

Texas Tech University
Economic Development Summit

*Wind and Water:
Redeveloping Regional Resources
for the New Economy*

Edited by Andrew Swift

*In cooperation with:
Texas Tech University; ING Financial Advisors, LLC;
Reese Technology Center; Market Lubbock, Inc.;
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Foreword

In the late summer of 2004, a group of government, business, and academic leaders assembled on the campus of Texas Tech University to discuss the issues and possibilities associated with the use of advanced wind power technology to purify water on the Southern Great Plains. The ultimate goal was the enhancement of the quality and quantity of water available in the region.

The use of wind to generate power and produce water in America can be traced to its early settlers who erected a handful of European-styled windmills that were primarily used to pump water, grind grain, or drive sawmills; however, in the later half of the nineteenth century, a new kind of wind-harvesting machine was born—the American windmill. Unlike its predecessor, the American windmill was small, easily transportable, and relatively inexpensive. As a result, large numbers of windmills began to dot the countryside, and it was these windmills that provided adequate water to sustain the burgeoning settlements.

Today, the Southern Great Plains can be viewed as a paradigm for the rest of the world. According to Dan Flores in Sherry Smith's *The Future of the Southern Plains*, the Southern Plains are “the cutting edge of the modernist experiment with the exploitation of North America. This is the place that is going to show us the outcome first.”¹

We hope that these summit proceedings illustrate the potential value in the use of renewable resources and the significance of their application on the Southern Great Plains. Our goal is to demonstrate how wind power can help purify and move water as part of the solution to the ever-increasing water issues in the region, the nation, and the world.

¹ Smith, S.L., ed. *The Future of the Southern Plains*, Norman, OK: University of Oklahoma Press, 2003.

Summit Overview and Vision

*Robert Sweazy, Vice President for Research, Technology
Transfer, and Economic Development, Texas Tech University*

In West Texas, population and personal income growth rates lag behind those for the rest of Texas as well as the United States. If the area is to remain economically viable, a new economy must emerge. As one of the most important economic assets in the entire region, Texas Tech University must be involved in developing this new economy. While Texas Tech is not attempting to define its composition, it is apparent that two resources—energy and water—must be readily available as the foundation and cornerstone. Beyond sustaining our current economic activities, abundant and affordable energy and water are essential to achieve higher rates of economic growth and diversification of the West Texas economy. Redevelopment of these two natural resources will allow West Texas to gain a comparative regional economic advantage that will encourage and attract new business, investment, and development.

In many parts of the country, water is used to produce energy via hydroelectric generation; but in this region, energy is used to produce water. Texas Tech University is proposing that the first step in the economic redevelopment of the region is to develop and utilize the abundant wind resources of the Southern Plains to generate electric power for a variety of purposes, including pumping and desalinating the vast reserves of brackish water that lie beneath the Ogallala Aquifer. There are almost 92 million acre feet of brackish water under the South Plains. While not all of the brackish water is suitable for use, this amount of water will satisfy the 50 million gallon per day demand of the area for 1,600 years. Simply redeveloping our wind and water resources will enhance the regional economy.

Currently, the region is energy constrained by a lack of high voltage transmission facilities. By constructing clusters of 6 to 8, 1.5

megawatt wind turbines, the capability to generate 9 to 12 megawatts of electricity per cluster is provided. By need-siting the clusters, the necessity for high voltage transmission lines is obviated. Erection of the wind turbines will create temporary jobs, but the structures themselves will represent huge, relatively permanent increases in the property tax base of small counties—about \$9 to \$12 million of taxable assets per cluster. Similar economic gains will accrue from the production and desalination facilities necessary to redevelop the water resource.

Such activity is possible with existing technology but will require cooperation and interaction between local, state, and federal governments, the private sector, and higher education. While all three entities will be involved in all facets of development and implementation, each will have a primary role.

Local, state, and federal government must initiate the process with start-up funding, appropriate policies, and political support. The national labs will bring invaluable scientific and engineering resources that will continue to improve and lower the cost of both wind energy production and water desalination technologies. The universities will be responsible for ensuring economic and technical feasibility, proof of concept, and research aimed at continued improvement of the process. This will include design and testing of wind power equipment—both keys to adapting to the unusual weather characteristics of our region compared to California and Western Europe where design and manufacturing now occur. Also, the academic community will be responsible for the education and training of the technicians, meteorologists, and managers necessary for these technologies.

The private sector's charge will be to commercialize the technology utilizing entrepreneurial spirit, manufacturing, marketing, and financial expertise. In the end, only private capital can drive a successful, market-oriented deployment of these emerging

technologies and spawn the envisioned industry clusters. Once we have collectively assured adequate energy and water resources for sustainable regional growth well into this new century, we can proceed with confidence to create the jobs and new sources of wealth that will expand opportunity and enhance the quality of life for all.

This summit is intended to present an opportunity for the governmental and private sector representatives to react to the above proposal, to express their views, and to introduce additional ideas, concepts, or strategies for redeveloping our natural resources and our regional economy.

The Technology and Economics of Wind Power and Water Desalinization

*Jim Lyons, Chief Engineer, GE Global Research,
Schenectady, New York*

General Electric (GE) is a leader in wind energy technology. GE Wind Energy was formed in May 2002 and now employs more than 1,700 people worldwide. They have the industry's largest installed fleet of MW class turbines (2400, 1.5 MW turbines) and have sold \$1.3 billion worth of turbines. Because of the rapid growth in wind energy, GE has expanded into commercial, service, and supplier networks. As a result, they have doubled their engineering staff and quadrupled their research and development staff. They are now working on more than 100 technology projects and have launched six-Sigma and reliability programs.

Energy Trends

Renewable energy is predicted to be the dominant energy source in the coming decades. Figure 1 shows the trends in energy sources over the past 100 years. Each energy source to date has reached a peak and then been replaced by another primary energy source—first wood, then coal, then oil.

Renewable wind energy is the first viable renewable source to come along. Although the majority of early wind farms

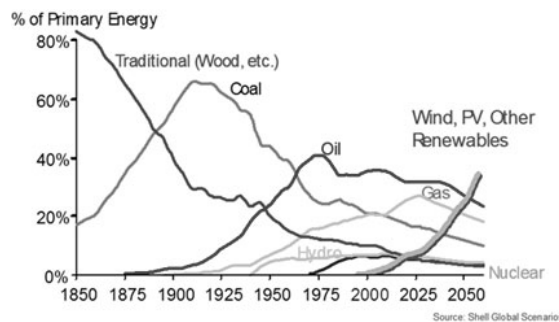


Figure 1: Energy Trends Over 200 Years.

were located in California and Denmark, other European countries are developing and using wind energy. There is also emerging interest around the world in countries such as India, Australia, China, and Japan. In coming years, growth in offshore segments is expected in the UK, Netherlands, Germany, and the US and in onshore development in France, Italy, the US, and Eastern Europe (Figure 2).

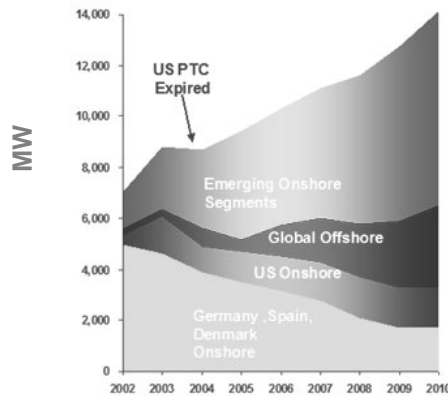


Figure 2: Wind Power Segment Growth Analysis.

Source: BTM/Carnegie/DEWI, GEWE

Other factors that should have a positive effect on the growth of wind energy include:

- Onshore – Land Capacity Becoming Constrained (e.g. Germany, Spain) Driving Off-shore Development
- Kyoto Protocol
- EU Renewables Directive
- Offshore Development Expanding
- Government Incentives Accelerating Growth (Italy, UK, France, Poland, Japan, Australia)

Offshore wind development is promising in areas such as the East and Gulf Coasts of the US, the Great Lakes, British Columbia, the United

Kingdom, and Germany. These are prime locations for this type of development due to the offshore water depths (10-40 m) and because of their proximity to population and load centers. Offshore development does face challenges, including hurricane exposure, waves, sea bed stability, deep water foundations > 40 m, and a difficult service environment.

