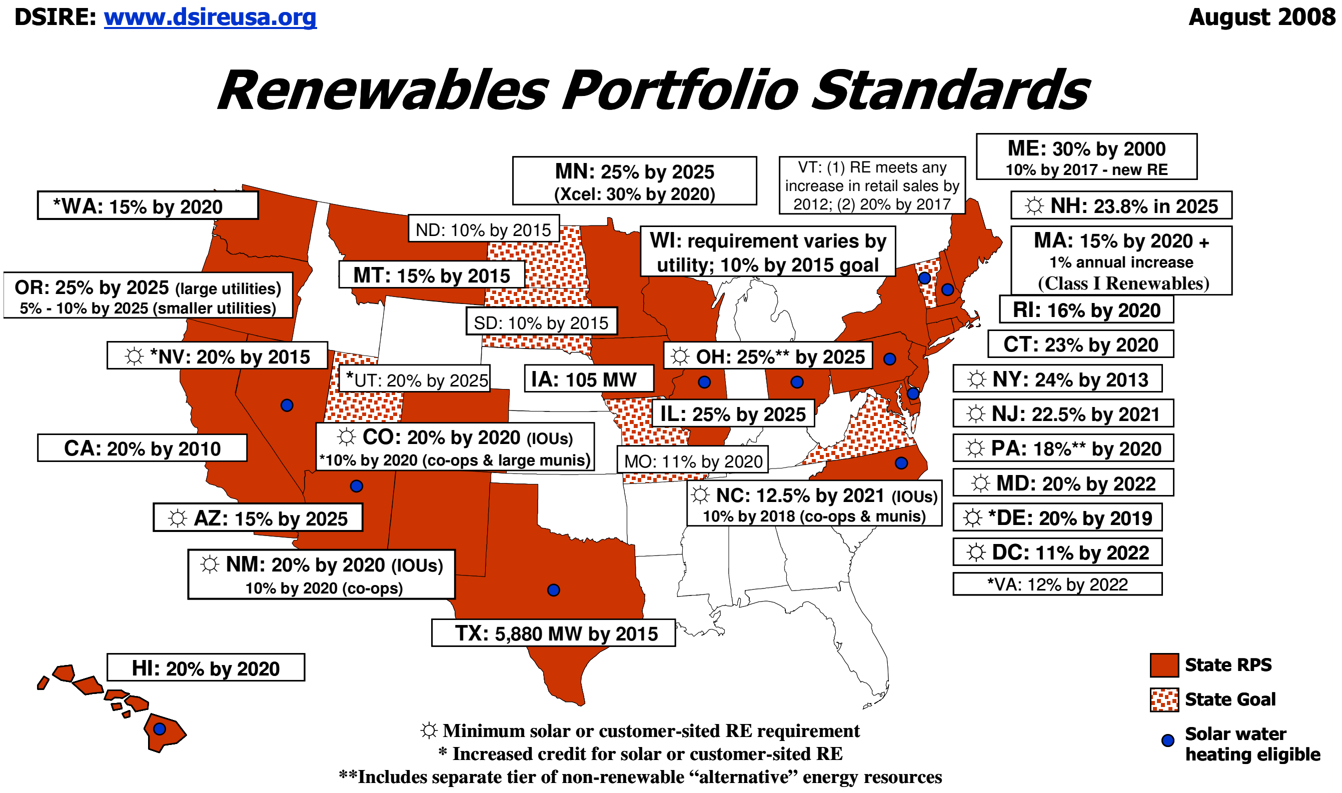


Figure 34. Renewable portfolio standards by state (Database of State Incentives for Renewables and Efficiency, August 2008).

Japan's version of the RPS, called "Special Measures Law on Use of New Energy, etc." was enacted in 2002 to increase the required annual contribution of renewable electricity from 3.3 TWh in 2003 to 12.2 TWh by 2010. So far, all 38 electric power enterprises have achieved their obligations faster than expected.[xi] The Australian government's Mandatory Renewable Energy Target requires the generation of 9.5 TWh of extra renewable electricity per year by 2010, resulting in an investment stimulus of over $3 billion and a 50% increase in generation of renewable energy.[xii]

Texas clearly has the potential to strengthen its RPS requirements. The state boasts outstanding wind and solar resources (Chapter 2) and a history of success in implementing cost-effective RPS programs. The U.S. Department of Energy has found that a 20% target for wind electricity is achievable nationwide by 2030 while maintaining system reliability [84]. Given the state's outstanding wind and solar resources, a renewable energy mandate of 20% or greater is clearly achievable in Texas. Also, any risks from a more stringent RPS to costs or reliability can be avoided, as SB 7 and SB 20 gave the PUC the authority to cap the prices of RECs and to suspend the standard if necessary.

