ARROYO

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Water Resources Research Center • College of Agriculture and Life Sciences • The University of Arizona

The Water-Energy Nexus

In a world of limited resources, water and energy are inextricably linked

Water and energy are fundamental components of our 21st century life, but they can no longer be considered separately. Just as producing energy consumes water, pumping, treating and distributing water requires energy. In other words, water is an energy issue; energy is a water issue. Called the water-energy nexus, this interrelationship is beginning to receive the attention it merits.

Disruptions to the complex infrastructure that supplies society with these resources highlight their often invisible connections. A few cautionary tales from the news illustrate this point in stark terms:

Sources: Oklahoma State University Extension, US National Park Service, Central Arizona Project, USDA Natural Resources Conservation Service, Montana Office of Economic Development.

- In August 2003 a blistering heat wave swept through France, killing nearly 15,000 people. Dropping water levels and warmer temperatures in rivers severely limited the supply of cooling water to nuclear power plants, which were forced to reduce electricity outputs just as demand for air conditioning spiked.
- In October 2007 a prolonged drought brought Atlanta, Georgia within months of running out of drinking water. Levels in Lake Lanier, which serves consumers as well as the Farley Nuclear Power Plant, dropped dangerously low, forcing complex choices between the supply of drinking water, the availability of electric power, and the survival of endangered species.
- In September 2008 Hurricane Ike made landfall on the coast of Texas, taking 20 percent of water systems in the Galveston area out of service. Fully one-quarter of backup generators stopped or ran out of fuel, while 14 percent of wastewater stations failed, discharging sewage into local rivers. All three of Houston's water pumping stations lost power, and officials warned residents to boil their water before drinking it.

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Water and energy are intricately linked, but they have not always been managed as interrelated resources. In May 2006, *Energy & Environment Publishing* began its report on a conference of experts meeting in Albuquerque, New Mexico, with this statement: "Water and energy may be two of the Southwest's biggest natural resource issues, but few policy makers or resource managers consider the two together in making decisions about them, even as Western states scramble to meet sky-rocketing demand for both."

The Energy Policy Act of 2005 represents the first time the federal government formally recognized the water-energy nexus. Section 979 directs the U.S. Department of Energy, in collaboration with other agencies, to "address energy-related issues associated with the provision of adequate water supplies," and "address water-related issues associated with the provision of adequate [energy] supplies." The resulting *Report to Congress on the Interdependency of Energy and Water* concluded that major changes in the generation, transmission and distribution of energy might be needed in certain regions to address water issues.

The water-energy nexus can be considered from two main points of view: energy consumed to pump, treat and deliver water and water used to produce energy. Awareness of both perspectives is essential for resource mangement.

Water Consumes Energy

Water does not pour from the tap without first consuming power to get there. The electricity requirements for the delivery of potable water are enormous. By some estimates, 80 percent of the cost of water provision is related to energy.

Energy is required at every stage: extraction, conveyance, treatment, distribution, use, wastewater collection, treatment and reuse or discharge. On a national level, water and wastewater energy consumption accounts for as much as 4 percent of all the electricity produced on an annual basis. In other words, consumers exchange electric power for clean water supplies.

Groundwater Extraction

Groundwater accounts for 40 percent of Arizona's water supply. Extraction of groundwater for potable use, on average, consumes 30 percent more electricity than diversions from surface water sources, primarily because of the pumping requirements. In some areas of Arizona that rely almost exclusively on groundwater, the energy costs of such dependence can be significant. Costs vary depending on the type of energy used, the depth to groundwater, and the physical characteristics of the aquifer. The Arizona Department of Water Resources estimates groundwater prices range from $20 to $166 per acre-foot—varied prices that represent varied energy requirements.

Groundwater depletion, a problem in a number of Arizona regions, can increase energy costs in several ways. Wells must be drilled deeper and the water itself must be lifted higher by pumps. If water quality diminishes with the lowering of the water table, this creates a need for energy-consuming treatment. In certain areas of Arizona, groundwater decline has caused the cost of pumping water for irrigation to rise. Combined with development pressures, this has resulted in some farmland going out of production.

Surface Water Diversion and Transportation

Surface waters, such as the Salt, Gila and Verde rivers, account for 56 percent of Arizona's water supply. That includes the state's single largest surface water source, the Colorado River on Arizona's western border. Capturing surface water often costs less than extracting groundwater, but when the water must be transported long distances away from the diversion point, energy costs are substantial.

This is borne out by the Central Arizona Project (CAP), the largest single user of electricity in Arizona. A 336-mile system of canals, pipelines and storage facilities, CAP delivers Colorado River water from Lake Havasu to its terminus south of Tucson. Last year CAP used approximately 2.8 million megawatt-hours of energy—about 4 percent of all the energy consumed in Arizona—to deliver 1.5 million acre-feet of water to central and southern Arizona.

All that power is needed to move water uphill: pumping plants lift water 2,900 feet over the length of the canal. On average, CAP uses 5.5 kilowatt-hours of electricity for each thousand gallons (kgal) of water it delivers. In other words, its energy intensity is 5.5 kWh/kgal. For comparison, a collaborative effort by University of Arizona and Northern Arizona University researchers found that the energy intensity of potable groundwater pumped for the cities of Patagonia and Benson was 1.4 and 3.1 kWh/kgal, respectively.

That, however, is not the whole story, because delivering water to Phoenix requires less energy than delivering water to Tucson, which is more than 100 miles farther and 1,400 feet higher in elevation. By one estimate, the energy intensity of CAP water delivered to Tucson is 9.8 kWh/kgal, nearly double the system-wide average.

CAP managers have long recognized the project's energy needs. Lifting water 824 feet from Lake Havasu into the Hayden-Rhodes Aqueduct accounts for about half the power consumed in the entire CAP system. Water is lifted at night to take advantage of lower, off-peak electricity costs, and stored overnight in this oversized section of the canal. Similarly, Lake Pleasant enables CAP to manage power costs on a seasonal basis. The lake is filled during the winter when energy is cheaper, and water is released in the summer when demand is high and energy is more expensive. This attention to cyclic patterns in electricity prices reduces the energy costs of the canal's operation, though not the total energy consumed.

Water Treatment

The water treatment process consumes energy in two ways. First, groundwater and surface water are treated before arriving at the tap. This does not normally consume a large portion of the total energy costs. An Arizona Water Institute study led by Chris Scott and Martin Pasqualetti found that water treatment methods in Tucson require only a fraction of a kilowatt-hour per thousand gallons treated. Energy costs are higher for lower-quality sources—CAP water, for instance, requires more treatment than most groundwater.

Energy Intensity and Water Intensity

One way to think about water-energy connections is to calculate how much of one is used to produce the other. The energy used to produce water is termed "energy intensity." Energy intensity is commonly calculated as kilowatt-hours consumed per 1,000 gallons (kWh/kgal). The converse is "water intensity," the volume of water required to provide a unit of power, usually gallons per megawatt-hour (gal/MWh). A megawatt-hour is a unit of power consumption equal to 1,000 kilowatt-hours. A 100-watt light bulb switched on for 10 hours consumes 1 kilowatt-hour. These crossover metrics are where the rubber meets the road in terms of understanding water-energy interdependencies.