Competitive Costs

The cost of wind energy is becoming more and more competitive. Figure 3 shows the cost of energy (COE) for wind and natural gas fueled power plants. The COE for wind is already below the five cent target and is expected to drop even further with continued technology improvement and the help of tax credits. This will bring wind energy to the low end of the band. In the next three years, thanks to help from the Department of Energy, the National Renewable Energy Laboratory, and Sandia Labs, wind should be the cheapest way to produce energy.

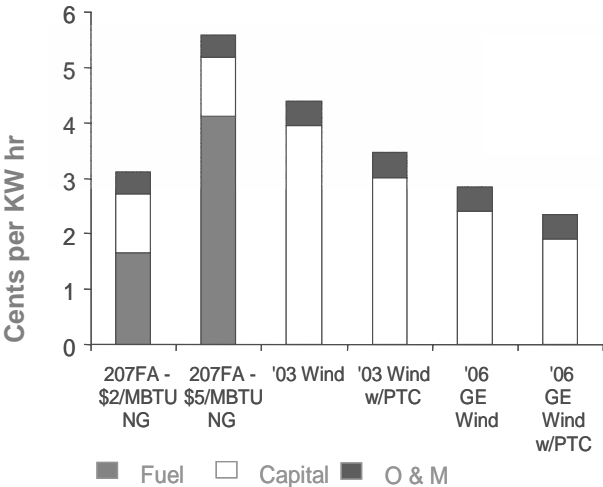


Figure 3: Cost of Energy for Several Natural Gas and Wind Power Plant Options.

The graph in Figure 4 shows the cost of wind power and increasing turbine size with time using our best guess for future turbine technology.

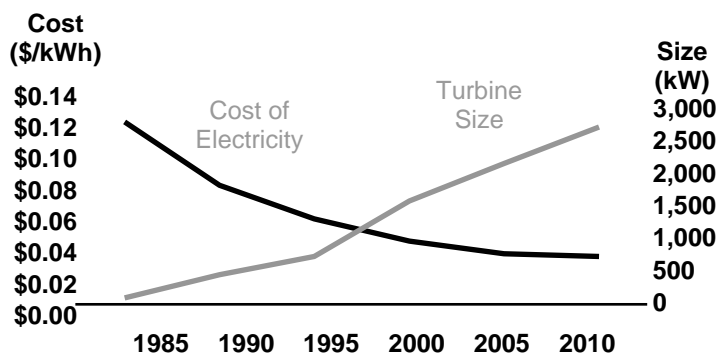


Figure 4: Cost of Wind Power versus Turbine Size.

The three main users of wind energy are Germany, Spain, and the United States. The table below shows a comparison of the development of wind energy in Germany, the UK, and the US. There is great potential for growth in the US as there are currently 100-500 MW utility wind farms being developed, and grid codes are rapidly evolving.

Germany has created an economy through wind power that employs 35,000 people, and the UK has taken a market based approach with their Renewable Obligation Certificates (ROC). Sporadic US tax policies (the Production Tax Credit (PTC)), along with state incentives, such as renewable portfolio standards (RPS), have helped drive the market in this country. Texas is one of fourteen states that has a renewable portfolio standard. Thanks to this policy, some of the largest projects in the world have been installed in Texas.

Table 1: Comparison of Wind Development in Three Countries.

	Germany	UK	US
Incentive	Tariff	ROC	Tax-PTC
Stability	20 years	New	Sporadic
RPS	12.5% (2010)	10% (2010)	State Partial
Customers	Developers	Mixed	Utility
Project IRR%	7%	11%	10%
MW Installed '98-'03	11,600	400	4,200
% Power	5%	<1%	<1%
Jobs '03	35,000	<3000	<3000

Texas and Wind Development

Texas has had a RPS in place since 1999. The RPS mandates 2GW renewable production by 2009. Additionally, the state has a Renewable Energy Credit (REC) trading system at \$12 per MWhr, fuel diversification, good wind resources (8.5 m/s), and zonal energy bids that encourage growth. GE has already installed several wind projects in the state including:

Location	Size
Desert Sky	160 MW
Trent Mesa, Sweetwater	150 MW
Delaware Mountains	30 MW
Clear Sky, Pecos County	25 MW
Total	365 MW

GE Developments

The following is an introduction to the GE line of turbines, including the 1.5 MW wind turbines and the 2.x MW wind turbine family.

1.5 MW Wind Turbines

The family of 1.5 MW wind turbines has improving reliability, COE reduction and global sourcing, best in class energy capture, and extended operations (Temp, IEC TC I/II). Additionally, GE is developing a near 1.5 MW xle turbine with an 82.5 m rotor. The chart below shows the specific features of each model in this family.

Table 2: 1.5 Wind Turbines.

	1.5e	1.5se	1.5s	1.5sle
Frequency	60 Hz	50/60 Hz	50/60 Hz	50/60 Hz
Wind Regime	IEC TC Ia+	IEC TC Ib	IEC TC IIa	TC s
Rotor Diameter	65m	70.5m	70.5m	77m
Rated Power	1.5 MW	1.5 MW	1.5 MW	1.5 MW
Hub Heights	65m	52-65m	65-85m	61-85m
Speed Range	11-22 rpm	11-22 rpm	11-22 rpm	10-20 rpm

2.x MW Turbine Family

The 2.x MW turbine family all have a common platform (IEC I, II, III), common 50/60 Hz design, and best in class energy capture and cost of energy. The chart below shows the specific features of each model.

Table 3: 2.x Wind Turbines.

	2.3	2.5	2.7
Wind Regime	IEC TC IIIa	IEC TC IIa	IEC TC Ib
Rotor Diameter	94m	88m	84m
Rated Power	2.3 MW	2.5 MW	2.7 MW
Hub Heights	100, 120m	85m	58,70m
Avg Wind Speed	7.5 m/s	8.74 m/s	10.0 m/s

Wind and Water

There is a global demand for clean water; however, there is limited energy to help with water purification. One third of the globe is off the energy grid, but wind is a cheap renewable energy source that can be used for:

- Isolated grid/island power systems, wind-diesels
- Desalination to create clean water/storage
- Hydrogen as energy storage with combustion engine or fuel cell
- Renewable hydrogen for cars

The water economy is a fragmented, \$360B industry with increasing demand and decreasing supply. Water is an undervalued resource, and demand continues to increase with the growth of populations and industrialization. If uncontrolled, demand will overtake supply. Water is plentiful for much of the world, but sufficient purity is a challenge. GE Water Technologies has already begun to work in this industry, but a need for more technology remains.

Supply

While water is plentiful, it is not always of the right quality or properly located. Water experts define areas where per capita water supply drops below 1,700 cubic meters per year as experiencing

"water stress"—a situation in which disruptive water shortages can frequently occur. The United States is predicted to be a high stress area.

In areas where annual water supplies drop below 1,000 cubic meters per person per year, the consequences can be more severe and lead to problems with food production and economic development. This can be averted if the region is wealthy enough to apply new technologies for water use, conservation, or reuse. According to an analysis, as of 1995, some 41 percent of the world's population (2.3 billion people) lives in river basins under water stress with per capita water supply below 1,700 cubic meters per year. Of these, some 1.7 billion people reside in highly stressed river basins where water supply falls below 1,000 cubic meters per year. Assuming current consumption patterns continue, the projections show that by 2025 at least 3.5 billion people, or 48 percent of the world's projected population, will live in water-stressed river basins. Of these, 2.4 billion will live under high water stress conditions.

Facing the Water Challenge

There are many ways to address the global water challenge, but all require the cooperation of public policy, technology investment, and infrastructure investment. The goal is to increase supply, transport supply to where it is needed, reduce waste, reduce demand, and improve quality.

Public Policy

The cost of water does not always reflect its value, resulting in wasteful practices. A solution for this problem is to use more appropriate water pricing models. For example, in Chile, property owners were given legally recognized, tradable water rights in 1981. Water rights had higher value than crops, so many farmers sold water back to the community for a profit, resulting in the more efficient use of water by farmers. Contrast this with Delhi, India where water is

sold for 4 percent of the cost to produce it, resulting in high waste levels and little investment in water infrastructure.

