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ANL/EVS/TM/08-8

Baseline and Projected Water Demand Data for Energy and Competing Water Use Sectors

Environmental Science Division

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Baseline and Projected Water Demand Data for Energy and Competing Water Use Sectors

prepared for
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National Energy Technology Laboratory

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The author wishes to thank James Kuiper, Christina Colantoni, and Brian Cantwell of Argonne National Laboratory for their work in preparing the geographical information system maps for this study. Without these maps, the analysis of regional water demand trends would have been virtually impossible.

NOTATION

Acronyms and Abbreviations

AEO	Annual Energy Outlook
BLM	Bureau of Land Management
CO_2	carbon dioxide
CTL	coal to liquids
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EPAct	Energy Policy Act of 2005
NETL	National Energy Technology Laboratory
PEIS	Programmatic Environmental Impact Statement
RFS	renewable fuel standard
RPA	Resources Planning Act
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WRR	Water Resource Region

Units of Measure

ac-ft/yr	acre-feet per year
bbl	barrel(s)
bgd	billion gallon(s) per day
d	day(s)
ft	foot (feet)
ft^3	cubic foot (feet)
gal	gallon(s)
GJ	gigajoule(s)
gpd	gallon(s) per day
J	joule(s)
J(th)	joule(s) (thermal)
kg	kilogram(s)
L	liter(s)
m^3	cubic meters(s)
mgd	million gallon(s) per day
TCF	trillion cubic feet
yr	year(s)

SUMMARY

The links between energy and water and the growing concerns about the adequacy of U.S. water supplies point to the need for data on water consumption by potentially competing economic sectors. Projected water consumption estimates can help identify possible locations and time periods in which energy production could be constrained because of competition for limited water resources. This report provides estimates of domestic freshwater demand as expressed by consumption (not withdrawal) to the year 2030 in five-year increments at the national and regional levels for energy and nonenergy uses. This report was funded by the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) Existing Plants research program. This program has an energy-water research effort that focuses on water use at power plants. This study complements this research effort by placing water use by power plants into the larger context of water use by other energy and nonenergy sectors.

ENERGY AND NONENERGY SECTORS

Energy sectors for which water consumption estimates are made in this study include coal (mining and slurry transportation), oil (crude oil exploration and production, liquids from unconventional sources, and refining), gas (processing, pipeline transport, and gas from tight sands and shale), biofuels (biodiesel and ethanol production), and hydrogen production. Water consumption estimates for these sectors are developed by multiplying energy-production projections that come from the DOE's Energy Information Administration (EIA) by sector-specific coefficients that relate water consumption to energy production.

For comparison purposes, the study includes water consumption projections for thermoelectric power generation. These projections are taken directly from the 2007 NETL report, *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements, 2007 Update* (NETL 2007).

Nonenergy water demand sectors covered in this report are irrigation, domestic and public, industrial and commercial, and livestock. Consumption estimates for these sectors are based on projections provided in the technical document, *Past and Future Freshwater Use in the United States*, prepared by the U.S. Forest Service (USFS) to support its 2000 Renewable Resources Planning Act (RPA) Assessment (Brown 1999).

FINDINGS

On the basis of the analysis conducted in this study, water consumption in the United States can be expected to increase from about 114 billion gallons per day (bgd) in 2005 to about 136 bgd in 2030—an increase of nearly 20% over the 25-year period. Most of the consumption (averaging about 79% of nonenergy water consumption throughout the projection period) is for irrigation (Figure S-1). This irrigation consumption does not include the water consumed for energy crop irrigation, which is estimated separately and reported under the energy sector. After irrigation, the next highest—and fastest growing—water-consuming sector over the