In addition to increasing the overall RPS target, Texas could provide larger set-asides for non-wind renewable energy resources in its RPS program. Given the abundant wind resources in Texas and the low costs of wind energy compared to other renewable sources of electricity, wind has dominated the Texas RPS program so far and does not critically depend on the implicit subsidy that RECs can provide. Emerging technologies such as solar and geothermal may need more of a boost to help them achieve greater scales that could reduce long-term costs. Senate Bill 20 set a voluntary goal that 500 MW of the overall RPS requirement for 2015 must be met by non-wind sources. However, many states have established much larger, mandated set-asides for solar energy and distributed energy resources. Even New Jersey, with far weaker solar resources than Texas, has set a standard of 2.1% solar electricity (1500 MW) by 2021. TREIA advocates a 3000 MW requirement for non-wind renewable electricity capacity in Texas, plus additional provisions to encourage distributed generation of electricity [148]. Provisions for non-wind renewable energy resources would create a market for emerging technologies and promote a diversity of electricity supply. Solar energy provides an especially good complement to wind, as it peaks on summer afternoons when winds are often relatively light. Geothermal, waste biomass, and landfill gas could also play contributing roles as sources of electricity.

Another consideration for modifying the Texas RPS is whether to include electricity sources not covered by the current program. Some of the options not included in the current Texas RPS are CHP/waste recovery (included in 9 states), renewable energy fuel

---

[xi] APP: 6.

[xii] Australia "Renewable Opportunities, A Review of the Operation of the *Renewable Energy (Electricity) Act 2000*" (http://www.mretreview.gov.au/report/index.html).

cells (5 states), and municipal waste (10 states) [144]. Including these options would enhance the flexibility of meeting the RPS and encourage adoption of these technologies, but could also complicate and dilute the existing program. Some of these options are also responsible for some air emissions. Thus, caution should be taken in making additional energy sources eligible for the RPS.

4.2.5 Infrastructure for renewable energy

A significant obstacle to exploiting renewable energy resources is the high upfront cost of building sufficient high-voltage transmission infrastructure to connect those resources with areas of greatest electricity demand. In Texas, much of the land best suited for wind and solar electricity generation is far removed from the urban and industrial centers with largest demand. Texas has been a recognized leader in developing solutions to its transmission challenges. Under S.B. 20 in 2005, the state launched an innovative effort to develop Competitive Renewable Energy Zones for renewable generation. The creation of those zones will allow transmission capacity additions to be most efficiently targeted and is expected to spur enormous growth of investment in renewable energy generation. In July of this year, however, the Texas Public Utility Commission approved the construction of $4.9 billion dollars of transmission lines over the next 6-7 years, connecting West Texas and Panhandle wind regions to urban areas. The transmission lines could potentially enable over 18,400 MW of additional wind capacity in Texas. That plan was a middle ground among four options that had been under consideration. It is crucial for these efforts to proceed effectively to facilitate continued growth of renewable energy generation in Texas.

4.3 Policies to promote distributed generation

Distributed generation (DG) refers to on-site power generation technologies such as CHP or solar photovoltaics. DG applications reduce strain on the electric grid; improve energy security, independence, and reliability; enhance efficiency by avoiding long-distance transmission loss; and tend to produce fewer emissions than most power plants.

Net metering and interconnection are crucial to promoting distributed generation of renewable energy, because they allow small-scale producers to sell surplus electricity back to the grid. Interconnection rules assure that electricity is supplied back to the grid in a reliable and consistent fashion. In 1999, Texas became the first state to develop interconnection rules for distributed generation (DSIRE). The Texas PUC is currently in the process of clarifying the state’s net-metering and interconnection rules. House Bill 3693 in 2007 tasked the Texas PUC with establishing rules for metering and interconnection of small generators. Crucial subjects to resolve in that process are the rates that customers will receive for electricity supplied to the grid and the fees associated with a meter. Bi-directional net metering (i.e., subtracting electricity supplied from electricity consumed), as practiced by Austin Energy and numerous states, essentially allows consumers to receive retail rates for the energy they supply back to the grid and provides a powerful incentive for distributed generation. However, in April 2008 the Texas PUC ruled that utilities could pay customers a lower rate for electricity supplied back to the grid and charge them for the meters. This could diminish the attractiveness of distributed generation. Net metering at retail rates faces resistance in deregulated markets, because competitive utilities have little incentive to have customers from which they must buy electricity. The upcoming legislative session could revisit these issues and insist upon approaches more conducive to promoting solar panels and other distributed generation.

To promote DG, some states have streamlined grid connection requirements, simplified permitting, and established ratepayer-financed incentive programs such as grants, rebates, state tax credits, and capital cost buy-down incentives. States have also reversed unintended utility rate barriers to DG by minimizing utilities' financial disincentives to deliver energy efficiency and DG resources and then instituting complementary incentive structures to promote and establish high-performing energy efficiency and DG resources.

The Australian government is working to remove impediments to – and promote the commercial uptake of – distributed generation technologies and practices in the Australian energy market. Actions include developing a national code of practice for distributed generation and improving electricity grid accessibility for renewable and DG applications.[xiii]

4.3.1 Policies to promote CHP and waste heat recovery

Combined heat and power (CHP) and waste heat recovery (the reuse of emission exhaust to power turbines) are powerful options for reducing energy consumption. Texas already generates 21% of its electricity from CHP and utilizes CHP more than any other state in the country. Still, studies have found much greater potential for utilization of CHP in Texas, especially in the commercial and institutional sectors for facilities such as hospitals and schools. ACEEE recommended that 6% of future Texas electricity consumption could be offset by increased application of CHP [81]. Lack of financial incentives and industry awareness has hindered the adoption of these technologies. ACEEE found that many applications of CHP would more than pay for

---

[xiii] APP: 5.

themselves under current conditions, but that incentives could catalyze more widespread adoption of these technologies.