Water is the lifeblood of industry, accounting for 20 percent of the world's annual water usage. Industry is also one of the least frugal water consumers, wasting over 75 percent of withdrawals. A possible solution is to create incentives for industrial water conservation and reuse. For example, a cooling tower treatment can enable water to be cycled eight times rather than just four.

Increasing Supply through Technology

One irony of the water dilemma is that 97 percent of the earth's water is salinated but plentiful where water stress is most severe. Unfortunately, the energy required to desalinate water can be prohibitively expensive. A potential solution is the development of advanced technology systems (wind and solar) that lower the cost of desalinating brackish/salt water. GE makes end-to-end products for membrane filtration and desalination needed in this process.

Cost of Water

For now, the focus of fresh water sources is on reuse and conservation. It currently costs \$2.00 per 1000 gallons to make clean water out of fresh water, and desalinization of seawater costs \$3.50 per 1000 gallons. Reverse osmosis is energy intensive, requiring 3 to 5 kWh per cubic meter. The impact is that desalination is not cost competitive with existing water resources. Finding ways to reduce energy cost is critical.

In the future, the focus will be on supplemental sources. Desalination in 2004 is responsible for 23 million cubic meters per day and is anticipated to grow to 2.3 billion cubic meters per day by 2025. By this time, the cost of fresh water is expected to rise to \$5.00 per 1000 gallons, and predicted desalination seawater costs should drop to \$2.50 per 1000 gallons. Desalination will be more attractive as fresh

water prices increase. For this to occur, technology needs to advance in several areas including:

- Utilization of renewable energy sources
- Advanced membranes
- Energy recovery devices
- Chemistry and membrane synergies

Future Projects

GE has begun working on the LWST (low wind speed turbine) Wind Desalination Concept Study. The program was awarded \$200,000 from NREL/DOE for concept development to minimize the cost of water and to satisfy water quality requirements.

The challenges for this project are to:

- Change the desalination design paradigm from steady state to dynamic operation,
- Design desalination operational strategy to adapt to wind power fluctuations while satisfying transient requirements,
- Minimize the need for external energy supply and expensive storage, and
- Develop cost-effective solutions for a hybrid system.

The GE Desalination Lab has already submitted a \$970K proposal to the Bureau of Reclamation for development of a lab facility. The objectives of this proposal are to:

- Develop and validate renewable-desalination system configuration,
- Develop an energy management and renewable-desalination operation strategy,
- Validate the cost of water models developed in the NREL program,

- Gain leverage for validation of new membrane technology and hybrid desalination concepts, and
- Act as a test bed for developing membrane monitoring and life extending algorithms to impact cost of water.

Significant potential remains for technology development opportunities to change desalination market dynamics. Development should include:

- Advanced anti-scalant and dispersants
- Membrane cleaners
- Pretreatment technologies such as NF/UF/MF filtration
- Predictive pre-treatment
- High efficiency energy recovery devices
- Beyond Pelton turbine and pressure exchangers
- Low energy, high reject membranes
- High performance membranes

Wind Power Options and Opportunities for the Great Plains

*Larry Flowers, National Renewable Energy Laboratory,
Golden, Colorado*

The Department of Energy has a robust wind power program that includes low wind speed technology, distributed wind technology, supporting research and testing, supporting engineering and analysis, technology acceptance, and systems integrations. General Electric (GE) is very involved in this program.

Due to economics and environmental benefits, wind energy is on the rise. Figure 1 shows a graph of the growth of wind technology across the world. As of 2003, the total world wind capacity is 37200 MW. Germany has the largest wind capacity at 14000 MW with the United States having the second largest capacity at 6374 MW. Other leaders are Spain (5780 MW), Denmark (3094 MW), and India (1900 MW). In the US, the growth is largely driven by economics and competitive advantages.

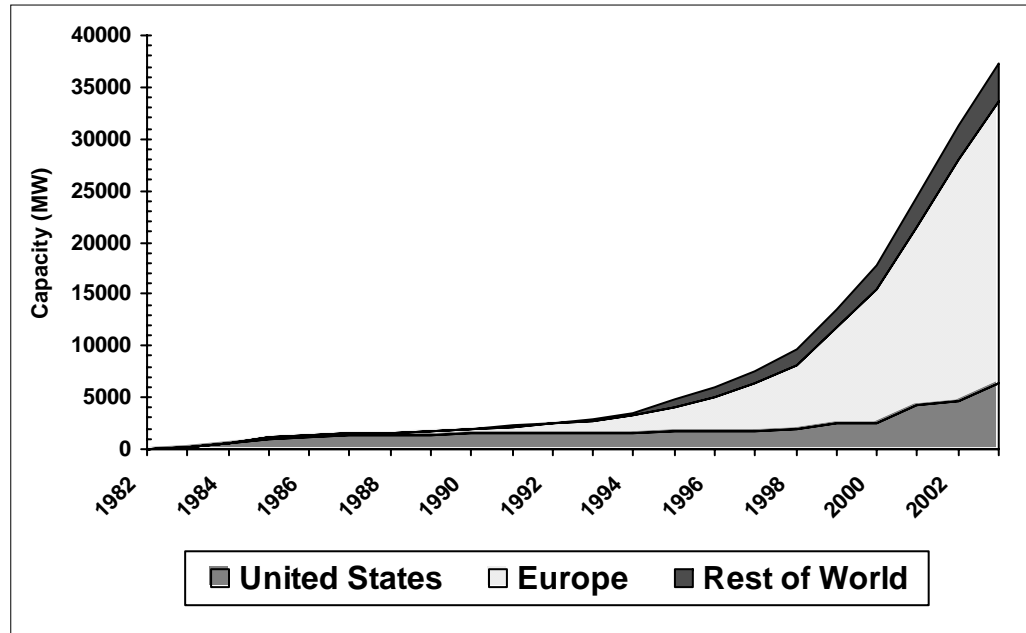


Figure 1: Total Installed Wind Capacity. Source: WindPower Monthly.

Wind energy in the United States started in California twenty years ago, but it is no longer just a California phenomenon. Wind technology can be found in the Northwest, the Southwest, the Great Plains, the Rust Belt, and even in New England where the environment and pristine views are important. Each state has its own story to tell and its own reasons for moving into this type of energy. Some regions, such as the Rocky Mountains, have little wind production, but this is not due to a lack of wind resources. It is a result of cheap coal and hydro resources in years past; however, the area realizes that the days of cheap coal and water are over and is now moving into a broader portfolio, including renewable energy resources.

Figure 2 shows the growing domestic energy capacity and the cost curve for wind energy. The drop in cost has occurred for a number of reasons.

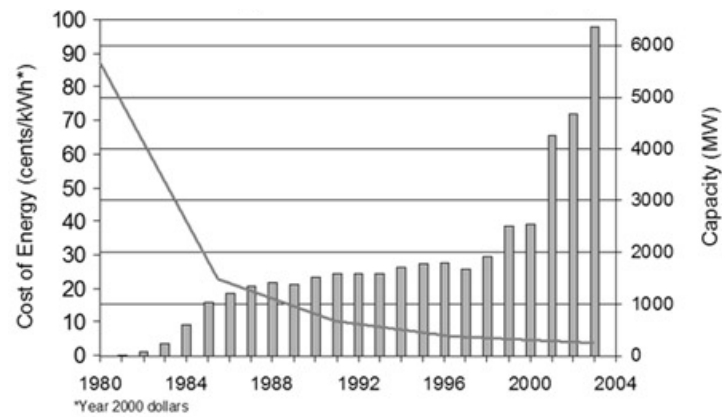


Figure 2: Cost of Wind Energy (line) and Cumulative Domestic Capacity (bars).

One factor that has aided the US industry growth is the declining cost of wind energy. When it first began in the early 1980s, wind energy was very expensive because of economy of scale issues, reliability, and a lack of efficiency. In the early days of wind farming, the average wind turbine produced 50 kW. Today, wind turbines are thirty times as large.

Over the last 20 years, there have been dramatic improvements in the efficiency of wind farms. Through the early wind farms in California, we learned to efficiently operate wind systems. Early farms allowed us to identify the best type of equipment and to fine tune the machines, making them more effective and less prone to maintenance. Due to mechanical problems, early wind turbines were only operational about 65 percent of the time. Today, turbines are operational 98 to 99 percent of the time. While we have made tremendous increases in technology and machine size, we have made equally important advances in the ability to efficiently operate and maintain the turbines.

