Tucson Electric Power Company has been responsible for providing energy to the greater Tucson area for the past thirty years. They have become a household name and appreciated for successfully and efficiently providing energy for the citizens of Tucson. But one thing many consumers do not realize is the amount of water used to bring energy to their homes. Water is probably not the first thing that comes to mind when you think of an electricity company or electricity in general. Every time a Tucson citizen turns on a light, they are also using water, indirectly, to create that energy. The Tucson Electric Power Company has three Tucson sites where they produce energy: Irvington (4 steam units powered by coal, 2 gas turbines), DeMoss Petrie (1 gas turbine) and the North Loop (4 gas turbines). There are also three sites located outside of Tucson, but within the state: Springerville: Springerville Generating Station (4 steam units powered by coal), Nogales: Valencia Generating Station (4 gas turbines) and Kingman: Black Mountain Generating Station (2 gas turbines). When it comes to determining the water usage of a station, gas stations do not use a significant amount of water for it to matter. The energy that is created at these plants is generated by using water. It is estimated that for every kilowatt-hour generated 0.5-0.75 gallons of water are needed for when coal is used. When looking at it on a daily basis or per household it would seem miniscule compared to how much water is used for other things, but on a large scale that amount of water is immense. Between 2000 and 2010, it took on average 16,235 AF of water per year to provide power to the greater Tucson area.

The burning of fossil fuels adds 1.92 pounds of carbon to the atmosphere for every kWh of energy that is produced.
Electricity for Phoenix

Located in central of Arizona, Phoenix is surrounded by deserts and rocky mountain terrain with extremely hot weather and a lack of water. Although residents pay their power bill, many take for granted of how much energy goes into powering their homes. If power companies stopped making electricity there would be no Internet, no computers, no refrigerators, and no air conditioning! Two companies handle the process of turning water, coal, wind, solar energy, nuclear power, and natural gas into electricity that powers Phoenix. Formed over one hundred years ago, the Salt River Project (SRP) and Arizona Public Service (APS) now provide electricity to over four million people. Both companies use water to generate electricity and in the past decade “Phoenix has kept its water consumption to 340,000 acre-feet a year even as its population has grown.”

Drawing from the Salt River SRP was founded in 1903 and has been providing electricity for Phoenix ever since. SRP operates seven hydroelectric plants, eleven electrical generating stations, and has agreements with major hydroelectric plants along the Colorado River. Reservoirs on the Salt River offer valuable water storage as well as a recreational spots for fishing and boating. Their main reservoir is Roosevelt Dam and Lake. When their resources are at their peak SRP generates around 9,000,000 kWh; 39% from hydro-power; 10% from solar power; 14% from wind turbines; 5% in landfill gas; plus 1% produce through biomass. Although we knew that water is used in most of these generation processes, we were unable to quantify it.

APS, founded in 1884, has expanded its service area from Phoenix into northern and central Arizona providing electricity to over a million people in eleven different counties. APS owns the nearly 30% of the Palo Verde Power Plant, the largest nuclear power plant in the USA. (for more details see separate article on the Palo Verde Plant which supplies more than 4,000,000 kWh to APS customers. This is supplemented by five natural-gas plants that produce upwards of 2,400,000 kWh of electricity. Recently APS has started to put solar panels in different areas around Phoenix to explore a new frontier in energy generation.

Navajo Generating Plant

Water is used to cool electric power plants all over the country including the coal burning Navajo Generating Station plant in northern Arizona. In the Southwest alone over 2,000 Acre-feet of water a day is used for this purpose. Typically the Navajo Generating plant consumes around a half gallon of water per kilowatt-hour of generated electricity. In fact in one year the Navajo Generating Station will consume eight million tons of coal, and a staggering 28,000 mWh of water producing 2,250 mWh of electricity. The Navajo Generating Station was completed in 1976 in the hopes of fulfilling the need for new electric generation in the Southwest as well as providing a large source of power for the operation of the Central Arizona Project (CAP) pumping stations. Operated by the Salt River Project (SRP), the station consists of three identical 750MW generators. Inside each unit is a generator, boiler, turbine, environmental control equipment, and a closed-cycle cooling system. Steam emitted via heated water inside the turbines, drives the turbines. The heat produced is removed via evaporation in six induced-draft cross-flow cooling towers. Coal is provided by the Kayenta Mine, which is transported, by the Black Mesa and Lake Powell Railroad. The station on average will consume 25,000 tons of coal in a given day at full operation. The water used at the plant is pumped directly from the neighboring Lake Powell. The demand for electricity in the Southwest solidifies the importance of the Navajo Generating Station to its consumers in this region. The power generated at the plant is distributed to six main divisions: the U.S. Bureau of Reclamation at 24.3 percent, SRP at 21.7 percent, LA Department of Water and Power at 21.2 percent, Arizona Public Service at 14 percent, NV Energy at 11.3 percent, and Tucson Electric Power at 7.5 percent. These consumers rely heavily on the plant to provide energy to millions of people across three states. Consequently the Navajo Generating Station is the thirteenth largest producer of greenhouse gasses in the country, releasing more than 19 million tons of carbon dioxide per year, equivalent to more the 3.2 million vehicles on the road. Many studies have been done in recent years to find out the exact effects that the Navajo Generating Station has had on its surrounding environment. Its close proximity to the Grand Canyon, Glenn Canyon Dam, and Lake Powell put many natural ecosystems, as well as humans, at risk.
**Hoover Dam**

