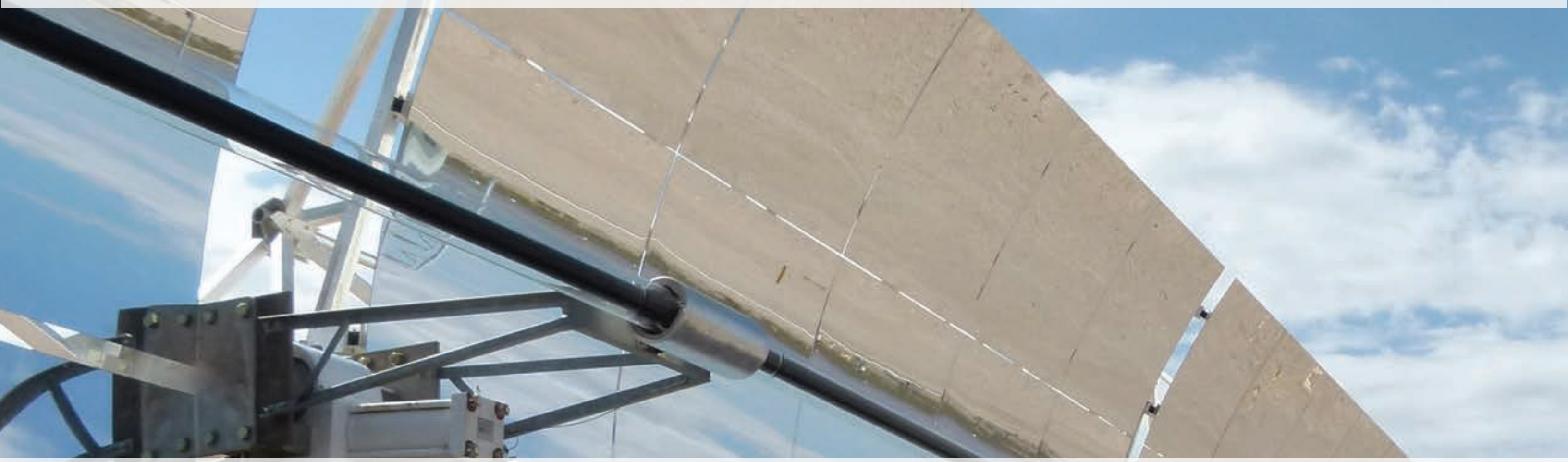
Water and Watts: How Electrical Generation Has and Will Continue to Shape the Colorado River

By Henry Madsen



Key Findings:

-In the basin approximately 300,000 acre feet (af) are consumed annually for electrical generation. This amount of water could provide for nearly two million people in the U.S.
-Around 90% of current U.S. power plants are thermoelectric and thus require water.
-The current electricity-generation portfolio of the basin, heavily reliant on nonrenewable fuels as seen in Figure 7 of this section, is unsustainable.
-In the last ten years, 17% of Department of Energy's (DOE) research and development funds were allocated to all renewable energy technologies, while over 25% was allocated to fossil sources, and over 25% was allocated to nuclear energy.
-Carbon Capture and Sequestration (CCS) plants use more water than conventional plants. It is estimated that CCS decreases carbon emissions by 99% per unit of electricity, yet increases water consumption by 35-100% per unit of electricity.
-The Energy Information Administration (EIA) has projected a 30% increase in electricity consumption for the United States by 2035.
-The water now used annually for generation in the study area will be almost 25% of our water deficit in 15 years.

The 2013 Colorado College State of the Rockies Report Card
Water Friendly Futures for the Colorado River Basin

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Introduction

It should come as no surprise to readers of this report that water will be in short supply in the future. Burgeoning populations will need water and electricity. These two needs are related. The prevailing methods that we use to generate electricity today could supply a population with water three times larger than Denver.[1] This amount of water will be very important as populations grow in the basin.

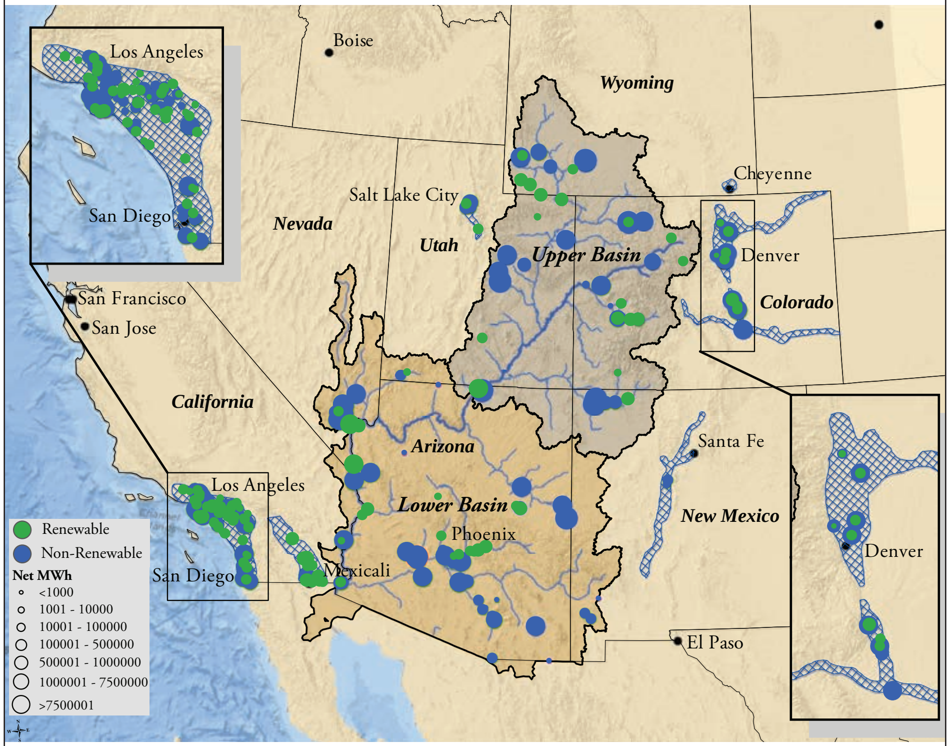
The seven states that encompass the Colorado River Basin (Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming) and trans-basin diversions to California include some of the fastest growing populations in the nation. For the purposes of this paper: a basin state qualifies by containing a portion of the Colorado River Basin as a hydrologic area and/or areas whose water is obtained from diversion out of the basin, as depicted in **Figure 1**. Historically, these states have primarily consumed energy in the form of nonrenewable fuels. Much of this energy comes as electricity generated with nonrenewable fossil fuels, and many states still rely heavily on fossil fuel electricity generation as seen by a majority of large blue markers in **Figure 2**. These plants generate the vast majority of the basin's electricity. The frequency of blue and green markers in **Figure 3** indicates the prevalence of coal and natural gas plants. With a recent push towards green energy, the electrical generation portfolio of the basin is changing. **Figure 4** depicts the growing number of diverse renewable generating plants in the basin states. Renewable plants represent good intentions, but they do not yet generate nearly as much electricity as the nonrenewable units (notice the discrepancy between legends). This means that the states have a long way to go to alter their electrical generation portfolios to become greener.

The manner by which the basin provides its future populations with electricity is important to the Colorado River. Water is necessary to produce electricity, some forms of generation requiring more than others. In the life cycle of a fossil fuel, from the ground to the furnace, water is consumed at every step. This water use is not explicitly stated to consumers of electricity. The amount of water consumed in the process of electrical generation is largely dictated by the cooling system used. Water is withdrawn from a source for cooling, and throughout the process of generation some evaporates. The amount of water withdrawn is much greater than that consumed. The withdrawal of water for power generation represents 49% of total water withdrawals in the country.[2] Only 2% to 3% is consumed (i.e., lost to evaporation), amounting to between 1.6 to 1.7 trillion gallons (4.9 to 5.2 million acre feet) of water annually for the country.[3] In the basin approximately 300,000 acre feet (af) are consumed annually for electrical generation.[4] This amount of water could