CHP and waste heat recovery would benefit from inclusion in the RPS or energy efficiency portfolio standards. Industrial awareness and technical competence of both methods are also severely lacking, rendering a gaping need for regional advocacy and education campaigns among trade associations and other stakeholders. The next legislative session could adopt a portfolio standard, incentives, or education efforts to promote greater application of CHP.

4.4 How could Texas better control emissions from power plants?

4.4.1 Existing coal power plants

As demonstrated in Chapter 2, existing coal power plants in Texas emit tens of thousands of tons more air pollutants and greenhouse gases than would be allowed by new power plant standards. These excess emissions are major contributors to ozone, $PM_{2.5}$, and mercury pollution in the state. Allowing grandfathered coal plants to emit pollutants at rates several times above the new plant limits also creates an unfair competitive advantage relative to other electricity providers. The Clean Air Interstate Rule and Clean Air Mercury Rule had been expected to prompt major investments to control emissions from some of those plants, but both rules have now been vacated by the courts. With more stringent ozone and PM standards looming and with excess mercury levels in many Texas watersheds, prompt action at the state or federal level is needed to control power plant emissions. State or federal cap-and-trade, regulatory, or incentive approaches could induce existing power plants to install new controls, or to be repowered or retired if necessary. Whatever approach is taken, the bottom line is clear: more should be done to reduce the emissions of existing power plants to help protect air quality and public health in Texas. Texas could use the North Carolina's Clean Smokestack Act (2002) as a model to control multiple air pollutants from old coal-fired power plants. The Act requires power companies to reduce their ozone- and PM-forming emissions by 75% by 2013 through actual reductions, not by buying or trading emissions credits from utilities in other states, as allowed under federal regulations (NC-DENR).

4.4.2. New coal power plants

Federal new source performance standards ensure that any new coal power plant will emit far less NO_x, SO_2, PM, and mercury than their predecessors, but still more than most alternative energy sources. However, recent proposals for new coal power plants in Texas have not committed to carbon capture and storage (CCS). Thus, the proposed plants would be enormous emitters of CO_2, albeit at slightly lower rates than their predecessors due to improved efficiency. With growing concern about global climate change and its potential impacts on Texas, and with a high likelihood that federal legislation may soon place a cost on CO_2 emissions, multi-decadal investments in new coal power plants without CCS are problematic. Regardless how effectively the emissions are scrubbed or sequestered, coal power plants rely on a non-renewable resource for which mining, processing, and transport result in substantial environmental degradation.

Hence, Texas faces a quandary: to permit proposed power plants that would be significantly cleaner than existing facilities, or to insist that CCS or alternative energy sources be adopted for new power generation. Powerful arguments can be made for both sides of this debate. The first option could improve air quality if it prompts the retiring or diminished use of existing power plants, but it would also enable the construction of new facilities that would be major emitters for decades to come and inhibit the push for cleaner alternatives. The second option could promote more widespread adoption of CCS technologies, but would also accentuate the competitive advantage enjoyed by existing dirtier power plants by setting an expensive threshold for new facilities. Texas environmental regulators may not have the final say in these decisions. A judge in Georgia recently overturned a permit for a new coal power plant because of its high projected CO_2 emissions, in spite of aggressive control technologies for other air pollutants.

4.5 How could Texas build on the success of the Texas Emissions Reduction Plan?

The Texas Emissions Reduction Plan (TERP) has been a resounding success, achieving cost-effective reductions of vehicle emissions while garnering praise from environmental and industry groups alike. While this report focuses on the electricity sector, much can be learned from the success of the TERP program. TERP provides grants to retrofits and replacements to reduce diesel NO_x emissions; funds research and development of pollution control technologies; supports a Clean School Bus Program; and provides rebates for the purchase or lease of clean vehicles.

A key factor in the success of TERP's Emissions Reduction Incentive Grants Program has been its market-based approach, allocating incentive funding on a cost-effectiveness basis. However, a limitation of this program is that it does not specifically target emissions other than NO_x. While some PM and other emissions reductions may be achieved as a co-benefit, cost-effectiveness for NO_x control is the key basis for ranking proposals. Given the damaging health effects of PM pollution and the borderline status of Texas cities relative to new PM standards, more could be done to consider PM in the selection of TERP measures. California has successfully adapted its Carl Moyer diesel incentives program to address PM along with NO_x.

TERP could provide a model for incentivizing emissions reductions or efficiency improvements at stationary sources. TERP competitively selects the most cost-effective proposals from a wide range of companies, and thus provides a model for how incentives can be targeted for optimal impact at minimal cost.