Hoover Dam is a large dam on the Colorado River between Nevada and Arizona. It was built between 1931 and 1936. At that time, it was the largest concrete structure ever. It produces energy for the states of Arizona, California and Nevada. The body of water held back by Hoover Dam is known as Lake Mead. Lake Mead’s water content level is $2.6 \times 10^7$ Acre Feet (AF). An AF is equivalent to 325,851 gallons or $3.258 \times 10^5$ Gal. On average, it receives $6.4 \times 10^6$ AF/year and it releases $5.2 \times 10^6$ AF of water downstream. The difference is the water lost via evaporation from Lake Mead or $1.2 \times 10^6$ AF/yr. The surface area of Lake Mead on average from 1942-1995 was 125,600 Acres (1.256 $\times 10^5$ AC). The measured average annual evaporation (Jan 1998-Dec 1999) was 7.5 ft., when multiplied by the lake area gives a total of evaporated water of $9.4 \times 10^7$ AF/yr. This is slightly less than estimated above from the differences from flow in and flow out, but approximately the same order of magnitude. This water is no longer able to be used; it is consumed by the atmosphere via evaporation from the surface of Lake Mead.

The released water through the turbines to generate electricity averages about $5.2 \times 10^6$ AF/year which is equivalent to $1.6 \times 10^{12}$ Gallons/year. In one year, the water that passes through the dam’s 17 generators creates 4.2 billion kWh of electricity or $4.2 \times 10^9$ kWh/yr, which means that it, requires 381 gallons to pass through the turbines to generate 1 kWh of electricity. If the water lost to evaporation is considered this becomes about 500 gallons per kWh.

**Palo Verde Nuclear Plant**

The Palo Verde Nuclear Generating Station is a unique point of discussion concerning water use and the generation of electricity in Arizona. The plant is located 45 miles west of Phoenix, and generates power for approximately 4 million people in Phoenix and parts of southern California. It is landmarked as the only nuclear power generating station in the world not situated directly on a large body of water. Instead, its cooling features are supplied using reclaimed sewage effluent from the 91st Ave wastewater treatment plant in the Phoenix area. The Palo Verde Plant uses 20 billion US gallons of treated wastewater per year. This composes about 25% of the annual overdraft of the Department of Water Resources Phoenix Active Management Area.

The plant generates electricity through a series of energy conversions from the nuclear reactor, heat, steam and propelling the turbines. This process begins with a nuclear reactor, which initiates a continuous nuclear chain reaction. The nuclear fission-taking place in the reaction generates heat, which is used to generate steam. This steam is then used to propel turbines, creating mechanical energy that is then converted to electricity. This process produces little pollution; it is considered a zero-emissions power source. All reactors need to be cooled in order to avoid an uncontrolled nuclear chain reaction. Running water through the system accomplishes this task, which is done by removing the heat from the nuclear reactors, which is supplied with enough water to cool the reactors.

The Palo Verde plant has three independent electricity-producing units, and has a capacity of 3,739 MW. Annually, the plant produces 29250mWh of electricity. The ratio of this electricity generation to water use becomes $2.9 \times 10^{13}$ Kwh per 20 billion gallons of treated wastewater, which equals approximately $4.725 \times 10^8$ kWh/acre-feet. When viewed in terms of electricity produced per gallon this is equivalent to 1450 kWh/gallon of water consumed, which makes it a very efficient use of water for generation of electricity.
Arizona Power Service has partnered with Abengoa Solar Inc., a Spanish company, in order to construct Solana, a solar-electric generation plant in western Arizona. Once completed in 2013, Solana will be a future icon in solar generating stations all over the world. The 1,900-acre plant is currently under construction in Gila Bend, Arizona. The plant will be using Concentration Solar Power (CSP) technology and will employ thermal energy storage. 2,700 parabolic mirrors will be used to concentrate the sun’s energy, and transfer it into a heating fluid to raise its temperature to about 735 degrees Fahrenheit. The hot fluid will then transfer its heat energy to water and create steam. This steam will then be used to spin turbines to generate electricity. Afterwards, the heating fluid will be sent back to the solar field. Some of the water that produces the steam will be reclaimed, but most of the steam will be vented into the atmosphere once it has been used to turn the turbines. At select times, the hot fluid will be used to heat molten salt, which will in-turn heat water to create steam even when the sun is not shining. Through this procedure the molten salt can store heat energy for up to six hours and electricity can be generated even at night.