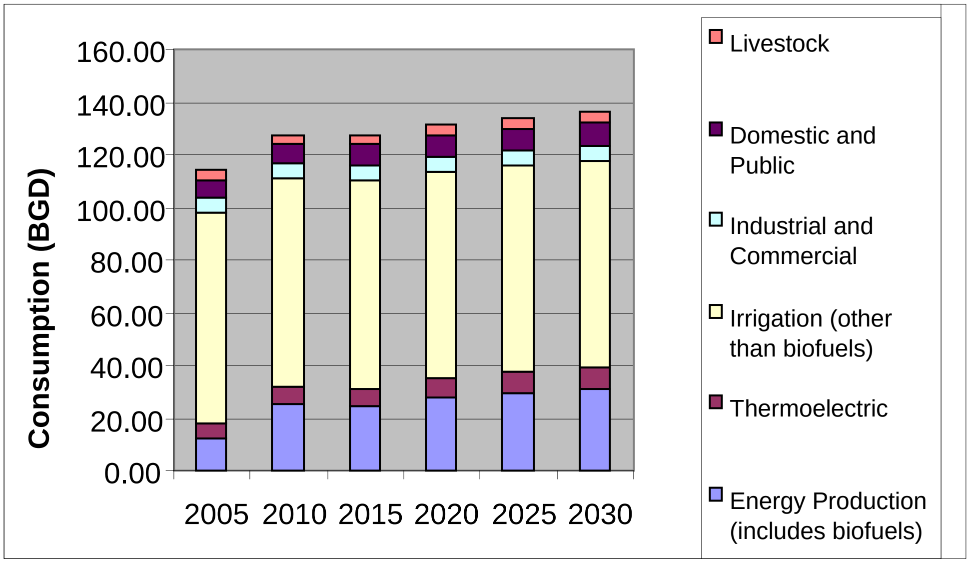

FIGURE S-1 Projected Trends in Water Consumption, 2005–2030

period is the energy-production sector. Water consumption for energy production is projected to nearly triple over the projection period—from about 12 bgd in 2005 to about 31 bgd in 2030.

High Water Consumption for Biofuels Production

Within the energy-production sector, biofuels production (ethanol and biodiesel) is projected to consume the greatest amounts of water, and most of this consumption is for energy crop irrigation. In 2030, water consumption for biofuels is projected to be about 26.3 bgd, with about 72% for ethanol and 28% for biodiesel. In 2005, total estimated water consumption for biofuels was 7.4 bgd, with about 80% for ethanol and 20% for biodiesel. Figure S-2 shows projected trends in water consumption for corn-based ethanol, cellulosic ethanol, and biodiesel production.

Key findings regarding biofuels water consumption include the following:

- *Corn-based ethanol.* Virtually all of the corn-based ethanol production is expected to occur in the West North Central U.S. Census Region (North Dakota, Minnesota, South Dakota, Iowa, Nebraska, Kansas, and Missouri). Water consumption in this region is projected to increase to nearly 19 bgd in 2030 (from 5.9 bgd in 2005) for ethanol production alone. This 12.9 bgd increase accounts for roughly 60% of the total projected nationwide increase in water consumption over the 2005–2030 period, and it is more than double the amount of water projected to be consumed for industrial and commercial use in 2030 by the entire United States.

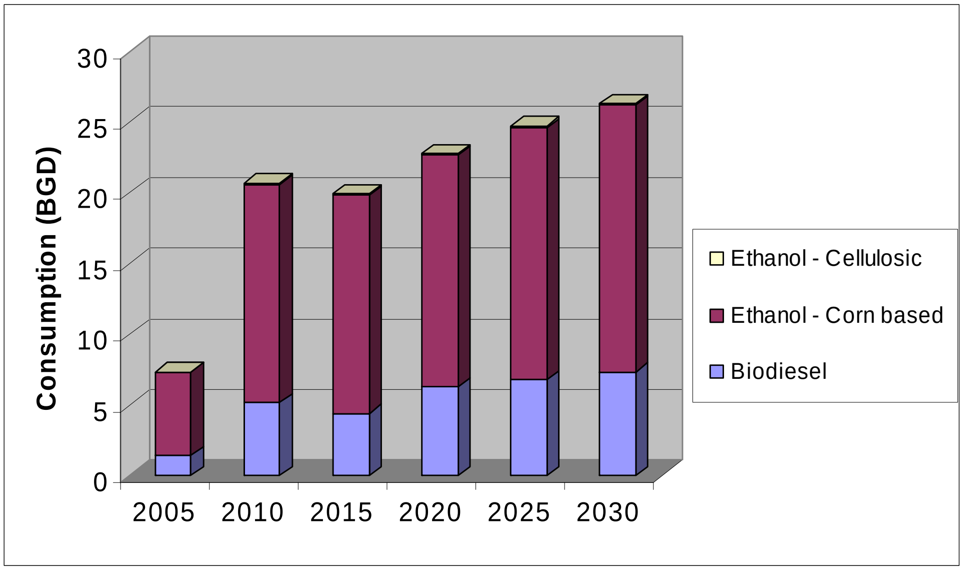

FIGURE S-2 Projected Water Consumption Trends for Biofuels Production, 2005–2030

- *Biodiesel.* Estimated water consumption for biodiesel production is projected to increase from about 1.5 bgd in 2005 to about 7.4 bgd in 2030. The regions projecting the highest consumption are the Pacific and West South Central U.S. Census Regions, where year 2030 water consumption for biofuels production is projected to be about 3.0 bgd and 2.0 bgd, respectively.

