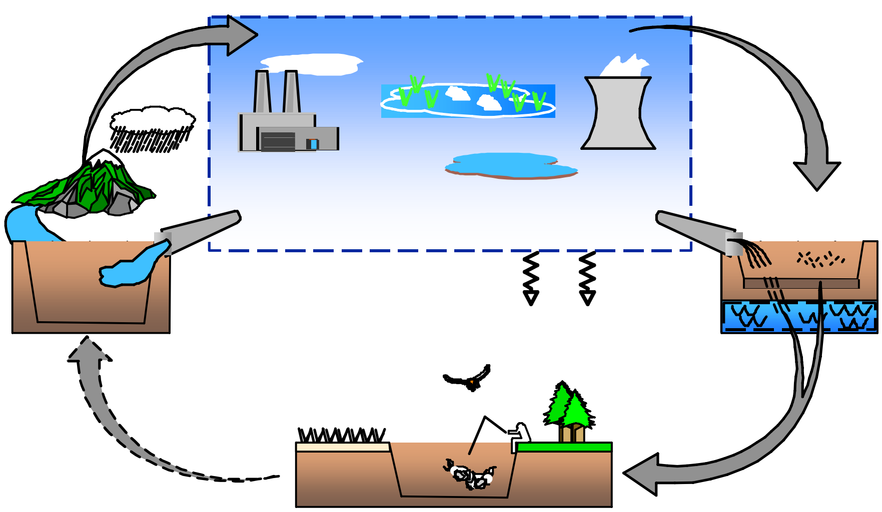
Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production - The Next Half Century

Technical Report



Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production—The Next Half Century

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Topical Report, March 2002

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REPORT SUMMARY

The fast growing demand for clean, fresh water—coupled with the need to protect and enhance the environment—has made many areas of the United States and the rest of the world vulnerable to water shortages for various human uses. As they interact with the electricity industry, these uses encompass agricultural irrigation, thermoelectric generation, municipal water/wastewater treatment and distribution, and industrial processes. The dependency of electricity supply and demand on water availability can impede societal and economic sustainability, adversely affect the future growth of electric demand, cause shortages in current electric supplies, and impact electric grid topology planning.

Background

Unlike gradually developing environmental concerns, such as climate change where long lead-times allow coping strategies to be developed from evolving scientific and technical innovations, water (and energy) shortages can occur relatively suddenly and cripple local and national economies. EPRI perceived a critical need to better understand and manage the interrelationship of water and energy, to improve environmentally sustainable economic development.

Objectives

- To identify major water-consuming power plant types.
- To determine typical water consumption per unit of generation for each plant type.
- To determine current generation and estimate future generation by power plant and cooling system type.
- To estimate future aggregate water consumption associated with thermoelectric generation.

Approach

The project team combined two decades of expertise in electricity, environmental, and water management efforts to develop a four-volume series of Water & Sustainability documents to meet the project objectives. This volume is *Water & Sustainability: U.S. Water Consumption for Power Production—The Next Half Century (Volume 3)*. The other volumes are *Water & Sustainability: Research Plan (Volume 1, EPRI report 1006784), Water & Sustainability: An Assessment of Water Demand, Supply, and Quality in the U.S.—The Next Half Century (Volume 2, report 1006785), and Water & Sustainability: U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century (Volume 4, report 1006787).*

Results

This screening study determined

- Closed-loop steam-based (Rankine) power cycles must condense large quantities of low-pressure steam back to water for return to the plant's heat source for re-boiling
- The relative fraction of freshwater consumption by power plants, compared with other uses in the economy, is shrinking.
- It is unclear whether total U.S. freshwater consumption by the power generation sector will increase or decrease over the next 20+ years, while generation itself will increase markedly. The trend will depend on the relative rate of decrease in unit (per MWh) cooling water consumption compared with the rate of increase in MWh produced. The latter depends on growth in electric demand. The former, unit freshwater consumption, depends on the future power plant mix and the types of cooling systems employed.
- It appears that the larger the shift from coal and nuclear to natural gas, the greater the decrease in water consumption for power generation (possibly as much as a 50% drop relative to the base case and a 35% drop relative to today's use).

EPRI Perspective

Given EPRI's Electricity Technology Roadmap projections of some 7000 GW of additional electric generation needs by the year 2050, it is imperative that any critical resource availability on which this projection rests be evaluated and addressed. This Water & Sustainability effort did find that water availability can constrain electricity generation siting and power production, both directly and indirectly. The actual impact depends on a number of interacting factors, such as water efficiency at individual plant sites along with growth in electric demand. The net effect of these factors can lead to increases or decreases in water consumption for power generation.

Keywords

Water management
Sustainability
Electricity generation
Electricity demand
Electric grid

EXECUTIVE SUMMARY

Closed-loop steam-based (Rankine) power cycles must condense large quantities of low-pressure steam back to water for return to the plant's heat source for re-boiling. The large quantities of heat that must be removed from the steam in the condensation process are typically transferred to cooling water, which in turn transfers this heat to the environment, primarily to the atmosphere through evaporation. Given that about 85% of U.S. electricity is produced via such closed-loop steam cycles, the quantities of cooling water "consumed" (evaporated to the atmosphere) during power production are substantial. Such water consumption—especially from freshwater sources—can be a significant component in overall assessments of water use and supply adequacy in the 21st century. Yet despite their importance, consistent estimates of water consumption as a function of actual generation by various thermal power plant types, and in various regions of the United States, have not heretofore been available (past estimates have concentrated on water body withdrawals). Table S-1 summarizes per-MWh water withdrawal and evaporation rates for the major water-consuming power plant types.

Fortunately—from the perspective of economic and resource planners—the relative fraction of freshwater consumption by power plants, compared with other uses in the economy, is shrinking. Trends in the power industry, especially the predominance of natural gas–fired combined-cycle plants for new capacity, are decreasing the quantity of water consumed per MWh generated. Combined-cycle plants derive 2/3 of their power from gas turbine (Brayton) cycles, which extract energy from hot, pressurized gases, not steam; just 1/3 of the total power output comes from a conventional steam cycle. Further, some of the new combined-cycle plants use air-cooled condensers for their steam cycles, creating plants that use virtually no cooling water.

As a result, it is unclear whether total U.S. freshwater consumption by the power generation sector will increase or decrease over the next 20+ years, while generation itself will increase markedly. The answer depends on the relative rate of decrease in *unit* (per MWh) cooling water consumption compared with the rate of increase in MWh produced. The latter depends on growth in electric demand. The former, unit freshwater consumption, depends on the future power plant mix and the types of cooling systems employed, which in turn depends on a number of economic and environmental factors, and will assuredly have strong regional variations.

To gauge the sensitivity of water consumption projections to such factors, this study employed scenarios, such as "coal predominates," "major shift to natural gas," and "restrictive fish protection regulations," based on plausible fuel price and regulatory possibilities. Results suggest that the larger the shift from coal and nuclear to natural gas, the greater the decrease in water consumption for power generation (possibly as much as a 50% drop relative to the base case, and a 35% drop relative to today's use). The greater the extent of environmental regulations requiring cooling towers in lieu of once-through cooling, the greater the increase in evaporative water consumption (possibly a 10% increase relative to the base case, and a 25% increase relative to today's use, albeit at reduced levels of water body withdrawals).

Table S–1
Cooling Water Withdrawal and Consumption (Evaporation to the Atmosphere) Rates for Common Thermal Power Plant and Cooling System Types

Plant and Cooling System Type	Water Withdrawal (gal/MWh)	Typical Water Consumption (gal/MWh)
Fossil/biomass/waste-fueled steam, once-through cooling	20,000 to 50,000	~300
Fossil/biomass/waste-fueled steam, pond cooling	300 to 600	300-480
Fossil/biomass/waste-fueled steam, cooling towers	500 to 600	~480
Nuclear steam, once-through cooling	25,000 to 60,000	~400
Nuclear steam, pond cooling	500 to 1100	400-720
Nuclear steam, cooling towers	800 to 1100	~720
Natural gas/oil combined-cycle, once-through cooling	7500 to 20,000	~100
Natural gas/oil combined-cycle, cooling towers	~230	~180
Natural gas/oil combined-cycle, dry cooling	~0	~0
Coal/petroleum residuum–fueled combined-cycle, cooling towers	~380*	~200

* includes gasification process water

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1 INTRODUCTION

EPRI's *Electricity Technology Roadmap* and other long-range technology and economic development studies foresee freshwater availability and management as perhaps *the* critical resource issue of the 21st century. Indeed, water is a fundamental ingredient in achieving virtually all human aspirations.

As EPRI and others plan and conduct research to boost the performance, cost-effectiveness, and environmental performance of technologies for power generation, transmission, and use, and as they seek to provide access to electricity for the some 2 billion people worldwide without power, water availability may emerge as a limiting factor.

Accordingly, EPRI's Strategic Science & Technology group is developing an initiative on the interrelationship of water and economic and environmental sustainability, first in the United States and then later in other countries. This report summarizes one of three screening studies conducted as preparatory material for that initiative—usage of freshwater by U.S. power plants today and in the future. The two companion screening studies summarized regional U.S. freshwater availability, quality, and anticipated demand, and the electricity required for U.S. freshwater supply and wastewater treatment, by economic sector.

The Prevalence of Steam-Based Power Systems

Closed-loop steam-based (Rankine) power cycles must condense large quantities of low-pressure steam back to water for return to the plant's heat source for re-boiling. Typically, this condensation step is accomplished via heat exchange with large quantities of cooling water. The warmed cooling water is either returned to a source water body from which it was removed or it is cooled itself for re-use via evaporative heat transfer in a cooling tower or pond. In either case, a portion of the cooling water is lost (consumed) via evaporation to the atmosphere. Given that about 85% of U.S. electricity is produced via such closed-loop steam cycles, the quantities of cooling water consumed during power production are substantial.

Steam-based power plants also consume freshwater for uses other than cooling, such as for making up "cycle water," transporting coal ash, and washing equipment. With the exception of water used for fuel processing in gasification combined-cycle plants, these other uses are much smaller than cooling water usage. Thus, this study's focus on cooling water usage (and gasifier fuel processing requirements)—and changes in that usage as old power plants are retired, new power plants are built, and new environmental regulations are met—is an accurate predictor of trends in freshwater consumption by the power industry.

2
ANALYSIS METHODS AND REGIONS

Because there are wide variations in freshwater availability, fuels for power generation, and environmental concerns around the United States, this study first developed a standard analysis procedure, and then applied it to 15 U.S. regions (defined by the U.S. Department of Energy to coincide with areas where utilities cooperate on electric transmission reliability). Regional results were summed to yield national totals (in most cases, actually just for the 48 conterminous states). Although this study accounted for both freshwater and saline water used for cooling, results are tabulated only for freshwater because of its greater economic and environmental versatility.

A “base case” and two alternative scenarios were employed to gauge sensitivity of water consumption projections to uncertainty in the ratio of power plant types (i.e., thermodynamic cycle and fuel combinations) and cooling system types expected to be used in 2020 and beyond.

Analysis Method

The following steps were used to estimate regional and national freshwater consumption (evaporation to the atmosphere) for the power production sector, in both 2000 and 2020.

1. **Identify major water consuming power plant types.** The study first determined which power plant types use substantial quantities of water for cooling and, in the case of gasification combined-cycle, for fuel processing. These proved to be coal-fired steam plants, natural gas– and/or oil-fired steam plants, nuclear plants, biomass-fired steam plants, municipal-solid-waste (MSW) fueled steam plants, natural gas– and/or oil-fired combined-cycle plants, and coal or petroleum residual–fueled gasification combined-cycle plants. Hydroelectric plants were not included, even though their water reservoirs allow for substantial evaporation, because they are typically managed for such multiple purposes as flood control, irrigation, and recreation, in addition to power generation. Further, the number of large U.S. hydroelectric facilities is not likely to change appreciably over the next 20+ years, although some dams may be removed for anadromous fish protection (i.e., seafaring species such as salmon that spawn upriver). There may be growth in the number of small hydroelectric facilities over the next 20+ years, but these are more often “run of river” type plants with smaller reservoirs and, hence, lower evaporation rates.

2. **Determine typical water consumption per unit of generation for each plant type.** For each of the plant types identified in Step 1, typical values or ranges of values were established for water withdrawals from a source body, water consumption (evaporation to the atmosphere), and water returns (discharges) to the source body. As noted, boiler cycle

makeup water and blowdown, ash sluice water, and other "service water" withdrawals and discharges were not included. Their quantities are small compared with cooling water use.

3. **Determine current generation and estimate future generation by power plant and cooling system type.** Generation forecasts by fuel type are published by the U.S. Department of Energy (DOE) Energy Information Agency, EPRI, and other sources. However, the definition of "regions" within the United States is not always comparable among sources, and for many, the "oil" and "natural gas" categories are not subdivided between steam plants and combined-cycle plants. In the case of the latter, comparisons of multiple data sets enabled reasonable estimates. Statistics on the cooling system types used in various plants are more difficult to find and typically only appear in databases listing a plant's rated capacity, not its actual annual generation. Thus, this study involved manual cross-referencing of data sources to estimate generation-weighted cooling system breakouts. Information on the source water body for various plants was also sometimes lacking, which was generally only a problem in coastal areas where it was important to distinguish between freshwater and saline water sources.

4. **Multiply plant/cooling system–specific generation forecasts by the appropriate values for water consumption per unit of generation.** This step was conducted systematically for the various regions analyzed, reference years (2000 or 2020), and generation and cooling system type scenarios.

5. **Summarize freshwater consumption results.**

Analysis Regions

DOE's Energy Information Agency (EIA) uses 15 regional "electricity market modules" in its widely cited *Annual Energy Outlook* electricity demand and production forecasts. These 15 regions are generally synonymous with the councils and areas used by the North American Electric Reliability Council (NERC) for transmission system reliability coordination.

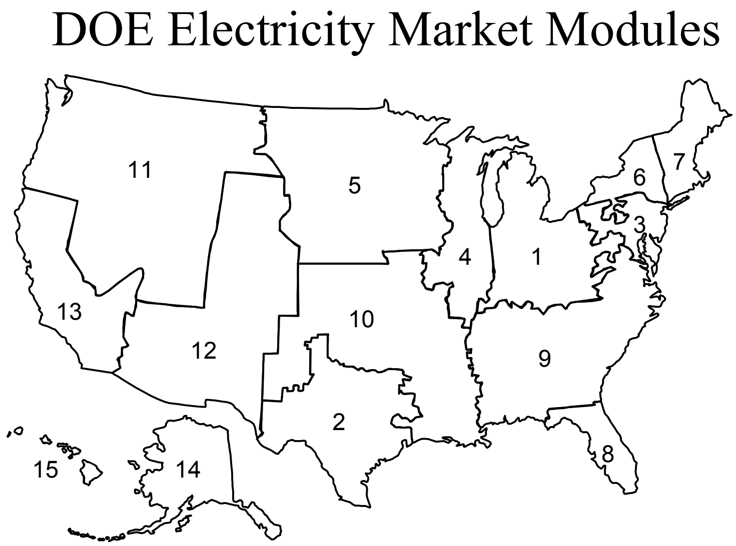

Figure 2-1
DOE-Defined Electricity Market Modules

Region 1 = NERC’s East Central Area Reliability Coordination Agreement (ECAR)

Region 2 = NERC’s Electric Reliability Council of Texas (ERCOT)

Region 3 = NERC’s Mid-Atlantic Area Council (MAAC)

Region 4 = NERC’s Mid-America Interconnected Network (MAIN)

Region 5 = NERC’s Mid-Continent Area Power Pool (MAPP)

Region 6 = NERC’s Northeast Power Coordinating Council, New York (NPCC/NY)

Region 7 = NERC’s Northeast Power Coordinating Council, New England (NPCC/NE)

Region 8 = NERC’s Southeastern Electric Reliability Council, Florida (SERC/FL)

Region 9 = NERC’s Southeastern Electric Reliability Council, non-Florida (SERC/STV)

Region 10 = NERC’s Southwest Power Pool (SPP)

Region 11 = NERC’s Western States Coordinating Council, Northwest Power Pool Area (WSSC/NWP)

Region 12 = NERC’s Western States Coordinating Council, Rocky Mountain and Arizona Power Areas (WSSC/RA)

Region 13 = NERC’s Western States Coordinating Council, California–Southern Nevada Area (WSSC/CNV)

Region 14 = Alaska

Region 15 = Hawaii

3
WATER USE BY POWER PLANT AND COOLING SYSTEM TYPE

Representative, or typical, values or ranges of values for each cooling system type and each major water-consuming power plant type were established by reviewing EPRI reports, statistics published by regulatory agencies (e.g., Nuclear Regulatory Commission), statistics published by industry associations (e.g., Nuclear Energy Institute), and engineering handbooks.