4.6 How could Texas use cap-and-trade markets to promote emissions reduction, efficiency, and/or renewable energy?

A form of output-based environmental regulation, cap-and-trade markets issue a finite number of tradable emissions allowances. Participants who exceed their allowable limit must buy permits from those who emit beneath the limits. The Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR) would have allowed states to establish policies for distributing emissions permits, including the option to award some allowances as a financial incentive to renewable energy providers or to utilities that reduce energy consumption. However, courts have recently overturned both CAIR and CAMR, leaving uncertainty about the future of these markets.

Ten northeast states will in 2009 launch the Regional Greenhouse Gas Initiative, creating a cap-and-trade program with market-based trading of CO_2 allowances. The initiative will require electric power generators in member states to reduce carbon dioxide emissions to 10% below 2009 levels by 2018. Similarly, the Western Climate Initiative, which includes seven western states and three Canadian provinces, has recommended the creation of a regional greenhouse gas control and offset trading system.

The United Kingdom uses a market-based trading scheme called Renewables Obligation Certificates (ROCs), which legally obligate licensed electricity suppliers to derive a specified proportion of their electricity supplies from renewable energy sources. Under the system, suppliers may buy and sell ROCs to meet their quotas or else pay a buy-out price in the absence of sufficient ROCs. Furthermore, revenue from buy-outs are redistributed to ROC suppliers, who receive a fraction of the total buy-out fund based on the number of ROCs they submit as a proportion of the total number of ROCs submitted [139]. The European Union Emission Trading Scheme (or EU ETS) is the largest multi-national, greenhouse gas emissions trading scheme in the world and was created in conjunction with the Kyoto Protocol. The scheme continues to undergo modifications, such as correcting for the initial oversupply of allowances and improving allowance distribution methods.

References

1. *El Paso Air Quality Trends. 1999-2007*. 2007, Joint Advisory Committee for Air Quality Improvement in the Paso del Norte Airshed.
2. TCEQ, *Point Source Emissions Inventory*. 2006.
3. TCEQ, *Mercury in Texas: Background, Federal Rules, Control Technologies, and Fiscal Implications. Implementation of Section 2, HB 2481 (79th Legislature)—A Report to the Texas Legislature*. 2006.
4. EIA. *State Carbondioxide emissions by sector and by fuel*. 2004 [cited 2008 August 22]; Available from: http://www.eia.doe.gov/environment.html.
5. DOE, *EERE State Energy Statistics*. 2005, Energy Efficiency and Renewable Energy.
6. ERCOT, *2008 ERCOT Planning-Long-Term Hourly Peak Demand and Energy Forecast*. 2008, Electricity Reliability Council of Texas.
7. ERCOT, *REPORT ON THE CAPACITY, DEMAND, AND RESERVES IN THE ERCOT REGION*. 2008, Electricity Reliability Council of Texas.
8. Cohan, D.S., et al., *Nonlinear response of ozone to emissions: Source apportionment and sensitivity analysis.* Environmental Science & Technology, 2005. **39**(17): p. 6739-6748.
9. Kim, S., D.S. Cohan, and D.W. Byun, *Contributions of inter- and intra-state emissions to ozone over Dallas-Fort Worth, Texas.* Civil Engineering and Environmental Systems, 2008, in press.
10. Cowling, E.B. and D.D. Parrish, *Final Rapid Science Synthesis Report: Findings from the Second Texas Air Quality Study (TexAQS II)*. 2007. p. 143.
11. Murphy, C.F. and D.T. Allen, *Hydrocarbon emissions from industrial release events in the Houston- Galveston area and their impact on ozone formation.* Atmospheric Environment, 2005. **39**(21): p. 3785-3798.
12. Bell, M.L., et al., *Ozone and short-term mortality in 95 US urban communities, 1987-2000.* Journal of the American Medical Association, 2004. **292**(19): p. 2372-2378.
13. Ito, K., S.F. De Leon, and M. Lippmann, *Associations between ozone and daily mortality - Analysis and meta-analysis.* Epidemiology, 2005. **16**(4): p. 446-457.
14. Carey SA, M.K., Trease LL, Wagner JG, Garcia GJM , Ballinger CA , Kimbell JS, Plopper CG, Corley RA, Postlethwait EM , Harkema JR, , *Three-Dimensional Mapping of Ozone-Induced Injury in the Nasal Airways of Monkeys Using Magnetic Resonance Imaging and Morphometric Techniques.* Toxicologic Pathology, 2007 **35** (1): p. 27-40.
15. Moore, K., et al., *Ambient ozone concentrations cause increased hospitalizations for asthma in children: An 18-year study in Southern California.* Environmental Health Perspectives, 2008. **116**(8): p. 1063-1070.
16. Davison, A.W. and J.D. Barnes, *Effects of ozone on wild plants.* New Phytologist, 1998. **139**(1): p. 135-151.
17. Fuhrer, J., *Ozone impacts on vegetation.* Ozone-Science & Engineering, 2002. **24**(1): p. 69-74.
18. Fuhrer, J., L. Skarby, and M.R. Ashmore, *Critical levels for ozone effects on vegetation in Europe.* Environmental Pollution, 1997. **97**(1-2): p. 91-106.
19. Sitch, S., et al., *Indirect radiative forcing of climate change through ozone effects on the land-carbon sink.* Nature, 2007. **448**(7155): p. 791-U4.
20. IPCC, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate*

Change, ed. S. Solomon, et al. 2007, Cambridge, United Kingdom: Cambridge University Press.