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Consumer Choices: The Energy-Water Nexus at Home

On a typical spring day in Tucson, you return from the store with groceries in hand and turn on the kitchen light. The air conditioner automatically switches on as the oven begins to warm up. For once, the dishes are clean and the laundry out of the dryer. After dinner, you might put the kettle on for tea and enjoy a hot shower before bed.

Every day, Arizona's 6.7 million residents participate in the water-energy nexus. Ordinary activities—bathing, drinking, cleaning dishes and washing clothes—require electricity to deliver and heat the water, run the appliances, and take the wastewater away. Appliances that consume or handle water account for almost a quarter of a household's energy needs.

But can consumer choices really have a statewide impact? In fact, residential use accounts for 45 percent of all the energy consumed in Arizona, with commercial at 39 percent and industrial at 16 percent. An enormous amount of power is required to keep our homes cool and our water hot—power that in turn required an enormous amount of water to produce. Small actions can simultaneously reduce energy and water use, like taking shorter showers or running only full loads of laundry and dishes. Larger decisions, such as choice of equipment, can make an even bigger difference.

Consider evaporative coolers and air conditioners, increasingly relied on by a booming population to endure the desert heat. Not surprisingly, indoor cooling is the largest consumer of energy in a household. Evaporative or swamp coolers operate by blowing air across a moist pad, while air conditioners use the compression and subsequent expansion of a refrigerant to cool air. But which technology has a lower water-energy footprint?

A study by the University of Arizona's Environmental Research Laboratory examined this question for a typical 2,000-square foot Tucson home. Air conditioners use between 2 to 4 times the electricity of a swamp cooler, but they do not require water. Evaporative coolers use less energy, but require continuous additions of water. The study found that if the electricity is generated by coal, the air conditioner is still a water saver, consuming only 425 gallons per month, while the swamp cooler uses more than 4,600 gallons per month. On the other hand, air conditioners are significantly more expensive to run, and their lower water footprint might not offset their greater energy consumption. These tradeoffs complicate the choices that environmentally-minded consumers face.

This solar-powered home in Tucson, Arizona makes energy out of the region's abundant sunshine. Source: GeoInnovation.

Swimming pools are another summertime favorite for escaping the desert heat. At the height of the housing boom, about 20,000 pools were being built in Arizona every year. But pools lose 4 to 6 feet of water annually to evaporation, and leaks can be hard to detect because fill valves automatically maintain the pool's level.

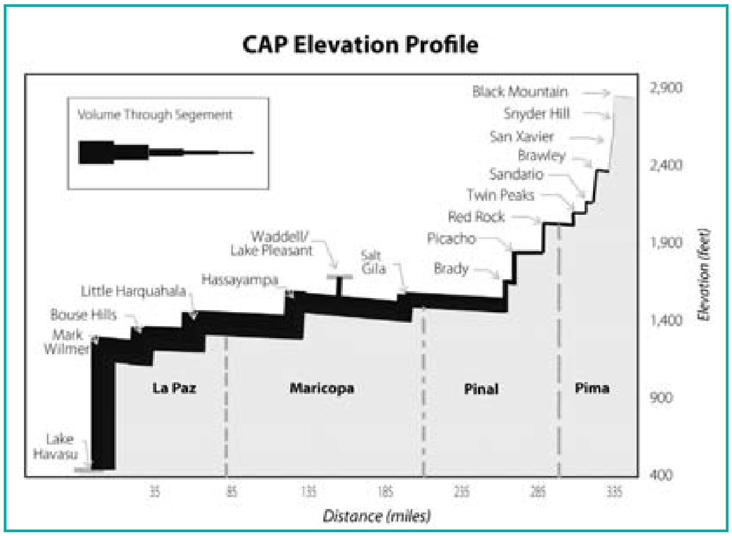
Apart from this straightforward consumption of water, pools require a lot of energy to maintain. The pump alone needs 3,000 kWh a year to operate, and is often left running longer than necessary. If the pool is heated, raising its temperature just 1°F (0.6°C) can increase costs by 10-30%. Simply covering the pool conserves energy and reduces evaporation at the same time. One Phoenix company, Deckover, has even developed a specialty converting in-ground pools into backyard decks, declaring that the homeowner will save about $50 a month just on water and energy costs.

As much as we want to stay cool in the summer, we want hot water on demand. Conventional hot water heaters hold 30 to 80 gallons and periodically fire to keep their contents warm. This continual readiness is why a hot water heater is the second-greatest consumer of energy in a household. Critics argue that a storage heater is like a toaster that stays red-hot even when there isn't any toast.

One alternative is a tankless water heater, a slender chamber with an inner maze of electric coils or a natural gas flame that heats water only when it's needed. Another option, particularly apt in Arizona, is a solar water heater. A high-quality solar panel can supply 100 percent of the required hot water in the summertime, and can be paired with a conventional heater to ensure hot water on cloudy days. Both systems are more expensive to install, although there are now tax credits available for solar water heaters.

Focusing on hot water is a good way for consumers to get more bang for their buck. Put simply, hot water represents a huge input of energy. For this reason, a California study published in Water Efficiency suggests prioritizing low-flow showerheads and faucet aerators as conservation measures. Likewise, a Colorado-based study by Stacey Tellinghuisen found that conserving 1,000 gallons of hot water saves between 60 and 210 kWh of electricity (depending on the temperature), while conserving 1,000 gallons of cold water saves less than 3 kWh. Bottom line: saving water is good, but saving heated water is even better.

In dozens of small ways—turning on a lamp, watering a garden, cooking dinner, making coffee—consumers partake in the complex interactions between energy and water. Responding to regional and global concerns, many individuals are looking for ways to live less wastefully. Sometimes they face problematic tradeoffs, where one resource is conserved only at the expense of another. More often, however, simple choices can reduce demands on both. Being aware of the water-energy nexus can double the benefits, and the joy, of careful stewardship.



CAP water is lifted in a star-step fashion and gravity-fed between pumping plants. Source: Central Arizona Project.

At the other end of the domestic water cycle, treatment facilities receive municipal waste that must be treated and then discharged or delivered for reuse. Wastewater treatment is more intensive than drinking water treatment because of the solids the wastewater contains. Scott and Pasqualetti found that collecting and treating wastewater in Tucson requires about 1 kWh/kgal. Small rural systems often have higher energy intensities because of limited budgets, or if they choose more intensive treatment technologies. In Benson, collecting and treating wastewater consumes 7.3 kWh/kgal, and in Patagonia, 13.5 kWh/kgal.

Currently, about 4 percent of Arizona's annual water supply comes from wastewater treated for reuse or recharge (storage underground). Extended droughts and groundwater overdraft necessarily raise costs and reduce supplies of groundwater and surface water, so the importance of treated wastewater—long overlooked as a potential supply—is expected to grow.

Wastewater treatment plants can sell effluent for a variety of uses—recharging aquifers, irrigating golf courses, filling artificial lakes. With further polishing to meet Arizona Department of Environmental Quality standards, its potential uses expand; excluding only direct contact with the drinking water system (see *Arroyo* 2009). Wastewater can be treated to a level of quality that matches its intended use, so the energy costs of its reclamation can be minimized.

It may even be possible to clean up wastewater while generating electricity, rather than consuming it. When naturally occurring bacteria break down organic matter in wastewater, they release electrons. Microbial fuel cells, an emerging technology, capture those electrons to create an electrical current. The technology is promising but still in the experimental stage.

