Chapter 6

ENERGY FROM WATER

Introduction

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

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— roughly 30 gallons for every kWh generated.[1] While the withdrawal quantity sounds high, over 95 percent of this withdrawn water is continually cycled between the power plant facility and adjacent cooling ponds and lakes without loss.

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

Significance of Resource: Historical, Present, and Future

Hydropower

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

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

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

Ocean Power

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

Wave Energy

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

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

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

Ocean Thermal Energy Conversion (OTEC)

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

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

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

Current Energy

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

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

Tidal Energy

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

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

Energy from Salinity Gradients

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

Pressure Retarded Osmosis and Reverse Electrodialysis

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

Salinity Gradient Solar Ponds (SGSP)

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

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

Development Issues: Considerations for Large Scale Use

Hydropower

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

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

Ocean Power

OTEC

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

Wave Energy

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

Tidal Energy

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

Current Energy

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

Salinity Gradients

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

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

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

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

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

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

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

Resource

Quantification of Resource

Hydropower

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

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

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

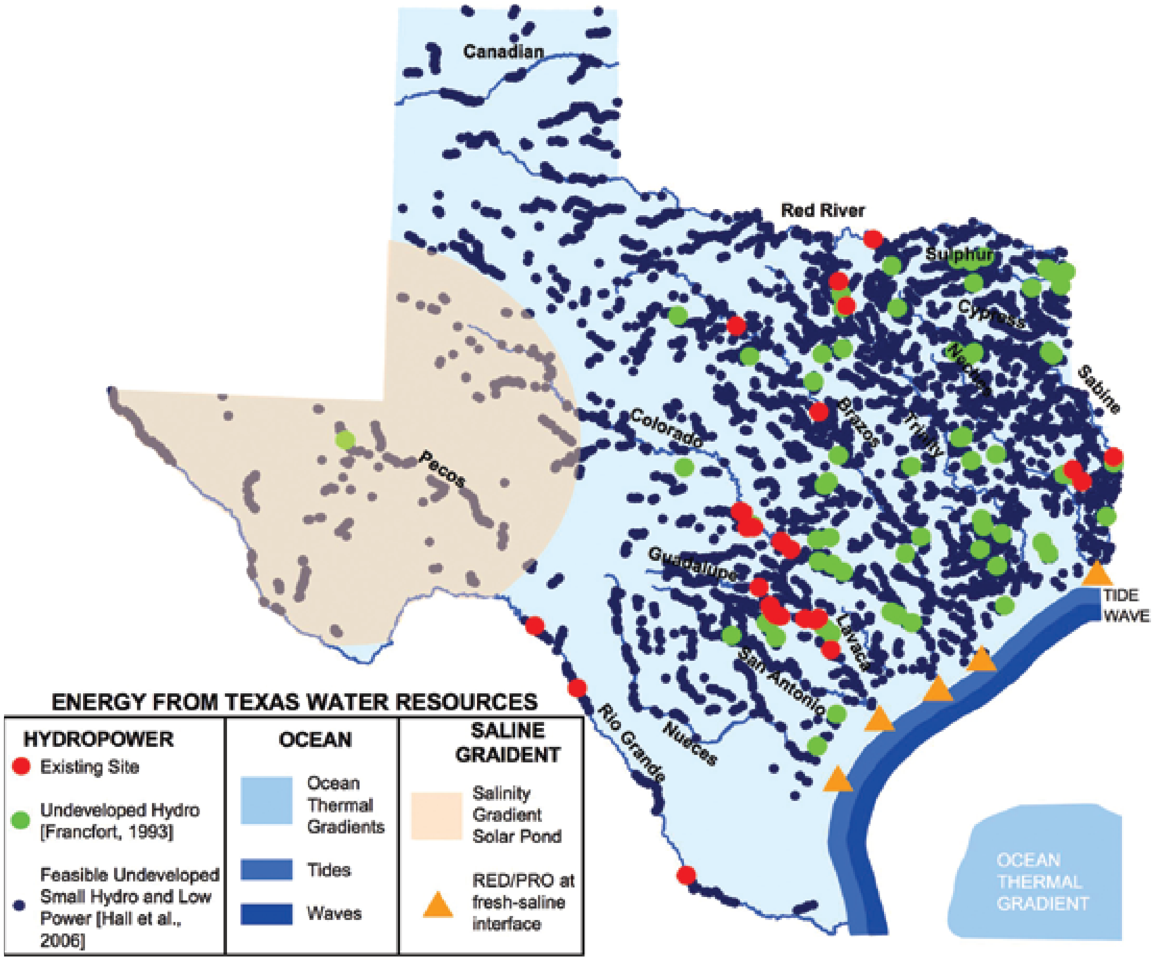
INL's 2006 resource assessment of the gross hydropower resource in Texas was 2,300 MWa with 104 MWa already developed and 2,040 MWa "available" (521 MWa of small hydro and 1,519 MWa of low power) after excluding federal and other restricted lands.[20] The feasible hydropower projects amount to 328 MWa,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