21. TCEQ, *Revision to the State Implementation Plan for the Control of Ozone Air Pollution: Dallas-Fort Worth Eight-Hour Ozone Standard Non-attainment Area. Proposed August 6, 2008.* 2008, Texas Commission on Environmental Quality.
22. Buzcu, B., Yue, Z.W., Fraser, M.P., Nopmongcol, U., and Allen, D., , *Secondary Particle Formation and Evidence of Heterogeneous Chemistry during a Wood Smoke Episode in Texas.* J. Geophys. Res.- Atmos., 2006. **111**(D10S13,).
23. Russell, M.A., D.; Collins, D.; Fraser, M, *Daily, Seasonal, and Spatial Trends in PM2.5 Mass and Composition in Southeast Texas.* Aerosol Science and Technology, Volume 38, 2004. **38**(Supplement 1): p. 14-26.
24. Brunekreef, B. and S.T. Holgate, *Air pollution and health.* Lancet, 2002. **360**(9341): p. 1233-1242.
25. Brunekreef, B. and B. Forsberg, *Epidemiological evidence of effects of coarse airborne particles on health.* European Respiratory Journal, 2005. **26**(2): p. 309-318.
26. Dockery, D.W., et al., *An association between air pollution and mortality in 6 United States cities.* New England Journal of Medicine, 1993. **329**(24): p. 1753-1759.
27. Pope, C.A. and D.W. Dockery, *Health effects of fine particulate air pollution: Lines that connect.* Journal of the Air & Waste Management Association, 2006. **56**(6): p. 709-742.
28. Miller, K.A., et al., *Long-term exposure to air pollution and incidence of cardiovascular events in women.* New England Journal of Medicine, 2007. **356**(5): p. 447-458.
29. Xu, X.P. and L.H. Wang, *Association of indoor and outdoor particulate level with chronic respiratory illness.* American Review of Respiratory Disease, 1993. **148**(6): p. 1516-1522.
30. Peters JM, A.E., Gauderman WJ, Linn WS, Navidi W, London SJ, Margolis H, Rappaport E, Vora H, Gong H Jr, Thomas DC. , *A study of twelve Southern California communities with differing levels and types of air pollution. II. Effects on pulmonary function.* Am J Respir Crit Care Med., 1999. **159**(3): p. 768-775.
31. Avol EL, G.W., Tan SM, London SJ, Peters JM. , *Respiratory effects of relocating to areas of differing air pollution levels.* Am J Respir Crit Care Med., 2001. **164**(11): p. 2067-2072.
32. CARB, *Methodology for Estimating Premature Deaths Associated with Long-term Exposures to Fine Airborne Particulate Matter in California*. May 2008, California Environmental Protection Agency Air Resources Board.
33. EPA-TTN, *Health and Environmental Effects of Particulate Matter - Fact Sheet.* 1997.
34. Pitchford, M., et al., *Big Bend Regional Aerosol and Visibility Observational Study Final Report*. 2004.
35. Mercado, S., Gribbin, *Proposed PM NAAQS and Texas PM2.5 trends and composition: A summary*. 2006, Air Quality Planning and Implementation Divisionm TCEQ.
36. EPMAP, E.P.M.A.P., *Mercury atrnosphenc processes. a synthesis report.* 1994, Electric Power Research Institute: Palo Alto, CA.
37. Landis, M.S., Keeler, G.J., Al-Walib, K.I. and Stevens, R.K., *Divalent inorganic reactive gaseous mercury emissions from a mercury cell chlor-alkali plant and its impact on near-field atmospheric dry deposition.* Atmospheric Environment, 2004. **38**(4): p. 613-622.