- *Cellulosic ethanol.* About 99% of the 0.1 bgd of water projected to be consumed for cellulosic ethanol in 2030 occurs in the Pacific U.S. Census Region, with the remainder in the South Atlantic U.S. Census Region. While both regions are expected to produce about 0.12 billion gal of cellulosic ethanol by 2030, water consumption is greater in the Pacific because of the need to irrigate.

- *Biomass.* Because the EIA assumes that energy crop production will be limited to areas that require no irrigation, this study does not project water consumption for the production of biomass used for power generation. It can be argued that the rainwater consumed for biomass production will not be available for groundwater recharge, thereby contributing to reduced groundwater flows. However, attempting to estimate the quantities of the rainwater that would unavailable for groundwater recharge is beyond the scope of this study.

The EIA's biofuels projections reflect the mandates of the Energy Policy Act of 2005 but not those of the Energy Independence and Security Act (EISA) of 2007, which requires increasing the minimum annual amounts of renewable fuels required in U.S. transportation fuels. Consequently, the water consumption estimates projected in this report may underestimate actual amounts if the EISA's requirements are met. At the same time, the water consumption projections in this report may overestimate actual amounts, because it is possible that the reference source for nonenergy water consumption estimates, the USFS, may already account for some portion of the requirements for biofuels production in its irrigation estimates. While virtually all parts of the country except for the Northeast and the East South Central U.S. Census Regions can expect increased water consumption for biofuels production, the greatest consumption is projected for the West North Central U.S. Census Region.

Non-Biofuels Energy Water Consumption Also High

Projected water consumption for other energy sectors, although less than that for biofuels, is still considerable relative to many other sectors. Indeed, projected water consumption for energy production, excluding biofuels, is comparable to that for both industrial and commercial use and for livestock use (Figure S-3). Trends in projected water consumption for energy sectors other than biofuels are shown in Figure S-4. Key findings for individual energy sectors include the following:

- *Oil.* By 2030, water consumption for oil refining is expected to increase to 1.5 bgd from 1.3 bgd in 2005, with most of the 2030 consumption projected to occur in the Gulf Coast (0.68 bgd) and the Midwest and West Coast Petroleum Administration for Defense Districts (PADDs) (about 0.29 bgd in each of these PADDs). At the same time, water consumption for oil exploration and production is projected to decrease to 1.3 bgd in 2030 from 1.5 bgd in 2005, in response to the projected decline in domestic oil production over the period.

- *Gas.* Estimated water consumption for conventional gas production (processing, transportation, and other gas plant operations) is projected to increase to about 1.63 bgd from 1.44 bgd in 2005. Most of this consumption is in the Rocky Mountain Oil and Gas Supply Region, where projected water consumption for conventional gas production is projected to increase by nearly one-third—from 0.32 bgd in 2005 to about 0.43 bgd in 2030. Water consumption for unconventional gas sources is low relative to that for conventional gas sources (about 0.002 bgd for tight sands and about 0.008 bgd for gas shale by 2030). Most of the tight sands gas production is expected to occur in the Rocky Mountain and Gulf Coast Oil and Gas Supply Regions; most of the water consumption for gas shale production is expected to occur in the Southwest and Northeast Oil and Gas Supply Regions.

- *Coal.* Projected water consumption for coal mining is low relative to that for biofuels, refining, and conventional gas production, but it is expected to increase at a faster rate in the 2025–2030 period than in the earlier part of the projection period. Areas with highest projected water consumption for coal mining by 2030 are the Northern and Central Appalachia, Eastern Interior, and Wyoming Coal Supply Regions.