In the meantime, effluent is an ideal source of water for generating electricity with conventional methods. The Arizona Department of Water Resources encourages power plants to use effluent for cooling water. Effluent is the only water source that grows with population, so it is logical for generating stations (which also "grow" with population) to look to this resource as a replacement for groundwater. At least three generating facilities in Arizona—Palo Verde, Redhawk and Kyrene—use effluent in their cooling towers, consuming a total of more than 63 million gallons a day.

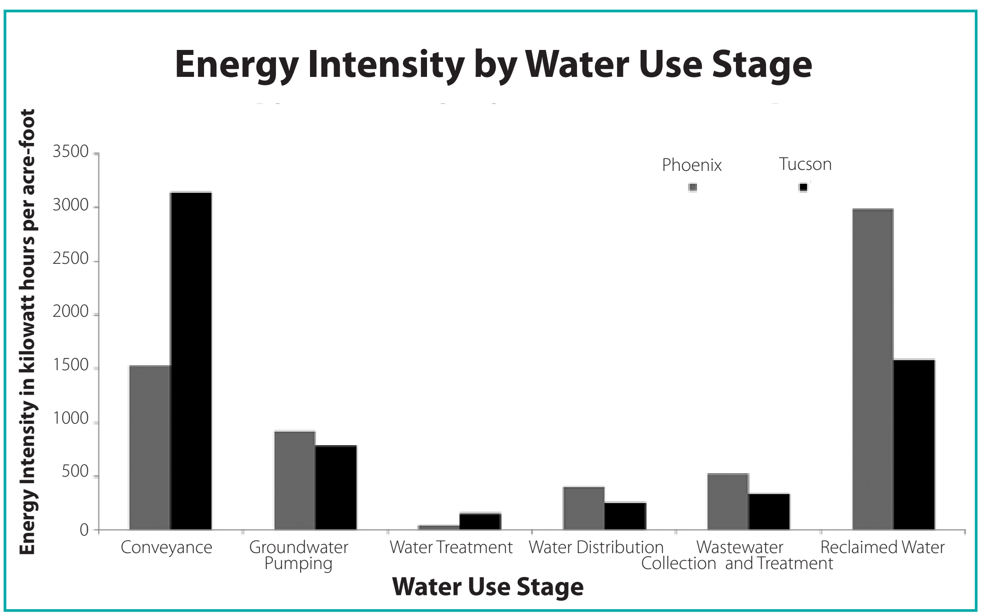
Energy Consumes Water

Thermoelectric power plants account for about 40 percent of all freshwater withdrawals in the United States —approximately 190,000 million gallons of water a day. But only about 3 percent of the freshwater is actually consumed. After circulating through the cooling system, the water can be reused or discharged back into the environment. Compared to the rest of the nation, Arizona power plants withdraw less water but consume a larger percentage of the water they withdraw.

Generating Electric Power

All power plants, with the exception of photovoltaic systems, generate energy with turbines. A fluid—steam, gas, water or wind—flows through the fan-like blades in the turbine, converting the kinetic energy of the movement into rotational energy. This rotational energy spins a magnet mounted inside a coil of insulated copper wire, causing electrons to flow. Wires conduct the electricity into a switchyard, ready to be sent out to consumers.

In a typical steam turbine, heat (from burning coal or natural gas or from nuclear fission) boils water to produce steam that pushes against the turbine's blades. As the blades turn, the steam loses energy in the form of heat. Efficient turbines minimize the energy lost as heat. There are two ways to make a turbine more efficient: increase



Every stage of handling water and wastewater requires an input of energy. Source: C. Scott, M. Pasqualetti, J. Hoover, G. Garfin, R. Varady, S. Guhathakurta, 2009.

the heat on the inlet side, or decrease the heat on the outlet side. The inlet temperature depends on the energy source; the outlet temperature depends on cooling water and the climate outside.

Gas turbines have higher inlet temperatures than steam turbines; therefore they can maintain efficiency without using as much cooling water on the outlet side. Hybrid or combined cycle turbines, which use gas and steam turbines in series, can be even more energy-efficient. After hot gases are used to turn the first turbine, the leftover heat is captured to create steam to turn a second turbine. Nearly half the turbines operating in Arizona are either gas or combined cycle, with inherently lower water requirements.

A power plant's water footprint also depends on cooling technology. In places where there is an ocean, lake or river nearby, excess heat can be discarded by drawing a large volume of water into the plant and returning it to the source a few degrees warmer. This "open loop" system doesn't consume a lot of water, but it requires a very large supply.

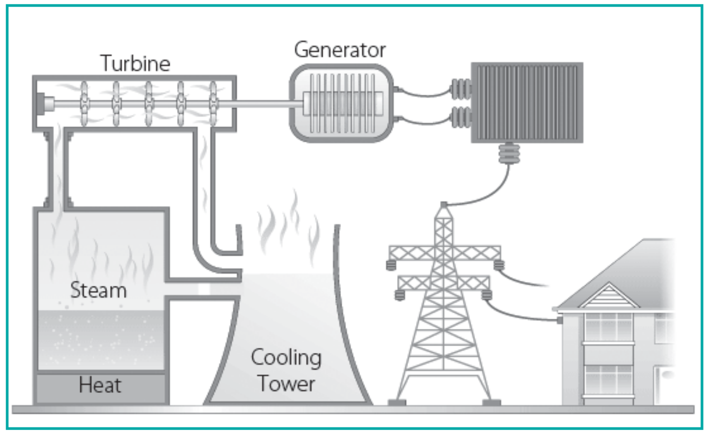
Energy Efficiency

It takes energy to make energy. Whenever one form of energy is converted into another, some of the energy is lost. Energy efficiency is a technical term meaning the ratio of the energy generated, say electrical energy, to the energy content of the source, such as combustion of coal or natural gas.

In Arizona, all generating facilities currently use "closed loop" cooling, also known as "wet cooling." For a typical steam operation, after the steam passes through the turbine it goes to a condenser, where it cools and becomes liquid water again to be reused. A separate stream of cooling water continually cycles through the condenser, removing heat from the steam without ever coming into contact with it.

The next step is to get rid of the excess heat. A closed loop system dissipates heat by evaporation in cooling towers, which consumes a great deal of water. Additionally, impurities concentrate as the water cycles through the system; eventually this "blowdown" water must be discarded and replaced with new "make-up" water.

Dry cooling, another type of cooling technology, works like the radiator in an automobile. Air is forced through condenser coils that contain the steam, transferring heat directly to the air. The use of dry cooling can reduce a plant's water consumption by 90 percent. But when the air is as hot as it often is in Arizona, efficiency suffers. A U.S. Department of Energy study estimated that if a proposed solar trough plant in the Mojave Desert used dry cooling, it would produce 5 percent less electricity annually, increasing electric prices by 7 to 9 percent.



Electricity generation for a typical steam turbine. Source: BBC.

Hybrid systems include smaller versions of wet cooling and dry cooling equipment in series. Other modifications to dry cooling systems, such as misters, can also significantly improve hot weather performance. The Department of Energy study found that hybrid cooling systems at concentrating solar plants can reduce water consumption by 80 to 90 percent while imposing a decrease of 2 to 10 percent in annual electricity output, depending on the location and other factors.