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

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

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

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



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

Ocean Power

Wave Power

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

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

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

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

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

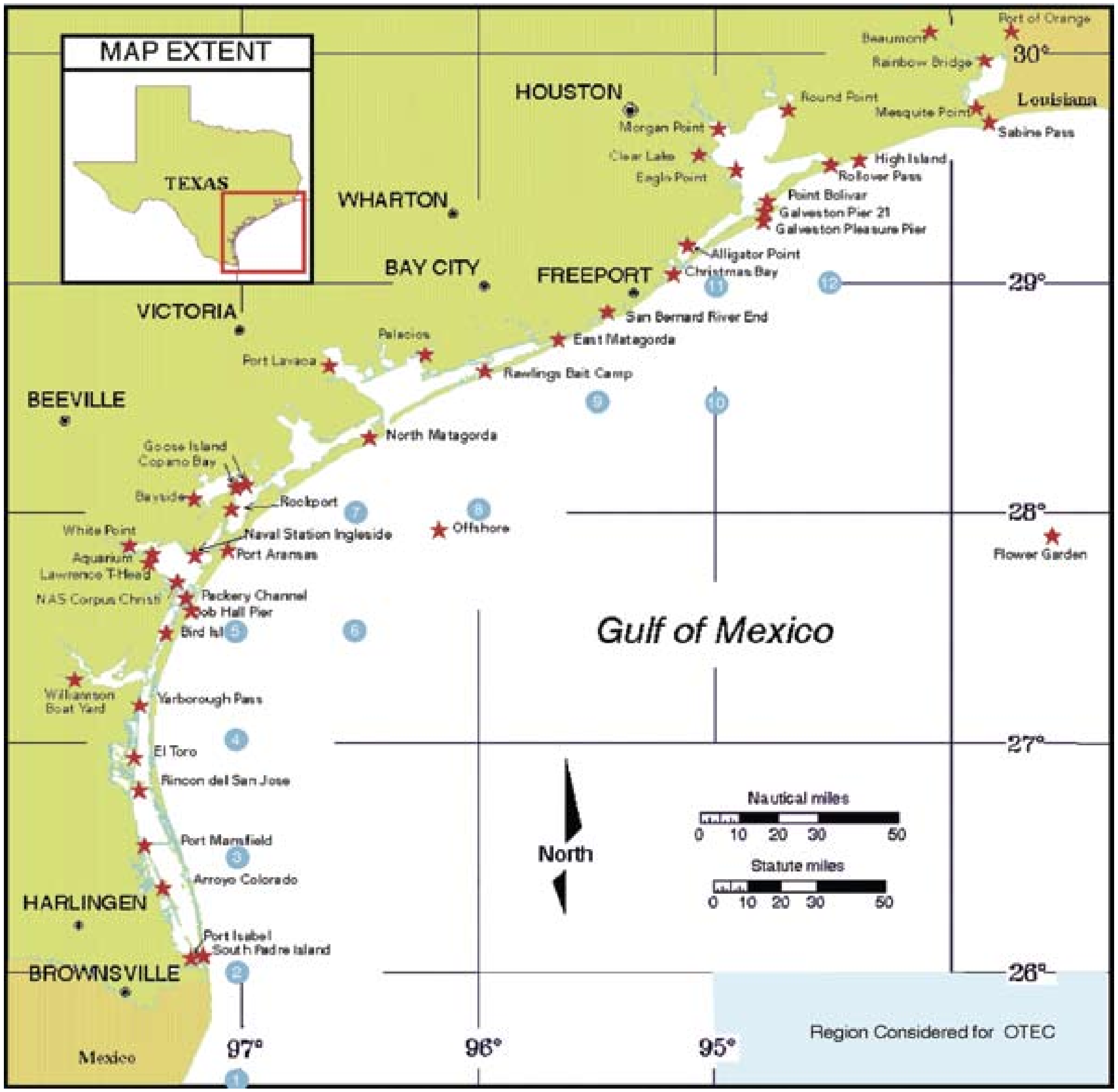
Good resources are considered to have power densities of at least 20 kW/m and densities near 40 kW/m are desirable. Texas' offshore wave power densities are typically well below 10 kW/m (**Exhibit 6-4**). For comparison, performance estimates of the Pelamis wave energy technology off the coast of Oregon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