38. Keeler, G., Landis, MS, Norris, GA, Christianson, EM and Dvonch, JT, *Sources of Mercury Wet Deposition in Eastern Ohio, USA*. Environ. Sci. Technol., 2006. **40**(19): p. 5874-5881.
39. Landis, M.S.K.G.J., *Atmospheric Mercury Deposition to Lake Michigan during the Lake Michigan Mass Balance Study*. Environ. Sci. Technol., 2002. **36**: p. 4518-4524.
40. TCEQ. *WATER BODIES IMPAIRED DUE TO MERCURY IN FISH, 2008*. 2008 [cited 2008 August 22]; Available from: http://www.tceq.state.tx.us/assets/public/implementation/water/mercurydocuments/2008_mercurymap.pdf.
41. Axelrad, D.A., et al., *Dose-response relationship of prenatal mercury exposure and IQ: An integrative analysis of epidemiologic data.* Environmental Health Perspectives, 2007. **115**(4): p. 609-615.
42. Trasande, L., P.J. Landrigan, and C. Schechter, *Public health and economic consequences of methyl mercury toxicity to the developing brain.* Environmental Health Perspectives, 2005. **113**(5): p. 590-596.
43. Griffiths, C., A. McGartland, and M. Miller, *A comparison of the monetized impact of IQ decrements from mercury emissions.* Environmental Health Perspectives, 2007. **115**(6): p. 841-847.
44. DeSoto, N.C. and R.T. Hitlan, *Blood levels of mercury are related to diagnosis of autism: A reanalysis of an important data set.* Journal of Child Neurology, 2007. **22**(11): p. 1308-1311.
45. Ip, P., et al., *Mercury exposure in children with autistic spectrum disorder: Case-control study.* Journal of Child Neurology, 2004. **19**(6): p. 431-434.
46. Lewandowski, T.A., *Questions regarding environmental mercury release, special education rates, and autism disorder: An ecological study of Texas by Palmer et al.* Health & Place, 2006. **12**(4): p. 749-750.
47. Palmer, R.F., et al., *Environmental mercury release, special education rates, and autism disorder: an ecological study of Texas.* Health & Place, 2006. **12**(2): p. 203-209.
48. Windham, G.C., et al., *Autism spectrum disorders in relation to distribution of hazardous air pollutants in the San Francisco Bay area.* Environmental Health Perspectives, 2006. **114**(9): p. 1438-1444.
49. Palmer, R., Blanchard, S, Wood, R, *Proximity to point sources of environmental mercury release as a predictor of autism prevalence.* Health & Place, 2008.
50. Virtanen, J.K., et al., *Mercury as a risk factor for cardiovascular diseases.* Journal of Nutritional Biochemistry, 2007. **18**(2): p. 75-85.
51. TCEQ. *Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR)*. [cited; Available from: http://www.tceq.state.tx.us/implementation/air/sip/caircamr.html.
52. Savonis, M.J., Burkett, V.R., Potter, J.R., *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.* 2008, U.S. Climate Change Science Program Synthesis and Assessment Product 4.7.
53. Bernard, S., Samet, JM, Grambsch, A, Ebi,KL, and Romieu, I, *The Potential Impacts of Climate Variability and Change on Air Pollution-Related Health Effects in the United States.* Environmental Health Perspectives 2001. **109**(Supplement 2): p. 199-209.
54. Seinfeld, J.H. and S.N. Pandis, *Atmospheric Chemistry and Physics: From air pollution to climate change*. Second ed. 2006, Hoboken, NJ: John Wiley & Sons.

55. Constable JVH, G.A., Schimel DS, Monson RK *Modelling changes in VOC emission in response to climate change in the continental United States.* Glob Chang Biol 1999. **5**: p. 791-806.
56. Bell, M., Goldberg, R, Hogrefe, C, Kinney, PL, Knowlton, K, Lynn, B, Rosenthal, J., Rosenzweig, C, Patz, JA, *Climate change, ambient ozone, and health in 50 US cities.* Climatic Change, 2007.
57. NAST, N.A.S.T., *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change,*. 2000, US Global Change Research Program: Washington DC.
58. EIA. *State Historical Tables, Retail Sales of Electricity by Provider by Sector (1990-2006).* 2008 [cited August 15, 2008]; Available from: http://www.eia.doe.gov/cneaf/electricity/page/at_a_glance/sales_tabs.html.
59. EIA, U., *Electric Power Monthly.* 2008(July).
60. EIA, *State Electricity Profiles* 2006, Energy Information Administration.
61. SECO, S.E.C.O. *Texas Wind Energy*. 2008 [cited 2008 August 18]; Available from: http://www.seco.cpa.state.tx.us/re_wind.htm.
62. Francfort, J.E., *U.S. Hydropower Resource Assessment for Texas*. 1993, U.S. Department of Energy, Idaho Operations Office: Idaho Falls, ID.
63. ERCOT, *Annual Report*. 2007, Electricity Reliability Council of Texas. p. 6.
64. EIA, E.I.A. *STEO Chart: Natural Gas Henry Hub Spot Price*. 2008 August 12, 2008 [cited 2008 August 15]; Available from: http://tonto.eia.doe.gov.
65. Swindell, G.S., *Changes in the Performance of Texas Gas Wells*. 2007.
66. BP, *BP Statistical Review of World Energy 2007*. 2007.
67. TCEQ, *Nonpoint Source Emissions Inventories for 2005*. 2005.
68. USEPA, *Toxics Release Inventory (TRI)* 2005.
69. U.S.EPA, *Clean Air Markets Data*. 2007.
70. Reuters, *Luminant announces details of voluntary emissions reduction plan*. 2008.
71. US-EPA, *Standards of Performance for Electric Utility Steam Generating Units, Industrial-Commercial-Institutional Steam Generating Units, and Small Industrial-Commercial-Institutional Steam Generating Units; Final Rule*, in *Federal Register*, U.S.E.P. Agency, Editor. 2006. p. 9866-9886.
72. Srivastava, R.K., et al., *Control of mercury emissions from coal-fired electric utility boilers.* Environmental Science & Technology, 2006: p. 1385-1393.
73. Elliott, R.N., Eldridge, M., Shipley, A.M., Laitner, J., Nadel, S., Silverstein, A., Hedman, B., SLoan, M., *Potential for Energy Efficiency, Demand Response, and Onsite Renewable Energy to Meet Texas' Growing Electricity Needs*. 2007, American Council for an Energy Efficient Economy.
74. ERCOT, *Report on the Capacity, Demand, and Reserves in the ERCOT Region: May 2008*. 2008.
75. AWEA, A.W.E.A. *US Wind Energy Projects*. 2008 [cited; Available from: http://www.awea.org/projects/.
76. ARCHR, A.C., Heating, Refrigiration, *Google and Fort Bliss Launch Record-Setting Solar Power Projects* 2006.
77. Wynn, W., *The Solar Industry in Austin, Texas*, in *1st Annual Solar America Cities Meeting*. 2008: Tuscon, AZ.