Conventional Energy Sources

The source of the power greatly affects how much water each megawatt requires. To examine this issue, the Arizona Water Institute funded two Arizona State University researchers, Martin Pasqualetti and Scott Kelley, to investigate state generation facilities. The data show which energy sources are generally more water-consumptive, although the type of cooling technology employed at each facility also has a major impact.

Hydroelectric Power

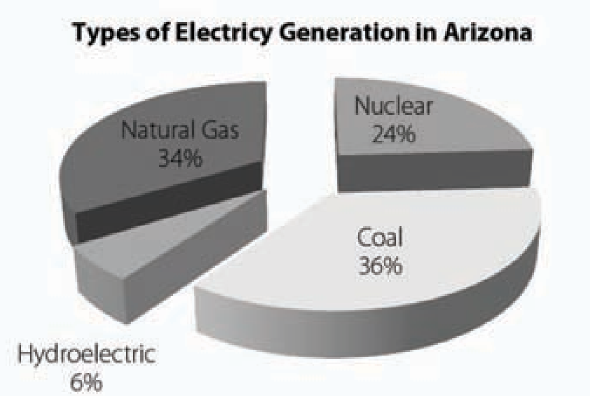
According to their calculations, hydroelectric power is by far the largest user of water. This result seems counterintuitive. Almost all types of energy generation require water, but hydroelectric is the only kind that generates energy directly from water. Hydroelectric plants, which account for about six percent of Arizona's energy generation, operate by allowing water to run through the turbines. But that water flows on to other uses without being consumed.

However, water that evaporates from hydroelectric reservoirs can be considered water consumption resulting from the generation of power. The National Renewable Energy Laboratory (NREL) conducted an analysis of Glen Canyon Dam and Hoover Dam, both in northern Arizona, which showed that the evaporation from the Colorado River in its former undammed condition had been only 3.2 percent of the average evaporation from the two reservoirs.

When all that reservoir evaporation is attributed to hydropower production, the water footprint of this technology skyrockets. NREL calculated it at nearly 65,000 gal/MWh. In most reservoirs, however, water is impounded for multiple purposes. Pasqualetti and Kelley calculated a lower water footprint of 30,078 gal/MWh by apportioning the total water evaporation among other reservoir uses—agriculture, recreation and domestic water supply—based on their relative economic benefits. This is still a startling high number, but no value was included in the calculation for flood control or the timing and reliability of water supply provided by multipurpose reservoirs. Arguably, one could attribute zero water loss to hydroelectric power in reservoirs like Lake Powell and Lake Mead that were built expressly for the purpose of water supply. There is more to the water-energy nexus than first meets the eye.

Coal and Natural Gas

The everyday energy demands of consumers draw on the utility's base level of power. In Arizona, this is usually provided by coal-fired plants. Spikes in demand, which occur



on daily cycles as well as during unusual circumstances like extreme heat or cold, require the utility to quickly increase the output from its network of power plants. Hydroelectric plants are very responsive to peak demands because reservoirs act like batteries, storing the energy of flowing water until it is needed. In Arizona, peak demands are usually met by hydroelectric or natural gas-fired facilities, which can generally be up and running within half an hour.

Coal- and natural gas-fired facilities account for about 70 percent of Arizona's electricity generation. Pasqualetti and Kelley estimate that coal consumes about 510 gallons for every MWh of electricity generated, with natural gas following closely at 415 gal/MWh. More efficient cooling technologies can reduce water consumption. The Redhawk Generating Station, a natural gas power plant west of Phoenix, is a "zero liquid discharge site," meaning that the one billion gallons of effluent it uses every year is continually reclaimed and recycled. Arizona Public Service data from 2007 indicates that this combined-cycle, wet-cooled plant has a water intensity of 296 gal/MWh.

Beyond energy generation, however, coal and natural gas have another link to the water-energy nexus as emitters of carbon dioxide, a major greenhouse gas. By altering climate patterns, fossil fuel emissions threaten not just regional but global water supplies. Changes in precipitation and increased temperatures brought on by climate change may reduce the water available to power plants while simultaneously increasing the need for cooling water. The result could be an upward spiral of increasing water and energy costs. The water footprint of fossil fuels is tied to its carbon footprint, creating a tradeoff between the present and the future.

Going Nuclear

As carbon-based energy sources look toward an uncertain future that may involve cap-and-trade regulations or emission standards, nuclear energy's status as carbon-neutral has propelled it to the head of the class. Arizona is no stranger to nuclear power, as it is home to the nation's largest nuclear generating facility, Palo Verde, in Wintersburg southwest of Phoenix.

Nuclear energy makes up about 24 percent of Arizona's electricity generation, third most after coal and natural gas. It is a large user of water, consuming 785 gal/MWh according to Pasqualetti and Kelley. Unlike fossil fuel power generation, which gets rid of one-third of its excess heat in air emissions, nuclear energy dissipates all of the heat in cooling waters. The Palo Verde Nuclear Generating Station—the only U.S. nuclear facility not located near a large body of water—pipes about 20 billion gallons of effluent every year from the nearby Phoenix area to use in its cooling towers.

The use of coal, gas and nuclear materials to produce energy has another link to the water-energy nexus beyond the consumption of cooling water. Mining these fuels has implications for water quantity and quality. For more than three decades, coal mined in the Black Mesa region of northern Arizona was delivered in slurry to the Mohave Generating Station in Nevada via a 273-mile pipeline. The operation used one billion gallons of groundwater from Navajo and Hopi lands every year until the mine suspended operations in 2005.

Arizona is also home to uranium ore deposits that could be in high demand as new nuclear plants are proposed around the country. The drive for non-carbon-based energy has spurred a sharp increase in mining claims—over a thousand within five miles of the Grand Canyon National Park, and thousands more in the surrounding area. Mining these deposits could contaminate seeps and springs that feed the Colorado River, which would affect millions of downstream users in Arizona, California and Mexico. On the other hand, continued improvements in technology help protect water quality, and recycling or using non-potable sources can mitigate the negative impacts of mining's water demands.

At the request of former Governor Napolitano, Secretary of Interior Ken Salazar called a two-year timeout on mining claims in the Grand Canyon region in 2009 to give his agency time to study the issue. The federal government can ban mining for up to 20 years, but the choice is difficult—clean energy at a risk to clean water.

Alternative Energy Sources

Multiple factors are accelerating the search for cost-effective new energy sources, including concerns with the global effects of fossil fuel combustion, requirements for national energy security and energy independence, and the potential for new jobs in the developing "green energy" sector. In the rush for new energy, however, it is essential to keep sight of its links with water. As a case in point, Arizona has become the focus of intense interest to solar energy entrepreneurs and investors.

Traditionally, Arizona's economy has been dominated by the Five C's: Copper, Cotton, Citrus, Cattle and Climate. That last 'C' may provide the largest opportunity for economic development in the future. Except

How Cleaner Air Becomes Pricier Water

The Central Arizona Project owns a 24 percent share in the Navajo Generating Station, a coal-fired plant near Page, Arizona. Along with small allocations from the Hoover and New Waddel dams, this share supplies the energy needed to power CAP's 15 pumping stations. The Environmental Protection Agency may require upgrades to the Navajo Generating Station to reduce its emissions of nitrogen oxides. According to CAP, the higher energy costs could double or triple the price of their water. Moreover, future cap-and-trade legislation on coal-based energy could make operations economically infeasible for the plant. If the Navajo Generating Station shuts down, CAP would have to purchase more expensive energy supplies elsewhere. Some of the costs of a cleaner atmosphere, therefore, may become reflected in the price of water.