Figure 1: Map of the Colorado River Basin with Adjacent Areas

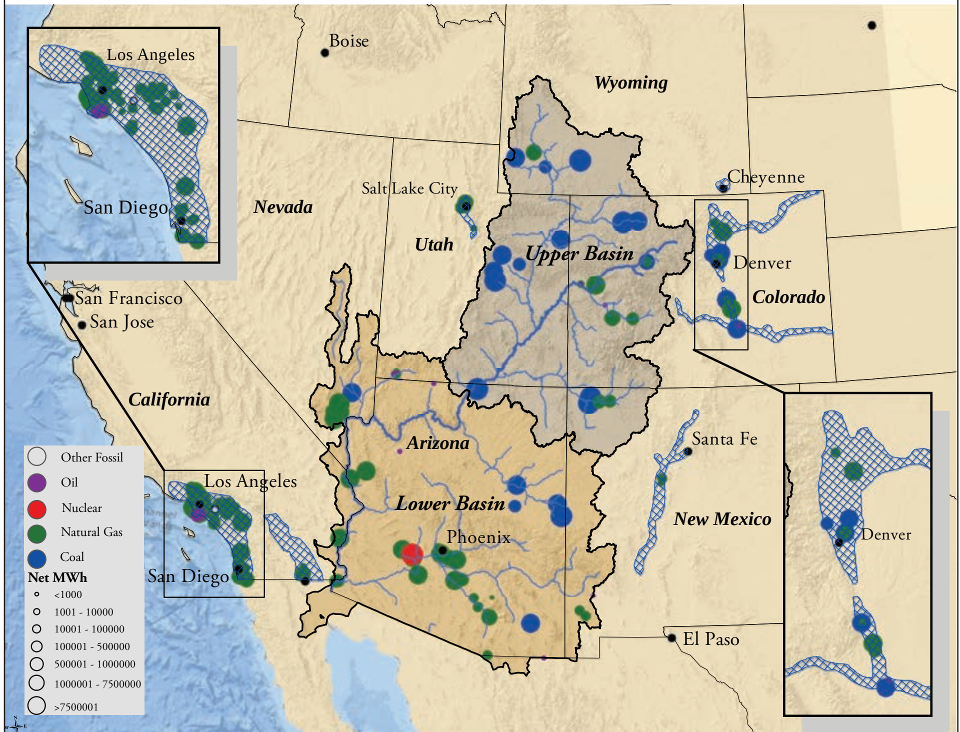
Source: Bureau of Reclamation

Figure 2: Power Plants by Fuel Type in the Basin



Source: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%)* Data Files. eGRID plant year 2009 data (4/27/12). 2012.

Figure 3: Nonrenewable Power Plants by Fuel Type in the Basin



Source: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files*. eGRID plant year 2009 data (4/27/12). 2012.

provide for nearly two million people in the U.S.[5] Power plants affect water sources in more ways than consumption for cooling.

Traditional fossil-fuel plants indirectly pollute water sources with emissions of chemicals and particulate matter. These emissions affect water sources in the form of acid rain. Once emissions have entered the atmosphere they inevitably enter the water cycle and affect all niches of an ecosystem.[6] These contaminated water sources must be cleaned before human consumption. This energy and water-intensive process highlights an additional externality of our reliance on traditional sources of electrical generation. There are multiple options to simultaneously conserve water and lessen pollution.

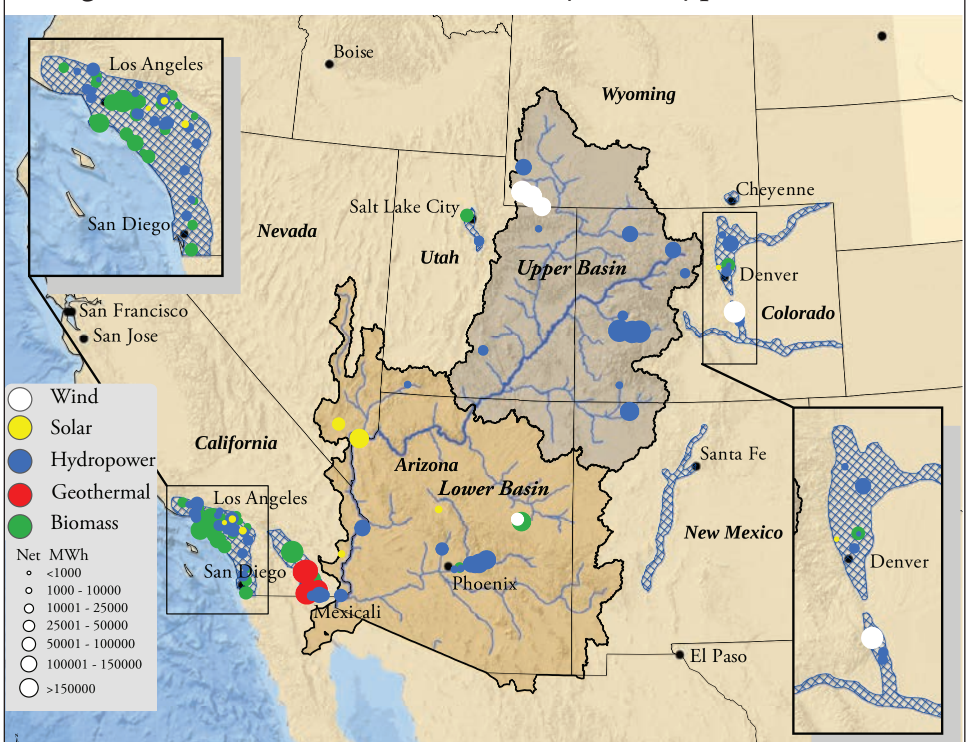
Technologies to limit emissions have arisen, but often consume more water. Traditional coal emits more pollution, yet consumes less water than coal generation with yet to be proven Carbon Capture and Sequestration (CCS) technology. These sorts of emission controls, resulting in less pollution but often additional externalities, are slowly becoming a more viable option for the future. Renewable fuels, such as wind and solar photovoltaic, are reliable water savers, only needing water to be cleaned, and they have no emissions while active. The emissions associated with these technologies occur during manufacturing. Choosing which option best suits our future requires an understanding of the current situation.

Understanding the water needs of our electricity generation sector and the electricity needs of the seven states will help us plan out a feasible and desirable water friendly future. The true cost of fossil fuels makes renewables seem more realistic; the market price of fossil fuels does not include the environmental impacts of their use, such as the water they require or pollution they emit. The country is beginning to understand these external costs, and incentives to change are being put in place. Renewable Portfolio Standards show the desire of the basin states to move away from fossil fuels. Many types of renewables are promising options that consume little water, produce little pollution, and generate moderate amounts of electricity. Fossil fuels are high water consuming, high pollution producing, and high electricity generating. We must make the correct decision in creating an energy portfolio that is at once low water consuming, low carbon producing, and high electricity generating.

Quantifying the Energy Portfolio of the Basin and the Water that Permits It

Whether we are aware or not, we use more water daily than what comes out of our faucets. Much of this water is hidden in energy intensive processes. How much water is consumed watching a movie? How much water is needed to

Figure 4: Renewable Power Plants by Fuel Type in the Basin



Source: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files*. eGRID plant year 2009 data (4/27/12). 2012.

manufacture a cell phone? How much water does a gas stove require? Water is used for nearly everything, even things that do not obviously require energy. For example, clothes constitute a significant input of water to produce their materials (a cotton T-shirt is estimated to require 718 gallons).[7] Earth is the water planet; life could not have evolved, as we know it, without water. Now the world is becoming increasingly dependent upon energy, a dependence that requires water. Much of this energy comes from generated electricity. In order to have water in the environment for necessities such as hydration, crop production, and healthy ecosystems, we must move towards minimal water use to obtain energy. For these reasons it is paramount to increase the water efficiency of all processes related to energy, especially electricity, while decreasing the amount of energy consumed.