The 280,000-kilowatt power plant will generate power for over 70,000 homes in Arizona. This facility will generate 600 million-kilowatt hours of electricity per year and will use 0.928 gallons of water for every kilowatt-hour of electricity generated. This means Solona will consume a total of 1,710 acre-feet of water per year, the same amount of water that 4,000 houses would consume in one year. The power plant claims it will use seventy five percent less water than the current agricultural use of the land. The plant will draw water from deep aquifers and because groundwater rights belong to the landowners, water will be readily available for the plant. The possibility of using treated wastewater is also an option that is being evaluated. Solona will also produce no greenhouse gasses and will prevent 350,000 tons of CO₂ from being emitted into the atmosphere every year if burning fossil fuels generated the electricity.
Water for Tucson

Lois Fozzard and Brenda Perez

In 1980, the Groundwater Management Act (GMA) was passed to set restrictions to the amount of groundwater that could be pumped. Active Management Areas were established to manage groundwater pumping. The Tucson Active Management Area management plan was drafted to ensure that the level of groundwater used remained in equilibrium with its recharge to prevent Tucson becoming a “sinking city.” In earlier times, Tucson pumped freely from the ground. Another stipulation introduced by the GMA is the maintenance of an Assured Water Supply, meaning that every city in Arizona has to store enough water to cover the city’s needs for the next 100 years. Tucson saves groundwater by combining it with Colorado River water brought to Tucson via the Central Arizona Project (CAP) aqueduct. Tucson is also replacing groundwater for golf courses and landscape irrigation with reclaimed water (treated sewage water effluent). Tucson is well-known for its water conservation methods.

In 2011 Tucson recharged about 123,800 AF of CAP water. Since water recharge activities started, approximately 990,000 AF of CAP were recharged by Tucson Water. The Arizona Banking Authorities manage CAP water in case of emergencies, such as shortages in the Colorado River or in times of canal shutdowns. In 2011, the Arizona Water Banking Authority stored 157,000 AF in storage facilities for Tucson Water. For the first time, in 2012, Tucson Water is ordering its full allotment of CAP water.

Tucson Water serves about 70% of the greater Tucson area. On average, Tucsonans daily consume 140 gallons of water. Tucson annually uses about 97,700 AF of drinkable water and 15,400 AF of reclaimed water. CAP delivers 1,500,000 AF total to Arizona, using 2.8 billion kWh of electricity. This means about 1,900 kWh are used to pump each AF of water to Tucson. About 65% of Tucson’s drinkable water comes from the Clearwater Renewable Resource Facility, which mixes CAP water with native groundwater and pumps the blended water to consumers.

Water for Phoenix

Alexa Wollach and Malcolm Daruwalla

The amount of water the city of Phoenix is using has started to decrease over the years. In 2003 single family residential use was 143 gallons per day per family, system-wide potable was 197 gallons, and system-wide total was 217 gallons. By 2008 water use started to decrease where the single family residential water use was 123 gallons, system-wide potable was 173 gallons, and the system-wide total was 184 gallons. It can be noted that the system-wide total water figure is the total amount of drinking water in the city, while system-wide potable water is the amount of water treated up to a certain degree and can be used for every single purpose in a city.

This water is treated up to a greater extent as compared to the system wide total water.

Phoenix is able to use several different resources that surround it in order to supply enough water to the city. The Phoenix water supply comes mainly from two different places the Salt River Project and the Central Arizona Project. The Salt River Project gets the majority of its water from the Salt and Verde Rivers. The Central Arizona Project gets its water from the Colorado River. It can also be noted that a small portion; less than 20,000 AF of Phoenix’s supply of water comes from wells, or groundwater. The water that is in the wells is distributed amongst the city in a complex system which requires energy.

The exact amount of energy used to transport the water to Phoenix has been hard to find. What has been clarified is that the Salt River Project does not use a lot of electricity to transport its water because the distance from the water sources to the water plant is downhill. But, considerable water is loss to evaporation from the reservoirs on the Salt and Verde Rivers. On the other hand, the Central Arizona Project uses 1,428 kwh’s to pump 1 acre foot of water from the Colorado River to Phoenix.
**Energy/Water Nexus Relationships**

**Water for Energy (water used in the generation of electricity)**
- Electricity for Tucson: 0.75 gal/kWh
- Electricity for Phoenix: 0.96 gal/kWh
- **Navajo Generating Plant**: 0.5 gal/kWh
- Hoover Dam: 500 gal/kWh
- Palo Verde Nuclear Plant: 1,450 kWh/gallon of water consumed
- Solano Solar Energy Plant: 0.928 gal/kWh

**Energy for Water (energy used in the delivery of water)**
- Water for Tucson: 1900 kWh/AF
- Water for Phoenix: 1428 kWh/AF
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**Palo Verde Nuclear Plant**


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**Solano Solar Plant**


Energy for Water

Water for Tucson


Water for Phoenix