The Water Costs of Electricity Generation			
Fuel Type	**U.S. Department of Energy 2006** Gal/MWh	**Arizona Public Service 2007** Gal/MWh	**Pasqualetti and Kelley 2008** Gal/MWh
Solar (CSP)	750-920	---	311-1,000
Nuclear	400-720	775	785
Coal	200-480	67-610	510
Natural Gas	100-180*	20-550	195-514
Solar (PV)	---	---	Negligible
**combined cycle only*			

for a narrow strip along the Mogollon Rim, Arizona receives more than 70 percent of possible sunlight every year. Arizona's 300-plus days of sunshine, boasted about on tourist brochures, may prove even more valuable as an energy resource.

One provision of the U.S. Energy Policy Act of 2005 mandates that within a decade a minimum of 10,000 MW of renewable (non-hydropower) generation capacity be located on federal lands—equivalent to almost three facilities with the capacity of the Palo Verde Nuclear Generating Station. Along with other regulations and incentives, this has encouraged a "gold rush" for solar power in western states. In Arizona, thousands of acres managed by the Bureau of Land Management and the Arizona State Land Department are considered excellent land for solar development. Nearly all of this land can produce more than 6 kWh of solar energy per square meter per day.

There are two types of solar energy technologies, each with very different water requirements. Concentrating solar power (CSP) facilities create heat to boil water for steam turbines by focusing sunlight with large mirrors. Cooling water is required, as for coal, gas and nuclear power generation. A U.S. Department of Energy report estimates that a wet-cooled parabolic trough plant requires 800 gal/MWh, although dry cooling and hybrid technology can shrink its water footprint to 80-450 gal/MWh.

Photovoltaic systems, on the other hand, convert sunlight directly into energy and require almost no water. The panels need to be washed occasionally to maintain their efficiency, consuming 20 gal/MWh or less.

Most of the interest in solar development focuses on CSP, because photovoltaic panels have significant limitations for large scale use. Solar energy is intermittent—interrupted by clouds and nightfall—while energy demand occurs in any weather and at any time of day. The electrical energy created by photovoltaic panels is difficult to store for use while the sun is not shining, whereas the thermal (heat) energy created by CSP plants has a variety of proven storage methods available.

As of January 2010, BLM had 34 pending applications for solar projects in Arizona—30 proposals for forms of CSP and 4 for photovoltaic systems. If all these applications were approved, more than 15,500 MW of generation capacity would be created, and roughly 450,000 acres would be developed. Much of this land is desert, untouched by other water claims.

Critics argue that instead of developing federal lands, utilities should buy land and water rights from the agriculture sector, converting cotton fields into solar farms. The Solana Generating Station, a proposed 280-megawatt facility scheduled to be online in 2012, will be built on private agricultural land near Gila Bend. Even though the CSP plant will use a substantial amount of water, the project managers estimate it will require 75-85 percent less water than the existing alfalfa farm.

Joseph Simmons, director of the Arizona Research Institute for Solar Energy (AzRISE), is an enthusiastic advocate of solar power. "The beauty of it is that the fuel is free," Simmons said. AzRISE is developing methods to reduce or eliminate the water requirements of solar energy, and Simmons is confident that workable technologies are only a year or two away.

The major challenge is finding an efficient way to store the energy. Batteries can store energy without requiring water, but they hold a limited amount and can be very expensive. An option Simmons calls "very promising" for Arizona is compressed air energy storage (CAES). When solar energy is abundant, the power plant can compress air and store it in vessels. When sunshine is not available, the compressed air is heated slightly and released to drive turbines.

A small system—like a solar panel on a house—could store compressed air in something like a propane tank. But a large solar

Mohave County: Little Water, Lots of Sun

Mohave County, 13,500 acres of desert in northwestern Arizona, is a land of little rain and lots of sun. The empty space and open skies seem perfect for solar power. Albiasa Corporation plans to build a 200-MW facility southeast of Kingman, while the 340-MW Hualapai Valley Solar plant intends to use 4,000 acres of private land to the north. Together, those two plants could require some 1.5 billion gallons of groundwater annually for their steam turbines and cooling towers, roughly the amount that the City of Kingman serves its 27,000 residents every year. Those residents have let their voices be heard: They don't want solar power to diminish the region's valuable water supplies.

Mohave County's General Plan states that it will only approve power plants using dry cooling technology if the aquifer is threatened with depletion. While power plant officials say that's not the case here, they are still faced with passionate public opposition to wet-cooled facilities. Albiasa and Hualapai Valley Solar contend that the cost to efficiency for dry-cooling or hybrid technology would be significant in such a hot climate.

However, in rural Arizona treated wastewater often goes unused, offering opportunities for more water-conscious solar power. Hualapai Valley Solar has expressed willingness to buy effluent from Kingman, promising the water can be recycled at least 58 times. Kingman could supply 1,800 acre-feet of effluent to the facility, about 80 percent of its expected requirement. The Arizona Corporation Commission's Power Plant and Transmission Line Siting Committee approved a Certificate of Environmental Compatibility for Hualapai Valley Solar in January 2010, partly because of its commitment to use effluent.

energy plant would need to store the compressed air in an aquifer, cave or abandoned mine. A technique for creating storage space, particularly applicable in Arizona, is solution mining—dissolving salt deposits with water to dig out underground caverns.

One obvious downside is the production of water contaminated with salts, and the costs of proper disposal. But Simmons envisions a future where solar energy not only supplies Arizona's energy needs but also helps turn salty water into a potable supply. Researchers at AzRISE and the University of Arizona are working on a process to use the waste heat from solar power generation for desalination.

"My vision of the future in Arizona is the area near Holbrook," Simmons said. The Holbrook Basin, a 3,500 square mile area of massive salt deposits, sits over the Navajo Aquifer, historically plagued with water quality problems. Simmons considers the region to be perfect for his plan—a solar-powered plant that simultaneously produces energy and desalinates brackish water.

"It would be a free result of doing solar electricity," Simmons said. "It would take billions of dollars to do that. But we could generate enough electricity for Arizona and probably some neighboring states. That's an interesting path for the future, to use solar energy to generate potable water, and it would be positive on the water side."

Another novel technology might offer a win-win scenario: the hydrogen fuel cell. The reaction that creates an electric current inside the cell also generates water. Apollo astronauts used their spacecraft's fuel cells to generate drinking water, but here on Earth the technology is still in the experimental development stage. Paul Westerhoff at Arizona State University found that a fuel cell operating at a capacity that meets a household's energy needs would generate just over four gallons daily—enough to supply the household's cooking and drinking water.

In rural Arizona, solar panels are commonly used to provide power to water supply wells where electric utilities are not available. Source: Richard Conway.