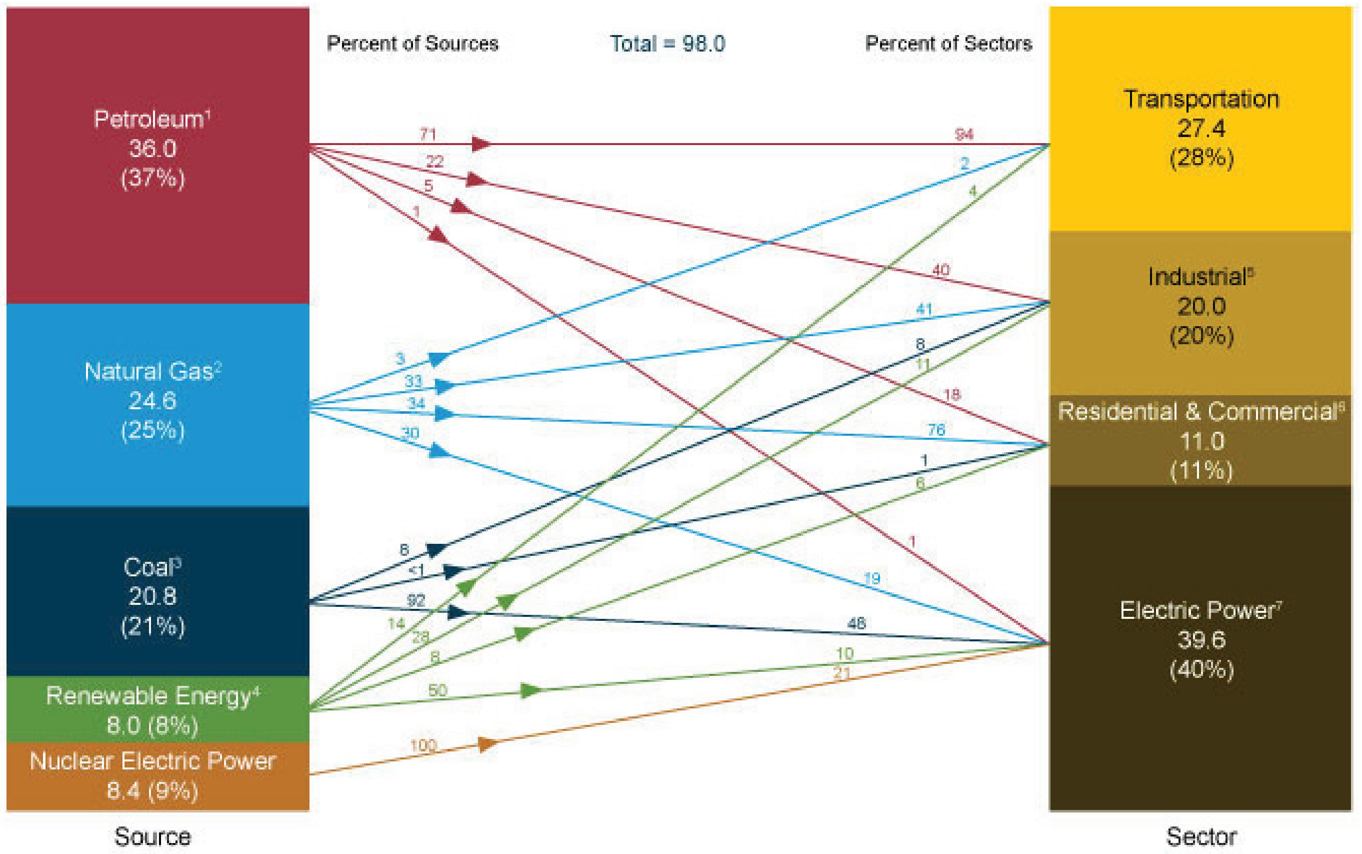
Energy consumption is broadly defined as the energy used per capita. It includes natural gas pumped to stoves, motor gasoline in cars, and electricity for appliances. Much of energy consumption is in the convenient form of electricity. Generation turns energy from fossil fuels into electricity, which is readily available for consumption. The electrical generation portfolio of the U.S. is still dominated by nonrenewable fuels, but renewable sources are making inroads. Nonrenewable fuels include: the fossil fuels coal, natural gas, and oil/petroleum fuels, as well as nuclear fuels.[8] Renewable fuels include: biomass, hydropower, geothermal, wind, and solar.[9] **Figure 5** illustrates the relationship between the total primary consumption of different fuels by sectors of the American economy, and the consumption of fuels for electrical generation. Electrical generation is of special concern because it comprises the majority of this breakdown.

Nonrenewable Fuels Are Embedded in Our History

The basin states have historically required fossil fuels in the proportions shown in **Figure 6**. This reliance has carried over to the modern day. A long history of these fuels has sometimes left brown smog over metropolises as its most blatant mark. Renewable sources were available in the past, much like today, but have faced implementation challenges. Hydroelectric power is an example. It has existed in the Colorado River Basin for many years, but cannot feasibly supply enough electricity on its own to meet the present and future demands of society. The demands of society, particularly in the West, have been for fast and cheap expansion. These demands mandated energy.

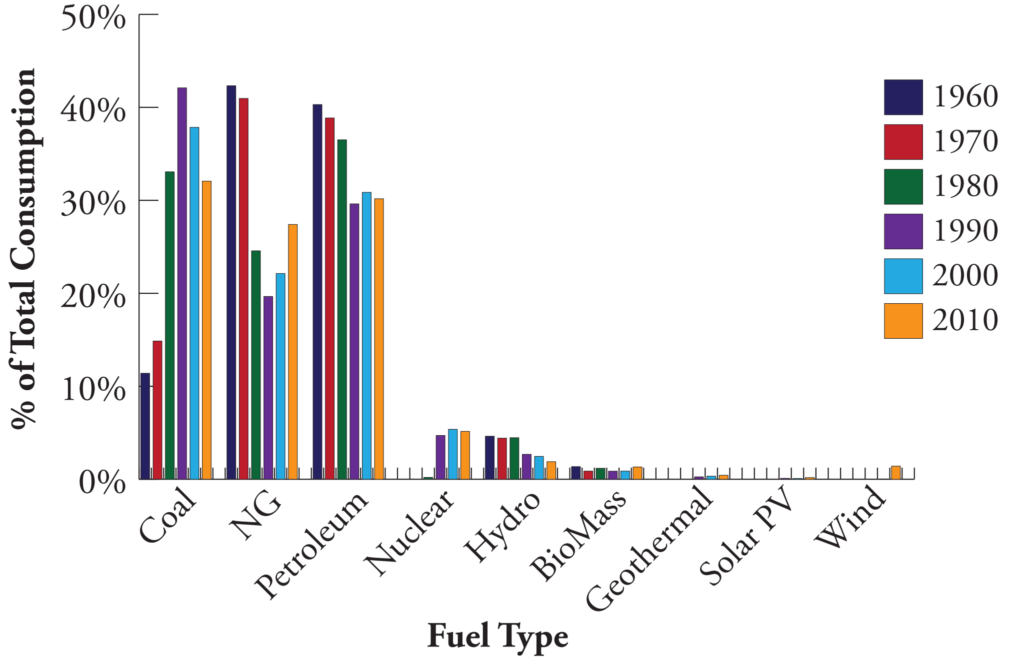
This development, expanding the bounds of society into the frontier of the Rocky Mountain West, was made possible with energy chiefly from utilities. The mission statement of 19th and 20th century utilities was "to deliver reliable, inexpensive electricity everywhere," a statement which could only be fulfilled by exploiting fossil fuels.[10] Fossil fuels have allowed life, as we know it, in the developed world. Now the crowding of the basin imposes limits on this traditional approach. The motto for 21st century utilities must be amended to include "at little or no cost to the environment." The path from the present to the desired future can be achieved multiple ways.

Figure 5: Primary Energy Consumption by Sector and Source



Source: U.S. Energy Information Administration, Total Energy, accessed July 31, 2012, http://www.eia.gov/totalenergy/data/annual/pecss_diagram.cfm.

Figure 6: Historical Primary Consumption in Study Area



Source: United States Energy Information Administration, *State Energy Consumption Estimates: 1960 through 2010*, accessed July 15, 2012, http://www.eia.gov/state/seds/sep_use/notes/use_print2010.pdf. AZ (p. 54-55); CO (p. 84-85); NV (p. 344-345); NM (p. 314-315); UT (p. 474-475); WY (p. 534-535), U.S. (p. 22-23).

The Prevalence of Nonrenewable Fuels Today

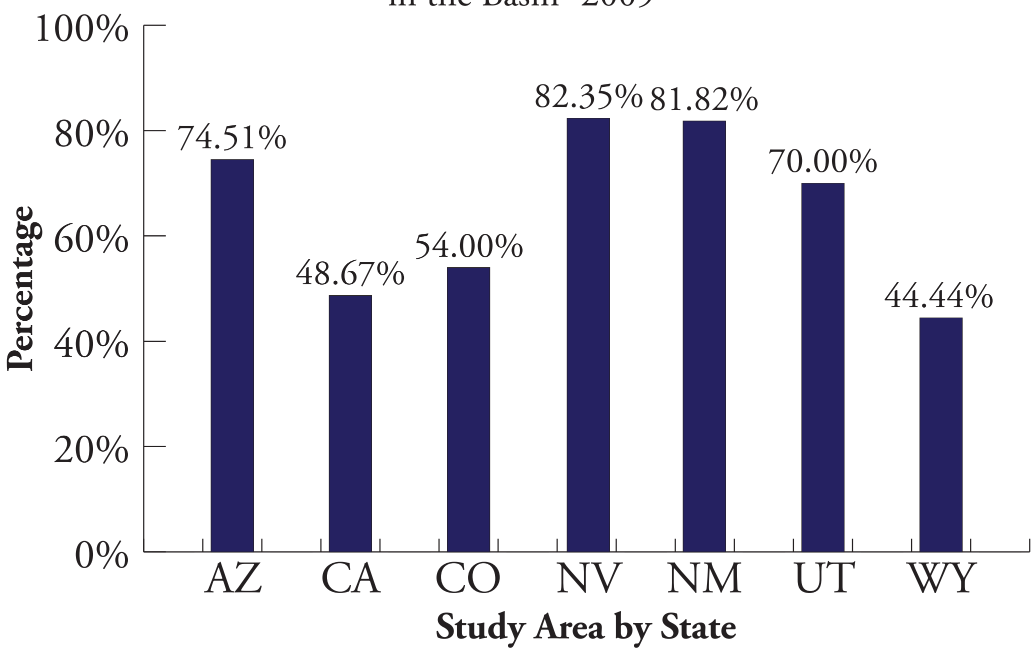
The values that shape our present situation will continue to contribute to the future of energy. Economic activity and the related need for energy sources are the driving factors behind energy portfolios around the globe. These factors make nonrenewable fuels an increasingly large part of the answer to utilities' mission statements. The immediate monetary advantages of nonrenewable fuels have not been overcome by concern about environmental issues. Renewable fuels have grown in prominence in past decades, but their role still remains minute because they are more expensive and receive fewer subsidies. **Figure 7** illustrates the ratio of power plants using nonrenewable fuels within the study area. See **Figure 8** for a more detailed breakdown of the major plants recognized within the basin and its adjacent areas by an EPA survey. The percentage of coal plants in this figure does not explain their popularity. **Figure 9** elaborates on the discrepancy between the percentage of plants from each fuel type and the amount of power provided by each. This is a measure of great importance. Coal is relatively more important than natural gas though there are four to five times more natural gas plants in the basin.