Conventional Cooling System and Power Plant Types

Once-Through Cooling

Once-through cooled plants *withdraw* large quantities of water from a source body, but virtually all of that water is returned to its source at a quality similar to that removed, albeit a bit warmer and sometimes with a trace of residual chlorine. Only a small quantity (about 1%) is *consumed* via increased evaporation to the atmosphere from the warm discharge water plume.

For all types of once-through cooling systems, the design cooling water flow rate is usually set on the basis of a maximum allowable temperature increase (above ambient water) or an absolute maximum discharge water temperature, as determined by state and local water quality regulatory agencies.

Fossil steam plants

Figure 3-1 shows the typical water withdrawal rates for Rankine-cycle plants burning coal, oil, or natural gas to be 20,000 to 50,000 gallons per MWh generated. The lower end of the flow rate range corresponds to the higher temperature differential, and vice versa. Because the product of the flow rate, specific heat of water, and temperature differential—the heat removal rate—is fairly consistent among plants for a given MW load (it's actually a function of the quantity and temperature of the steam being condensed and the condenser efficiency), a single "typical" value for the net increase in downstream evaporation from a fossil steam unit is suitable.

Nuclear plants

Conventional U.S. lightwater-cooled plants employ thermodynamically lower steam conditions than do fossil plants, and thus produce less electricity per pound of circulating steam. Accordingly, greater steam circulation rates (more lb/hr) are needed for a given MW load.

Because cooling water requirements (water withdrawal rates) are proportional to the quantity of steam being condensed, they are therefore also greater on a per MWh basis in a nuclear plant—25,000 to 60,000 gallons/MWh (see Fig. 3-1). As with fossil fuel units, the low flow rate value corresponds to the high temperature differential, and vice versa. The typical evaporation rate for a nuclear unit is also higher than a fossil unit: about 400 gal/MWh vs. 300 gal/MWh.

Other steam plants

In this study, the steam conditions—and therefore the cooling water withdrawal and evaporation rates—for Rankine-cycle plants burning biomass or municipal solid waste are assumed to be comparable to those in a fossil-fired unit.

Combined-cycle plants

Natural gas– and oil-fired combined-cycle plants derive roughly 2/3 of their net power output from the gas turbine (Brayton cycle) and 1/3 from the steam turbine (Rankine cycle). Accordingly, the associated cooling water withdrawal and evaporation rates for combined-cycle units are about 1/3 of those for a Rankine-cycle plant. Figure 3-2 depicts typical values. As with the other steam plants, the lower withdrawal rate corresponds to the higher temperature differential, and vice versa.

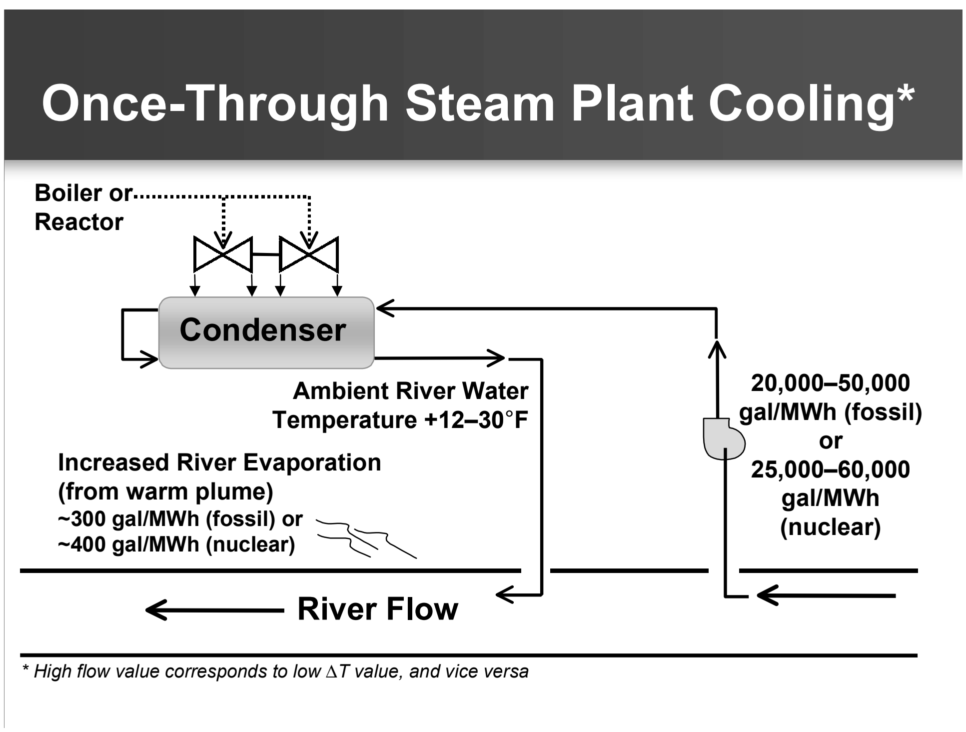

Figure 3-1
Water Withdrawal and Evaporation Rates in Rankine-Cycle Plants with Once-Through Cooling

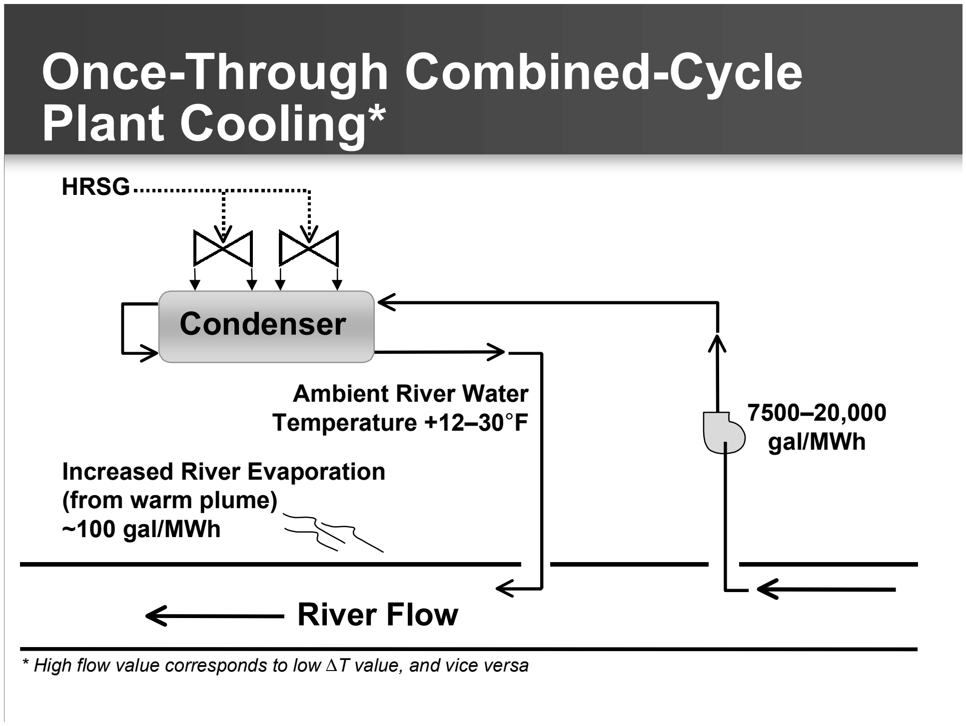

Figure 3-2
Water Withdrawal and Evaporation Rates in Combined-Cycle Plants with Once-Through Cooling

Recirculated cooling

Power plants using recirculated cooled water have much lower water *withdrawal* rates than plants with once-through cooling, but most of the withdrawn water is evaporated through a cooling tower or pond. Water returned to its source body via a blowdown stream is concentrated in dissolved and suspended solids and, like discharge water from once-through systems, is warmer and sometimes contains a trace of residual chlorine.

Fossil steam plants

Figures 3-3 and 3-4 show typical cooling water withdrawal and blowdown rates for cooling towers and cooling ponds, respectively, in plants burning coal, oil, or natural gas. The lower end of the makeup water flow rate range corresponds to the lower blowdown figure (higher cycles of concentration), and vice versa. The difference between the makeup water rate and the blowdown rate is the water consumption (evaporation) rate. A mid-point value of 480 gal/MWh was used in water consumption calculations for both cooling towers and ponds.

Nuclear plants

Analogous to the fossil steam plants, Figures 3-3 and 3-4 also show values for nuclear plant cooling water withdrawal, blowdown, and evaporation rates for tower- and pond-based cooling systems, respectively. A mid-point value of 720 gal/MWh was used in water consumption calculations for both cooling towers and ponds.

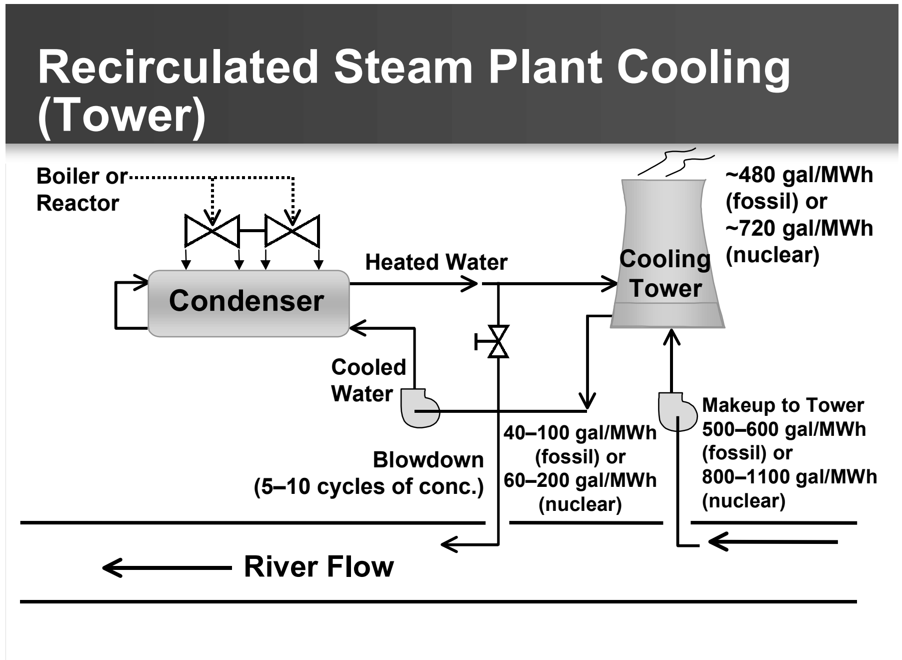

Figure 3-3
Water Withdrawal and Evaporation Rates in Rankine-Cycle Plants with Cooling Towers

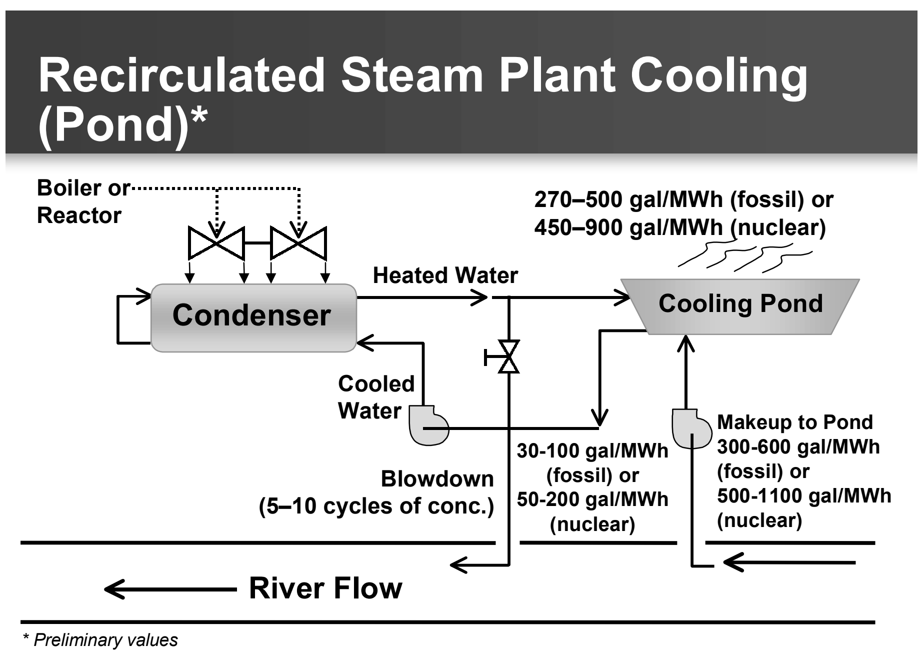

Figure 3-4
Water Withdrawal and Evaporation Rates in Rankine-Cycle Plants with Cooling Ponds

Other steam plants

As with once-through cooling systems, the cooling water withdrawal, blowdown, and evaporation rates for tower- and pond-cooled biomass and MSW plants are assumed to be comparable to those in fossil plants. A value of 480 gal/MWh was used in water consumption calculations.

Combined-cycle plants

Natural gas– and oil-fired combined-cycle plants with recirculated cooling systems generally use cooling towers rather than ponds. A few in difficult-to-permit locations must use the more-expensive air-cooled condensers, which require virtually no cooling water (see Fig. 3-6). Many new tower-cooled plants are required to use treated wastewater from publicly owned treatment works (POTW) as their source for cooling water. Because treated wastewater tends to have higher dissolved and suspended solid levels than raw water, plants using it usually operate at lower cycles of concentration. As a result, the typical value used for evaporation in water consumption calculations—180 gal/MWh—is slightly higher than 1/3 of the value for a fossil steam plant (which would the ratio based on power output; see Fig. 3-5).