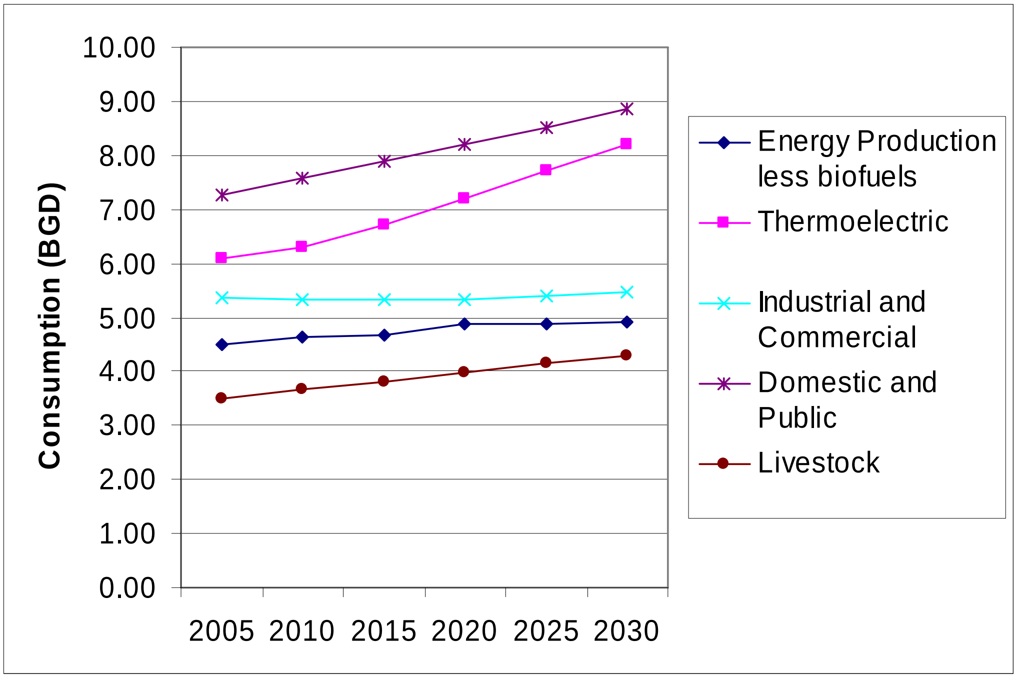

FIGURE S-3 Comparison of Projected Energy-Sector Water Consumption, Excluding Biofuels, with Nonenergy Sectors

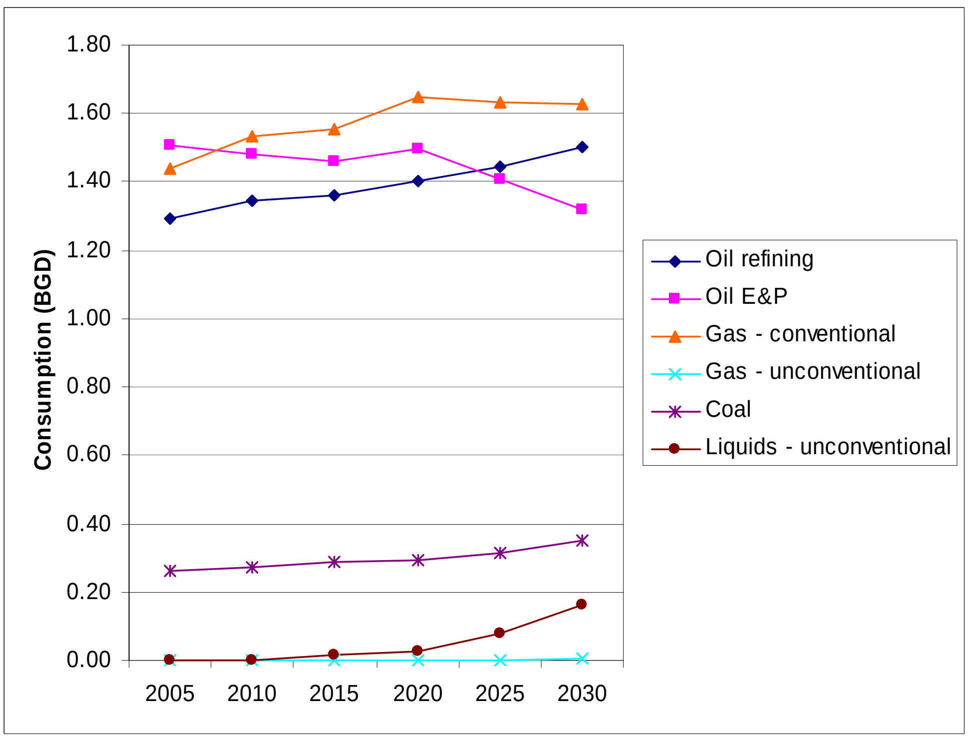

FIGURE S-4 Projected Water Consumption for Highest Water-Consuming Energy Sectors Other than Biofuels