Wind Power Drivers

There are many factors that drive the increased use of wind power—the number one factor being the declining cost of wind energy. Unsteady fuel prices (Figure 3) have prompted states to look for more reliable sources of energy. The problem with natural gas as a primary energy source is that while industrial, residential, and commercial uses of natural gas stay relatively stable with only slight growth, the need for natural gas for electric generation has risen dramatically. When combined with varying prices that are likely to continue due to world events, an economical, home-grown energy replacement is very attractive.

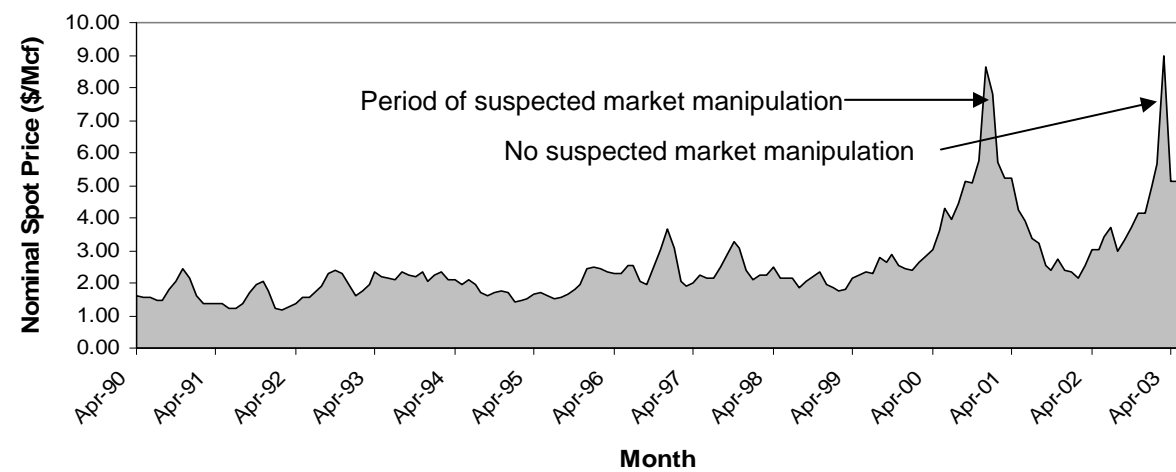


Figure 3: Volatile Natural Gas Prices (Spot Prices 1990-2003).

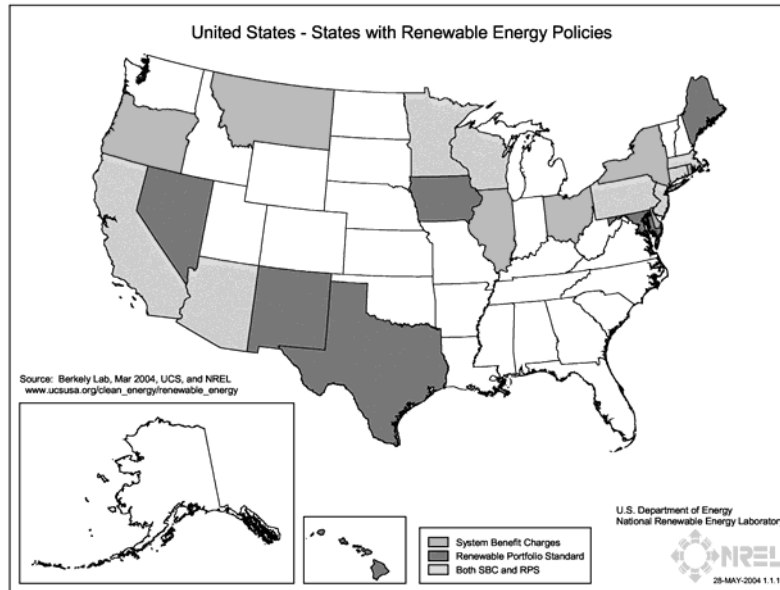


Figure 4: States with Renewable Energy Policies.

Furthermore, federal and state policies are helping to create incentives to invest in wind power. Existing policies include system benefit charges and renewable portfolio standards. The leading states for wind energy development—California, Texas, Minnesota, and Iowa—all have policies in place. Figure 4 shows the states with renewable energy policies.

Other aspects of wind energy, such as its classification as green power, create an easy way to introduce wind energy to legislators, farmers, and the agricultural community. To date, there are 600 utilities across the country that use green power products (Figure 5).

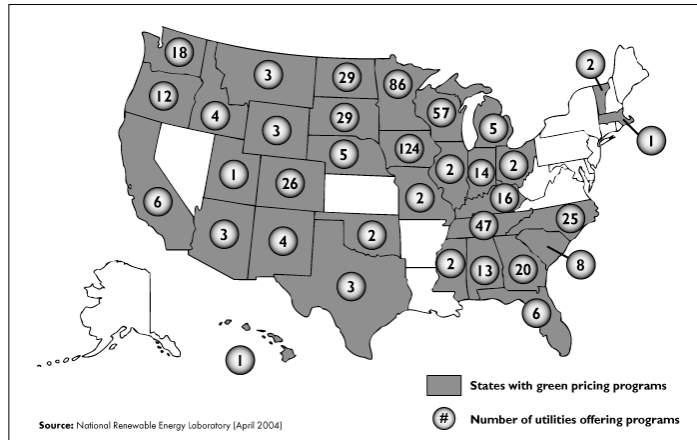


Figure 5: Utility Green Pricing Activities.

Economic Development

Wind can benefit the world economy with three major cash flows from wind turbines: jobs, payment to land owners, and tax revenues. Construction of a wind farm creates an estimated 1 to 2 jobs per MW. When the wind farm begins production, high quality jobs in operation and maintenance remain at an estimated 2 to 5 permanent jobs per 50 to 100 MW.

Furthermore, construction of wind turbines increases land value. Land lease payments to land owners usually bring 2 to 3 percent of gross revenue, or about \$2500-4000 per MW per year. Incentives, such as production tax credits and accelerated depreciation, are also available to equity owners.

Tax revenues from local property taxes tend to bring \$500K to \$1 million per year for 100 MW turbines. Some examples of this type of economic development can be seen in the Texas RPS and in a project in Prowers County, Colorado.

Case Study: Texas RPS

Utilities and wind companies invested \$1 billion in 2001 to build 912 MW of new wind power, resulting in the following:

- 2,500 quality jobs with a payroll of \$75 million,
- \$13.3 million in tax revenues for schools and counties,
- \$2.5 million in 2002 royalty income to landowners,
- Another 2,900 indirect jobs as a result of the multiplier effect, and
- \$4.6 million increased in Pecos County property tax revenue in 2002.

Case Study: Prowers County, Colorado

162 MW Colorado Green Wind Farm boosts the local economy.

- Mortensen employed 87 people to pour 35,000 yards of concrete.
- Christensen employed 46 people to install 20 miles of underground cable.
- Ridge Crane devoted two cranes to the project for three months.
- All-Rite Paving supplied concrete for 32 miles of poles
- Country Acres Motel and RV Park was booked solid for months.
- Hay Stack Steak House experienced a 30% increase in business.
- Property tax revenues increased \$2 million.

Key Deployment Issues for Wind Power

Although there are many advantages to wind power, there are a few key deployment issues that must be considered. Permitting and siting can occasionally require mediation, and some local citizens may be concerned with issues such as aesthetics, noise, land use, and wildlife impact. Issues also remain with transmission (capacity allocation,

RTO formation, new line builds/planning) and power variability and its impact on utility operations.

Opportunities for Wind/Water Processing

Economic and energy development are increasingly in conflict with water availability as the population in drier regions increases. Wind development works hand-in-hand with water processing and can help solve water shortages. Integration of wind development has opportunities in the following applications:

- Stock watering,
- Desalination,
- Irrigation,
- Thermal electric generation water treatment,
- Municipal water supply,
- Wind-hydro integration,
- Oil, gas, coal bed methane water treatment, and
- Village power.

Private Sector Development of Wind Energy

*Walter Hornaday, President, Cielo Wind Power,
Austin, Texas*

Cielo Wind Power, located in Austin, Texas, is the largest wind development company in the Southwest. They specialize in all aspects of wind development, including wind resourcing, project development, site acquisition, engineering, construction, operations, and maintenance.