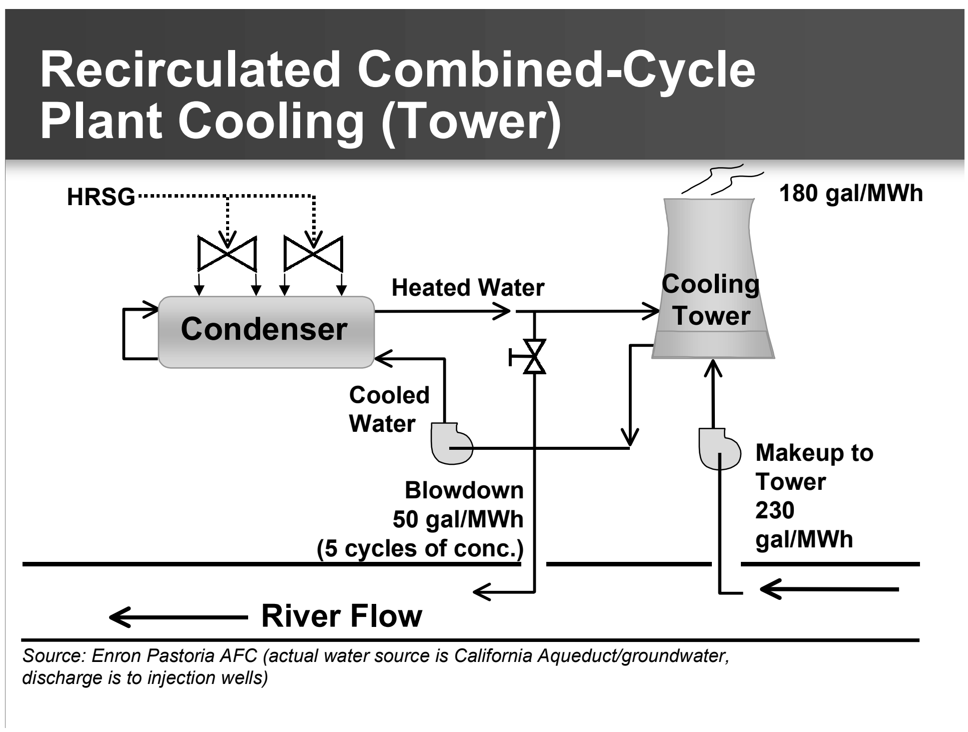

Figure 3-5
Water Withdrawal and Evaporation Rates in Combined-Cycle Plants with Cooling Towers

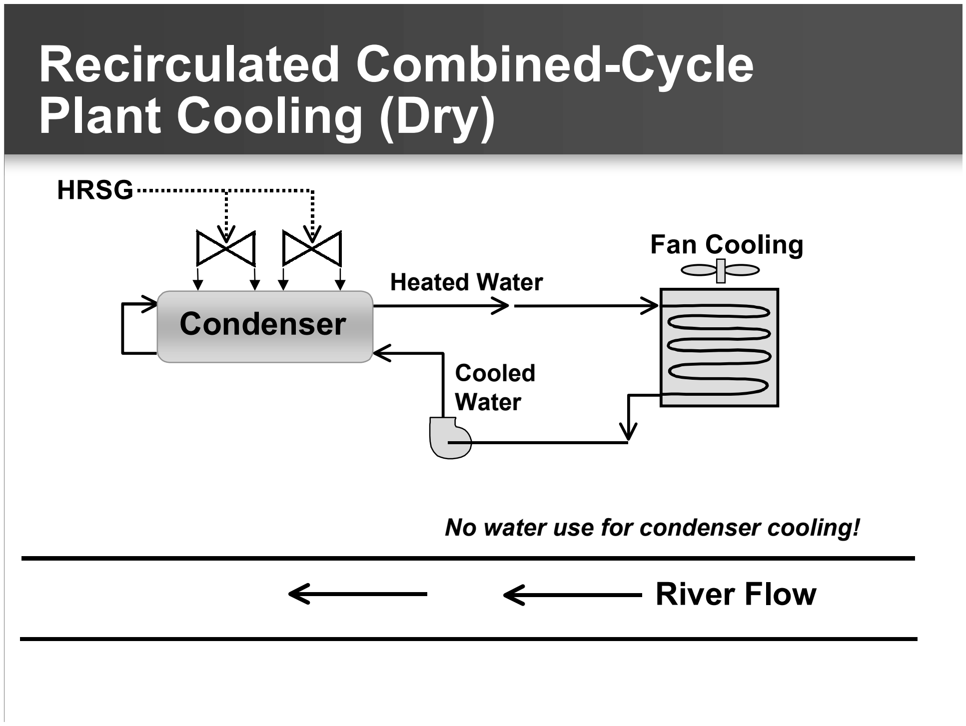

Figure 3-6
Combined-Cycle Plants with "Dry" Cooling Use Air-Cooled Condensers

Advanced Power Plant Types

Beyond 2020, advanced power plant types may find significant use, both in large central power stations and in distributed generation.

Central station technologies include gasification combined-cycle plants firing coal and petroleum residuals and possibly advanced nuclear plants using helium-cooled reactors and gas turbine power cycles. Figure 3-7 depicts the most likely advanced plant configuration—a cooling tower–based gasification combined-cycle unit that also withdraws water for the gasification process. Such a plant uses less water than a coal-fired steam plant, but considerably more water than a natural gas–fired combined-cycle plant.

The leading distributed generation technologies are small and "micro" gas turbines, advanced internal combustion (IC) engines, and fuel cells.

The gas turbines are virtually all simple-cycle designs and therefore do not involve steam cycles. All IC engines use air-cooled radiators for engine block heat exhaustion, with the possible exception of the very largest, slow-speed machines, which could use cooling towers. These would be too small in number, however, to worry about quantifying for freshwater consumption projections.

Fuel cells don't use cooling water, but may use freshwater in the process of hydrogen fuel generation. Steam reforming of natural gas, the most common commercial means of producing hydrogen, uses about 2 pounds of water per pound of natural gas feedstock. When integrated with a fuel cell, however, some of the fuel cell's steam exhaust can be recycled to the reforming step, resulting in net water consumption on the order of 30 gal/MWh (or less).

Because this is an order of magnitude lower than the evaporative consumption of cooling water in other power plant types, and because of uncertainty over the timing and market penetration rates for stationary power fuel cells, water consumption by fuel cell power systems was not considered in estimates of overall power sector freshwater demand.

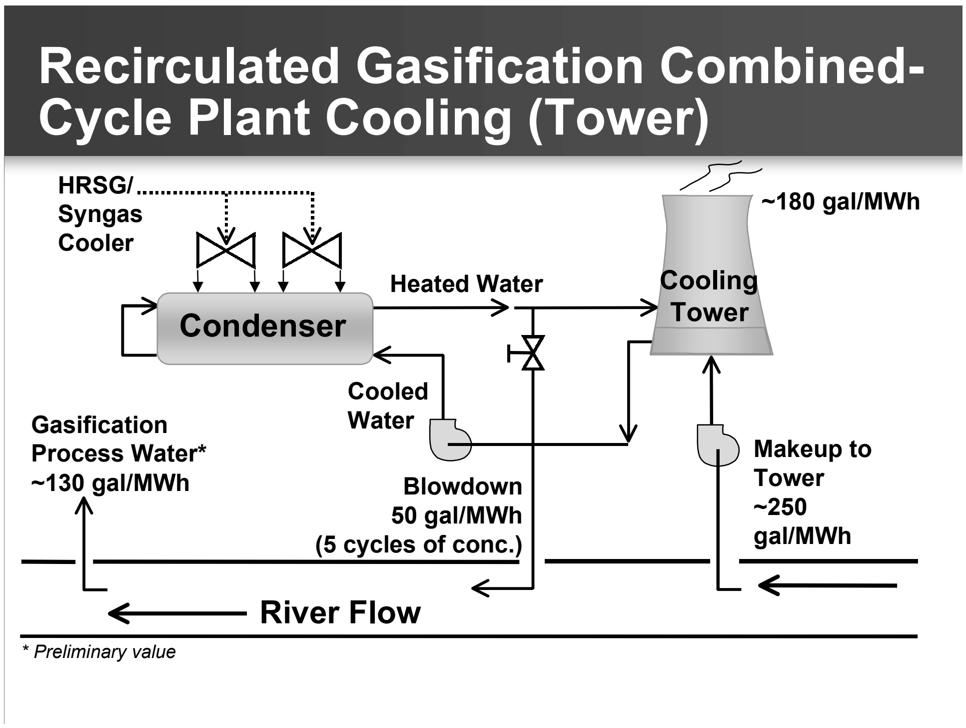

Figure 3-7
Water Withdrawal and Evaporation Rates in Gasification Combined-Cycle Plants with Cooling Towers

4
POWER GENERATION PROJECTIONS

This study uses two leading estimates of U.S. electric power production over the next 20 years: the DOE EIA *Annual Energy Outlook 2000* (AEO2000) and EPRI's "Energy-Environment Policy Integration and Coordination" (E-EPIC) study. Each source estimates annual generation by plant and fuel type for each of the 13 DOE "electricity market modules" (regions) residing in the conterminous 48 states, for the next 20 years. Table 4-1 lists the 48-state totals for the plant types of interest for 2000 and 2020.

Scenarios for 2020

The DOE EIA AEO2000 projection serves as the "base case" for this study. Figure 4-1 shows its 2000 generation values by region. Figures 4-2 and 4-3 show forecast regional generation growth from 2000 to 2020, in absolute and percentage terms, respectively.

Prior to publication of *Annual Energy Outlook 2001*, EIA analysts stated that they planned to lower their estimates of 2020 coal-fired steam plant generation in AEO2001, and increase their estimate of natural gas combined-cycle generation. In fact, projected coal generation remained about the same, but projected natural gas generation did indeed increase significantly, thereby boosting its fraction of total generation relative to coal. Thus, the DOE EIA AEO2000 values represent a "coal predominates" bounding scenario.

The E-EPIC forecast predicts generators' response to environmental restrictions likely to be imposed under the "current policy direction" in regulations, particularly for SO_2, NO_X, and CO_2 emissions. The study's "current policy direction" scenario envisions massive premature retirement of coal-fired steam plants and a huge boom in the construction of natural gas combined-cycle plants. Thus, relative to the DOE AEO2000 forecast, the E-EPIC study represents a "major shift to gas" scenario.

Neither the publicly posted version of the DOE EIA AEO2000 forecast nor the EPRI E-EPIC generation data distinguished between steam plants and combined-cycle plants in their "oil" and "natural gas" categories. Such breakouts are needed because of the differing cooling water requirements between the two plant types.

DOE EIA analysts were able to provide steam plant vs. combined-cycle plant breakouts. E-EPIC breakouts were then developed by applying the DOE EIA steam plant generation figures to the E-EPIC totals and attributing the difference to combined-cycle plants. This approach is reasonable because the primary difference between the forecasts was in the coal steam and natural gas combined-cycle generation, not the gas steam generation.

Table 4-1
Generation Predictions by Plant and Fuel Type for the Conterminous 48 States

Plant and Fuel Type	2000: 10^6 MWh, DOE EIA AEO2000	2000: 10^6 MWh, EPRI E-EPIC CPD	2020: 10^6 MWh, DOE EIA AEO2000	2020: 10^6 MWh, EPRI E-EPIC CPD
Coal steam	1887	1906	2307	300
Gas/Oil steam	316	232	94	94
Nuclear	688	664	427	593
Biomass/MSW steam	24	37	50	133
Combined cycle	84	172	899	2431
Total	**2999**	**3011**	**3777**	**3551**

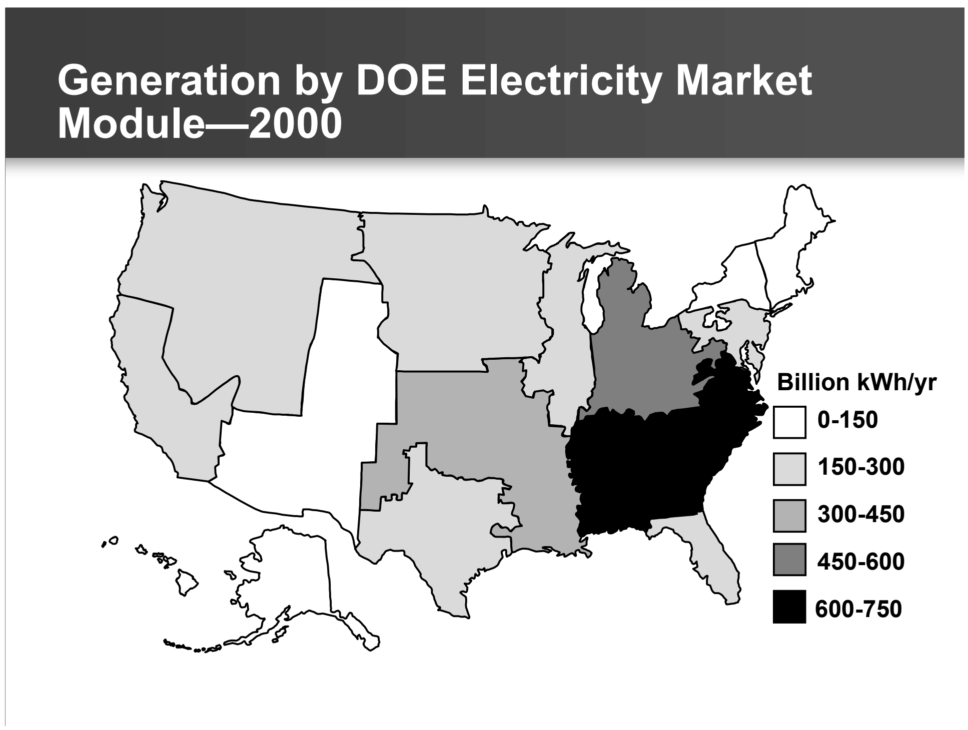

Figure 4-1
"Dedicated" (Commercial) Generation in 2000 for each "Electricity Market Module," from DOE EIA *Annual Energy Outlook 2000*

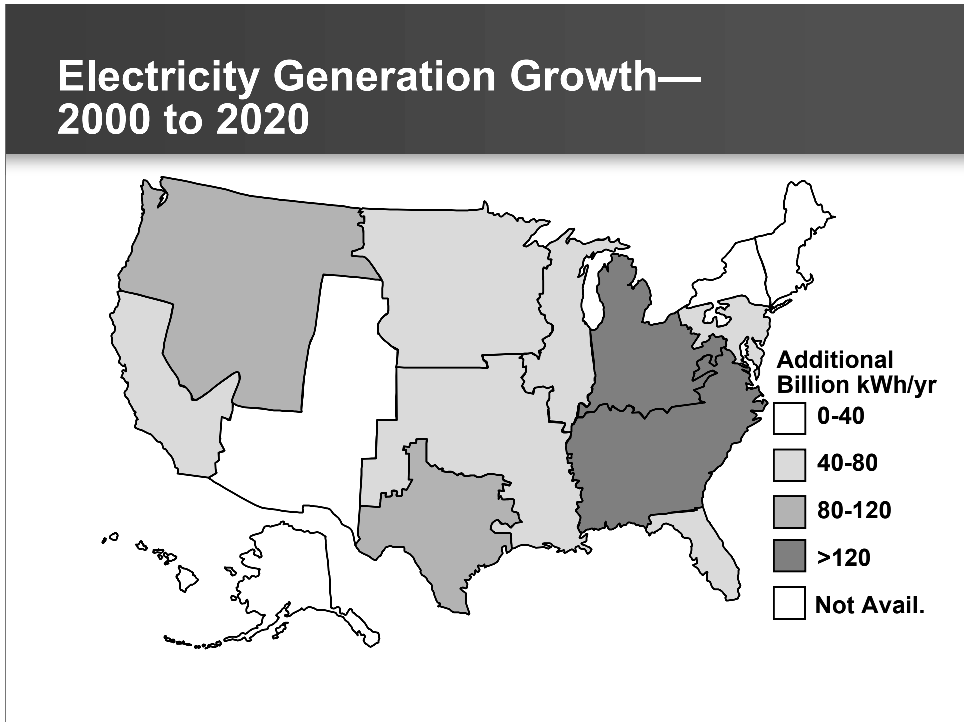

Figure 4-2
Forecast Growth in "Dedicated" (Commercial) Generation, 2020 vs. 2000, for each "Electricity Market Module," from DOE EIA *Annual Energy Outlook 2000*

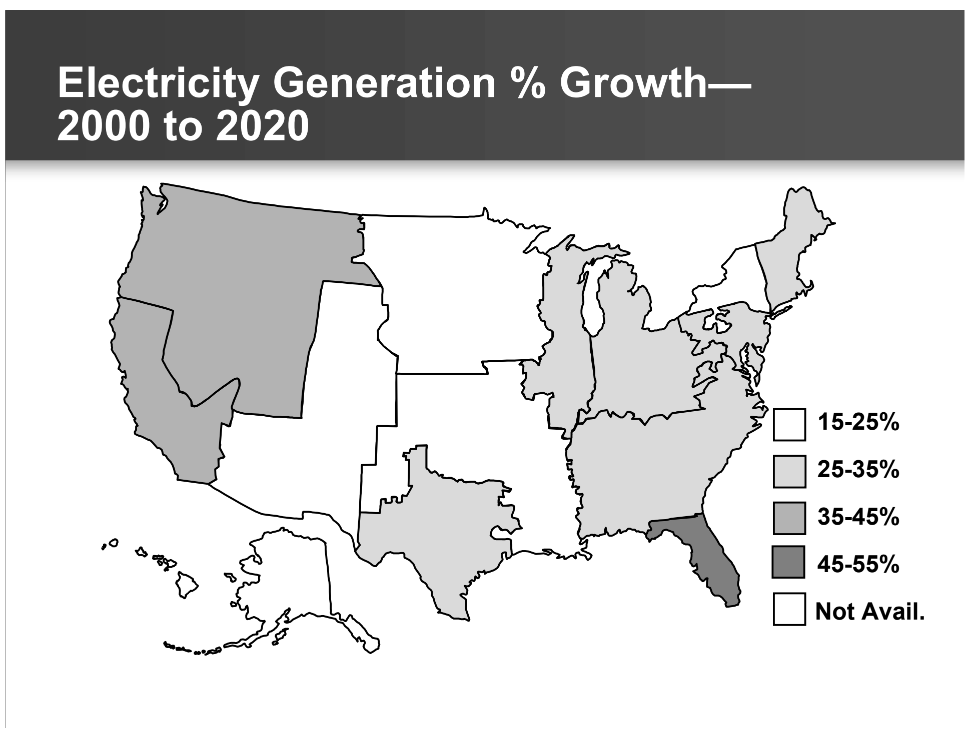

Figure 4-3
Forecast Percentage Growth in "Dedicated" Generation (Commercial MWh), 2020 vs. 2000, for each "Electricity Market Module," from DOE EIA *Annual Energy Outlook 2000*

Extrapolation to 2050

The DOE EIA Annual Energy Outlook forecasts do not extend beyond 2020. Linearly extrapolating the 2000-to-2020 trends in generation by plant type out to 2050 suggests the emergence of natural gas combined-cycle plants as the dominant power plant type in 2050 (see Figure 4-4).