- *Liquids from unconventional sources.* The production of liquid fuels from coal and oil shale consume large amounts of water, but because fuel production estimates for these two energy sources remain relatively low over the period, projected water consumption at the national level is also relatively low. Site-specific water demands can be significant, however, particularly in areas where water supplies are limited, such as parts of the Rocky Mountain states.

- *Hydrogen.* The water requirements for hydrogen production are high on a gallon-of-water-per-kilogram-of-hydrogen–produced basis. However, estimated national-level projected water consumption for this energy source is low, because hydrogen contributes relatively little to the energy mix over the projection period. Nonetheless, in several areas, including the Pacific and West-South Central U.S. Census Regions and in Hawaii, water consumption for hydrogen production is expected to be high.

Nonenergy Sector Consumption Relatively Stable

For nonenergy uses, total water consumption is projected to increase over the period by about 1.16 bgd—from 100.08 bgd in 2005 to 101.24 bgd in 2030. The relatively small overall increase (about 1%) in water consumption over the 25-year period, despite projected population increases, results largely from assumed continued water-use efficiency improvements expected in the municipal, industrial, and thermoelectric sectors. A reduction in total irrigation consumption of about 1.6 bgd by 2030 also contributes to the relative overall stability in nonenergy-related water consumption. The largest increases in projected nonenergy water consumption are for domestic and public uses (1.6 bgd—a 22% increase over the projection period) and livestock (0.8 bgd—a 23% increase over the period). Industrial and commercial water consumption is expected to increase by about 0.13 bgd—a 2% increase—over the 25-year projection period.

Regional Trends

For all sectors combined, there appears to be a shift in water consumption over the 2005–2030 period from the Northeast, and to a lesser extent, the Southeast—areas where water is relatively plentiful—to the Midwest and the West, where water supplies are of much greater concern. Nebraska and the West Coast states (California, Oregon, and Washington) are expected to be the highest water consumers in 2030. States (or portions of states) projected to experience significant increases in water consumption are California, Washington, Oregon, Nebraska, South Dakota, Minnesota, Iowa, and Missouri. With the exception of Florida, most of the Eastern states project lower consumption in 2030 than in 2005.

Much of the growth in water consumption projections comes from the energy sectors, and the highest demands and the greatest increases are projected for the North Central Region of the country due to high ethanol production projections in Nebraska, North Dakota, South Dakota, Minnesota, Iowa, Kansa, and Missouri. Many of the unconventional fuel resources (e.g., oil shale), which require significant water for production, are expected to be produced in Colorado, Utah, and Wyoming, where water resources are limited. By 2030, states with the highest projected water consumption by energy sectors include Nebraska, North Dakota, South Dakota, Minnesota, Iowa, Kansas, and Missouri—largely due to projected increases in biofuels production.

For the nonenergy sectors, there is relatively little change in projected water consumption patterns over the projection period. Exceptions are the Lower Mississippi Water Resource Region (WRR), which projects an increase in water consumption of about 2 bgd (a 23% increase) between 2005 and 2030; the Tennessee WRR, which projects an increase of about 0.05 bgd (18%); and the South Atlantic–Gulf WRR, which projects an increase of 0.09 bgd (17%) between 2005 and 2030. This overall relative stability is because the USFS (the source for the nonenergy consumption estimates) assumes continued improvements in water efficiency over the period (Brown 1999). By 2030, the WRRs projecting the highest water consumption for the nonenergy sectors are the California WRR (24% of the total), the Missouri Basin WRR (14% of the total), the Lower Mississippi WRR (11% of the total), and the Pacific Northwest WRR (9% of the total). These regions also have the highest irrigation demands.