The Message in a Bottle of Water

Arizona's famous dry heat is a good reason to carry a bottle of water whenever you go outside. But intense debate surrounds the environmental implications of bottled water. "Purified" water, accounting for 44 percent of the U.S. bottled water market, is often simply municipal water subjected to an extra, energy-consuming treatment step. Robert Glennon, author of Unquenchable, calls bottled water "the epitome of a luxury item." Manufacturing the bottle requires twice as much water as it ultimately holds, and petroleum-based plastics consume large amounts of crude oil.

Over 8.2 billion gallons of bottled water were sold in the U.S. in 2006, more than milk and beer and second only to soft drinks. What are the energy implications of all those bottles moving off the shelves? That depends on how far they have to travel. Purified municipal water delivered and sold within 125 miles of its source consumes about 1,950 kWh/kgal, while spring water produced in the South Pacific and sold in the U.S. requires nearly 3,560 kWh/kgal. In comparison, city tap water requires about 1.8 kWh/kgal, or one to two thousand times less energy.

In southeastern Australia, a small town called Bundanoon recently voted—by show of hands—to prevent the sale of bottled water within the town's limits. The drastic action was provoked by an Australian company's proposal to tap a local aquifer, truck the water 100 miles to Sydney, and then bring it back in bottled form. The community chose instead to fill their own bottles at new outdoor fountains supplying the local water.

Desalination

These innovative visions of energy and water synergy have yet to become reality for ordinary consumers. For now, when freshwater is scarce, making salty water potable requires energy-consuming treatment. Desalination is at the heart of the water-energy nexus. It can increase the supply of high-quality water, but also requires large amounts of power. Many proposals for desalination facilities include the co-location of generating stations so that each can take advantage of the other.

In January 2009 Herb Guenther, director of the Arizona Department of Water Resources, testified before the Arizona House Committee on Water and Energy that desalination was the "direction for the state to head, as it is the only drought-proof and truly sustainable supply of water available." Two major sources of saline water could feasibly supply Arizona: the Pacific Ocean/Sea of Cortez and brackish groundwater.

According to a 2006 Pacific Institute study of California plants, the most efficient facilities operating today consume around 12 kWh to produce 1,000 gallons of desalinated water. The energy intensity varies widely depending on the salinity of the source water among other factors. Seawater has a total dissolved solids (TDS) concentration around 35,000 mg/L. Definitions of brackish water vary, but generally range between 1,000 mg/L and 20,000 mg/L. Thus the energy required to treat brackish water to freshwater levels—the Environmental Protection Agency recommends 500 mg/L or less for drinking—can be much lower than the energy required for seawater.

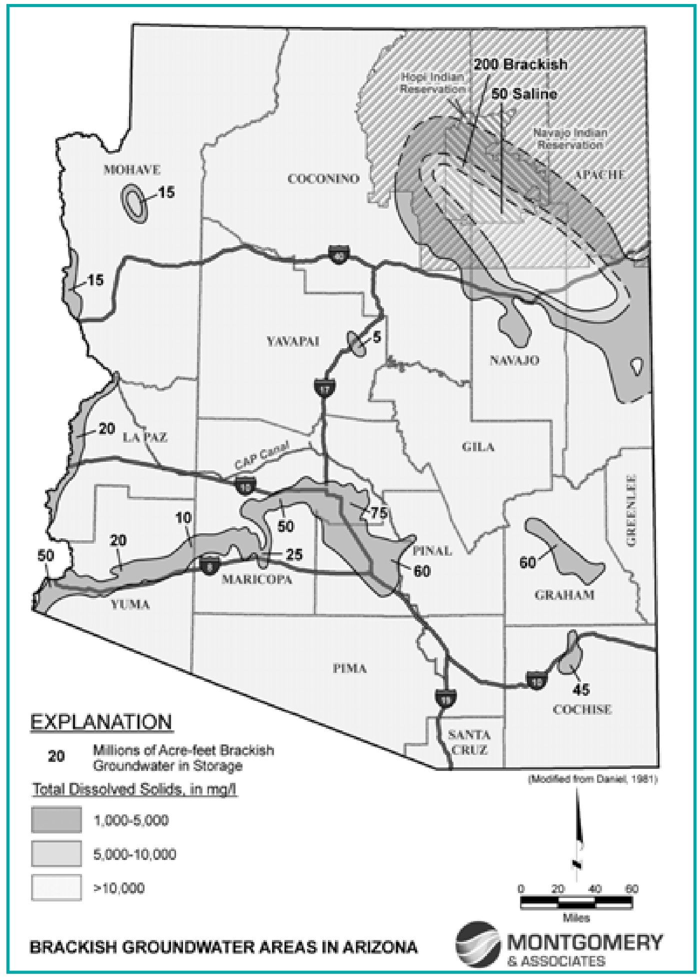
By one estimate, roughly 600 million acre-feet of brackish groundwater exist in Arizona at depths less than 1,200 feet (see map). Deeper aquifers also contain huge quantities, though the exact amounts are unknown. A promising region is the brackish groundwater extending along the Gila River from the Picacho Basin to Yuma, which could potentially augment CAP deliveries to southern Arizona. Ideally the desalination effort would be coupled with renewable energy supplies. Gila Bend is already the site of one of the world's largest solar projects, the Solana Generating Station scheduled for completion in 2012.

Oceans seem a much less likely source of water for landlocked Arizona. But as early as 1965, President Johnson and President Diaz Ordez signed an agreement to explore the possibility of supplying the border region with desalinated seawater. In 1968, the U.S., Mexico and the International Atomic Energy Agency published a report that gave a hopeful outlook to paired nuclear power and desalination plants in the region. The same year, the U.S. Bureau of Reclamation identified two sites, one near San Diego and one near Puerto Peñasco in Sonora, Mexico, where such a project might be possible. The study even proposed an aqueduct route to bring water from the Gulf of California to Lake Mead.

While the U.S. and Mexico never followed through with their plans, the proposed Puerto Peñasco desalination plant continues to intrigue water managers on both sides of the border. The City of Puerto Peñasco, struggling with low-quality dwindling groundwater supplies, has already begun planning for a seawater desalination plant. Puerto Peñasco officials hope to construct a renewable energy facility, such as a solar array, to power the desalination plant. Yet if Arizona wants a share in the venture, additional energy will be required to treat more water and to convey it across the border. A binational coalition led by the Arizona-Mexico Commission is studying the possibility of jointly operating a desalination facility to provide fresh water to both Arizona and Sonora.

On one hand, transporting desalinated seawater into southern Arizona could provide a measure of water security to the state. For example, by piping water from Mexico to the Imperial Dam in Arizona, more water could remain for upstream users in Lake Mead. But the energy costs of such an undertaking would be enormous.

With both water and energy in short supply, the tradeoff is daunting. The Pacific Institute study concluded that the cost of producing desalinated water is unlikely to drop below $980 per acre-foot. Energy accounts for one-third to one-half of the cost of the produced water, making the supply vulnerable to changing electricity prices. Transportation is another important factor. Consultants for the Central Arizona Project suggest water from the Puerto Peñasco project could cost as much as $1,200 to $1,800 per acre-foot. For comparison, CAP's water rates in 2009 ranged from $45 to $110 per acre-foot. There is a large economic gap between the vision of seawater desalination and reality, but that situation may change as technologies improve and the need for new water supplies becomes more severe.



Desalination of brackish groundwater may become important in Arizona. Source: Ed McGavock (Montgomery & Associates) and Chuck Cullom (Central Arizona Project) 2008.