Conversely, the E-EPIC study predicts a potential re-emergence of coal-fueled capacity between 2020 and 2050, in the form of gasification combined-cycle units. The study assumes that the heavy reliance on natural gas in next two decades will push gas prices to unacceptably high levels, creating the opportunity for clean coal's competitive emergence.

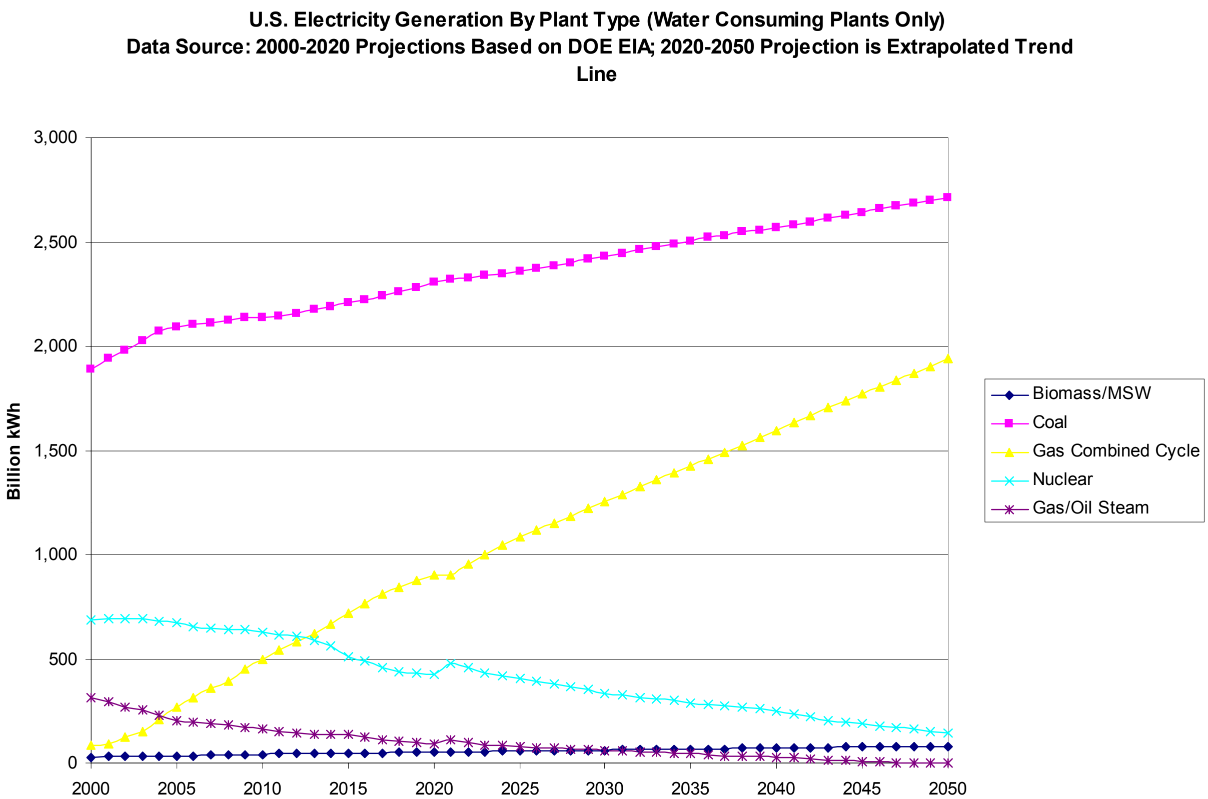

Figure 4-4
Forecast Growth in Annual "Dedicated" (Commercial) Generation, 2000 to 2050, based on linear trending of data from DOE EIA *Annual Energy Outlook 2000*

Cogeneration and Distributed Generation

The DOE EIA AEO2000 forecast includes estimates of cogeneration by region, but these have not been included in water consumption projections. Like hydro reservoirs, cogeneration units are operated with multiple objectives, including process steam production, which reduces the need for condenser cooling. Also, the E-EPIC study did not include cogeneration estimates, and omitting them from the AEO-based projections as well made comparisons between the two forecasts easier.

Some analysts expect distributed generation (DG) to make significant market inroads by 2020; others predict its impact will come later. As noted, the predominant DG technologies for 2020 appear to be small gas turbines and microturbines, advanced internal combustion engines, and fuel cells. Neither the DOE EIA *Annual Energy Outlook 2000* nor the EPRI E-EPIC study provides generation forecasts for these plant types. And because they are not major water consumers, this study did include attempt to quantify DG plant output or freshwater consumption.

Estimates of Generation by Plant Type by Cooling System Type

The most difficult aspect of this study was estimating the fraction of generation for a given plant type within a given region attributable to the various cooling system types. Except for nuclear plants, there is a paucity of available information relating generation to cooling system types. And even for nuclear plants, most of the cooling system data are based on a plant's rated *capacity* (MW), not its actual *generation* (MWh). Neither the DOE EIA Annual Energy Outlook nor the EPRI E-EPIC generation forecasts provide breakouts of cooling system types.

Thus, estimates had to be developed on the basis of available EPRI statistics on plant-by-plant generation and cooling system type and on the basis of trends observed in the industry with respect to permit requirements for condenser cooling systems.

Table 4-2 summarizes the approaches used for the various plant types. To gauge uncertainty with respect to cooling system types, an alternative scenario considers the implication of an extreme potential rulemaking by the U.S. Environmental Protection Agency on Section 316(b) of the Clean Water Act (CWA), which requires the agency to establish fish protection measures for power plant intake structures. This "restrictive CWA 316(b)" scenario assumes that new plants must use cooling towers (or air-cooled condensers for combined-cycle plants where local permitting agencies require "dry" cooling), and that even existing plants with once-through or pond cooling systems must retrofit cooling towers.

Table 4-2
Method for Estimating Generation-Weighted Breakouts of Cooling System Types for Current and Future Generation by Plant Type

Scenario	Coal Steam Plants	Gas/Oil Steam Plants	Nuclear Steam Plants	Biomass/MSW Steam Plants	Combined Cycle Plants
2000 Generation	Based on generation-weighted average of units in the ERAM database (established by EPRI) that produce more than 1 million MWh/yr.	Based on generation-weighted average of units in the ERAM database (established by EPRI) that produce more than 1 million MWh/yr.	Based on state-specific and plant-specific data from the Nuclear Regulatory Commission and the Nuclear Energy Institute.	Assumed to be in equal proportion to cooling type breakouts for coal-fired steam plants.	Region 13 based on California Energy Commission data; Region 8 assumed to be 67% cooling tower and 33% pond; other regions assumed to be 90% cooling tower and 10% saline, except in inland areas (where 100% cooling tower is assumed).
2020 Generation: DOE EIA scenario and EPRI E-EPIC scenario	New units assumed to be 90% cooling tower and 10% saline, except in inland areas (where 100% cooling tower is assumed); existing unit breakouts assumed to be the same as for 2000.	Assumed to be in equal proportion to cooling type breakouts for 2000.	Assumed to be in equal proportion to cooling type breakouts for 2000.	Assumed to be in equal proportion to cooling type breakouts for coal-fired steam plants.	New units assumed to be 80% cooling tower, 10% saline, and 10% dry, except in inland areas (where the 10% saline is allocated to either cooling towers, in non-arid areas, or to dry cooling in arid areas); existing unit breakouts assumed to be the same as for 2000.
2020 Generation: DOE EIA data with restrictive CWA 316(b) fish protection regulations scenario	Same breakouts as the 2020 scenarios above, except that all non-saline once-through and pond systems are assumed to be converted to cooling towers.	Same breakouts as the 2020 scenarios above, except that all non-saline once-through and pond systems are assumed to be converted to cooling towers.	Same breakouts as the 2020 scenarios above, except that all non-saline once-through and pond systems are assumed to be converted to cooling towers.	Same breakouts as the 2020 scenarios above, except that all non-saline once-through and pond systems are assumed to be converted to cooling towers.	Same breakouts as the 2020 scenarios above, except that all non-saline once-through and pond systems are assumed to be converted to cooling towers.

5
WATER CONSUMPTION PROJECTS

Multiplying the appropriate generation projections by plant and cooling system type (from Chapter 4) by the typical rates of water consumption per unit of generation (from Chapter 3) yields estimates of the changes in water consumption for power generation.

Figures 5-1 and 5-2 show the absolute and percentage growth, respectively, in freshwater consumption for power generation, by region (from Chapter 2), for 2020 vs. 2000, for the DOE EIA AEO2000 base case.

Figures 5-3 and 5-4 show the absolute and percentage growth, respectively, in freshwater consumption for power generation, by region, for 2020 vs. 2000, for the EPRI E-EPIC "current policy direction" scenario.

Figures 5-5 and 5-6 show the absolute and percentage growth, respectively, in freshwater consumption for power generation, by region, for 2020 vs. 2000, for DOE EIA AEO2000 generation data under the scenario of restrictive regulations for CWA Sec. 316(b) fish protection.

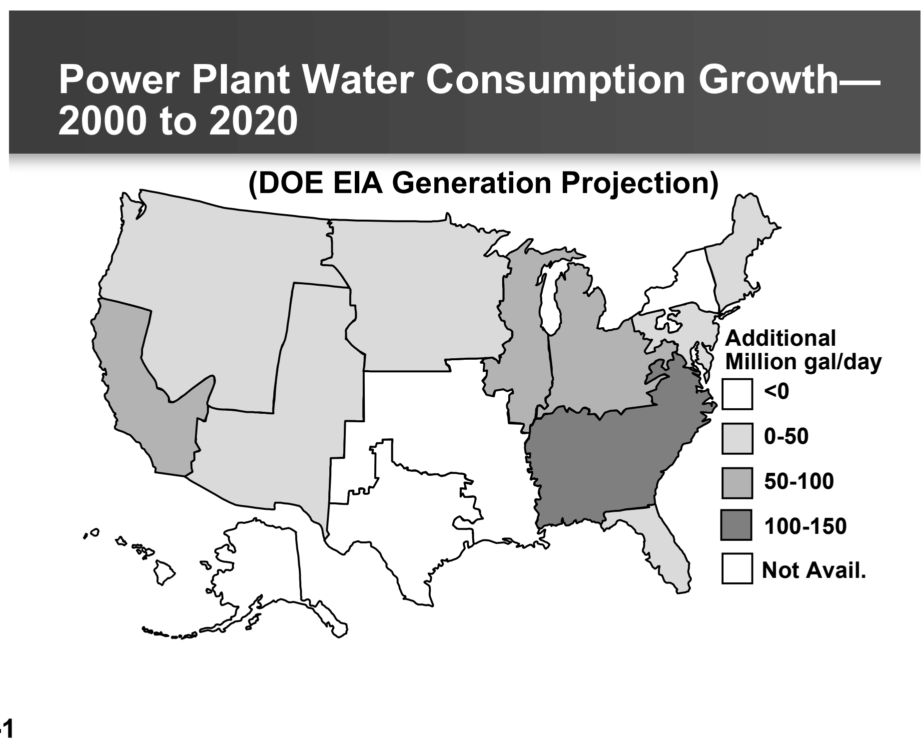

Figure 5-1
Increase in Daily Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); DOE EIA AEO2000 Generation Projection

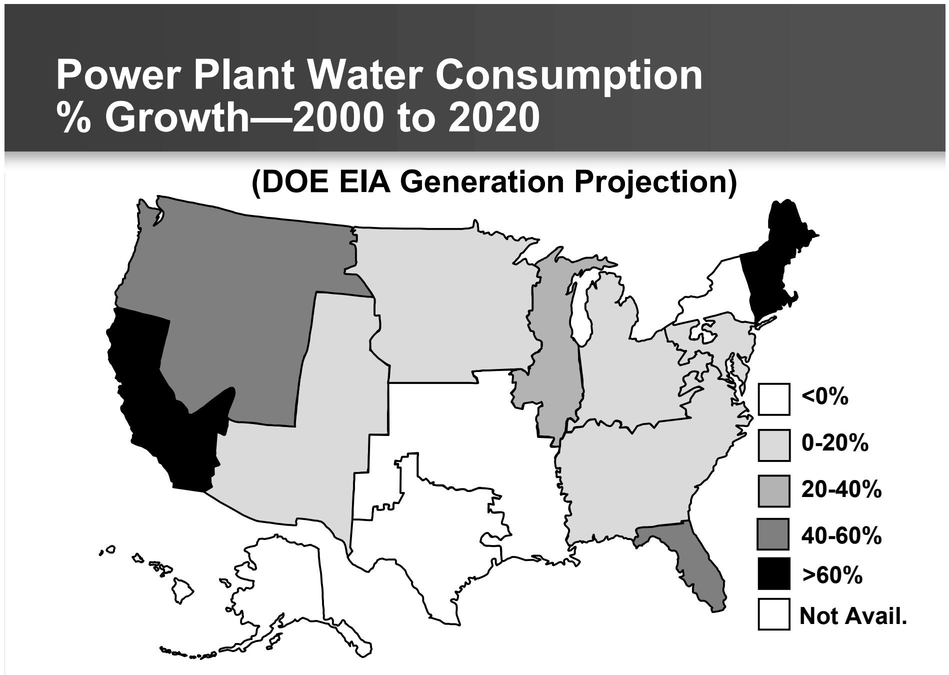

Figure 5-2
Percentage Increase in Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); DOE EIA AEO2000 Generation Projection

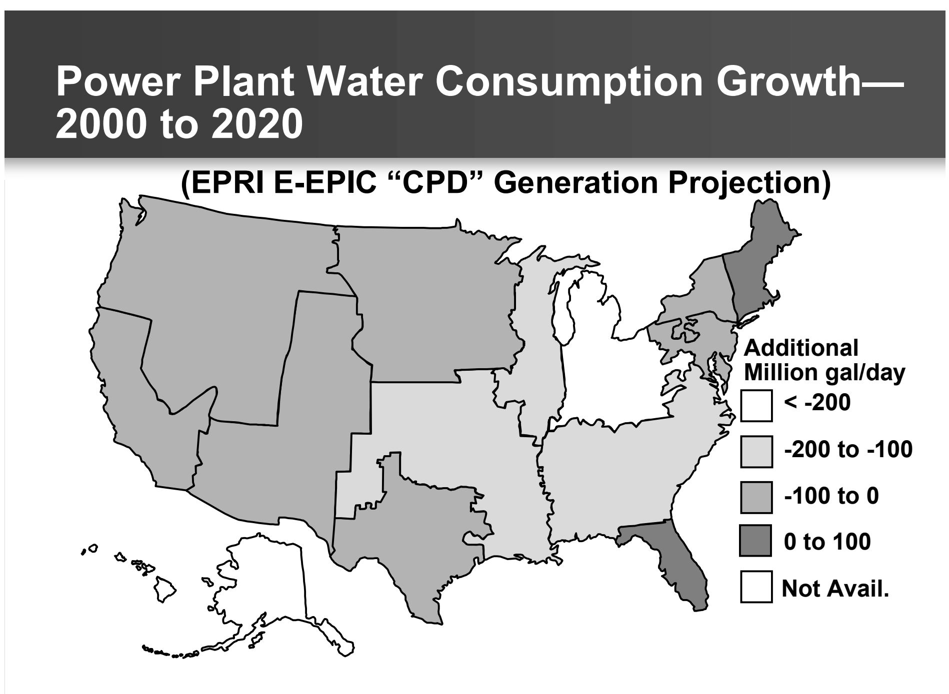

Figure 5-3
Increase in Daily Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); EPRI E-EPIC CPD Generation Projection