CAVEATS

Several caveats must be considered when regarding the findings reported in this study. A key caveat for comparing water consumption by energy and nonenergy water sectors is that the data come from different sources with different assumptions. For example, to obtain the total estimated 2030 water consumption, the NETL projections of thermoelectric water consumption were substituted for those provided by the USFS. However, the assumptions used to produce the NETL projections of water consumption for thermoelectric power likely differ from those used by the USFS. Further, there is likely overlap among some nonenergy sectors and some of the energy-production sectors. For example, water consumption for coal mining may be included in both the energy-production category (developed in this report) and the industrial category (projected by the USFS).

Second, assumptions made in original source data and in this report may be inaccurate or subject to change. Third, in addition to the assumptions embedded in the original data sources, many of the calculations in this study required the making of additional assumptions. Although made on the basis of the best data and information available at the time, these assumptions may be incorrect, and even if they are correct today, they may change with time. The compounding of assumptions made in this report with those made in the original data sources likely weakens the robustness of the ultimate estimates and projections. As a result, the conclusions presented in this report should be viewed as one possible indicator of potential trends and areas of concern regarding U.S. water consumption.

An estimation of the effects of changing the assumptions used in this analysis is beyond the scope of this report. However, conducting a series of sensitivity analyses—that is, calculating the quantitative impacts of modifying the assumptions on the resulting estimates—could help identify the relative impacts of changing assumptions on water consumption estimates and trends both within specific sectors and on the relative contributions of individual sectors to total water consumption at the national and regional levels. The conduct of such a follow-up analysis is recommended.

1 INTRODUCTION

In September 2007, the National Energy Technology Laboratory (NETL) issued a report, *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements* (NETL 2007). This report updated an August 2006 NETL report of the same title. In both reports, which estimate future freshwater needs for coal-fired power generation and for total thermoelectric power generation, NETL noted the importance of competing water uses. It stated:

> "Concerns over limited water quantities are not restricted to thermoelectric generation . . . Water availability and its withdrawal and consumption are top priorities on the public agenda in many nations throughout the world. It is likely that the issue will also filter to the top of the U.S. public agenda in the near future. In water-stressed areas of the country, power plants will increasingly compete with other water users."

Information on the current and projected extent and location of water demand by competing users can help identify potential constraints on energy supply and production. Such knowledge can help decision makers develop policy and technology recommendations to avoid potential supply issues and ensure that the nation's energy demands are met in a cost-effective manner. This report provides information for identifying possible water use conflicts and suggests areas that may warrant more detailed investigations. The report was funded by NETL's Existing Plants research program, which has an energy-water research effort that focuses on water use at power plants. This study complements this research effort by placing water use by power plants into the larger context of water use by other energy and nonenergy sectors.

This report estimates freshwater consumption to the year 2030 in five-year increments by region for energy and nonenergy sectors. Because the audience for this report is energy-oriented, water consumption is reported at a more disaggregated level for the energy sectors than for the nonenergy sectors. Thus, water demand is projected for coal (mining and slurry transportation), oil (crude oil exploration and production, liquids from unconventional sources, and refining), gas (processing, pipeline transport, and gas from tight sands and gas shale), biofuels (biodiesel and ethanol production), and hydrogen production. For comparison purposes, water consumption projections are presented for thermoelectric power generation, but, unlike the other energy water consumption estimates made in this study, the water consumption projections for power generation are taken directly from NETL (2007).

This study also provides nonenergy water demand projections for irrigation, livestock, domestic and public, and industrial and commercial uses. These projections are derived from the U.S. Forest Service Year 2000 Resources Planning Act (RPA) Assessment of Forest and Rangeland (USFS 2000) and its supporting documentation (Brown 1999).

In this report, unless indicated otherwise, the term "water demand" refers to water consumption. Water consumption is the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. (Water withdrawal is water removed from the ground or diverted from a surface water source for use.)

The remainder of this report contains four chapters. Chapter 2 describes the general approach for developing the water demand projections; Chapter 3 presents the estimated water consumption projection results for the energy sectors and describes the assumptions and methodologies used to derive those projections; Chapter 4 describes the assumptions and projections for the nonenergy sectors; and Chapter 5 compares energy and nonenergy water consumption projections. Appendix A contains maps of the various regions for which water demand is reported. Appendices B through F explain the calculations used to derive energy sector–specific water-use coefficients, and Appendix G provides base year (2005) and year 2030 water consumption estimates for the nonenergy sectors.