Current Projects

Cielo Wind Power has developed wind power projects in Texas, New Mexico, and Nevada. Their current projects include five wind ranches located in Texas.

- Caprock Wind Ranch™
The Caprock Wind Ranch is located in Borden and Scurry counties. It produces a total of 80 MW of energy for Xcel Energy.
- Brazos Wind Ranch™
The Brazos Wind Ranch is also located in Borden and Scurry Counties. It has been operational since December of 2003 and produces 160 MW for TXU.
- Llano Estacado Wind Ranch™ at White Deer
The Llano Estacado Wind Ranch, located in Carson County, has been operational since December 2001 and produces 80 MW of energy for Xcel Energy. This wind ranch supplies enough energy for 28,000 households per year.
- King Mountain Wind Ranch™
The King Mountain Wind Ranch is located in Upton County and produces 279 MW for Reliant Energy, Austin Energy, and TNMP. It has been operational since December of 2001.

- Woodward Mountain Wind Ranch™
Woodward Mountain Wind Ranch is located in Pecos County and supplies 160 MW for TXU since July 2001.

Comparison of Modern Wind Turbine Technology

The remainder of this report will compare modern wind turbine technology. The comparison will primarily focus on the specifics of the turbine, generator, tower, and control systems for 4 models of turbines: the 1000kW Mitsubishi WTG, 1500kW GE WTG, 3000kW Vestas WTG, and the 4500kW Enercon WTG. A brief comparison of the models' major features can be seen in Table 1.

Table 1: Comparison of Modern Wind Turbine Technology.

	1000kW Mitsubishi WTG	1500kW WTG- WZII	3000kW Vestas WTG	4500kW Enercon WTG
Turbine				
Type	Blade-pitch controlled upwind	Active blade pitch control		Gearless, variable blade pitch
Rated Capacity	1,000kW/250kW	1,500kW	3,000 kW	4,500 kW
Rotor Diameter	56 m	77 m	90 m	114 m
Rotor Speed	21 rpm/14 rpm	10.1-20.4 rpm	10.1-20.4 rpm	Variable, 8-13 rpm
Number of Blades	3 (GFRP)	3	3	3
Swept Area		4,657 sq m		10,207 sq m
Rated Wind Speed	13 m/s	11.8 m/s		
Cut-in Wind Speed	3.0 m/s	3 m/s		2.5 m/s
Cut-out Wind Speed		25 m/s		28-34 m/s
Generator				
Type	Induction generator			Direct-driven synchronous
Voltage	550 V			440 V
Frequency	50 Hz/60Hz			variable
Tower				
Hub height	60 m	61.4/80/85/100m	80 m	124 m

1000kW Mitsubishi WTG

Turbine

The 1000 kW Mitsubishi WTG is a blade-pitch controlled upwind turbine. This three blade turbine reaches rated power for wind speeds of 13 m/s and has a cut-in wind speed of 3.0 m/s. It has a survival wind speed of 60 m/s.

Generator

This model has a three-phase induction generator with a rated output of 1000 kW/250 kW. It produces 550 V with a frequency of 50 Hz/60 Hz.

Tower

The tower is a monopole with a hub height of 60 m.

Control System

The 1000 kW Mitsubishi WTG control systems includes pitch control power regulation and yaw control.

Additional Features

The 1000 kW Mitsubishi WTG also has a number of safety features, including overspeed, excessive nacelle vibration, yaw control disorder, generator overcurrent, and controller disorder.

1500kW GE WTG

Turbine

The 1500 kW GE WTG reaches rated power at wind speeds of 11.8 m/s. The three rotor blades, each with a 77 m diameter, sweep an area of 4657 sq m. The rotor also has variable speeds from 10.1 rpm to 20.4 rpm. Versions of this wind turbine also feature the ability to cut-in, cut-out, and cut-back-in based on wind speeds.

- Cut-in wind speed: 3 m/s
- Cut-out wind speed
 - 300s average: 25 m/s
 - 30 s average: WZ II: 23 m/s, IECs: 28 m/s
 - 3 s average: WZ II: 25 m/s, IECs: 30 m/s
- Cut-back-in wind speed
 - 300 s average: WZ II: 17 m/s, IECs: 22 m/s

Tower

The towers come in several heights. The hub heights for the WZ II are available in 61.4/80/85/100 m. The WZ III/IECS is available with 64.7/80/85 m hub heights.

Control System

The power control system has active blade pitch control.

3000kW Vestas WTG

The 3000 kW Vestas WTG is a three-blade turbine. Each blade is 44 m in length and has a rotor diameter of 90 m. The tower has a hub height of 80 m. Vestas is currently testing and documenting the performance of this turbine with plans to enter serial production some time early this year. As a result, most data are unavailable. Preliminary operating data shows that it has a rated capacity of 3000 kW. Rotor speed is variable between 10.1 and 20.4 rpm.

4500kW Enercon WTG

Turbine

The 4500kW Enercon WTG is a gearless, variable blade pitch turbine. It has a rated capacity of 4500 kW with the ability to cut-in at wind speed of 2.5 m/s and cut-out at wind speeds of 28-34 m/s.

This turbine has three blades made with fiberglass (reinforced epoxy) with integral lightning protection. The rotor has a diameter of 144 m and has active pitch control. Rotor speed is variable between 8 and 13 rpm.

Tower

The tower has a hub height of 124 m.

Generator

The generator is a direct-driven synchronous Enercon ring generator with tapered and cylindrical roller bearings. It has variable frequency and a voltage of 440 V.

Control System

The pitch control has three synchronized blade pitch systems with emergency supply. This model also features rotor brake and rotor lock for service and maintenance.

Water Issues and Opportunities and their Connections with Renewable Energy Sources

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Water Issues

International organizations increasingly recognize water as an international security problem. In 1990, poor water supply and sanitation was the second leading cause of death and disability worldwide. Currently, over 50 percent of the world's major rivers are dry or heavily polluted. Additionally, the amount of water needed continues to grow. By 2025, 20 percent more fresh water will be needed for irrigation and 40 percent more for cities to maintain current per capita water levels. As the need for water increases, we can no longer solely rely on traditional water resources—nontraditional resources must be used to address water shortages.

Figure 1 shows the total amount of freshwater withdrawn in 1995 as a percentage of the available precipitation. The higher values are indicative of the extent of water resource development in an area, and values higher than 100 are indicative of imports from other regions. As this figure illustrates, water is used extensively across the nation, and the Southwest meets its water demand almost exclusively from groundwater.

Reliable, affordable energy and abundant, clean water are inextricably linked. If water becomes scarce, both electricity and water prices will rise. The higher water rates will be a direct result of the elevated electricity costs; therefore, our ability to produce affordable supplies of either will be hindered.

But water is not only linked to electricity. Energy systems that we may one day rely on, such as hydrogen, coal liquefaction/gasification, and biomass, are also reliant on water. These systems require water as

a source of hydrogen, for process cooling, for additional electricity production, and for plant growth. Other energy related issues, such as carbon sequestration, are also linked to water (aquifers as target for CO₂ injection).

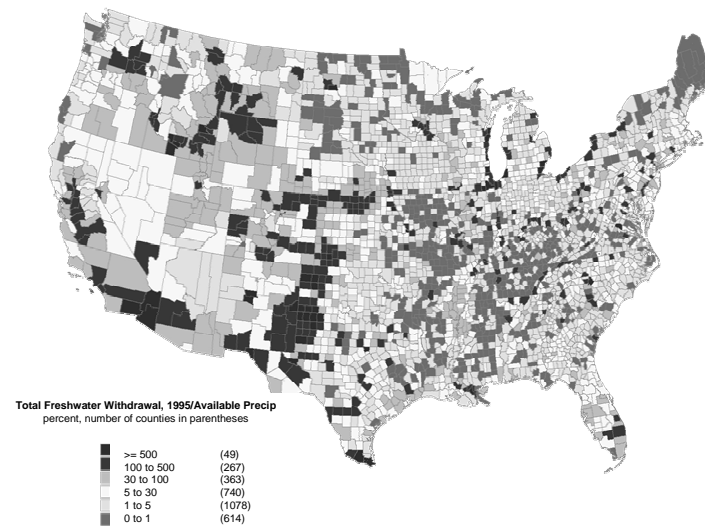


Figure 1: Total Freshwater Withdrawal Versus 1995 Available Precipitation.