The External Costs of Cheap Energy

The current electricity generation portfolio of the basin, heavily reliant on nonrenewable fuels as seen in **Figure 7**, is unsustainable. Running out of coal, gas, and oil may be far in the future, but their use is unsustainable for other reasons. The emissions associated with these fuels are dangerous to life, and the quantity of water used by them is needed elsewhere. In this sense not all fuels are equal. Each fuel used today has characteristic advantages and disadvantages. The relationship between water, pollution, and energy for coal and natural gas is different from wind and solar as seen in **Figure 10**. From these statistics it is obvious that no fuel is perfect, but some are superior to others. As the costs of pollution and water use aggregate, the water-pollution-energy portfolio of our fuel sources will become more important. To tackle these issues requires comprehensive strategies; pollution and water use are associated by nature.

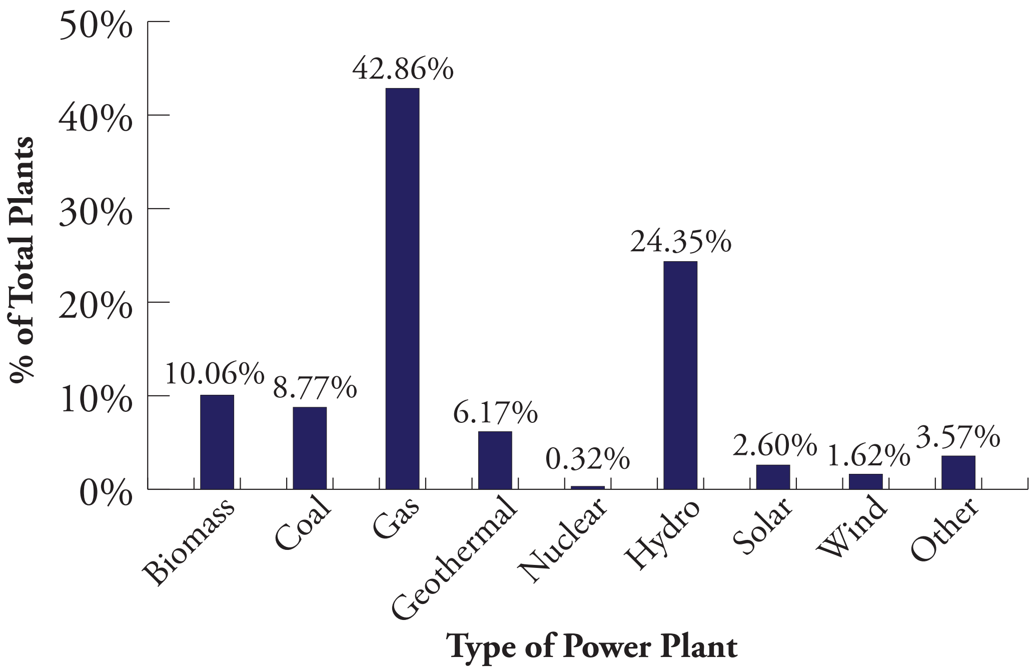
The control of pollution is important for reasons both obvious and obscure. Nitrous Dioxide (NO2) belongs to a family of chemicals called Nitrous Oxides (NOx) and is regulated by the EPA. Once emitted into the atmosphere, NO2 reacts to form Ozone (O3) and acid rain. Ozone is important in the stratosphere (upper atmosphere) because it blocks harmful radiation from

Figure 7: Percent of Power Plants Using Nonrenewables in the Basin- 2009



Source: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files*. eGRID plant year 2009 data (4/27/12). 2012.

Figure 8: Percent of Major Plants by Type in the Basin - 2009



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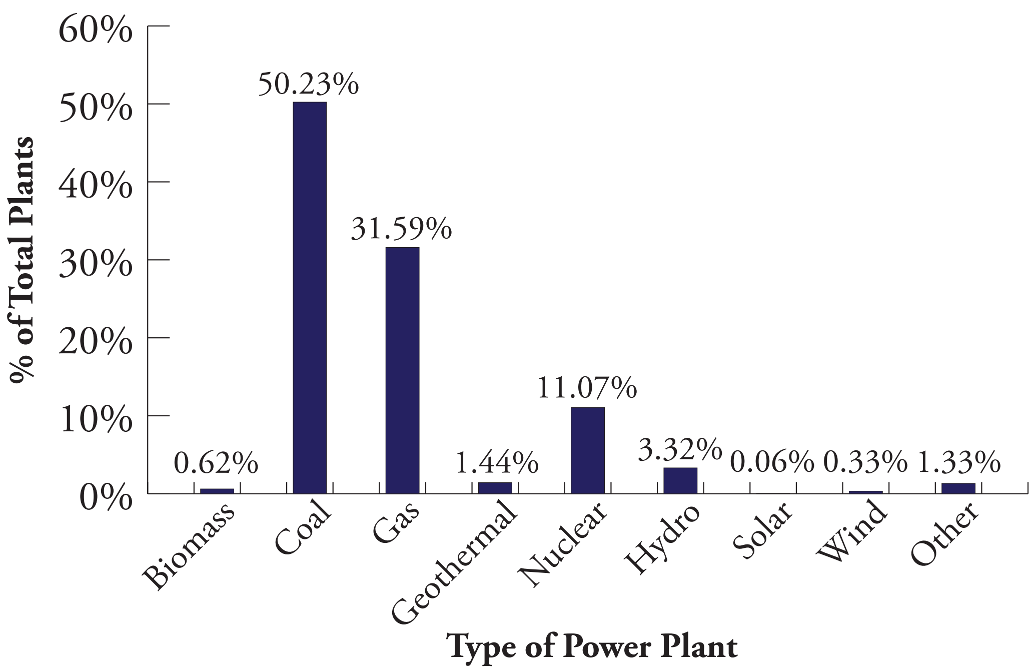
reaching Earth. When emitted in excess by human activities, this harmful chemical spends time in the troposphere (lower atmosphere) where it may be inhaled and cause health problems. Ozone is also a major component of "smog," which is visually unappealing.[11] Sulfur Dioxide (SO2) is also a respiratory irritant present in fossil fuel emissions. In as little as five minutes of exposure it can lead to bronchoconstriction (constriction of the lungs' airways) and asthma attacks. In the atmosphere, SO2 can react to form particulate matter (PM), which may become lodged in the respiratory system and cause adverse effects to health, such as heart attacks and decreased lung function.[12] These emissions are also harmful to ecosystems.

Ecosystems are affected in subtle ways by our energy use. The effects of SO2, NOx, and their subsequent interactions with the environment manifest as acid rain and then alterations in soil composition. Higher levels of SO2 harm plants and trees and reduce crop productivity.[13] Increased levels of NOx can cause harm and/or death to plants, and lower the pH of the soil. These changes result in increased damages to agricultural production.[14] NOx can lower the pH (acidification) of soil beyond the range that ecosystems can tolerate; a low pH increases the solubility of toxic elements and decreases the solubility of essential nutrients.[15] Damage to the entire biological system is probable as a consequence of delicate changes like this. The effects of pollution on humans are easily quantifiable.

It is obvious to most that emissions from fossil fuels have an adverse effect on human health. The Clean Air Task Force, a non-profit public health and environmental advocacy group, estimates 24,000 deaths in the United States are attributable to power plant pollution each year. Each death represents a life cut short by an average of 14 years.[16] A study from Wharton and Stanford suggests that Americans value a year of life at approximately $129,090.[17] This number considers average medical expenses paid for a healthy quality year of life for the ill. Combining these numbers (24,000 deaths * 14 years/ death * $129,090 / year), Americans theoretically value reducing emissions from electrical generation at over $43 billion dollars. That statistic only considers how much we value human life. This is one example of the "external" costs of traditional energy production, demonstrating that society is far more impacted than what market prices depict and most of us suspect. The problem with our current energy situation has been so far easy to define. The solution to this problem will almost certainly prove difficult to discover and implement.

Figure 9: Percent of MWh Generated by Plant Type in the Basin - 2009



Source: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files*. eGRID plant year 2009 data (4/27/12). 2012.