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

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

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

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



Ocean Thermal Energy Conversion (OTEC)

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

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

Tidal Power

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

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

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

Current Power

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

Salinity Gradients

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

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

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

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

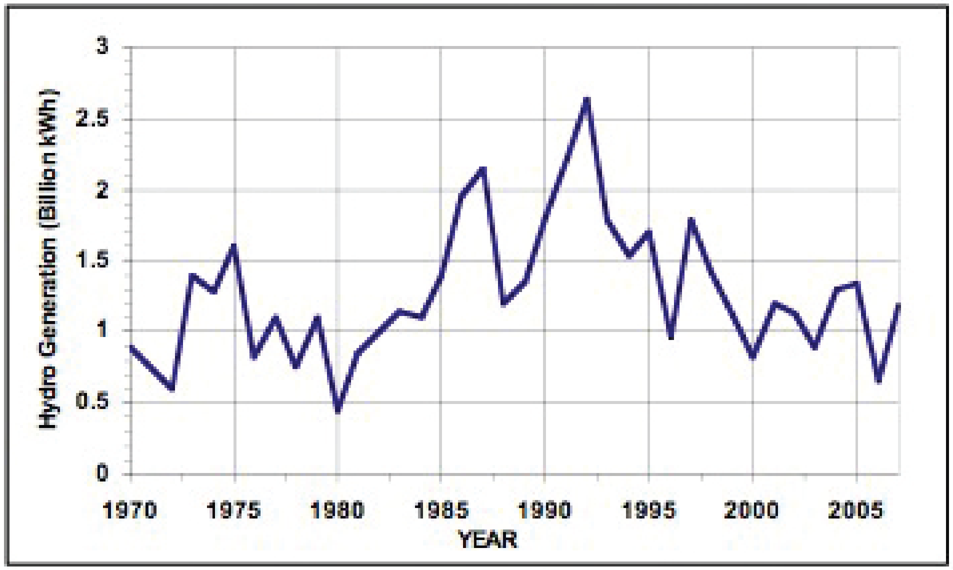
However, given the general scarcity and high value of water resources in West Texas, the use of almost all regional brackish groundwater for less than 2% of Texas' electricity is difficult to imagine. Because water used in SGSPs continually evaporates, the sustainability of the saline reservoirs to supply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

Variability

Hydropower

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

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



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

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

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

Ocean Power

Wave Power

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

Ocean Thermal Energy Conversion (OTEC)

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

Tidal and Ocean Current Power

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

Salinity Gradients

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

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

Utilization

Overview

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

Conversion technology

Hydropower

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

Ocean Power

Wave Power

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

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

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

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

Ocean Thermal Energy Conversion (OTEC)

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

Tidal Power

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

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

Salinity Gradients

Pressure retarded osmosis (PRO)