Source: Roy, Sujay B., Summers, Karen, V., and Goldstein, Robert A., 2003. "Water Sustainability in the United States and Cooling Water Requirements for Power Generation," Universities Council on Water Resources, *Water Resources Update* 126, 54-59, November.

Water Withdrawals and Usage

Figure 2 illustrates withdrawal, not consumption, of freshwater. Surprisingly, the amount of water used by the thermoelectric sector is second only to the amount used by the agricultural industry. Water withdrawn for thermoelectric power production is primarily used for fossil, nuclear, and geothermal power. Figure 2 only represents electricity production; it does not include the entire energy cycle, such as fuel mining, refining, and transport (e.g., slurry pipeline)—these also impact water quantity and quality. This also does not include hydroelectric power, which has its own set of issues, such as evaporative loss from dammed rivers.

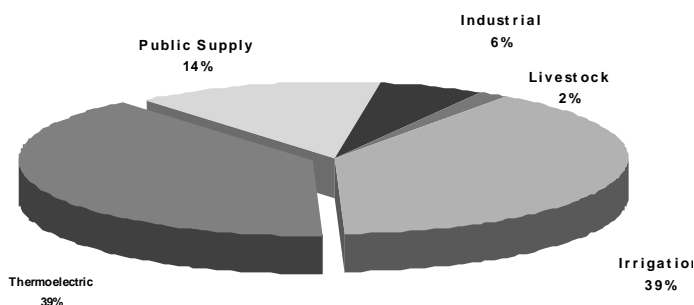


Figure 2: Estimated Freshwater Withdrawals by Sector, 2000.

The total freshwater use for all sectors is about 346 billion gallons per day with the thermoelectric sector using 136 billion gallons and irrigation using 137 billion gallons per day (USGS circular 1268, 2004).

Figure 3 takes a closer look at water consumption. It compares the amount of water used indirectly (running appliances, etc.) and directly (showers, watering lawn, etc.) by individuals in a given day. The figure indicates that indirect usage accounts for a much larger portion of water consumption than direct usage. Since energy requires water, household water used for purposes of electricity is similar to that used by agriculture to produce food and dwarfs that consumed directly at home.

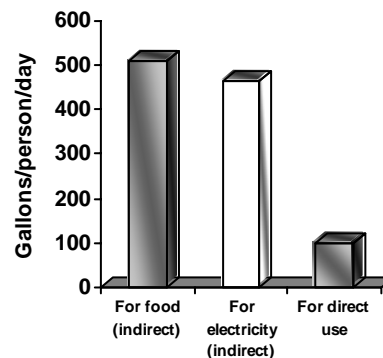


Figure 3: Water Consumption Per Person Per Day.

Source: (J.E. McMahon, LBNL from Gleick, P. World's Water 2002-2003 The Biennial Report on Freshwater Resources, Pacific Institute for Studies in Development Environment and Security, Island Press 2002.

- 510 gallons of water per day is used for food production, including irrigation and livestock
- 465 gallons per day is used to produce household electricity
 - Range: 30 to 600 depending on technology
- 100 gallons per day goes toward direct household use, such as bathing and watering the lawn

Water requires energy for pumping, treating, and delivery—requirements that will increase as the use of currently marginal water increases and new energy intensive technologies are employed (see Figure 4).

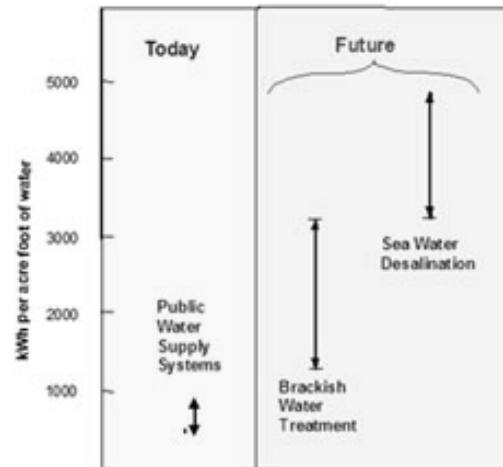


Figure 4: Power Requirements for Current and Future Water Supply.

Currently, public water supply systems consume about 500 kWh per acre foot of water, and wastewater treatment consumes 470 kWh per acre foot of water. This is a total of about 1000kWh per acre-ft (EPRI Report 1006787 2000 “Water and Sustainability (vol 4): US Electricity consumption for water supply and treatment”). It should be noted that this is an average nationwide figure, assuming nationally 0.5 surface water and 0.5 groundwater. The figure could be higher in areas with more significant pumping costs.

According to figures from the Water Desalination Task Force, treatment of brackish waters would require between 1300 to 3250 kWh per acre foot. Sea water desalination requirements are even greater, ranging from 3260 to 4900 kWh per acre foot (Water Desalination Task Force; cover letter from California Department of Water Resources, dated October, 2003. Water Desalination: findings and recommendations).

As one can see from these numbers, energy growth will demand more water, both consumptive and non-consumptive (e.g., cooling) and impacts water quality. Competing demands for water (quantity and quality) will also increase (e.g., agriculture, population, environment). Other factors, such as climate variability and change, will affect water availability and demand. Furthermore, water availability is already impacting energy nationwide, and competition will only increase.

This list of headlines offers a sense of the problem across our nation:

- Georgia Power Loses Bid to Draw Water from Chattahoochee
 - *Miami Herald*, February 2002
- EPA Orders Mass. Power Plant to Reduce Water Withdrawals
 - *Providence Journal*, RI, July 2002
- Idaho Denies Water Rights Request for Power Plants
 - *U.S. Water News Online*, August 2002
- Duke Power Warns Towns in Charlotte, N.C., Area to Cut Water Use
 - *The Charlotte Observer*, NC, August 2002
- Company Ends Fight for Power Generator on NJ-NY Border
 - *The Record*, NJ, September 2002
- New Mexico Utility Plans to Increase Power, Use No More Water
 - *Albuquerque (NM) Journal*, June 2003
- Pennsylvania Nuclear Power Plant to Use Wastewater from Coal Mines
 - *The Philadelphia Inquirer*, July 2003
- Utilities Warn of Power Crunch if Flows Are Cut
 - *Greenwire*, July 2003

One possible solution to this water problem is to consider desalination to increase the amount of usable freshwater supplies.

Current Desalination Trends

Currently, there are 12,500 desalination plants worldwide supplying about 5.5 billion gallons per day (BGD) or 1 percent of world's drinking water. Reverse osmosis and distillation are the most common systems and are the primary applications used for sea water. They provide constant supply and easy disposal. Tables 1 and 2 show the concentration of types of water, including fresh, brackish, and saltwater, and the desalinization process typically used with each type of water.

Table 1: Saline and Brackish Water Characterization.

TYPE	TDS
Fresh	<1,000 mg/l (500 mg/l is commonly accepted drinking water level)
Brackish	
Mildly	1,000 - 5,000 mg/l
Moderately	5,000 – 15,000 mg/l
Heavily	15,000 – 35,000 mg/l
Seawater	~35,000 mg/l
Brine	>~35,000 mg/l
Concentrate	From Desalination Process

Table 2: Desalination Processes and Typical Concentrate.

Process	Reverse Osmosis Brackish	Reverse Osmosis Seawater	Multi- Stage Flash Distillation	Multi- Effect Distillation
Feedwater	Brackish	Seawater	Seawater	Seawater
Recovery, %	60-85%	30-60%	30%	20%
Final Concentration Factor	2.5 – 6.7	1.4 – 2.5	<1.15	<1.15

It is anticipated that there will be a \$10 billion investment in next 5 years to increase desalination by 1.5 BGD. An additional \$70 billion investment is expected in the next 20 years to increase desalination by 10 BGD. The number of desalination treatment plants is rising. Figure 7 shows the growth trend for US membrane treatment plants since 1971.