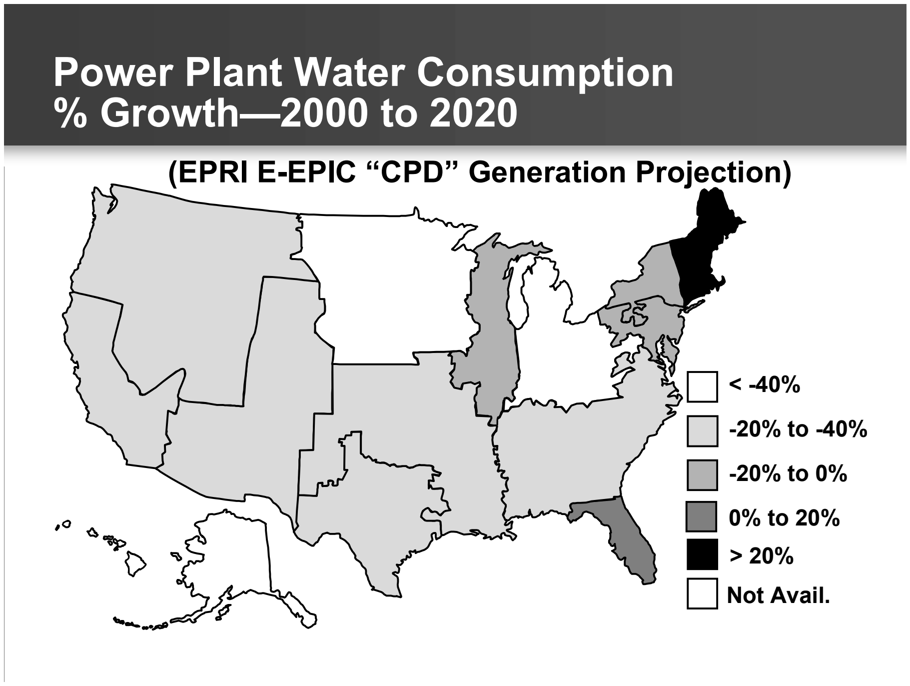

Figure 5-4
Percentage Increase in Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); EPRI E-EPIC CPD Generation Projection

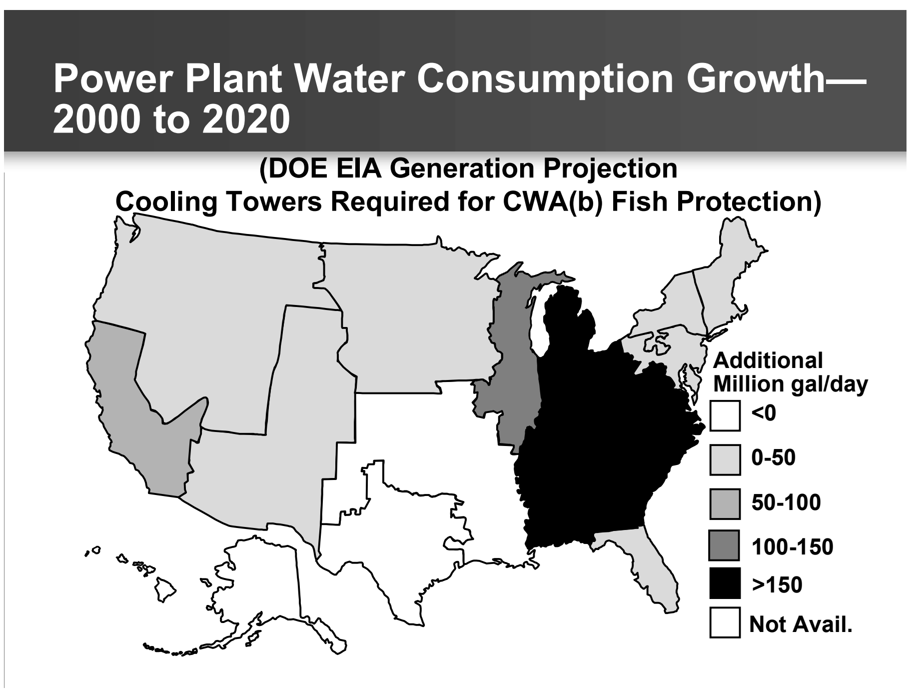

Figure 5-5
Increase in Daily Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); DOE EIA Generation Projection with Cooling Towers Required for Clean Water Act Section 316(b) Fish Protection

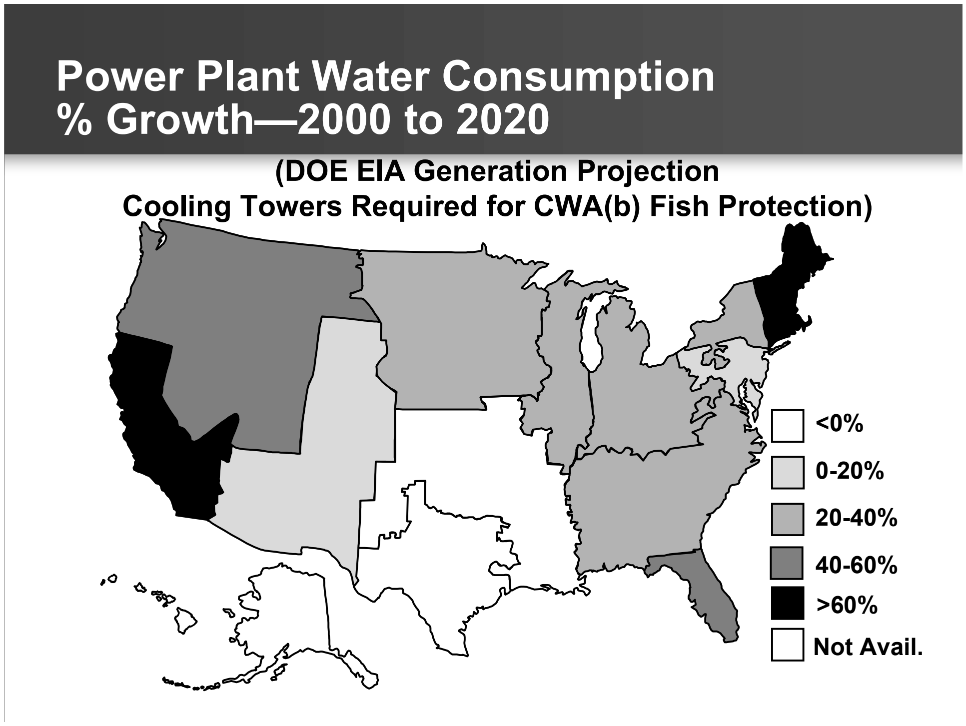

Figure 5-6
Percentage Increase in Power Plant Freshwater Consumption (Evaporation to the Atmosphere) for Cooling by DOE Electricity Market Module: 2020 Relative to Today (2000); DOE EIA Generation Projection with Cooling Towers Required for Clean Water Act Section 316(b) Fish Protection

6
CONCLUSIONS

Trends in the power industry, such as the predominance of natural gas combined-cycle plants for new capacity, are decreasing both the quantity of water withdrawn and the quantity consumed (evaporated to the atmosphere) per MWh. Total U.S. water consumption by the power generation sector over the next 20+ years may increase or decrease, depending on the rate of decrease in *unit* freshwater consumption (which in turn depends on the plant and cooling system mix employed) and on the rate of growth in MWh produced.

The “coal predominates” and “restrictive fish protection regulations” scenarios showed modest freshwater consumption increases for 2020 relative to 2000, whereas the “major shift to gas” scenario showed a substantial decrease (see Figures 6-1 and 6-2).

National

Figures 6-3 through 6-5 show stacked bars of water consumption by power plant type, for 2000 and 2020, for the DOE EIA AEO2000, EPRI E-EPIC “current policy direction,” and “restrictive CWA Sec. 316(b) fish protection” scenarios, respectively.

Regional

Regionally, some areas are expected to see increased freshwater consumption for power production in 2020, whereas other areas should see decreases. In general, increases will occur in areas projected to add significant amounts of coal-fired steam plants. Decreases will occur in areas with significant retirements of coal-fired and nuclear steam plants.

Figures 6-6 through 6-8 show the regional variations in power production and water consumption growth, for 2020 relative to 2000, for the DOE EIA AEO2000, EPRI E-EPIC “current policy direction,” and “restrictive CWA Sec. 316(b) fish protection” scenarios, respectively.

Figures 6-9 through 6-21 show stacked bars of regional water consumption by power plant type, for 2000 and 2020, for the DOE EIA AEO2000 “base case” scenario.

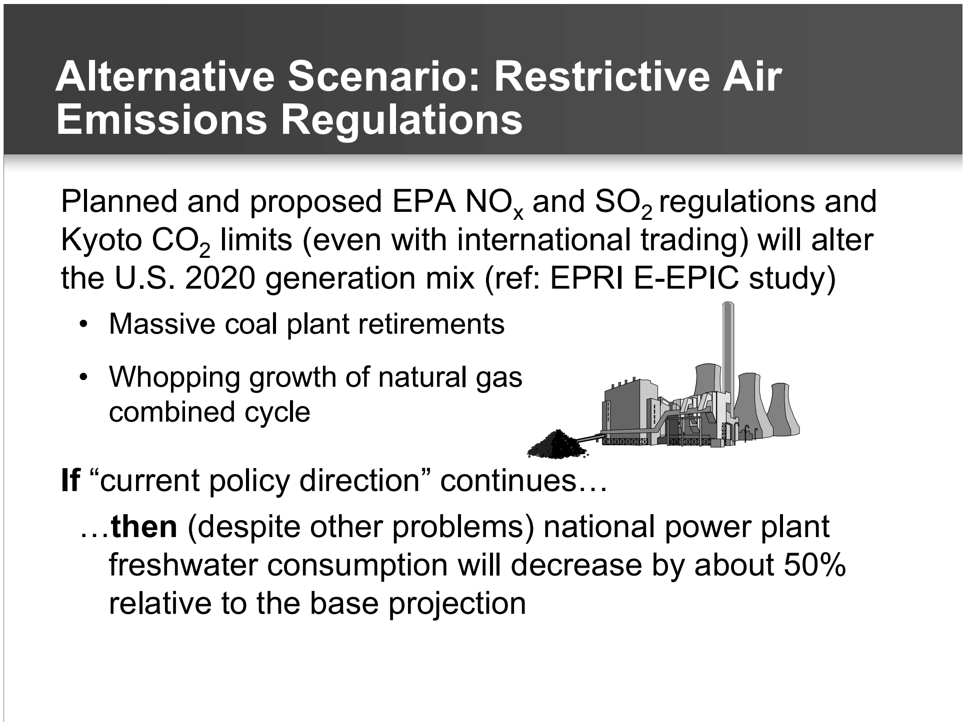

Figure 6-1
Conclusion for the E-EPIC Scenario: A Lower Bound Case for Power Plant Freshwater Consumption Relative to the DOE EIA AEO2000 "Base Case"

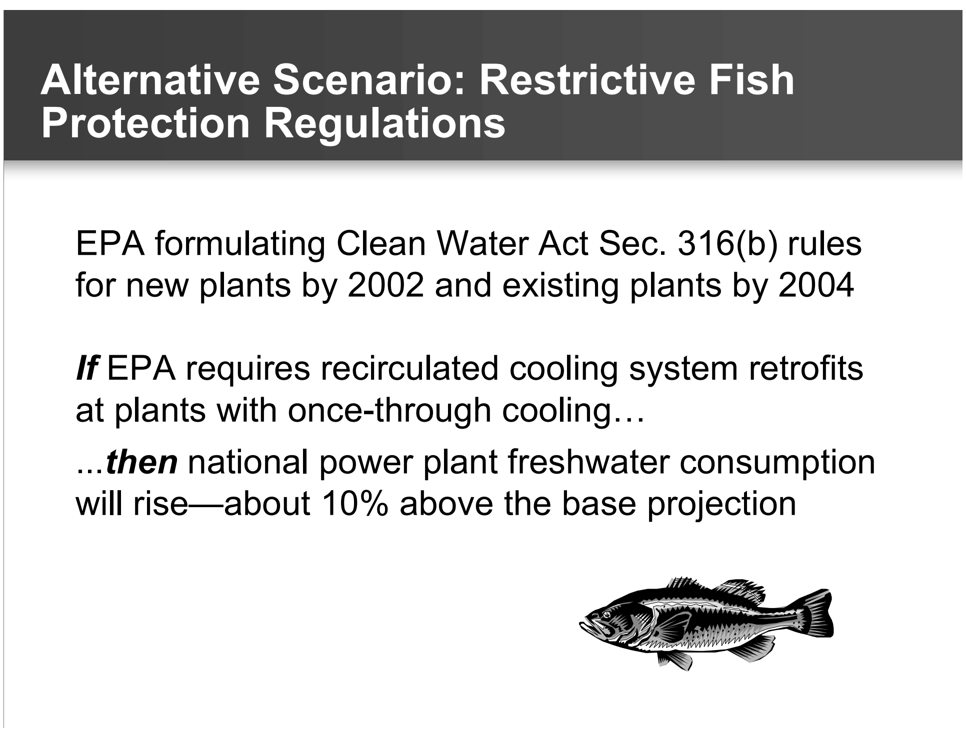

Figure 6-2
Conclusion for the Restrictive CWA Sec. 316(b) Scenario: An Upper Bound Case for Power Plant Freshwater Consumption Relative to the DOE EIA AEO2000 "Base Case"

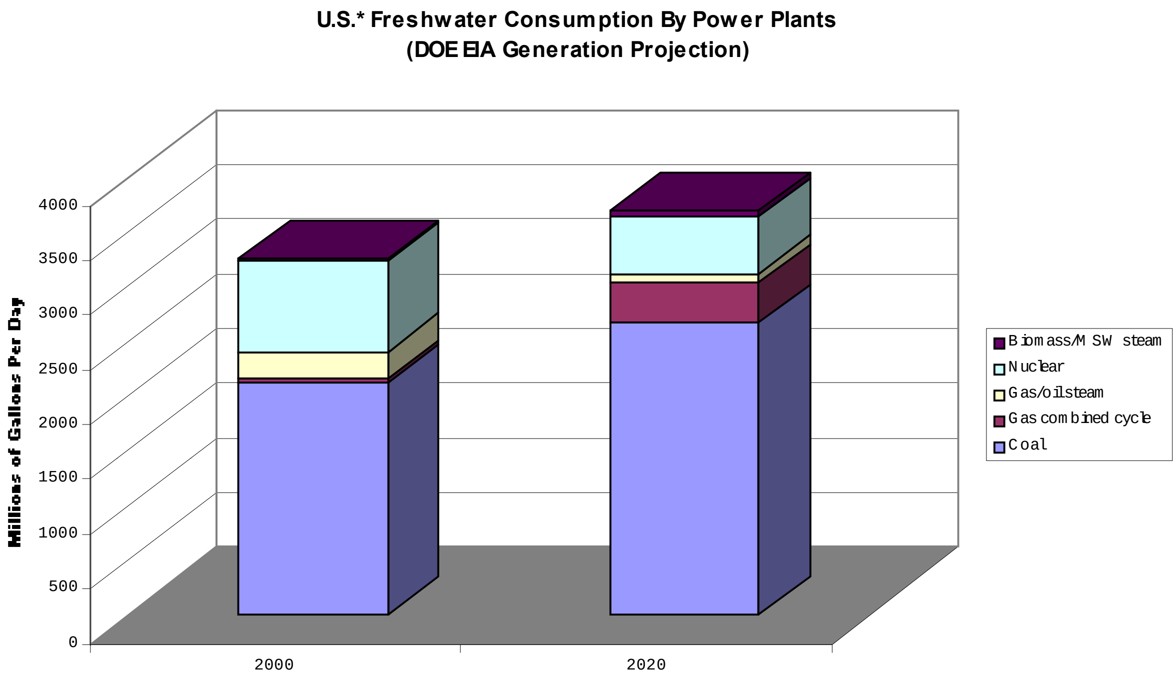

Figure 6-3
Daily Power Plant Freshwater Consumption (Evaporation) for Cooling for the 48 Conterminous States*, by Plant Type, for 2000 and 2020; DOE EIA AEO2000 Generation Projection