Figure 10: The Pollution-Water Intensity of Fuel Sources

Source	Cooling System	Gallons of Water/ MWh[1]	CO2 (lbs)/MWh[2]	NOx/MWh[2]	SO2 (lbs)/MWh[2]
Solar CSP	Cooling Tower	865	(uk)	(uk)	(uk)
	Dry	52	(uk)	(uk)	(uk)
	No Cooling Required	5	(uk)	(uk)	(uk)
Coal	Cooling Tower	687	2000	4.1	12
	Pond	545	2000	4.1	12
	Once-Through	250	2000	4.1	12
Natural Gas	Cooling Tower	198	1000	2.3	0.045
	Pond	240	1000	2.3	0.045
	Once-Through	100	1000	2.3	0.045
	Dry	2	1000	2.3	0.045
Solar PV*	No Cooling Required	0-26	44.09-396.83	0.0882- 0.3968	0.1102- 0.9921
Wind	No Cooling Required	0	(n/a)	(n/a)	(n/a)

Notes: *Solar PV projections include life-cycle analysis of panel creation.
(n/a) = negligible.
(uk) = unknown.
Sources: [1]HeadWaters, *Water Consumed to Generate Electricity*, Winter 2012, p. 15.
[2]National Research Council of the National Academies, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use, Washington, D.C.*, National Academies Press, 2010, pp. 97, 99, 121, 123, 143, 151.

Power Plant Cooling Systems and Water Use[18]

Water is necessary for the operation of thermoelectric power plants. Around 90% of current U.S. power plants are thermoelectric and thus require water. To create electricity, a fuel is combusted and the heat from this is added to water to produce steam. The steam rises through a turbine, causing it to turn and generate electricity through a series of magnetic and conductive materials. This steam must be converted back to water so that the power plant can continue to utilize it.
In order to turn the steam back into water, it is brought into contact with a cool water source. The cool water source heats up while it turns steam back into water; thus the cooling water source is now hot enough for some of it to be lost through evaporation. This is the main source of water consumption in these plants. This evaporated cooling water exits through a cooling tower, constituting the plume exiting the plant that looks like pollution but is, in fact, only water. There are three main types of cooling systems, listed here in order of descending popularity:

•**Once-Through Cooling:** This system requires a large nearby water source, and is most prevalent in the eastern U.S. Water from this source is circulated through the pipes to condense steam back into water, and then exits back into the water source at a higher temperature. Because of the close relation of these plants to large bodies of water, they tend to be the most environmentally disruptive. This system has the most adverse effects on the body of water it utilizes (thermal pollution, getting organisms caught in intake screens, etc.). Thermal pollution adds heat to a body of water. Warm water holds less dissolved oxygen than cold water. This alteration in the basic chemistry of the aquatic ecosystem affects what microscopic organisms (such as types of algae) occupy the lowest trophic system (the basis of the food chain). Some trout eggs do not hatch in warm waters, and some fish do not even spawn in warm waters.[19]

•**Closed-Loop Cooling:** These systems are more prevalent in the western U.S. Similar to a once-through system, water is used to absorb heat from steam and condense it back into water. This cooling water is not discharged like a once-through system, but exposed to ambient air to bring it back to a desirable temperature. Some of this cooling water evaporates and must be replaced. This system consumes the most water.

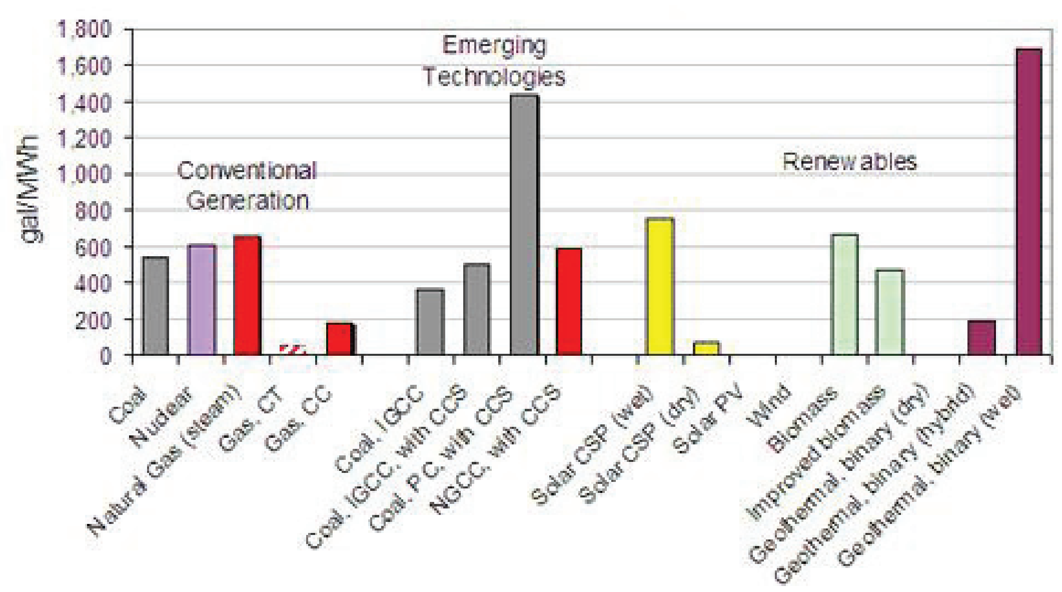
•**Dry Cooling:** These systems use air to cool the steam exiting from a turbine. Their efficiency is related to air temperature, making them less desirable; power demands peak in the summer when the air is warmest and dry cooling is least effective. This system is the least efficient and most variable in places like the arid west.

Suggested Methods for Solving the Problem

The problem with our situation is that the infrastructure of modern society in the U.S. requires large amounts of energy, most often produced through nonrenewable sources. This energy is provided in the form of electricity from power plants. These much needed plants will not be easily replaced. Efficiency measures for pre-existing plants are utilized as a quick fix to reduce human impacts. A recent push to limit impacts from power plants is due to the danger of pollutants and the ensuing governmental regulations to limit their emission. These regulations require implementation of efficiency measures. An example of these efficiency measures is emission capture. Emission capture technology mitigates the environmental effects of traditional electrical generation. This technology may also be referred to as emission sequestration. This solution introduces one problem by solving another.

Emerging sequestration technologies focus on inhibiting emissions. However, there is a trade-off; Carbon Capture and Sequestration (CCS) plants use more water than conventional plants. It is estimated that CCS decreases carbon emissions by 99% per unit of electricity, yet increases water consumption by 35-100% per unit of electricity. CCS is an expensive retrofit that requires incentives to install. Incentives exist in limited quantity outside of governmental regulations; i.e., using sequestered carbon to more efficiently recover oil from older wells and thus see a return on investment.[25] Incentives are necessary because the retrofits are expensive. A rough estimate for installing CCS equipment would be around $500 million per plant; it must also be noted that CCS reduces the efficiency of the plant thus requiring additional fuel purchases and an enlargement of combustion facilities to offer the same net generation.[26] Other options exist to reduce our net emissions.

Figure 11: Water Intensity by Fuel Source



Source: Western Resource Advocates, Water Use for Energy, accessed July 12, 2012, http://www.westernresourceadvocates.org/water/waterenergy.php.

A number of large-scale options are available to limit emissions from electrical generation. Installing nuclear power is one option. Nuclear plants emit between 3.5 and 12 pounds of CO_2 per Megawatt-hour (MWh),[27] a reduction of over 99.5% from coal plants. Investing in nuclear power and retrofitting fossil fuel plants with CCS do not require dismantling the current systems in place for generation. Installing renewable power and upgrading the country's energy efficiency (a cheaper and cleaner option)[28] breaks the trend from relying on large nonrenewable energy sources. Energy efficiency is cheaper because consumers can directly assume some of the costs of new appliances. Water can also be saved by some of these options.

Our traditional forms of generation are highly water consumptive. In contrast, the least water consumptive forms of generation are those of emerging technologies, such as wind and solar photovoltaic technologies. Greater efficiency in our use of electricity also saves water by lessening the amounts of electricity and the water they need. (See the following section on renewables for greater coverage of the implementation of emerging energy technologies in the Colorado River Basin).

Major Basin Power Plants and Water Use

To illustrate water consumption by power plants, consider the water use portfolio of four of the basin's major plants. Arizona's Navajo Generating Station (26,274 acre-feet/year), New Mexico's Four Corners (24,826 acre-feet/year) and San Juan plants (19,977 acre-feet/year), and Wyoming's Jim Bridger plant (25,333 acre-feet/year), aggregate over 94,000 consumed acre feet a year.[20] Assuming the average U.S. household consumes 127,400 gallons annually, or .391 acre feet, these four power plants consume water that could provide for over 246,570 homes for one year.[21] These four power plants generate over 58 million MWh annually.[22] An average home consumes 11.496 MWh of electricity annually,[23] so these plants provide well over five million homes with electricity. They consume a substantial amount of water relative to residential needs, yet supply about 1/6th of the basin's over 30 million dependents with power. Combined they emit (assuming the average two tons of CO_2/MWh per coal plant) over 116 million tons of CO_2 annually, an amount equal to the average annual emissions of 20,634,005 passenger vehicles, or the sequestration of carbon from 2,698,292,954 tree seedlings grown for ten years.[24] Yet a population the size of Colorado's relies on them for power. It is this reliance that makes the situation precarious and difficult to amend.