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

Reverse electrodialysis (RED)

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

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

Saline gradient solar ponds

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

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

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

Infrastructure considerations

Hydropower

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

Ocean Power

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

Salinity Gradients

PRO and RED

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

Saline Gradient Solar Ponds

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

Economics

Costs

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

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

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

Benefits

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

Subsidies

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

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

Key Issues

Hydropower

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

Ocean Power

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

Salinity Gradients

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

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

Information Sources

Hydropower

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

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

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

Ocean Power

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

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

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

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

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

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

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

Salinity Gradients

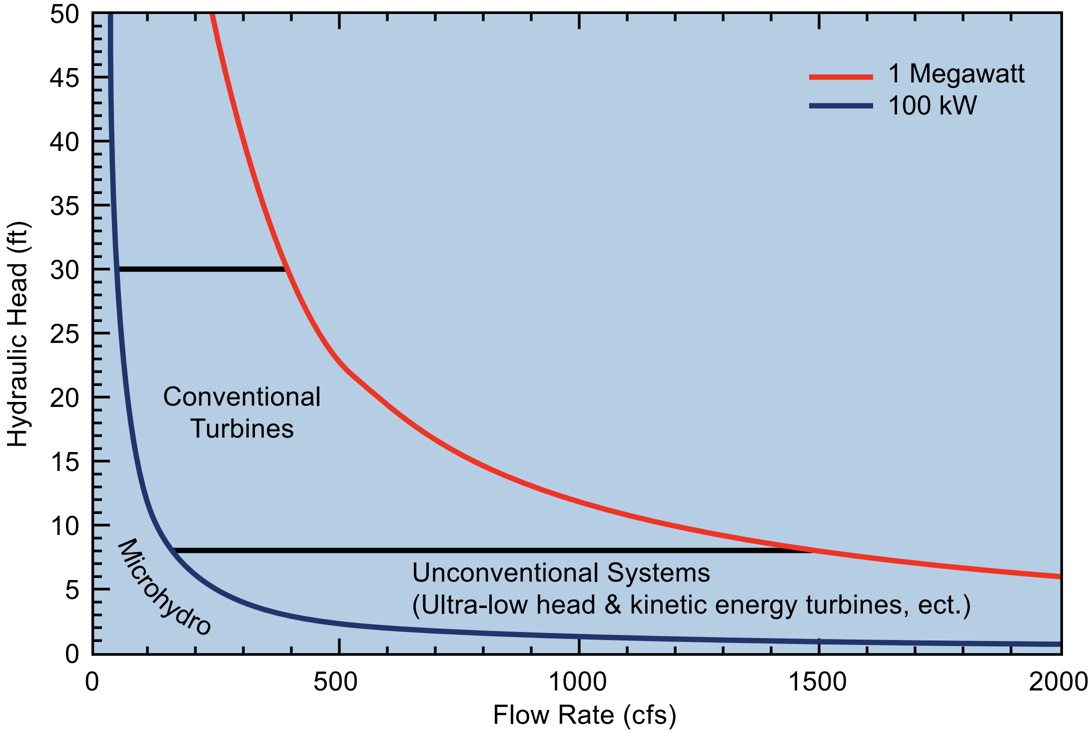
University of Texas at El Paso and El Paso Solar Pond station
http://www.solarpond.utep.edu/

Definition of Small Hydro for Idaho National Laboratory Hydropower Assessment

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

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

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



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INL. Idaho National Laboratory Hydropower assessment. Available at: http://hydropower.inl.gov/resourceassessment/ , and specifically for Texas at: http://hydropower.inl.gov/resourceassessment/index_states.shtml?id=tx&nam=Texico

[19] MWa = MWaverage: the annual average power rating of a potential hydropower facility. This unit of measure inherently incorporates the capacity factor to account for annual variations in flow rate. Using the value of 104 MWa [Hall et al., 2006] for existing hydropower facilities with nameplate capacity of 675 MW gives a potential "rule of thumb" for interpreting MWa from MW installed capacity, but future installations could perform differently.

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