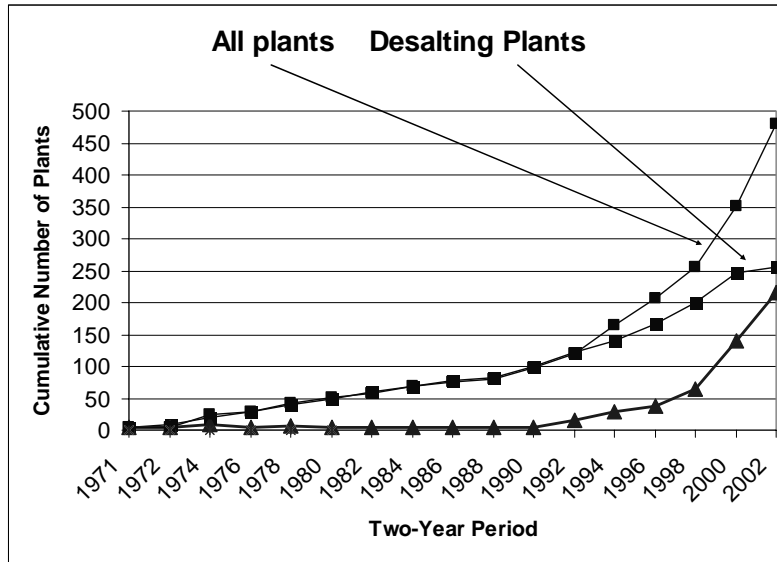


Figure 7: Growing Trend in US Membrane Treatment Plants.

Current Challenges

There have been many case studies to determine the use of desalinated water for inland urban and rural area needs. The first study is the consideration of inland municipal areas, such as Las Vegas, NV, Phoenix, AZ, and El Paso, TX. These areas are all grappling with sustainability and adequacy concerns resulting from persistent drought. The goal is to provide affordable water and address the need for reclamation and reuse while assuring adequate supplies through recycling, upgrading impaired water, mitigating demand, and purchasing water rights. An additional major concern is the disposal of concentrate.

The cost objectives for desalinating water will likely be the most important driver. In the near term, the cost improvement for these processes is aggressive and can only be met by a well managed and

well funded program. As part of these objectives, the goal is to reduce capital cost, increase energy efficiency, reduce operational cost, and reduce the cost of zero liquid discharge processes by 2010. Zero liquid discharge (ZLD) processes are those processes that produce no liquid concentrate. ZLD processes are very important for the inland west. The long term objectives to be reached by 2020 are motivated by the desire to reduce the difference between the cost of conventionally treated fresh water and advanced treatment of impaired water. This national need will stem the movement of water away from agriculture, industry, and the environment to the urban communities. Six million dollars worth of initial roadmap research funding allocated in the FY04 annual research fund is being considered.

The final two figures show promising brackish groundwater yields.

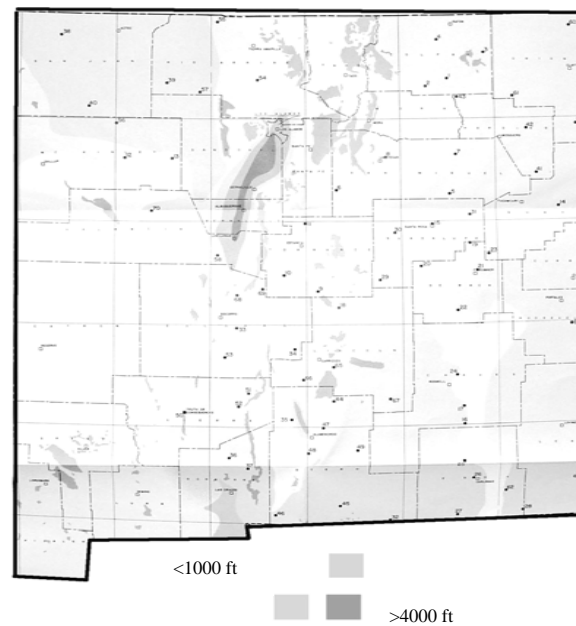


Figure 8: Brackish (<3000 mg/l TDS) Aquifer Thickness.

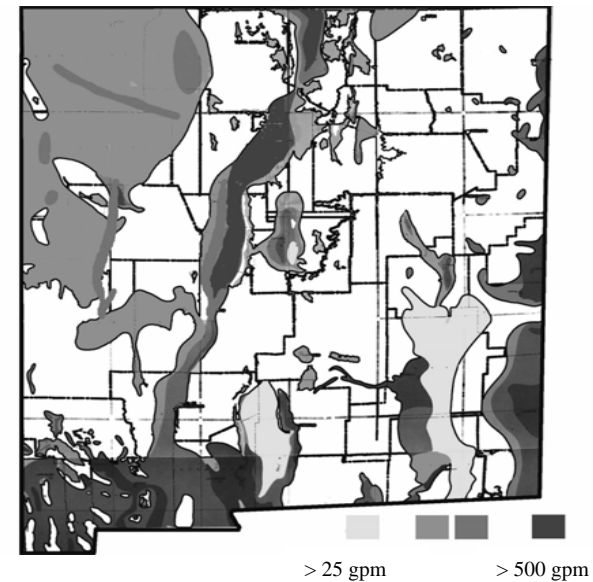


Figure 9: Brackish Ground Water Aquifer Yields.

Needs and Opportunities

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The underpinning of strong economic development is more than just the production of jobs—it is the combination of energy, water, and a skilled workforce. Texas Tech is dedicated to helping develop a strong economy through wind and water resources and technologies. This is an overview of how Texas Tech plans to use our available skill sets to meet the needs and opportunities for wind, water, and economic development.

To successfully address the issues involved in energy and water resources, local organizations must work with technical organizations in a collaborative effort. We must reach out to local, financial, political, and other stakeholders in the region, as well as to key groups in the state and the nation. Texas Tech is addressing the needs of all of these involved groups.

Why Texas Tech?

There are many reasons why this economic redevelopment effort should be located at Texas Tech—the first being location. Texas Tech is located in the heart of the Southern Great Plains in the midst of wind, solar, and water resources. The region is located on top of a diminishing freshwater aquifer and a very large brackish aquifer. Furthermore, Texas Tech has the supporting academic departments needed to successfully address the wind and water issues. The university has an extensive suite of field and analysis facilities to support analysis of wind and water systems.

And finally, Texas Tech has the Wind Science and Engineering Research Center. This Center has been a part of the Texas Tech campus for more than 30 years and is nationally recognized. Additionally, Texas Tech has all of the required technologies and

academic departments, including engineering, atmospheric sciences, physics, and law, needed to make this a successful plan.

Vision and Plan

Collaboration & Outreach

Texas Tech has a strong commitment to collaboration and outreach. This means reaching beyond the university into communities to develop, adapt, and implement technologies. One important part of this collaborative effort is the Texas Tech Reese Technology Center, a 67-acre full-scale test site dedicated to wind research, testing, and engineering. This center has a unique 200m tower that can analyze wind and measure and record atmospheric conditions at ten levels. This facility can provide invaluable information for all groups interested in developing better wind technologies.

The Eight Initiatives

The overall program is organized into eight wind, water, and economic development initiatives. The accomplishment of these initiatives will support the creation of added jobs and increased economic activity throughout the Southern Great Plains and beyond.

1) Wind Turbine Systems Test

Through establishment of the Great Plains Wind Test Center with a utility-scale 1.5 MW wind turbine, this facility will help create jobs and serve the needs of the wind industry in addition to the two principal national laboratories that are focused on the development and testing of advanced wind turbine systems in low wind speed environments. This test center will be located within the existing Texas Tech Wind Engineering site at the Reese Technology Center. This initiative will further the cost-effectiveness of wind turbines and contribute to the development of future sites. This in turn increases the supply of reliable, non-fossil energy and supports expanded economic activity and job creation.

2) Wind-Driven Water Desalination Systems

Through extension of the industrial and federal laboratory wind partnerships associated with the Great Plains Wind Test Center, GE and TTU will initiate a water desalination demonstration project using innovative wind-driven water desalination systems now under development. This initiative takes advantage of the growing evidence that wind turbines provide the cheapest shaft power on the planet. This application of wind turbine-generated power has the potential, within five years, to more than halve the cost of the input power and energy required for the operation of water desalination systems. These developments and their commercialization will contribute to the second underpinning of increased economic vitality in the form of abundant potable water supply.