Saving Water Is Not Simple

The relationship of water intensity for various types of electrical generation can be seen in **Figure 11**. This figure is a simplification of the solutions; it seems obvious which technologies are ideal. Economics drive decisions in reality. A wet solar CSP plant may exist in a desert because a dry solar CSP plant overheats in that climate. When the dry plant overheats, it is less efficient, and the investors receive less money. Water laws can change this; a heavier tax on water could make the less efficient, dry CSP plant the more economical option. Conundrums like this one illustrate the unique obstacles that proponents of a water and pollution friendly future face.

Impediments to a Green Future

The solar and wind potential in the U.S. could easily supply our electricity needs.[29] Then why have we not yet begun the transition from traditional sources of electrical generation? One issue facing renewables is unreliable base prices. When oil experiences a price spike, renewables get investments. Then oil sees a dip, and it is no longer economically feasible to invest in renewables. The U.S. government lowers the price of fossil fuels that consumers pay with various forms of subsidies (totaling $15 billion in 2010[30]), rendering the public unaware of their true cost. The percentage of money that the Department of Energy commits to research and development for each source matches these subsidies; in the last ten years 17% of DOE's research and development funds were allocated to all renewables, while over 25% was allocated to fossil sources and over 25% was allocated to nuclear energy.[31] There are also physical obstacles to a green future.

Renewable fuels face an issue with transmission. Areas with high solar and wind potential are often not proximate to our cities. Electricity generated in remote areas may need to be moved vast distances through regions without transmission corridors. Projects to install transmission lines face numerous natural and legal obstacles; from private land to mountaintops, it is costly and time-consuming to conquer nature and nimbyism (best described as a "not in my backyard" attitude).[32] The basin is an ideal place to tackle these challenges. All of the basin states have high potential for wind and solar energy. Wyoming has enough wind potential to meet the state's electricity needs 116 times over,[33] yet 93% of the state's electricity (nearly 43,000,000 MWh) comes from fossil fuels.[34] Coal has been the long time winner in the nonrenewable versus renewable debate. This is starting to change in favor of a new fossil fuel.

Natural gas generation has increased recently, largely due to declining production costs emanating from new efficient technologies. These include advancements in hydraulic fracturing and directional drilling that suggest a cheap future for gas. Natural gas plants emit half as much CO2 and consume less than half the water per unit of electricity than coal plants with a comparable cooling system, as seen in **Figure 10**. Natural gas still emits significantly more pollution and uses more water than wind and solar photovoltaic. Natural gas is not the resource of the future, but one to supplement dirtier coal plants while legislation and investments allow renewables to come online. The supplementation of natural gas for coal may very well turn into natural gas market dominance. The key to avoiding a natural gas monopoly is to remember that its supply in the U.S. is estimated at 92 years,[35] it still emits 1,000 pounds of CO2 per MWh, and its extraction from the earth raises a number of issues related to the protection of groundwater. The future demands more energy and we are at a critical tipping point as to how this energy is provided.

Future Expectations: Energy-Water Needs of Increasing Populations

The basin offers unique landscapes, abundant recreational opportunities, and the remainders of the pioneer frontier. The population is expected to double in the study area by 2060 as previously implied in **Figure 12** of the Overview. Each member of the new population will require some amount of electricity. This is an influx that our current electric generation infrastructure cannot manage.

Hidden Costs of Water in Daily Energy Use

The 11.496 MWh of electricity used annually by a household represents nearly 31.5 kWh per day. This is the energy the average home uses to watch television, heat water, charge phones, and other such things. In Colorado, one kWh of electricity takes about .46 gallons of water to produce.[36, 37] This essentially means that the average Colorado household consumes about 14.5 gallons of water daily just to power itself. In the United States, an average person consumes over 158 gallons of water a day. In most developing countries, a family uses 5.3 gallons of water per day.[38] Embedded in the electricity that one household in Colorado uses daily is the water a family in the developing world needs overall in a day. The food we consume throughout the day accounts for a surprising amount of water as well; the average American has a diet that directly and indirectly involves about 4,500 gallons daily (the production of one pound of beef requires approximately 1,799 gallons of water[39]).[40] Understanding these numbers is essential to making direct and easy changes to lifestyles.

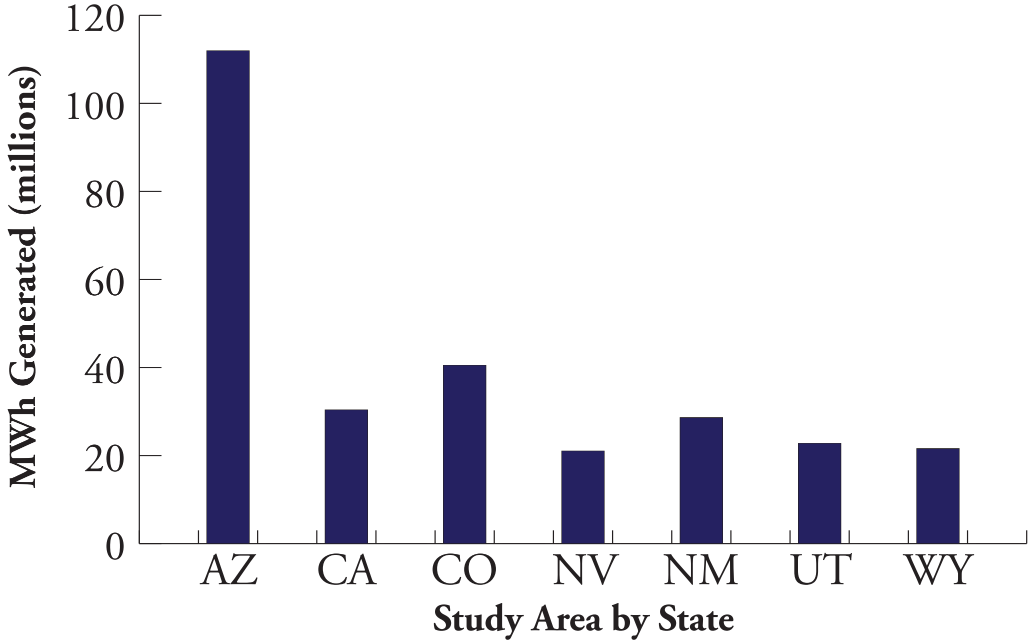
Electricity Needs

More electrical generating capacity will be needed in order to support needs of a growing population. The future will consume more electricity than the amount we now generate as shown in **Figure 12.** The EIA has projected a 30% increase in electricity consumption for the United States by 2035.[41] The manner in which we meet this blossoming demand is consequential to the basin. Air quality and water availability hinge on the nature of new electrical generators.

Water Needs

The water required by future populations will not be easily met by the Colorado River (see Municipal and Industrial Water Use section of this *Report Card*). Some of this water can be obtained from our electrical generation sector. Extending the use of our current electrical generation portfolio to a more demanding future gives the expected unsustainable result. The amount of water that is consumed by electrical

Figure 12: Total MWh Generated in the Basin- 2009



Source: United States Environmental Protection Agency. eGrid Survey. Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files. eGRID plant year 2009 data (4/27/12). 2012.

generation within the study area currently exceeds 300,000 af annually. This amount is equivalent to the water needs of over 767,263 homes for a year (at .391 af per home per year).[42] In the 2011 census, there was an average of 2.59 people per home.[43] This means that the 767,263 homes represent almost 1.98 million people. The water that currently is used for electrical generation could supply approximately 6.6% of the basin's dependents. This deficit will increase drastically in the future if society continues to obtain electricity from a similar ratio of fuel sources.

In fact, the amount of water consumed for electrical generation in the basin will be over 335,000 af within two years. The water now used annually for generation in the study area will be almost 25% of our water deficit in 15 years. The amount of water used for electrical generation will accelerate to match population growth. It is estimated that the water needed for electrical generation in the study area will increase to over 452,000 af by 2035 and over 531,000 af by 2060.[44] The total deficit for the study area is predicted to be 2,405,640 af in 2060. The amount of water we are projected to use for energy will be over 22% of the deficit at that time. This could supply almost 1.36 million households (or 3.5 million people) with water.[45] **Figure 13** displays these numbers.

The projected increase in water needed for electrical generation will not be easily met in the future with a growing Study Area deficit. It is important for society to select fuels for electrical generation that are not water-intensive to achieve a sustainable, water friendly future. We may come to use only what we need and will be able to support the future with a high standard of living through this transition. Utilities are an interface between society and resources that can provide incentives to their customers, as Denver Water's motto displays in **Figure 14**.

Figure 14: Denver Water's Motto

Source: Denver Water, Campaign Overview, accessed July 13, 2012, http://denverwater.org/Conservation/UseOnlyWhatYouNeed/CampaignOverview/.