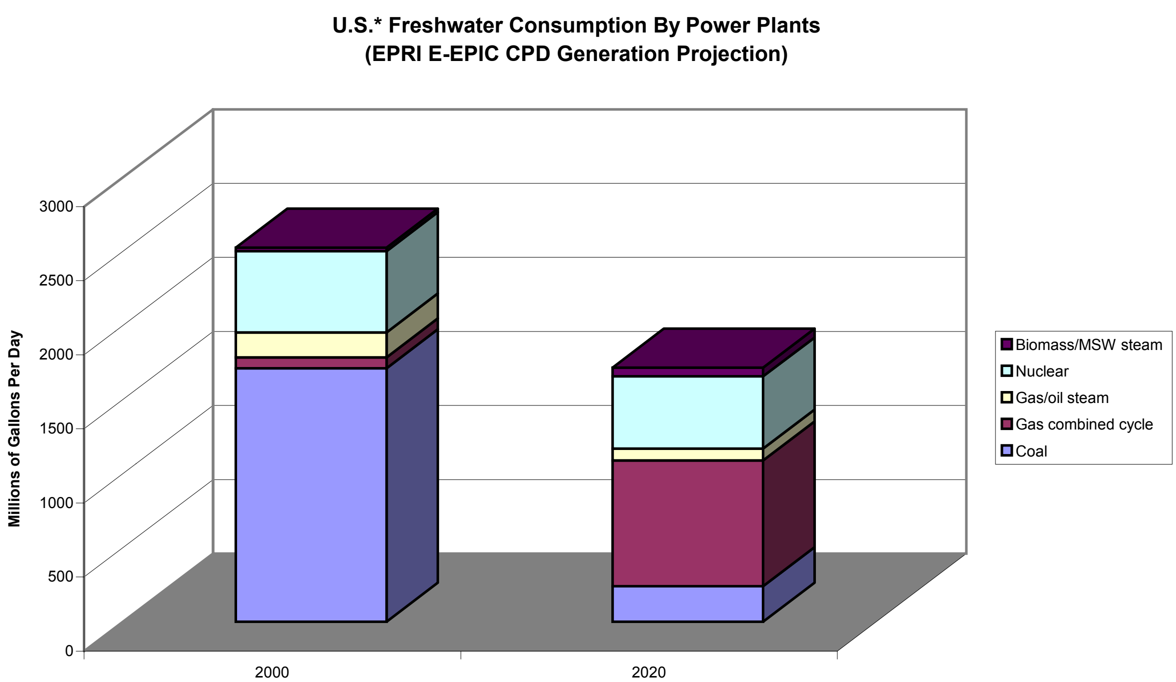

Figure 6-4
Daily Power Plant Freshwater Consumption (Evaporation) for Cooling for the 48 Conterminous States*, by Plant Type, for 2000 and 2020; EPRI E-EPIC Generation Projection

U.S.* Freshwater Consumption By Power Plants (DOE EIA Generation Projection, Cooling Towers Required for CWA 316(b) Fish Protection)

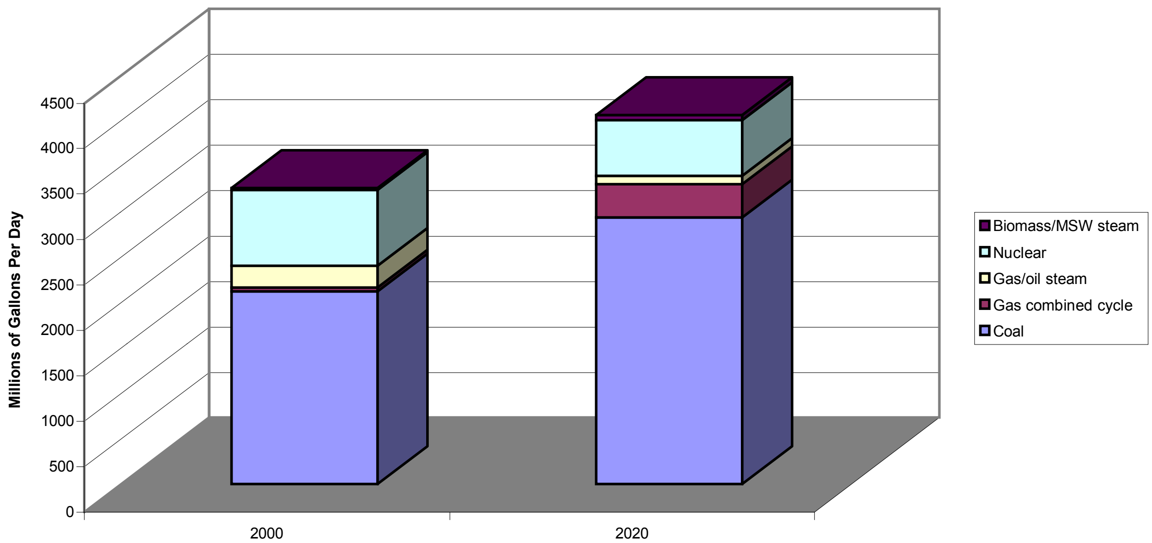

Figure 6-5
Daily Power Plant Freshwater Consumption (Evaporation) for Cooling for the 48 Conterminous States*, by Plant Type, for 2000 and 2020; DOE EIA Generation Projection with Cooling Towers Required for Clean Water Act Section 316(b) Fish Protection Regulations

Change in Electricity Production and Power Plant Freshwater Consumption: 2000-2020 (DOE EIA Generation Projection)

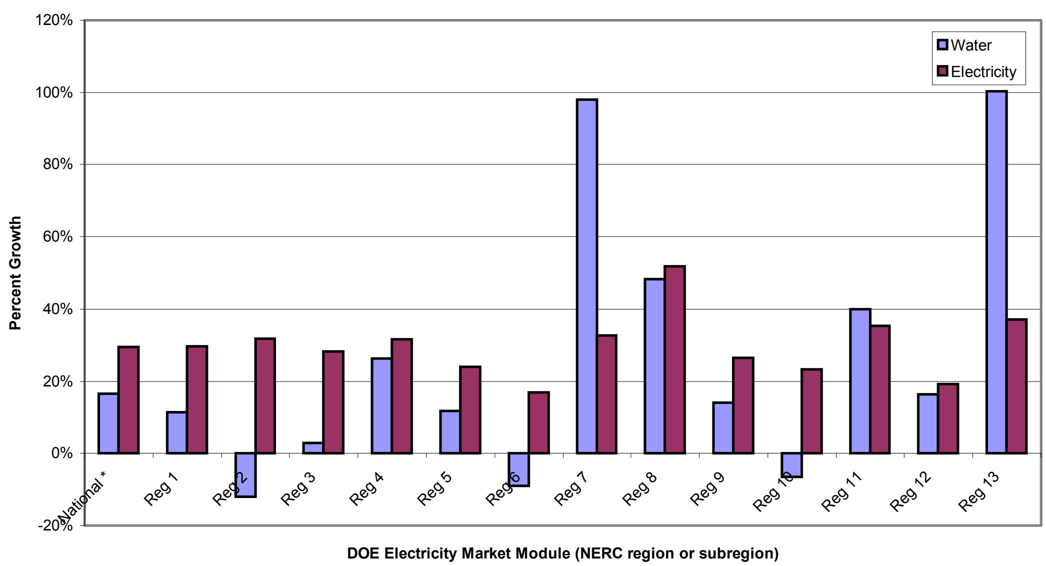

Figure 6-6
Percentage Growth in Power Production and Power Plant Freshwater Consumption (Evaporation), for the 48 Conterminous States* and by Region: 2020 Relative to Today (2000); DOE EIA Generation Projection

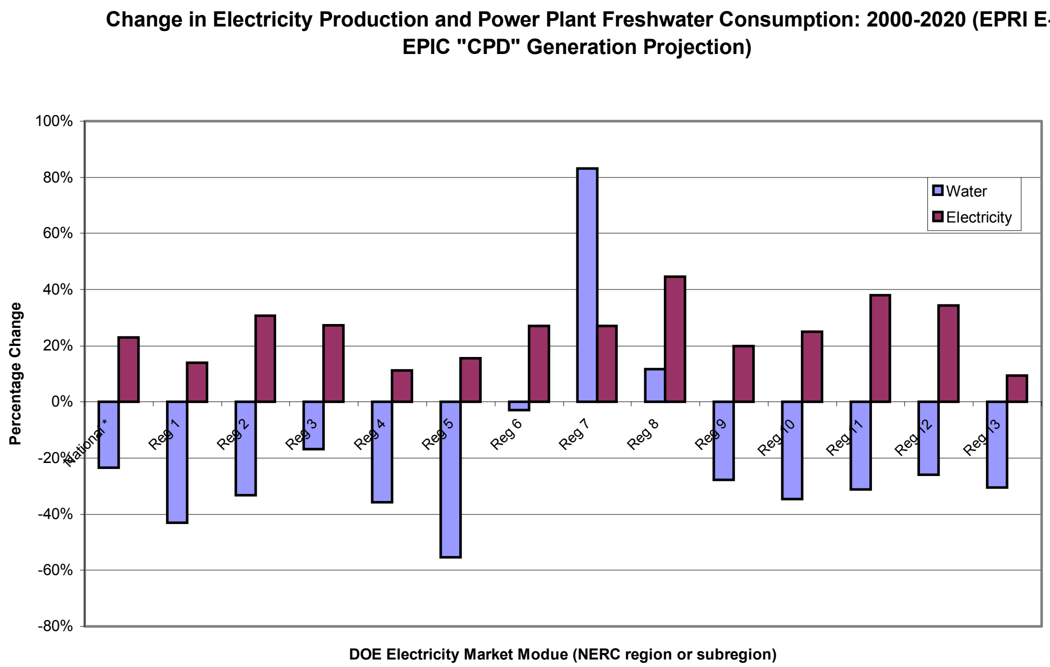

Figure 6-7
Percentage Growth in Power Production and Power Plant Freshwater Consumption (Evaporation), for the 48 Conterminous States* and by Region: 2020 Relative to Today (2000); EPRI E-EPIC Generation Projection

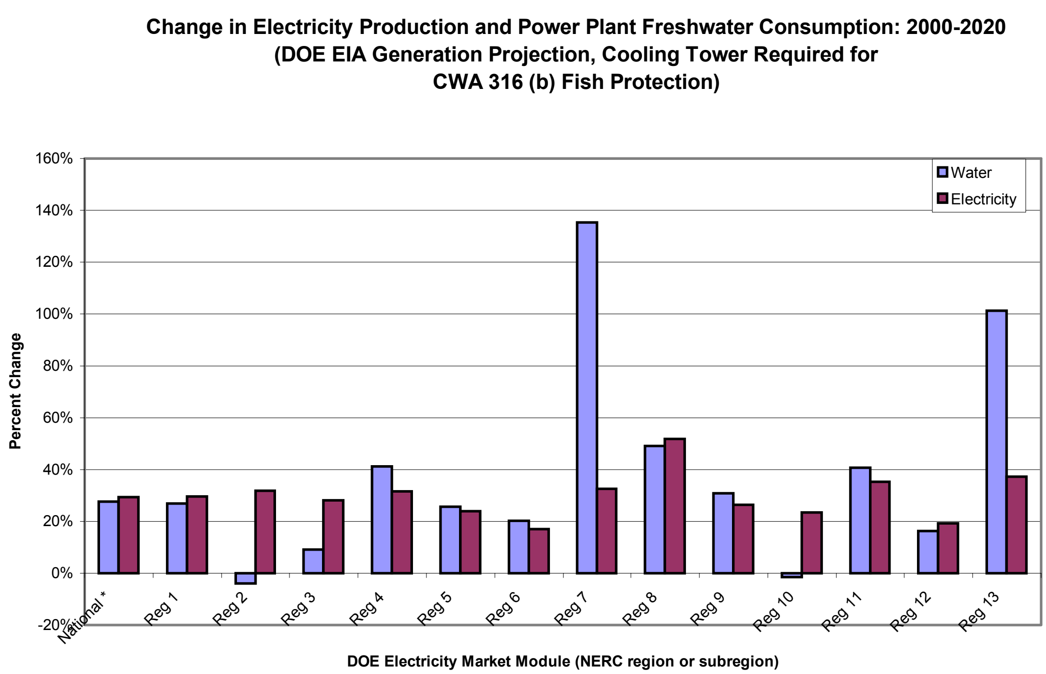

Figure 6-8
Percentage Growth in Power Production and Power Plant Freshwater Consumption (Evaporation), for the 48 Conterminous States* and by Region: 2020 Relative to Today (2000); DOE EIA Generation Projection with Cooling Towers Required for CWA Sec. 316(b) Fish Protection

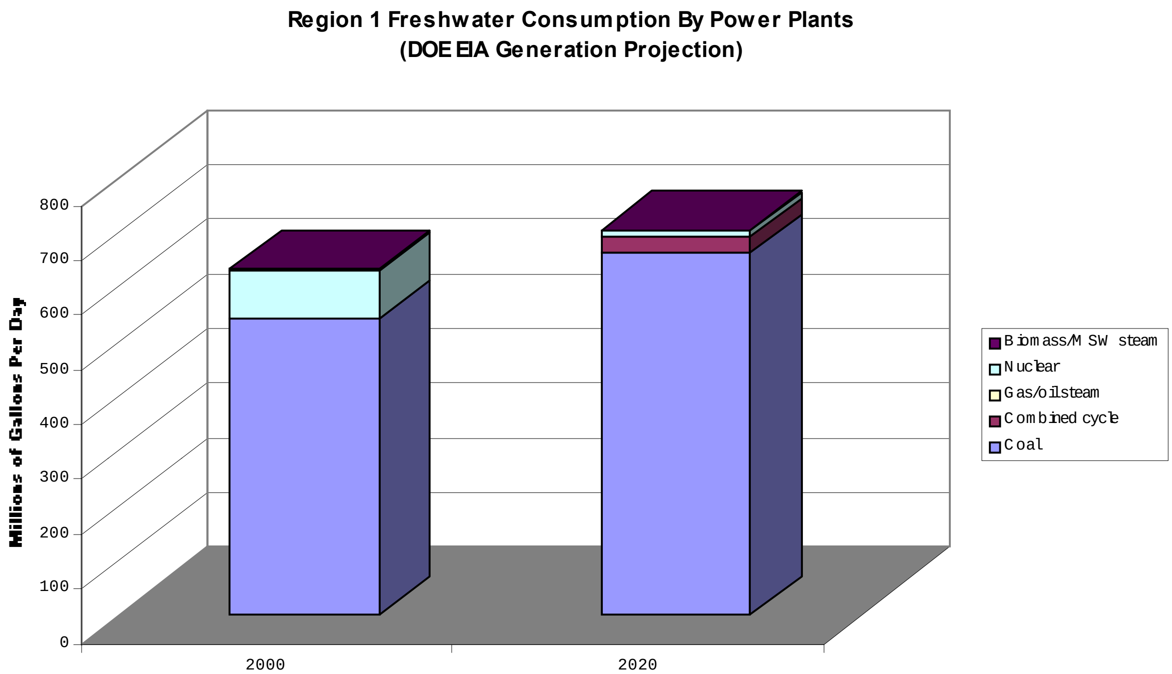

Figure 6-9
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC ECAR Region; DOE EIA AEO2000 Generation Projection