3) Cluster Wind Installations

Through outreach, education and the establishment of a private-sector-funded prototype demonstration installation adjacent to the TTU Reese test site, this five-year program will facilitate jobs and economic activity associated with a new mode of grid-connected wind turbine installations (cluster wind installations) consisting of one to eight utility-scale wind turbines. These are particularly suited to the Southern Great Plains in that they do not require access to high-voltage (e.g., 345 kV) transmission lines but rather can be connected at the less-costly distribution voltage (e.g., 21 kV) level. In addition, such smaller, distributed systems provide technical advantages to the regional grid system. Such installations will also be ideally-suited to serve as the energy source for wind-driven water desalinations systems planned throughout the region.

4) Finance and Enhanced Regional Economic Activity

Through outreach to regional financial institutions and investors, this initiative will lead to significantly enhanced regional economic activity through a new mode of financing such cluster wind and water installations. In contrast to securing capital from New York and European financial centers, this new mode presents the region with significant capital retention advantages. The return of the principal and interest associated with the regional financing of cluster installations in the Southern Great Plains will support enhanced economic activity that is significantly greater than that associated with the usual mode of financing the installation of large wind farms comprised of a hundred or more utility-scale wind turbines.

5) Wind Technician Training and Certification

This initiative will create jobs and serve the needs of the wind industry through establishment of a Wind Technician Training and Certification program. Initial certification will be with GE wind turbines and equipment. This will be accomplished in cooperation with South Plains College. SPC has established a number of similar training programs, including the primary mechanics' training program for Caterpillar Tractor.

6) Bridge to Next-Generation Wind-Water Systems Engineers

Persons entering the Wind Technician Training and Certification program have already committed to a career in the wind industry and, by extension, to water systems. This element provides the support for enabling talented, motivated participants to continue their studies to an undergraduate engineering degree, and onto graduate degrees. These persons will provide the necessary engineering talent for the next-generation wind and water

systems. This in turn provides sustained improvements in their technology and economics and continued manufacturing, sales and maintenance jobs. Outreach will also be made to regional high school students.

7) Warehouse and Depot Maintenance Facilities

The central location of Lubbock relative to the existing and planned wind and water installations together with the TTU wind-centered engineering and test programs are expected to lead to the private sector establishment of warehouse and depot maintenance facilities at the Reese Technology Center. The center has ample available warehouse space, is recognized as a foreign trade zone and is the location of the existing Texas Tech Wind Engineering facilities on 67 acres. Discussions are ongoing with GE for the establishment of such facilities. In addition to the jobs associated with such facilities, their existence will result in the clustering of support companies such as electrical generator rewind shops, gearbox overhaul shops, construction companies and the suppliers to these companies.

8) Manufacturing, Assembly, and Service Jobs

It is expected that the relationships established by Texas Tech through the test and demonstration of water desalination systems will lead to the manufacture, assembly and servicing of such systems within the Southern Great Plains region. Discussions have been initiated with GE for the establishment of such a facility. Due to close proximity to the Great Plains Wind Test Center and the South Plains College training programs, the associated manufacturing facilities and jobs are also likely to be located near the Reese Technology Center.

The initiatives of this five-year program will make significant contributions to advances in the technology, economics, and development of industry infrastructure for sustainable energy systems and large-scale, cost-effective water desalination capacity in the United States. The energy and water systems addressed in this program have immediate application to needs in the regional economy; however, these non-fossil energy and water systems have application throughout the nation and beyond. Thus while the economic and sustainability benefits will have their initial and primary impacts on the West Texas Southern Great Plains region, the effects will be felt throughout Texas and nationwide.

Energy and water are the underpinnings of jobs and a sustainable economic future for the region, the state, and beyond. We need your advice and involvement. We need your help.

Bibliography

Carta, J.A., J. Gonzalez and V. Subiela, *Operational analysis of an innovative wind powered reverse osmosis system installed in the Canary Islands*, Solar Energy, Volume 75, Number 2, August 2003, p 153-168.

Carta, Jose A., J. Gonzalez and V. Subiela, *The SDAWES project: An ambitious R and D prototype for wind-powered desalination*, Desalination, Volume 161, Number 1, February 2004, p 33-48.

Feron, P., *Use of windpower in autonomous reverse osmosis seawater desalination*, Wind Engineering, Volume 9, Number 3, 1985, p 180-199.

Fries, S., J. Mohn and G. Petersen, *Sea water desalination powered by wind energy*, BHRA Fluid Eng, 1981, p 167-172.

Garcia-Rodriguez, L., V. Romero-Ternero and C. Gomez-Camacho, *Economic analysis of wind-powered desalination*, Desalination, Volume 137, Number 1-3, May 2001, p 259-265.

Garcia-Rodriguez, Lourdes, *Desalination by wind power*, Wind Engineering, Volume 28, Number 4, 2004, p 453-463.

Kiranoudis, C.T., N.G. Voros and Z.B. Maroulis, *Wind energy exploitation for reverse osmosis desalination plants*, Desalination, Volume 109, Number 2, May 1997, p 195-209.

Liu, C.C.K., R. Migita and J.-W. Park, *System development and testing of wind-powered reverse osmosis desalination for remote Pacific islands*, Water Science and Technology: Water Supply, Volume 2, Number 2, 2002, p 123-129.

Liu, Clark C.K., J. Park, R. Migita and G. Qin, *Experiments of a prototype wind-driven reverse osmosis desalination system with feedback control*, Desalination, Volume 150, Number 3, November 2002, p 277-287.

Manwell, James F. and J.G. McGowan, *Recent renewable energy driven desalination system research and development in North America*, Desalination, Volume 94, Number 3, January 1994, p 229-241.

Miranda, Marcos S. and D. Infield, *A wind-powered seawater reverse-osmosis system without batteries*, Desalination, Volume 153, Number 1-3, February 2003, p 9-16.

Mohamed, Essam Sh. and G. Papadakis, *Design, simulation and economic analysis of a stand-alone reverse osmosis desalination unit powered by wind turbines and photovoltaics*, Desalination, Volume 164, Number 1, March 2004, p 87-97.

Neris, A.S., G.B. Giannakopoulos and N.A. Vovos, *Autonomous wind turbine supplying a reverse osmosis desalination unit*, Wind Engineering, Volume 19, Number 6, 1995, p 325-346.

Petersen, G., S. Fries, J. Mohn and A. Muller, *Wind and solar powered reverse osmosis desalination units- Design, start up, operating experience*, Desalination, Volume 39, Number 1-3, December 1981, p 125-135.

Rheinlander, Jurgen, E.W. Perz and O. Goebel, *Performance simulation of integrated water and power systems – Software tools IPSEpro and RESYSpro for technical, economic and ecological analysis*, Desalination, Volume 157, Number 1-3, August 2003, p 57-64.

Subiela, Vicente Javier, J. A. Carta and J. Gonzalez, *The SDAWES project: Lessons learnt from an innovative project*, Desalination, Volume 168, Number 1-3, August 2004, p 39-47.

Tahri, K., *The prospects of fresh water supply for Tan Tan City from non-conventional water sources*, Desalination, Volume 135, Number 1-3, April 2001, p 43-50.

Thomson, Murray, M. S. Miranda and D. Infield. *A small-scale seawater reverse-osmosis system with excellent energy efficiency over a wind operating range*, Desalination, Volume 153, Number 1-3, February 2003, p 229-236.

Tzen, Eftihia and R. Morris, *Renewable energy sources for desalination*, Solar Energy, Volume 75, Number 5, November 2003, p 375-379.

Van Gauwbergen, D. and J. Baeyens, *Macroscopic fluid flow condition in spiral-wound membrane elements*, Desalination, Volume 110, Number 3, September 1997, p 287-299.

Warfel, C., J.F. Manwell and J.G. McGowan, *Techno-economic study of autonomous wind driven reverse osmosis desalination systems*, Solar & Wind Technology, Volume 5, Issue 5, 1998, p 549-561.

Witte, Tomas, S. Siegfriedsen and M. El-Allawy, *WindDeSalter Technology: Direct use of wind energy for seawater desalination by vapour compression or reverse osmosis*, Desalination, Volume 156, Number 1-3, August 2003, p 275-279.

Robinson, Rod, Goen Ho and Kuruville Mathew, *Development of a reliable low-cost reverse osmosis desalination unit for remote communities*, Desalination, Volume 86, Number 1, 1992, p. 9-26.