78. McKinsey&Co, *Reducing U.S. Greenhouse Gas Emissions: How much at what cost?*, in *US Greenhouse ABatement Mapping Initiative Executive Report*. 2007.
79. Cho, S., et al., *Recommendations for 15% Above-Code Energy-Efficiency Measures for Commercial Office Buildings*. 2007, Texas A&M Energy Systems Lab.
80. Malhotra, M., et al., *Recommendations for 15% Above-Code Energy Efficiency Measures for Single-Family Residences*. 2007, Texas A&M Energy Systems Lab.
81. ACEEE, *Potential for Energy Efficiency, Demand Response, and Onsite Renewable Energy to Meet Texas's Growing Electricity Needs*. 2007, American Council for an Energy-Efficient Economy.
82. NRC, *Environmental Impacts of Wind Energy Projects*. 2007: National Research Council Committee on Environmental Impacts of Wind Energy Projects.
83. *The Energy Report*. 2008, Texas Comptroller of Public Accounts.
84. US-DOE, *20 Percent Wind Energy by 2030: Increasing wind energy's contribution to U.S. electricity supply*. 2008, U.S. Department of Energy.
85. US-DOE, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*. 2008.
86. ERCOT, *Analysis of Transmission Alternatives for Competitive Renewable Energy Zones in Texas*. 2006.
87. Cohen, J. and T. Schweizer, *Technology Improvement Opportunities for Low Wind Speed Turbines and Implications for Cost of Energy Reduction*. 2008, National Renewable Energy Laboratory.
88. Son, Y. *Dispatchable Wind Power Valuation in Texas*. in *IEEE*. 2005.
89. US-DOE, *Annual Energy Outlook 2008*. 2008, U.S. DOE Energy Information Administration.
90. Lazard, *Levelized Cost of Energy Analysis Version 2.0*. 2008.
91. SECO. *Texas Renewable Portfolio Standard*. 2008 [cited July 8, 2008]; Available from: http://www.seco.cpa.state.tx.us/re_rps-portfolio.htm.
92. U.S.-DOE. *Wind Powering America*. 2008 [cited; Available from: http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp.
93. TCPA, *The Energy Report*. 2008, Texas Comptroller of Public Accounts.
94. Wetsel, R.E., Carmichael, H.A., and and L. Chavarria, *Current Issues in Texas Wind Energy Law: Leases, Ownership of Wind Rights and Litigation*. 2007, The University of Texas School of Law and the Oil, Gas and Energy Resources Law Section of the State Bar of Texas
95. Dominguez, T., et al., *Renewable energy supervision and real time production control in Spain*. 2008.
96. IEA, *Variability of Wind Power and Other Renewables: Management options and strategies*. 2005, International Energy Agency.
97. UWIG, *Utility Wind Integration State of the Art*. 2006, Utility Wind Integration Group.
98. Elliot, J., *Utility panel sees plan adding 18,456 megawatts of energy capacity*, in *Houston Chronicle*. 2008: Houston, TX.
99. Wald, M., *Two Large Solar Plants Planned in California*, in *The New York Times*. 2008.
100. NREL, *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*. 2003, Prepared by Sargent and Lundy LLC Consulting Group for National Renewable Energy Laboratory.