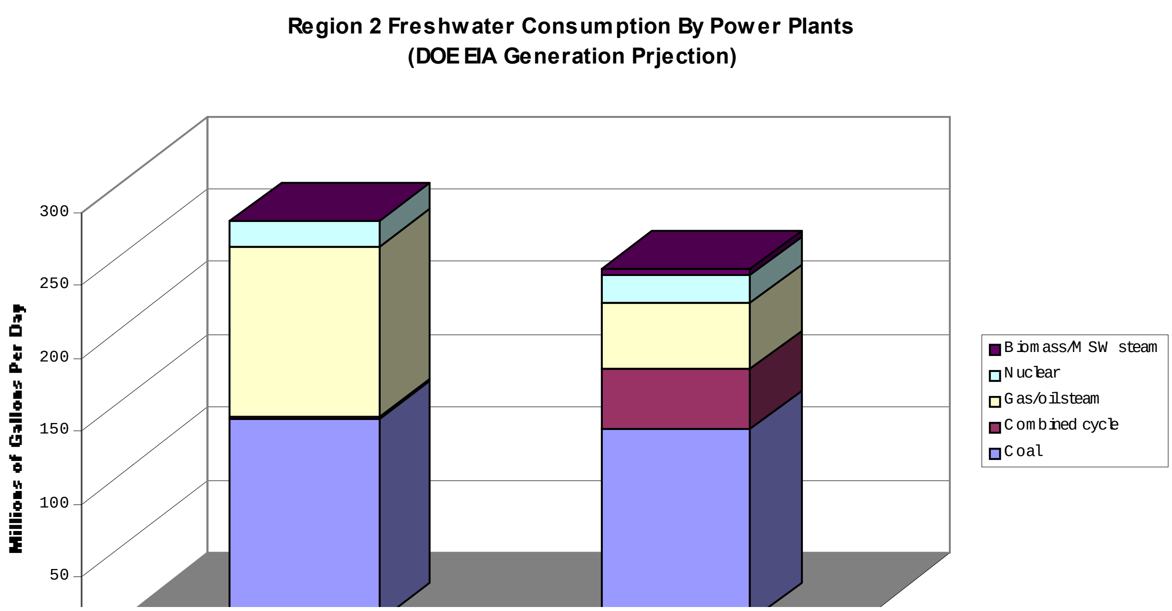

Figure 6-10
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC ERCOT Region; DOE EIA AEO2000 Generation Projection

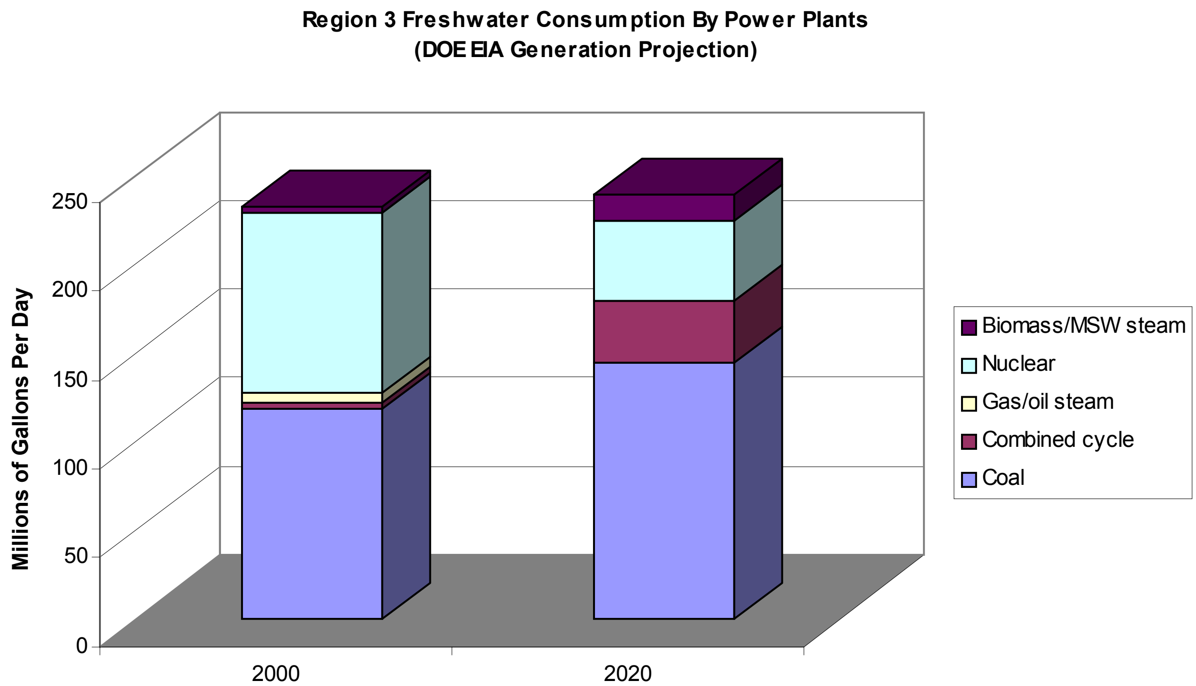

Figure 6-11
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC MAAC Region; DOE EIA AEO2000 Generation Projection

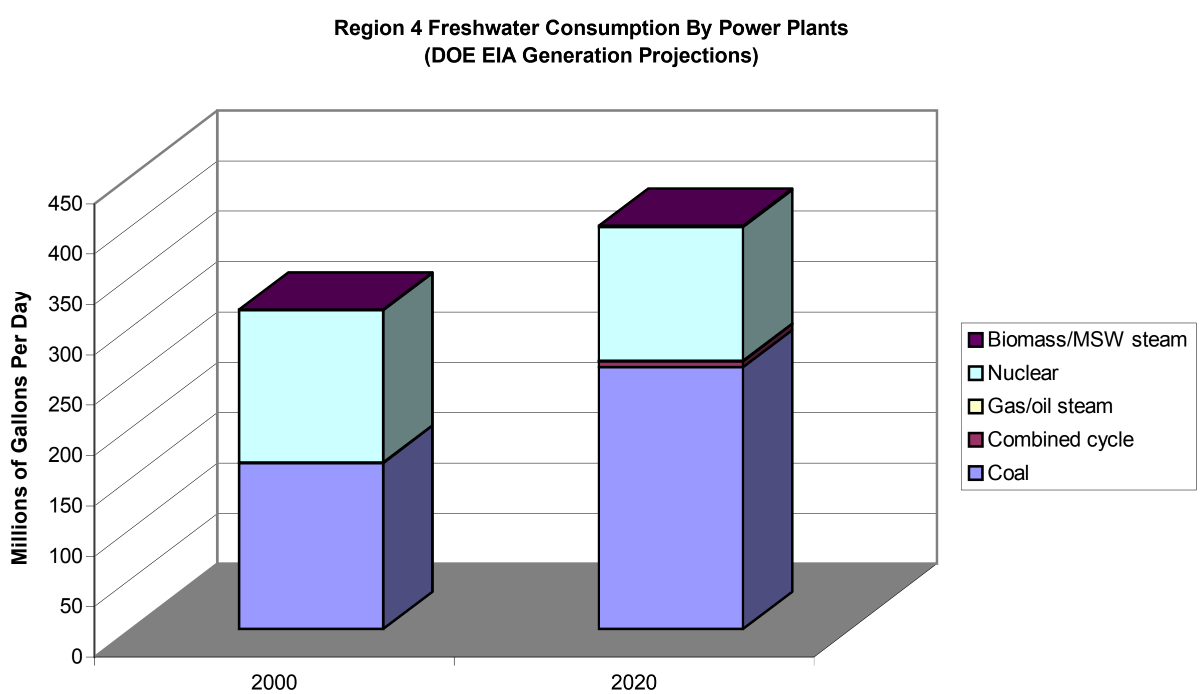

Figure 6-12
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC MAIN Region; DOE EIA AEO2000 Generation Projection

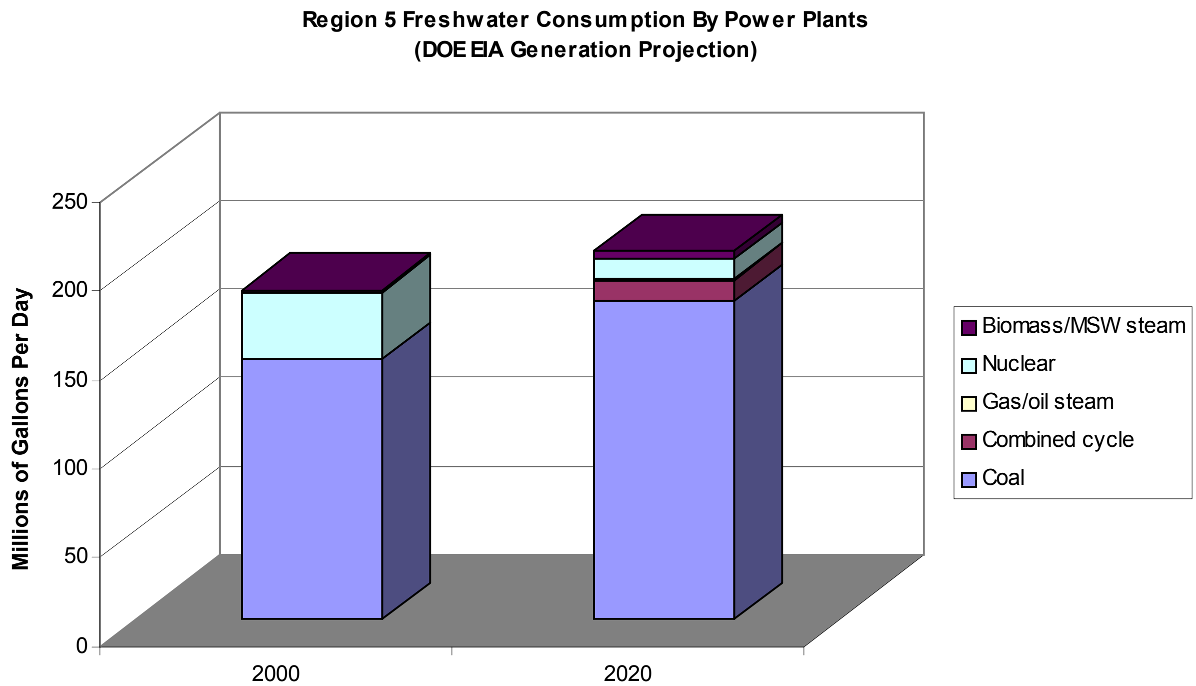

Figure 6-13
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC MAPP Region; DOE EIA AEO2000 Generation Projection

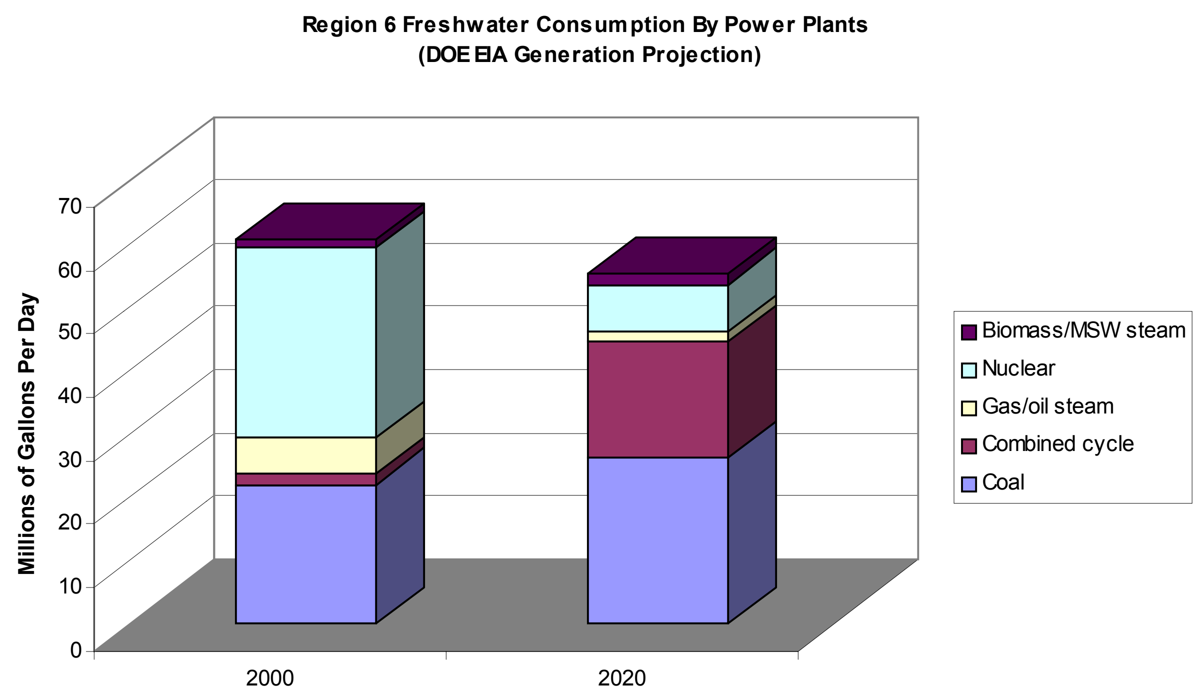

Figure 6-14
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the New York portion of NERC's NPCC Region; DOE EIA AEO2000 Generation Projection

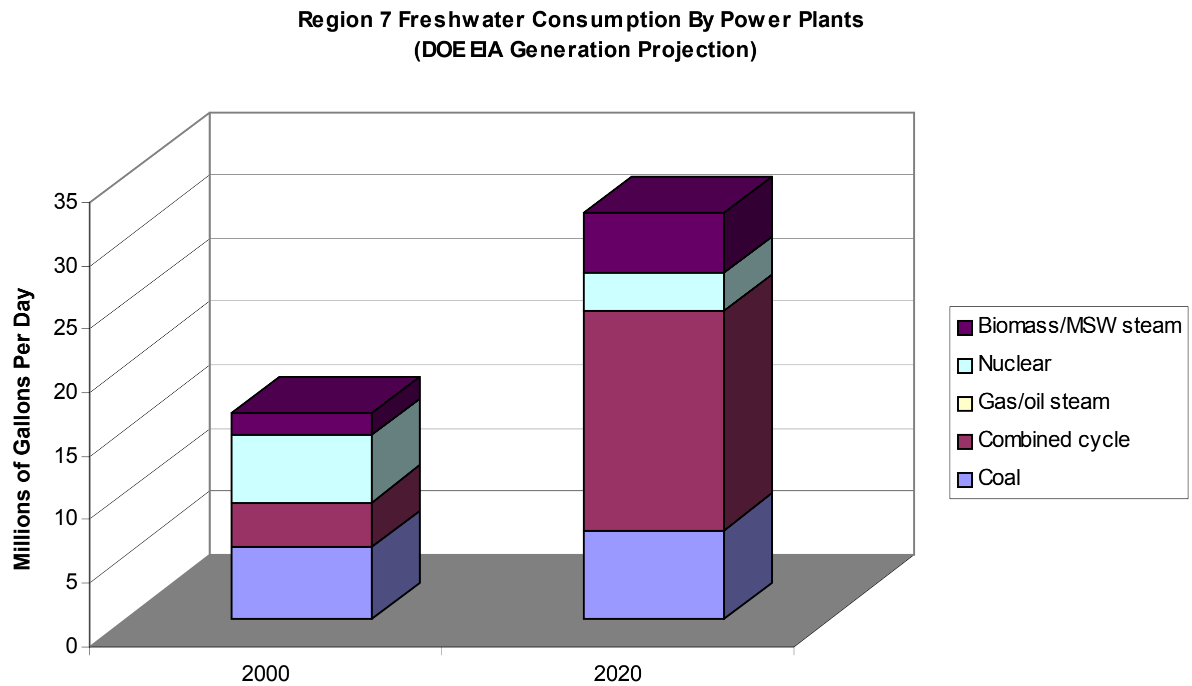

Figure 6-15
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the New England portion of NERC's NPCC Region; DOE EIA AEO2000 Generation Projection