Regulation

Water and electric utilities are classic examples of industries that are considered natural monopolies. Because large capital investments are required for infrastructure to transmit and distribute water or electric power, it is usually too costly for new firms to enter an established market. As a result, utilities often exercise monopoly control within a region.

Governments regulate monopolies for the protection of consumers. They oversee and limit the actions of the monopolies, at the same time protecting them from competition and permitting them a reasonable profit. In Arizona, the Arizona Corporation Commission (ACC) is responsible for oversight of privately owned electric and water utilities, making it uniquely positioned to address concerns surrounding the water-energy nexus.

Proposed power plants in Arizona must receive approval from the ACC before moving forward with construction. Among other requirements, the facility must obtain a Certificate of Environmental Compatibility (CEC) from the ACC. The proposals are measured with the "balancing test," which requires the commission "to balance, in the broad public interest, the need for an adequate, economical and reliable supply of electric power with the desire to minimize the effect thereof on the environment and ecology of this state." In the last decade, the choice to grant or deny a CEC often had water issues at the core:

- In November 2001, the ACC denied a CEC for the first time ever, voting against a proposed power plant that would have been built near Wikieup in Mohave County. The decision was partly based on concern that groundwater pumping for cooling water would adversely affect habitat for the endangered Southwestern Willow Flycatcher.
- In February 2002, the ACC denied

a CEC to a proposed facility near Picacho Peak that would have consumed more than 10,000 acre-feet of groundwater every year, potentially exacerbating land subsidence already occurring in the area.

- In another case, the ACC required an expansion of the Arlington Valley Energy Facility in Maricopa County to use dry cooling technology. However, in April 2002 the ACC approved a CEC that allowed wet cooling, after the facility agreed to recharge at least 3,900 acre-feet of water per year into the Agua Fria aquifer.

These types of decisions exemplify the tradeoffs that often occur when both energy and water issues are at stake.

Deregulation

The Energy Policy Act of 1992 changed the landscape of the electric industry in the U.S. when it opened up transmission lines to non-utility power generators. Following this federal vision, the ACC began implementing a new set of rules in January 1999 to deregulate electric utilities. This opened up the generation of electricity to competition, with transmission and distribution purchased on existing infrastructure from the regional power provider. Non-utility power generation—referred to as merchant power—allows consumers to shop around for rates and services, ultimately choosing how their energy is created.

Merchant plants do not operate all the time and can be called into service on short notice. Between 1997 and 2007, the percentage of Arizona's power generated by merchant plants increased from 1 percent to 22 percent. Almost all these new plants are fired by natural gas, because of lower prices and the flexibility to meet peak demands. Over the same period, regulated utilities have increased their use of natural gas, from 3 percent to 13 percent. Natural gas now supplies one-third of Arizona's total power generation, second only to coal. Moreover, all of the Arizona merchants that have gone online since 2001 use combined-cycle turbines, the most efficient and least water-consumptive type. These trends are gradually improving the water footprint of Arizona's electricity generation.

On the other hand, merchant facilities are generally free to sell their power to the highest bidder, and electricity shipped out of state embodies an export of water. After subtracting the energy imported into the state from the amount of energy exported, Martin Pasqualetti and Scott Kelley conclude that Arizona annually exports 30,000 acre-feet of water in the form of electric power—enough water to supply some 120,000 Arizonans.

MONTGOMERY & ASSOCIATES
Water Resource Consultants

Engineering Student Authors Arroyo

A principal author of this newsletter, David Newman, was the recipient of the 2009 Montgomery & Associates Summer Internship at the WRRC. A student in the UA's Department of Chemical and Environmental Engineering, he will be graduating with a master's degree in Environmental Engineering in May. During his internship, David divided his time between his research and writing responsibilities at the WRRC and maintaining his laboratory research. He has been an active member in the UA Student Chapter of Engineers Without Borders and a committed fundraiser for Tucson charities.

In April 2002, the ACC approved the construction of a merchant power plant in La Paz County only after placing 40 restrictions on its operation. A natural gas-fired facility, the La Paz Generating Station met a requirement to mitigate groundwater withdrawals by purchasing over 2,000 acres of irrigable land and permanently retiring the associated water rights. The approval also included a provision that the 1,080-MW plant first offer its power to companies serving Arizona consumers before pursuing customers in other states. These conditions illustrate how concerns about the water footprint of Arizona's energy generation can influence policy decisions.

Transportation Fuels

Involving much more than electrical power, the water-energy nexus is just as relevant to the production and use of the energy that moves the world's transportation systems. Approximately 28 percent of the energy consumed in the United States is used for transportation. The extraction, refinement and delivery of both conventional and alternative transportation fuels have associated water costs.

Gasoline represents 62 percent of the fuel used in the U.S., while diesel and aviation fuel follow at 24 percent and 8 percent, respectively. The process of refining crude oil into these products consumes 1 to 2.5 gallons of water for every gallon of product. Extracting oil usually consumes very little water. However, enhanced oil recovery, which is used in aged or impaired well fields, can require anywhere between 2 and 350 gallons of water to extract a gallon of oil. Generally this process uses water that is unfit for most other uses.

Extracting fuel from oil shale—"the rock that burns"—has been proposed as a new energy source, but one that would have a significant impact on water supplies in the West. Oil shale is a kerogen-containing limestone that can be processed into fuel for thermal power plants or into a substitute for jet fuel, diesel or gasoline. The U.S. contains the largest known reserves of the resource, with vast deposits in Colorado, Utah and Wyoming. It takes an estimated 2 to 5 gallons of water to recover a gallon of oil-equivalent fuel.

Arizona is a net consumer of transportation fuels: In 2007 Arizona produced only 46,000 barrels of crude oil—second-lowest of any U.S. state—while consuming around 110 million barrels of petroleum products. Moreover, Arizona does not possess refining capacity, though a facility in Mohawk Valley near Yuma is expected to become operational in 2012 and will receive crude oil supplies from Alberta, Canada. The net import of transportation fuels represents an import of the water embodied in the extraction, refinement and delivery of that fuel.

Ethanol

While Arizona may not possess abundant oil reserves or refining capacity, it does have plentiful farmland. A 2007 U.S. Department of Agriculture census classified 26 million acres in Arizona as farmland, and identified 876,000 acres as irrigated cropland.

The Energy Independence and Security Act of 2007 (EISA) mandated that 15 billion gallons of corn ethanol be produced in the

U.S. per year by 2015, and that 16 billion gallons of cellulosic biofuel be produced per year by 2022. Those 31 billion gallons of biofuel would be energy-equivalent to 21 billion gallons of gasoline—roughly 15 percent of the gasoline consumed in the U.S. every year.

Cleaner-burning than gasoline, ethanol could help the U.S. mitigate climate change and move toward energy independence. But there is a hidden cost to the increased production of corn: water. A recent study in *Environmental Science & Technology* estimated that a car driven on ethanol made from Nebraska-grown corn would consume the equivalent of 50 gallons of water per mile. For comparison, one study estimated it takes between 0.07 and 0.14 gallons of water to produce enough gasoline to drive one mile.