101. NREL, *Fuel From the Sky: Solar Power's Potential for Western Energy Supply*. 2002, Prepared by RDI Consulting for National Renewable Energy Laboratory.
102. Philibert, C., *The Present and Future Use of Solar Thermal Energy as a Primary Source of Energy*. 2005, International Energy Agency.
103. *Opportunity on the Horizon: Photovoltaics in Texas*. 2007, IC2 Institute, University of Texas at Austin.
104. GEA. *Update on U.S. Geothermal Power Production and Development*. 2007 [cited; Available from: http://www.geo-energy.org/.
105. USEPA, *Energy Projects and Candidate Landfills*.
106. SECO. *Texas Biomass Energy*. 2008 [cited 2008 August 20]; Available from: http://www.seco.cpa.state.tx.us/re_biomass.htm.
107. Xu, W., Carraway, B., *Biomass from Logging Residue and Mill Residue in East Texas, 2005*. 2007, Texas Forest Service - Texas A&M University System.
108. HARC, H.A.R.C., *Combined Heat and Power Potential using Agricultural Wastes*. 2008.
109. U.S.EPA. *"Non-Hydroelectric Renewable Energy,"*. [cited 2008. April 20]; Available from: http://www.epa.gov/cleanenergy/energy-and-you/affect/non-hydro.html.
110. Bullock, D., *Distributed Electricity Generation Using Combined Heat and Power (CHP)*. 2008, Houston Advance Research Center.
111. TCHPI, T.C.H.a.P.I., *Twice the Power at Double the Efficiency: Providing Secure Energy in Texas With CHP*. 2007.
112. DOE. *Electricity Delivery and Energy Reliability - Distributed Energy Program*. [cited; Available from: http://www.eere.energy.gov/de/.
113. Srivastava, R.K., et al., *Nitrogen oxides emission control options for coal-fired electric utility boilers*. Journal of the Air & Waste Management Association, 2005. **55**(9): p. 1367-1388.
114. U.S.-EPA, *Documentation for Base Case 2006, IPM v. 3.0*. 2006.
115. Srivastava, R.K. and W. Jozewicz, *Flue gas desulfurization: The state of the art*. Journal of the Air & Waste Management Association, 2001. **51**(12): p. 1676-1688.
116. US-EPA, *Documentation for Base Case 2006, IPM v. 3.0*. 2006.
117. IPCC, *Carbon Dioxide Capture and Storage*. 2005.
118. US-EPA, *Analysis of the Lieberman-Warner Climate Security Act of 2008*. 2008.
119. CBO, *Cost Estimate for America's Climate Security Act of 2007*. 2007, Congressional Budget Office.
120. U.S.-DOE, *Report to Congress on the Interdepedency of Energy and Water*. 2006.
121. US-EPA, *Environmental Footprints and Costs of Coal-Based Integrated Gasification Combined Cycle and Pulverized Coal Technologies*. 2006.
122. MIT, *The Future of Nuclear Power*. 2003.
123. *Nuclear Power Joint Fact-Finding*. 2007, The Keystone Group.
124. Lovins, A.B. and I. Sheikh, *The Nuclear Illusion*. Ambio, 2008. **preprint version**.
125. ERCOT, *Transmission Issues Associated with Renewable Energy in Texas: Informal White Paper for the Texas Legislature*. 2005.
126. Haberl, J., et al., *Statewide Air Emissions Calculations from Wind and Other Renewables*. 2007, Texas A&M Energy Systems Laboratory.
127. Eldridge, M., et al., *The State Energy Efficiency Scorecard for 2007*. 2007, American Council for an Energy-Efficient Economy.

128. PUCT, *Report to the 80th Texas State Legislature: Scope of Competition in Electric Markets in Texas*. 2007, Public Utilities Commission of Texas.
129. *Energy Efficiency Accomplishments of Texas Investor-Owned Utilities, Calendar Year 2006*. 2007, Frontier Associates.
130. Nadel, S., *Energy Efficiency Resource Standards: Experience and Recommendations*. 2006.
131. US-DOE, *Electric Power Annual*. 2007, U.S. Department of Energy.
132. *Database of State Incentives for Renewables & Efficiency*. 2008 [cited August 1, 2008; Available from: www.dsireusa.org.
133. McKinsey, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* 2007.
134. US-EPA. *Green Power Partnership Data for July 2008*. 2008 [cited; Available from: www.epa.gov/grnpower/toplists/top10localgov.htm.
135. Nadel, S., *Energy Efficiency Standards: Experience and Recommendations*. 2006, American Council for an Energy-Efficient Economy.
136. ACEEE, *Energy Efficiency Standards Adopted and Pending by State*. 2008.
137. SECO. *Texas Tax Code Incentives for Renewable Energy*. 2008 [cited August 7, 2008]; Available from: http://www.seco.cpa.state.tx.us/re_incentives-taxcode-statutes.htm.
138. US-EPA, *Clean Energy-Environment Guide to Action: Policies, Best Practices, and Action Steps for States*. 2006.
139. IEA. *Energy Policies of IEA Countries*. 2006 [cited August 2008; Available from: http://www.iea.org/Textbase/country/index.asp.
140. *Texas General Land Office press release, .* June 2007.
141. LBNL, *Evaluating Experience with Renewable Portfolio Standards in the United States*. 2004, Lawrence Berkeley National Laboratory.
142. Musier, R., *US Mandatory REC Markets—An established environmental infrastructure*. 2006.
143. UCS, *Renewable Electricity Standards at Work in States*. 2007, Union of Concerned Scientists.
144. US-EPA. *Renewable Portfolio Standards Fact Sheet*. 2008 [cited July 31, 2008]; Available from: http://www.epa.gov/chp/state-policy/renewable_fs.html.
145. Wood, E., *Green Trading: Why the chase is on for US RECs.* Renewable Energy World, 2007. **10**(3).
146. Cohan, D.S., et al., *Convective injection and photochemical decay of peroxides in the tropical upper troposphere: Methyl iodide as a tracer of marine convection.* Journal of Geophysical Research-Atmospheres, 1999. **104**(D5): p. 5717-5724.
147. UCS, *Increasing the Texas Renewable Energy Standard: Economic and Employment Benefits*. 2005, Union of Concerned Scientists.
148. TREIA. *TREIA 2009 Legislative Agenda*. 2008 [cited August 6, 2008]; Available from: www.treia.org.