Figure 13: Projected Water Deficits and Use for Energy

Year	Projected Deficit (af)[1]	Projected Water Use for Energy (af)[2]	% of Deficit Used for Energy	Households this Energy Water Could Supply	People (at 2.59 people/household)[3]
2015	339,420	335,000	98.7%	856,777	2,219,054
2035	1,603,400	452,000	28.2%	1,156,010	2,994,066
2060	2,405,640	531,000	22.1%	1,358,056	3,517,366

[1] Doug Kenney, "CR Basin Historical and Future Depletion."
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Incentivizing a Green Future

Municipal utilities can only provide a portion of the needed push to a green future. Other interests are pushing for this future as well. The basin states have implemented Renewable Portfolio Standards (RPS) to ensure that the growing populations of the future are not left with clouds of haze and water-stressed ecosystems, but rather impressive wind turbines and water aplenty. The Renewable Portfolio Standards of the basin states are seen in **Figure 15**. They should reduce carbon emissions and water consumption once in effect. For example, Colorado's wind energy sector saves around 2.18 billion gallons, or 6,690 af of water a year[46] that would be consumed if the same power came from fossil fuels. The state's wind power only accounts for about 6% of its current generation portfolio.[47] A full 25% of the deficit expected in 2025 could be provided if the basin's entire generation portfolio was renewable. These good intentions will require hard work.

Figure 15: Percent of Electricity from Renewables in 2009 and RPS Goals by State

State	% of Generation from Renewables-2009	Target % of sales	Year
AZ	6%	15%	2025
CA	26%	33%	2020
CO	10%	30%	2020
NV	11%	25%	2025
NM	5%	10% to 20%	2020
UT	3%	20%	2025
WY	7%	n/a	n/a

Sources: Center for Climate and Energy Solutions, *State RPS Details*, accessed July 7, 2012, http://www.c2es.org/docUploads/state-rps-aeps-details.pdf. United States Environmental Protection Agency. eGrid Survey. Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files. eGRID plant year 2009 data (4/27/12). 2012.

From **Figure 15** it is obvious that most states are not yet close to their RPS goals. Colorado must gain 20%, Arizona 9%, California 7%, New Mexico 15%, Nevada 14%, and Utah 17%. Many billions of gallons of water will be saved annually when these states begin generating this much power with renewables. The economic incentives to encourage this transition are slow in coming, though public opinion regarding a transition to a renewable energy economy is growing. According to the Colorado College State of the Rockies Project 2012 *Conservation in the West Poll*, western citizens already support the implementation of renewable energy over fossil fuel energy.[48]

Conclusion

As we move into a future of rising water demand and projected dwindling water supply in the Colorado River Basin, the electricity generated from nonrenewables must be weighed against their environmental effects and the cost of lowering their emissions to government mandated levels. This section ends with an example of what is afoot to modify existing energy facilities even as renewables gradually take on a larger role. Xcel Energy recently unveiled a third unit at its Front Range Comanche Station in Pueblo, CO, a coal-fired generating unit. With the addition of this third unit and conservation measures for the rest of the plant, Comanche will actually emit less pollution than it previously did. "The entire plant's mercury emissions are lower than they were prior to the addition of Comanche 3," says Xcel. Pollution isn't the only thing the plant is cutting back on; "The plant's new Unit 3 has a low-water use system (air cooled condenser) that provides additional cooling capability, reducing water use on the unit by half," says Xcel.[49] The utility claims that such "new plants are needed to meet future demand."[50] However, fossil fuel plants are getting more expensive to run as they must meet stricter EPA air regulations. Some public opposition claims the money would have been better spent on renewables; one environmental organization source claims, "Several local residents have criticized Xcel for investing in the $1.3 billion dirty coal plant and for not promoting cleaner, renewable energy sources, such as solar, effectively."[51] Due to Colorado's strict legislation regarding plant emissions, and the subsequent burdensome cost of retrofitting the plant to meet emission requirements and use less water, Xcel Energy may never build another coal plant. But economic conditions, mainly the growing demand for electricity on Colorado's Front Range, necessitated the building of Comanche 3. The Xcel chief executive claimed, "We (are building) Comanche 3 because we need the power. Even today, it is still the best thing we could have done for both the customers and the environment."[52] It may be the best thing at the moment, but as restrictions on emissions become more stringent and renewables become cheaper, it is likely that a coal plant will no longer be the best option for electrical generation. To paraphrase a panelist at the 2012 Clyde Martz Summer Conference: *A Low-Carbon Energy Blueprint for the American West* in Boulder, CO, "renewables have already won the fight, now it is just a matter of the speed of implementation."[53]

Will Stauffer-Norris

Bald eagle on Lake Powell and the Navajo Generating Station.

Case Study: Navajo Generating Station vs. Mohave Generating Station

Introduction

Fossil fuel power plants impact water sources: direct consumption is necessary for cooling and steam production, while air pollution contributes to acid rain and thus affects water sources.[54] This pollution alters basic ecosystem processes, affecting the organisms that rely on stable habitats, and on a human level, it can affect those residents who live in the ecosystems. The Navajo Generating Station (NGS), seen in **Figure CS1**, began full operation in 1976 in Page, Arizona, near the Grand Canyon and the Navajo Nation. A year later the Grand Canyon qualified for Class 1 Federal Air Quality Protection under the Environmental Protection Agency (EPA), and in 1990 the Clean Air Act was amended, allowing the Navajo Nation to create the Navajo Nation EPA (NNEPA) to control air quality.[55, 56] The plant was built to power the Central Arizona Project (CAP), as well as other interests for a reasonable cost; this lead to its reputation as one of the dirtiest coal-fired plants in the nation. Now, 42 years after the Clean Air Act and 35 years after Class 1 Federal Protection for the Grand Canyon, the NGS faces strict U.S. EPA and NNEPA regulations that are forcing it to invest in cleaner emissions regulations, or shut down. This is exactly the choice that faced the Mohave Generating Station, as seen in **Figure CS2**, once located nearby in Laughlin, Nevada. Under pressure to clean up the plant or close down, the owners opted to close down the plant in 2005, indicating that it was too expensive to retrofit (it would have cost nearly $1 billion to meet requirements).[57]

Figure CS1: The Navajo Generating Station

Source: Merchant Circle, *City Gallery*, accessed July 6, 2012, http://www.merchantcircle.com/directory/AZ-Page/cityphotos/4.

A closer examination of two of the nation's dirtiest coal plants helps to predict the future of electric generation in the basin; will "dirty" power continue to be "cheap?" Will social and environmental concerns lead to the demise of more fossil fuel powered generating stations?

In 2005, the NGS was declared the fifth dirtiest coal-fired plant in the U.S.[58] The installation of SO2 scrubbers in 1991 helped to mitigate emissions from the plant and more recently, the installation of low-NOx burners in 2009-2011 has reduced the NGS' emissions further.[59] The water footprint of the NGS is approximately twice as large as the closed Mohave; it consumes approximately 24,500 acre-feet of Lake Powell water annually (whereas the Mohave consumed 13,000 af annually[60]), but reviews to alter the water intake to increase its efficiency are underway.[61] The Navajo Nation currently trucks in 40% of its water from an array of other basins.[62] The water that the NGS consumes could supply twice-over the Nation's annual consumption of 12,000 acre-feet.[63] From a public health perspective, it is estimated that the 2,250-megawatt NGS contributes to 16 deaths, 25 heart attacks, and 300 asthma attacks annually.[64] The 1,580 megawatt Mohave Plant, which was forced to close down because of its emission rates, had similar emission rates to the Navajo, as seen in **Figure CS3**.

Figure CS2: The Mohave Generating Station

Source: Merchant Circle, *City Gallery*, accessed July 6, 2012, http://www.merchantcircle.com/directory/AZ-Page/cityphotos/4.

Figure CS3: Pollution and Water Intensity of the Mohave and the Navajo Stations

Criteria	Mohave	Navajo
MWh annual	10,000,000	16,140,683
CO_2 tons/1000MWh	986	1,178
NO_x tons/1000MWh	1.92	1.89
SO_2 tons/1000MWh	3.91	0.28
Acre Feet/1000MWh	1.30*	1.52

Note: * Estimated by comparing the capacities ((Mohave capacity/Navajo capacity) x Navajo water consumption).

Sources: United States Environmental Protection Agency. eGrid Survey. *Year 2009 eGRID2012 Boiler, Generator, Plant, State, PCA, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%)* Data Files. eGRID plant year 2009 data (4/27/12). 2012. Las Vegas Review-Journal, *Laughlin Coal Fired Power Plant Going Away*, accessed August 8, 2012, http://www.lvrj.com/business/47761602.html. Center for Energy Efficiency and Renewable Technologies, *Clearing California's Coal Shadow from the American West*, accessed July 19, 2012, http://www.ceert.org/PDFs/reports/Coalreport.pdf.