The water requirements of ethanol vary widely from state to state, depending on regional climates. The irrigation required by Arizona-grown corn raises its water footprint. Three Arizona State University researchers, Christopher Harto, Robert Meyers and Eric Williams, calculated that a gallon of ethanol derived from irrigated corn consumes between 190 and 2,260 gallons of water. Because Arizona is at the high end of this range, it is unlikely that many farmers here will switch to corn to meet U.S. energy needs.

However, corn is not the only source of ethanol. Researchers at the University of Arizona are looking into the viability of sweet sorghum for ethanol production. Sweet sorghum is a heat- and drought-resistant crop that is typically grown for animal feed, though it can be used for sugar production. Studies led by UA agronomist Michael Ottman show that sweet sorghum grown in Tucson has similar irrigation requirements to Tucson-grown corn. On the other hand, sweet sorghum has a longer growing season—potentially two crops could be grown per year. It is better suited to thrive on less-than-optimal amounts of water, and can be irrigated with effluent or brackish water supplies. These factors may make it more appropriate than corn for dry western states.

Ethanol is fermented from the sugar-laden juice that is squeezed from sweet sorghum stalks. Because of its high sugar content, the sap from sweet sorghum can produce between 400 and 600 gallons of ethanol per cultivated acre, which, on the high end, is almost twice that of corn-based ethanol. Existing corn-to-ethanol facilities would require some modifications to handle sweet sorghum as a raw material, but after modification, the facility would use less water and energy because sweet sorghum juice does not require the starch degradation step needed for corn processing.

Pinal Energy, the first ethanol production facility in Arizona, began operation in August 2007. Located in Maricopa County, the facility uses local and Midwestern corn and milo to produce 50 million gallons of ethanol per year. Pinal Energy is investigating the possibility of using sweet sorghum as an ethanol feedstock. Working with University of Arizona researchers, they are close to commercialization of the crop.

Biodiesel

Another option for alternative fuels is biodiesel, a cleaner-burning diesel fuel made typically from vegetable-based oils, such as soybean. In Arizona, fewer than 1,000 acres of soybeans are cultivated. Like corn, soybean's water requirements are daunting—a gallon of biodiesel from irrigated soybeans in Arizona could consume as much as 9,040 gallons of water.

Arizona does, however, have an abundance of sunshine and marginal lands—perfect for growing algae. Researchers have considered algae to be a promising source of oil to make biodiesel for some time, but only recently has industrial-scale production appeared feasible. This is an active area of research at Arizona State University's Biodesign Institute, and several University of Arizona researchers are members of a consortium that received a $44 million dollar grant from the U.S. Department of Energy in January 2010 to develop marketable algae-based biofuels. One of the UA researchers, Joel Cuello, is working on a cost-effective way to grow algae.

There are two primary methods of cultivating algae: open ponds and closed bioreactors. Open ponds filled with nutrient-laden water, such as partially treated wastewater, are a simple way to grow algae, but less efficient because temperature, sunlight and other environmental factors fluctuate. The more costly closed bioreactors grow algae inside large containers, usually in the form of long tubes, where environmental conditions can be tightly controlled. The algae are then harvested from the water—an energy-intensive process—and dried before processing.

Both methods use less water than the existing agricultural fields they could replace. Phoenix-based XL Renewables has begun building a 400-acre algae farm in Vicksburg, Arizona that will grow algae in the nitrogen- and phosphorus-rich effluent from dairy operations. Many of the oil-rich strains of algae are best suited for brackish and even saline waters. Furthermore, after being processed for its oil content, the algae residue can be used as animal feed, extending the crop's economic potential.

Fuel From Waste

Waste cooking oil (WCO) collected from restaurants and from homes after Thanksgiving meals is also being used to generate biodiesel. This approach utilizes a waste material which needs to be captured before it reaches the sanitary sewer. With minimal processing, it can be readily made into fuel for nearly any diesel engine. A "Grecycle" production facility for WCO biodiesel will open in 2010 in Tucson.

It has not been all smooth sailing for algae biodiesel, however. One of the highest profile operations in the world, based at the Arizona Public Service's Redhawk Generating Station west of Phoenix, recently closed its doors, unable to secure additional funding to continue development. However, their GreenFuel Technologies process demonstrated the potential of growing hydrocarbon-rich algae by sequestering carbon dioxide from flue gas emissions. In fact, one of the facility's challenges was that the algae grew faster than it could be harvested.

If the technological and process hurdles can be overcome, Arizona could become a major producer of biodiesel. What does that mean for the state's water use? The Harto, Meyers and Williams study concluded that closed bioreactors used to grow algae would consume between 44 and 63 gallons of water per gallon of biodiesel, and open pond-grown algae would consume between 223 and 1,000 galW/galB. The higher number for open ponds results from their greater evaporation rates and lower productivity.

If either of these technologies were scaled up to address 50 percent of Arizona's transportation needs, and if all production occurred within Arizona, the researchers found that production with closed bioreactors would consume almost 1 percent of the water used annually in Arizona, while the open ponds would consume 11 percent. If Arizona chooses to enter a new national market for algae-based biofuel, it will have to dedicate a considerable portion of its water supply. Compared with other sources of biodiesel, however, the water challenges do not seem insurmountable.

Overcoming the Dilemna

Undoubtedly, the water-energy nexus involves many tradeoffs, and the solutions to shortages are not always clear-cut. Officials are now aware not only that water has energy costs and energy comes with water costs, but also that these costs must be understood as dynamically linked. These links complicate planning and policy making, as decisions that conserve one resource may have detrimental impacts on the other. One thing is clear: recognizing the importance of the water-energy nexus is a critical first step toward a sustainable future.

As our search for new water supplies takes us to more distant and lower-quality sources, energy for transport and treatment will be increasingly in demand. Likewise, the nation's new commitment to developing alternative energy presents difficult water choices to dry regions like Arizona. Shifting away from fossil fuels means a closer look at nuclear power, hydropower, and concentrating solar power —all three generally more water-intensive than coal or natural gas. Biofuel-run cars are cleaner, but currently guzzle more water than gasoline, particularly if the crops are grown in dry regions.

Under normal circumstances—a rapidly growing population in a region with finite resources—the water-energy nexus seems like an unsolvable puzzle. Climate change only complicates matters, potentially reducing resources just as the need for water and energy becomes more acute. Yet inventive people across the state are seeking out ways to make simultaneous gains in water and energy conservation. Guided by federal and state regulations, power providers are becoming more efficient and cities are reconsidering their sources and uses of water. Researchers developing alternative energy have begun to recognize that water supply is intricately connected—either a cost to weigh, or a potential benefit for which to strive.

Individual consumers, too, can make meaningful choices as they consider the interactions of water and energy. Simply switching off a light bulb can help preserve the state's water supply, just as turning off the faucet represents a savings in energy. Understanding this nexus allows consumers to prioritize choices that have double benefits, like conserving heated water. Policymakers, scientists and citizens all have a role in finding and adopting the win-win path to water and energy sustainability.

A Bright Idea

Curly, fluorescent light bulbs have become a symbol of sustainable thinking. As it turns out, it's a two-for-one bargain. Researchers at Virginia Tech calculated that a normal 60-watt light bulb, burning 12 hours a day for one year, consumes between 3,000 and 6,000 gallons of water depending on the energy source. Switching to a single compact fluorescent light bulb reduces a household's energy bill while simultaneously saving 2,000 to 4,000 gallons of water a year.

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