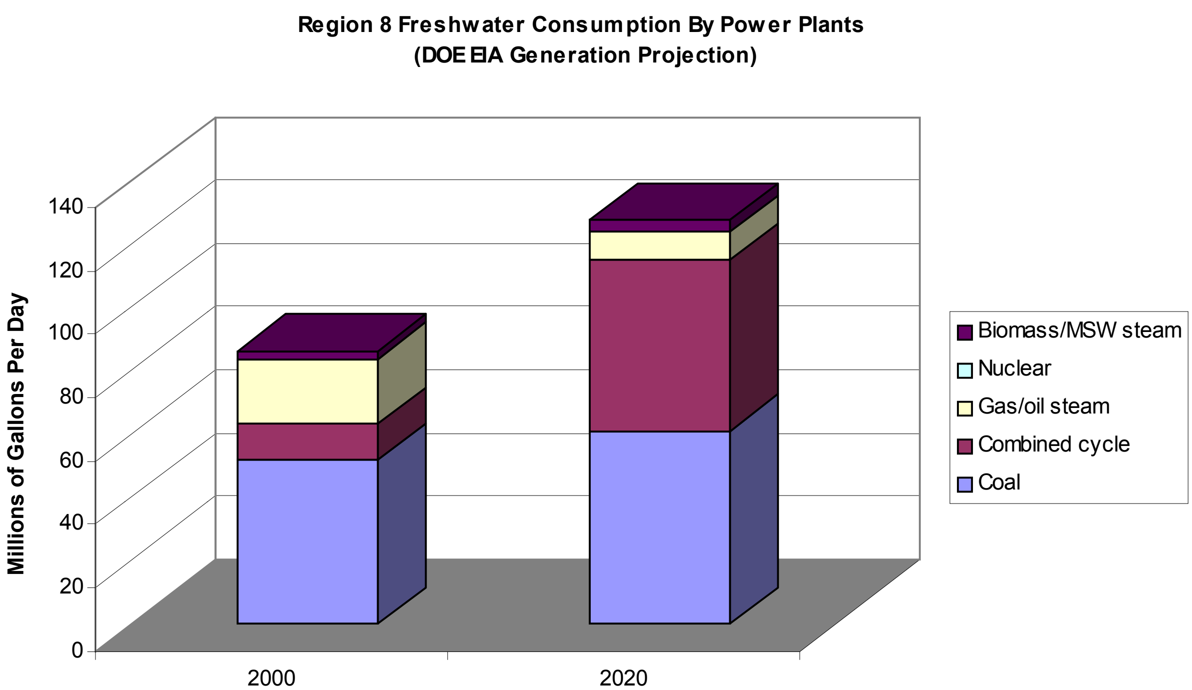

Figure 6-16
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the Florida portion of NERC's SERC Region; DOE EIA AEO2000 Generation Projection

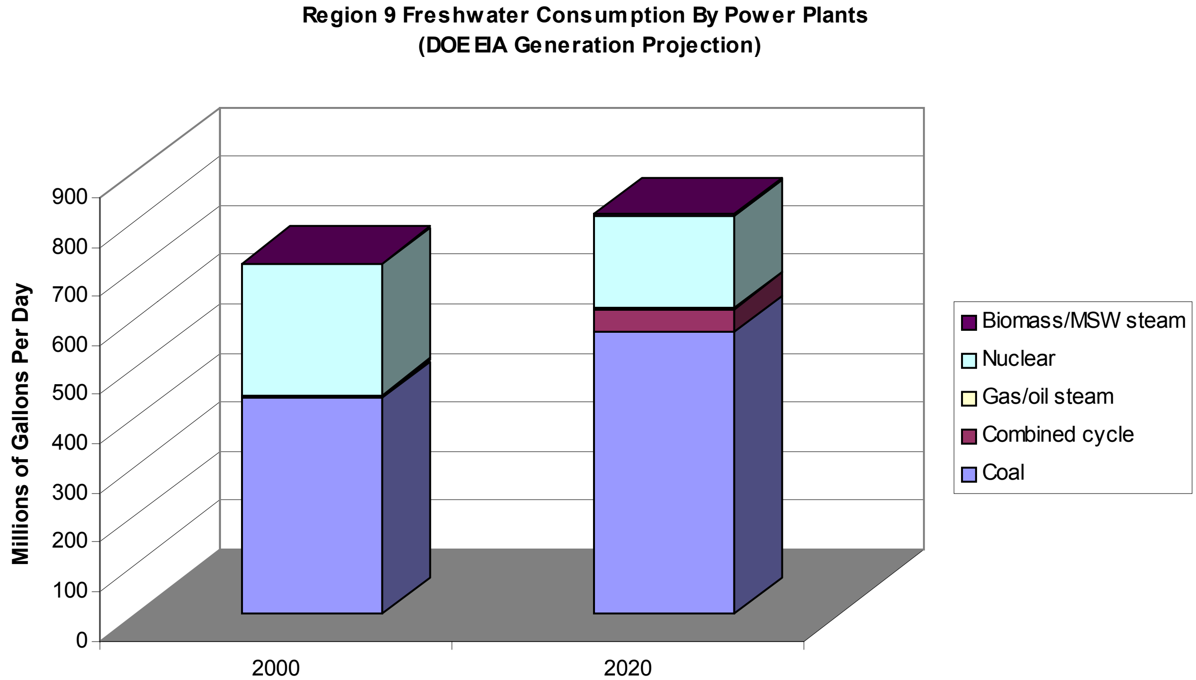

Figure 6-17
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the non-Florida portion of NERC's SERC Region; DOE EIA AEO2000 Generation Projection

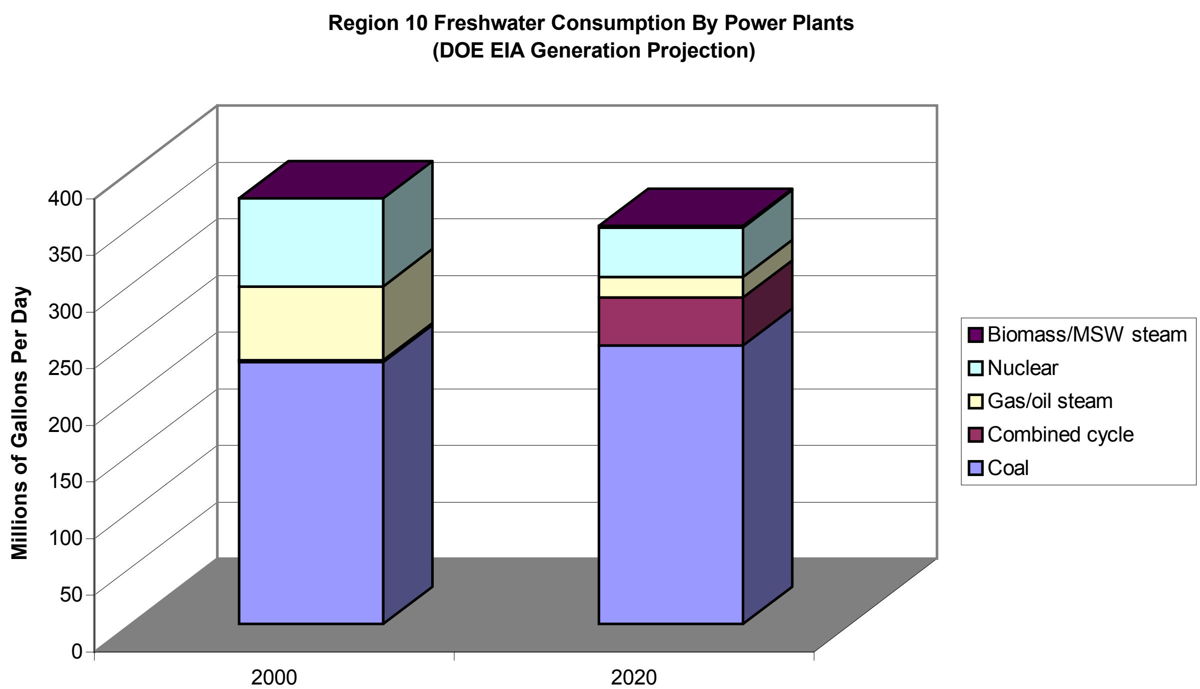

Figure 6-18
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the NERC SPP Region; DOE EIA AEO2000 Generation Projection

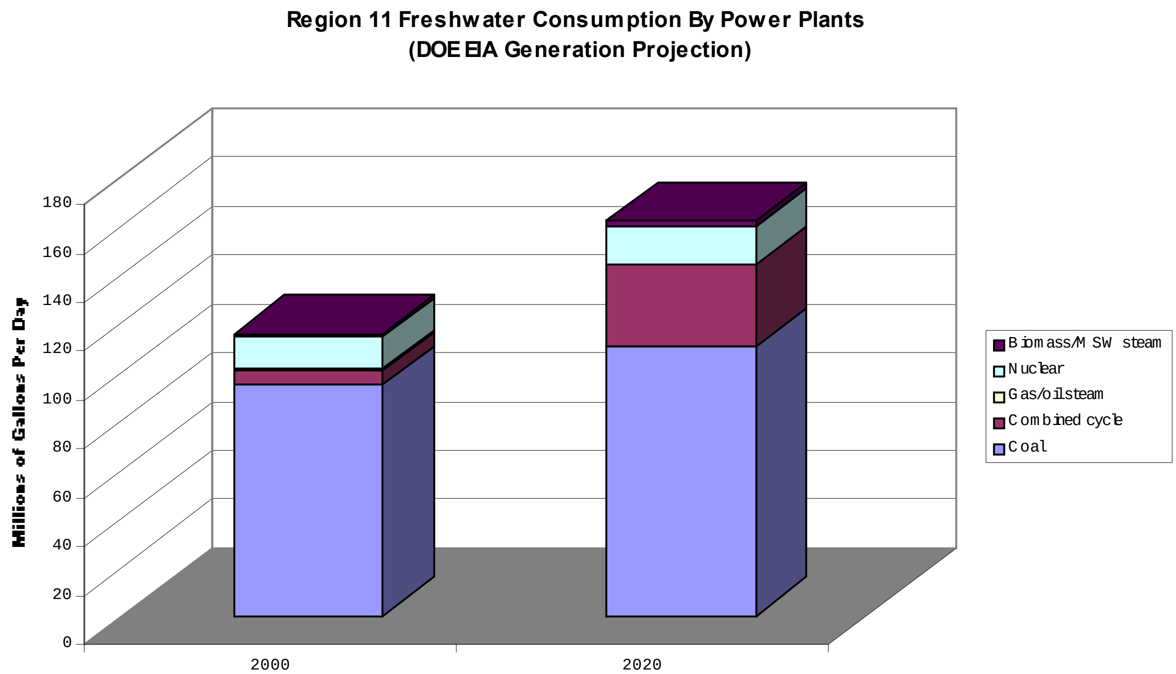

Figure 6-19
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the Northwest Power Pool area of NERC's WSSC Region; DOE EIA AEO2000 Generation Projection

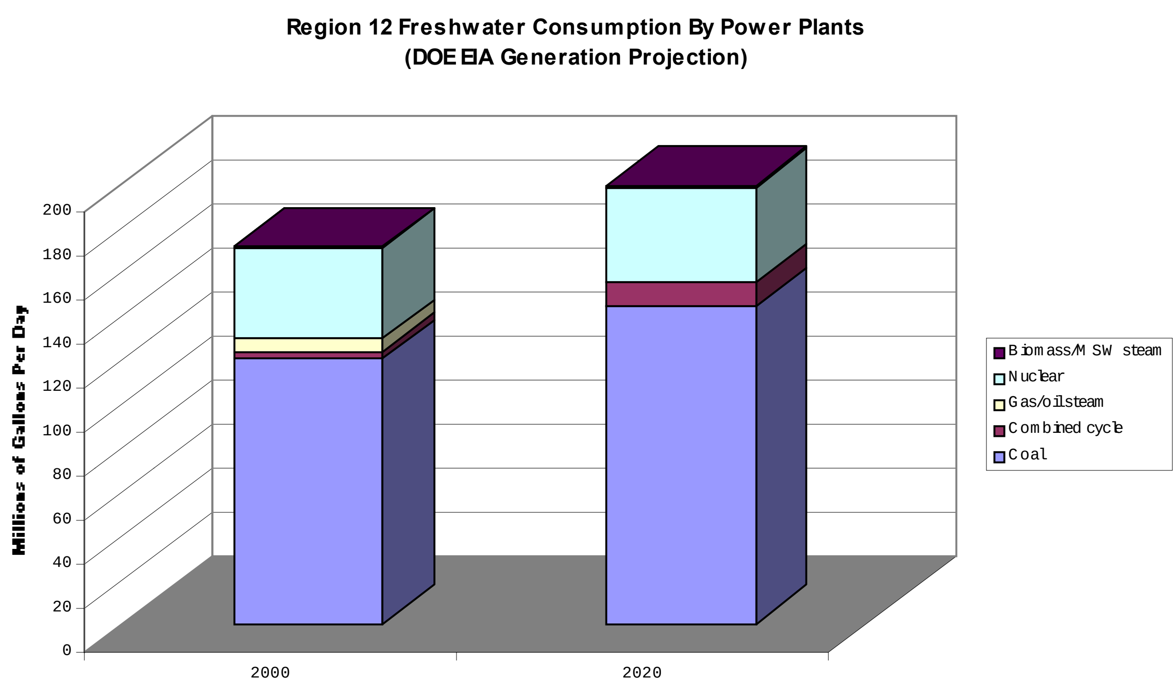

Figure 6-20
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the Rocky Mountain/Arizona areas of NERC's WSSC Region; DOE EIA AEO2000 Generation Projection

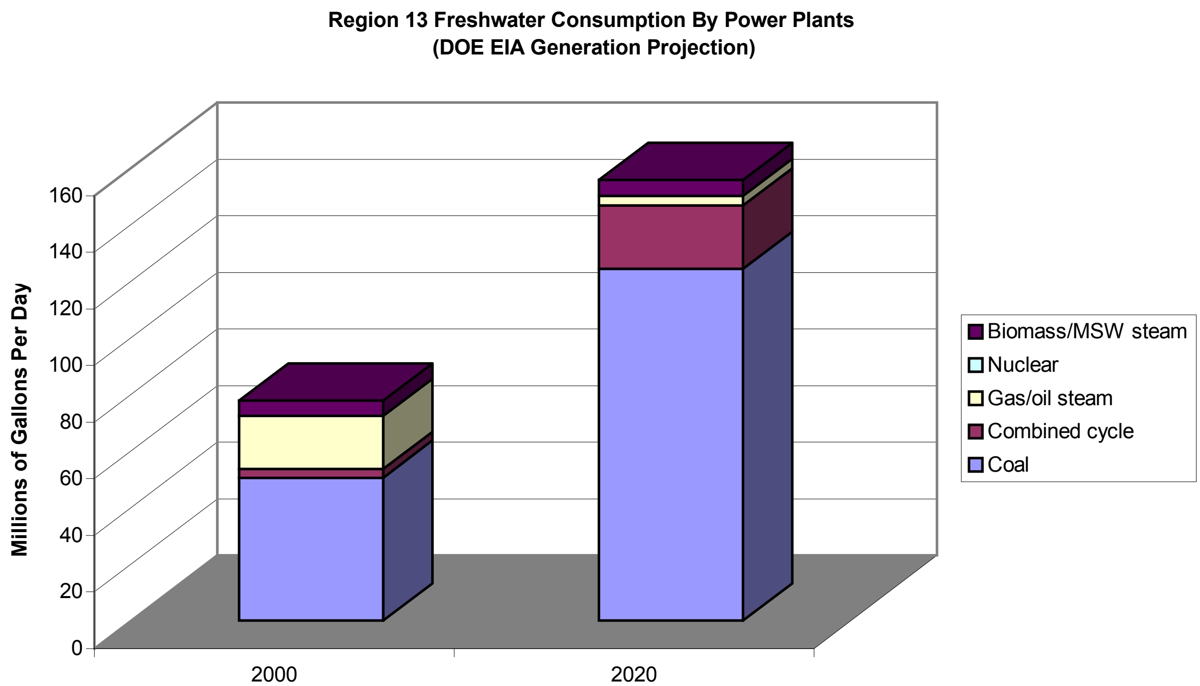

Figure 6-21
Power Plant Freshwater Consumption (Evaporation), by Plant Type, for 2000 and 2020, in the California and southern Nevada areas of NERC's WSCC Region; DOE EIA AEO2000 Generation Projection

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EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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