The Navajo Generating Station Situation

The Navajo Generating Station is unique for many reasons. Controversial in its proximity to the Grand Canyon and Navajo Tribal Lands, it is nonetheless crucial for the Central Arizona Project and thus the ability for Arizona to use its full apportionment of the Colorado River Compact.[65] The employment of Navajo and Hopi tribal members at the Kayenta and Navajo Mines, which provide the plant with coal,[66] places the NGS in an additionally delicate situation. In 2007, the NGS began planning to meet the EPA's Best Available Retrofit Technology (BART) requirements.[67] BART requires plants to meet emission requirements with retrofits. To meet BART, the NGS has three options: 1) operate at a major financial deficit to meet the passage of the strictest (and most expensive) of EPA emission requirements; 2) to retrofit with fiscally feasible technologies that meet but do not surpass EPA minimum standards; 3) or to close down.[68] This is the choice which the Mohave Plant faced seven years ago, with the owners choosing option three. To analyze all options, the NGS hired EN3Professionals to plan the phasing-in of environmental controls to keep the plant open while considering all stakeholder interests.[69]

The choice preferred by NGS authorities is to retrofit with fiscally feasible technologies.[70] The Central Arizona Project, which receives most of its 2.8 million MWh energy requirement from the NGS, would see a 20% spike in energy prices with the passage of the strictest EPA requirements.[71] The major shareholders in the NGS are: 24% Bureau of Reclamation, 22% Arizona's Salt River Project utility, 21% L.A. Water and Power, and tribal and community groups.[72] In order to moderate the proceedings, the National Renewable Energy Laboratory (NREL) has begun research to quantify the technical and economic benefits of various scenarios of compliance and to analyze any alternatives.[73] Though by no means a final decision, an authority from the Salt River Project (SRP) (with 22% ownership in the NGS) has released a "strawman," or initial document meant to describe the desired evolution of the plant. Many groups have an interest in some aspect of the plant, whether it be employment, power, or income. No decision will make all groups happy, but it is important to consider all opinions when moving forwards. The SRP, political representatives from the Navajo Nation, EPA, and community representatives from the Navajo Nation each have a unique stance on the subject:

SRP Stance

The NGS is critical to the economies of Arizona and the Navajo and Hopi Tribes, and to the fulfillment of the CAP. The plant can be kept open by implementing emissions controls voluntarily in exchange for flexibility with future requirements, addressing community concerns, and considering a transition to renewable energy on the reservations. The SRP wishes to offset past pollution by investing in a Fish and Wildlife Conservation Program, and meeting standards for hazardous emissions. The SRP will analyze the cost of converting the NGS to a renewable unit. SRP has proposed to invest $6 million in a Community Benefit Fund for all communities within a 100-mile radius of the plant and the Kayenta mine. The SRP interests at the NGS support research of renewable options, aid to economic development on reservations, and support of public health research.[74]

NNEPA Stance

The Navajo Nation Environmental Protection Agency catalyzed the requirement of strict controls at the plant by issuing air control permits in 2009. These permits were subsequently challenged by the Peabody Coal Mine in 2010, and then upheld by the U.S. EPA in March of 2012. With the backing of a federal agency, the NNEPA is asking the NGS to undergo changes for the betterment of the Navajo Nation and to comply with a clean future.[75] The NNEPA is distinct from other Navajo Nation groups in that they have quantifiable U.S. government backing.

EPA Stance

The NGS has complied with Arizona emission guidelines. However, since the passing of the EPA's tribal authority rule, which declares that state guidelines do not carry over to plants on reservations, the EPA has had to create new guidelines for the NGS that are federally enforceable. The EPA finalized a Federal Implementation Plan in 2010 for the station to protect tribal air that will limit sulfur dioxides, total particulate matter, opacity, and dust. Though requirements may be stringent, they are necessary for the health of the surrounding area. Further requirements will be made in the future.[76]

Forgotten People Stance

The Forgotten People (FP) is a non-profit public charity with the goal of improving life and building communities for the Navajo People. The FP feel that the NGS is doing irreparable harm to their landscape, such as laying "coal dust over black mesa" and replacing "desecrated cemeteries" with coal mines. The FP will educate the NGS on its effect on Navajo communities. The Forgotten People have pulled out of the proceedings in deciding the future of the NGS because they see the continuation of NGS operations under stakeholder interests as stalling voluntary submission to EPA regulations. The opinion of the Forgotten People that they "cannot afford to be used to keep the NGS operating" is due to the fact that they see "water sources degraded and diminished like sacred Sagebrush Spring, people living without electricity and piped water, and impassable, ungraded dirt roads…."[77]

The Mohave Generating Station Situation

An example of a similar situation depicts the problem that the Navajo Nation faces with the continued operation of the NGS:

> "Because of EPA regulations, the Mohave Generating Station near Laughlin, Nevada, closed its operations. As this power plant was the sole buyer of coal from Black Mesa Mine, it had to close its operation on January 1, 2006. Closure of this mine has had very adverse economic impact not only on the 160 or so people laid-off from the mine, but also on the Navajo Nation coffers."[78]

The Mohave Generating Station emitted much more SO2 per MWh than the NGS currently emits. SO2 is a pollutant measured by the EPA and its high concentrations in the plant's emissions likely contributed heavily to the closure of Mohave. The NGS emits similar amounts of CO2 and NOx per MWh, and uses more water per MWh than the Mohave required. The Mohave was under contract to receive 19,000 acre feet of water annually, but its use never exceeded 13,000 acre feet.[79] The NGS uses nearly twice this much water at 24,500 acre feet of annual use. Water use is not currently a concern for power plant operators as it is not restricted by government. In the foreseeable future this may change, and if the NGS is still open, it will have to face another choice; shut down or reduce water use.

If the EPA enforces its most stringent requirements, thus forcing the plant to install more expensive technologies, the NGS plant could be forced to close. This would cause both the Hopi Tribe and Navajo Nation considerable economic harm and stall the CAP. Stalling of the CAP would shift the demand of the area to local water sources, which cannot supply the desired amount for long.[80] Workers from the Navajo Nation provide coal for the NGS and are employed at the plant. These workers directly and indirectly provide much of the energy for the Southwest at the NGS and FCPP (Four Corners Power Plant), but many Navajo homes lack sanitation and piped water.[81] Revenue from the NGS provides at least one-third of the Navajo Nation's government operating costs.[82] Tribal leaders know power plants will provide their people with jobs and combat rampant unemployment, but they also are coming to realize that power plants have serious health-related side effects.[83] Therefore, it is paradoxically in the best interest of the plant and the tribal revenues to avoid installing unaffordable top-of-the-line pollution control. This will keep the power plant open and provide the tribes with jobs, yet emissions of pollution will continue unless the power can be provided from renewable sources or stringent emission regulations are met.

Conclusion

The industries surrounding coal, from its producers to those that work to generate electricity, have entrenched the fuel source in American society as a way of life. This traditional fuel source for electric generation continues to be popular due to its low cost and high energy per volume. However, the growing costs of inputs and the externalities it places on public health are beginning to overshadow the traditional equation that has made coal the solution to the nation's energy needs. The growing recognition of the need for a new energy portfolio for the nation, and particularly the West, is not without controversy.

The communities and the owners associated with coal power plants have differing opinions of coal's future. Communities surrounding the two previously discussed plants see investments in cleaning up coal plants as investments that should have gone to renewables. Though the owners of the NGS support clean energy, it is not yet an economically sound investment. More government mandates are needed to make renewables more profitable than fossil fuels before coal is pushed to the background of any energy portfolio. The profits from the NGS support more than just the owners of the plant. Surrounding Native American communities rely on the plant for economic security, and far away interests rely on the plant for energy security. If EPA regulations force the NGS to close for financial reasons, the Nation will need jobs and the CAP will need power. The cost of transmission for the CAP is over $8 billion annually,[84] and the NGS is currently the only way to provide the energy. The CAP is a good incentive for the plant to stay open, but the emissions from the plant are an incentive for surrounding communities to ask for change.

There are different modes that can create this change. It is more reasonable to expect some modes than others. The SRP has declared their intention to begin implementing renewables at the station. Nonetheless, the coal-fired portion of the plant will be necessary into the foreseeable future, as renewable plants capable of producing as much energy do not yet exist in reality. The cost of cleaning up the NGS' emissions is high, and the former Mohave Plant portrays the possibility of closure. The owners of the NGS will want the plant to remain profitable, and the importance of the plant to the CAP all but necessitates its existence. Though meeting regulations is expensive, emissions controls will likely be installed as the most viable option to continue to provide the needed power. Situations like this are often unforeseeable, but the NGS teaches us valuable lessons.

It is best to not rely heavily on any one source of power. It would be easier for a natural gas plant to comply with the regulations because they emit far less pollutants. Renewable energy can cover some, but not all, of the burden. Retrofitting is a solution to a problem that was not predicted when the plant was built. Outside forces, in the form of the EPA and NNEPA, are working with internal interests, in the form of stakeholders, to achieve an optimum solution.

This solution will be a compromise between communities. Some communities directly rely on the power, and some rely on jobs the power provides. Through increasing government regulations the Navajo Nation and Hopi Tribe will achieve the clean air that anyone, anywhere, deserves. Their communities will be stronger and healthier when the pollutants are lessened. The stakeholders will continue to profit from the plant if they follow regulations. Someday renewables may be the answer to help them profit more. The only way to reach a satisfactory solution is to give all concerned an equal say, and to deeply consider the repercussions of any decision.

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