2 APPROACH

The approach for estimating water consumption for the energy sectors in this report is similar to that used by NETL (2007) for thermoelectric generation. That is, water demand is correlated with energy projections developed by and presented in the EIA's *Annual Energy Outlook 2007* (EIA 2007a), or AEO 2007, reference case scenario. AEO 2007 provides long-term projections of energy supply, demand, and prices in five-year increments through 2030. These projections are based on results from EIA's National Energy Modeling System and are updated each year to reflect changes in energy prices, the influence of developing countries on worldwide energy requirements, recently enacted legislation and regulations, and changing public perceptions of issues related to the use of alternative fuels, emissions of air pollutants and greenhouse gases, and the acceptability of various energy technologies, among other factors (EIA 2007a). In this study, EIA's energy-sector projections are multiplied by corresponding water-demand coefficients to obtain estimates of water demand for each energy sector. A water-demand coefficient is a ratio of the amount of water consumed (in gallons) to a specific energy-related process—for example, tons of coal mined, barrels of oil produced, or gallons of ethanol produced. The water-demand coefficients are taken directly or are derived from information in a variety of existing studies, which are referenced in the sector-specific discussions in Chapters 3 and 4. When necessary, these coefficients are modified, for example, to allow for reporting in consistent units.

2.1 NATIONAL AND REGIONAL-LEVEL PROJECTIONS

For each energy sector, this report estimates base-year (2005) national-level water demand for the AEO 2007 reference case and projects estimated water demand in five-year increments through 2030. The reference case is based on the assumption that current policies affecting the energy sector remain unchanged throughout the projection period. The report also estimates regional-level water demand for the same years, where AEO energy projections at the regional level are available. As with NETL 2007, the regions reported in this study are those used in the AEO. Unfortunately, the states and portions of states included in these regions vary among energy sectors. For example, while thermoelectric power generation is reported for the former 13 North American Electric Reliability Council (NERC) control regions, hydrogen production is reported according to the U.S. Census Regions. Table 2-1 identifies, for each energy sector, the regional levels for which EIA provides energy projections, and hence the levels for which water-demand projections are reported. Appendix A contains maps showing the regional reporting levels.

The projections for nonenergy sectors come from a study prepared by the USFS (Brown 1999) that estimated freshwater demands for aggregated demand categories through 2040. The study, *Past and Future Freshwater Use in the United States*, was prepared as a technical support document to the 2000 USFS assessment (USFS 2000) of renewable resources required by the RPA. The study, hereafter referred to as the RPA study, projected water demand on the basis of extrapolations of historical U.S. Geological Survey (USGS) water use data, assuming that water-use efficiency trends would continue into the future. Because the USGS has changed its water-use reporting categories over time, the reporting categories have been

TABLE 2-1 Regional Reporting Levels for Water Demand Sectors

Sector	Regional Level
Coal	Coal Supply Region
Oil exploration and production	Oil and Gas Supply Model Region
Coal to liquids	Oil and Gas Supply Model Region
Oil Shale	Petroleum Administration for Defense District
Petroleum refining	Petroleum Administration for Defense District
Conventional gas production	Oil and Gas Supply Model Region
Unconventional gas production	Oil and Gas Supply Model Region
Biofuels	U.S. Census Region
Hydrogen	U.S. Census Region
Nonenergy sectors	Water Resource Region
Thermoelectric power generation	North American Electric Reliability Council Region

aggregated to allow comparisons on a consistent basis over time. The RPA study, and hence this study, report water demand for the following nonenergy sectors: irrigation, livestock, domestic and public supply, and industrial (including mining) and commercial.

2.2 WATER CONSUMPTION DATA MANAGEMENT AND DISPLAY

Location-specific analyses of water consumption and the maps developed for this report were made using a Geographic Information System (GIS). Maps and data corresponding to the regions listed in Table 2-1 were converted to GIS "layers" that could be superimposed on the same map. In some cases, data were available in GIS format, while in others it was necessary to manually create GIS layers from the map files themselves. Each GIS layer was converted to the Albers Equal Area Conic map projection, centered on 96° west longitude. Except for cases of offshore energy production, portions of GIS layers extending beyond the U.S. state boundaries or into coastal waters were removed using the GIS "clip" function so that boundaries from the various sources would match and could be compared directly. Within the GIS layers, each unique area was stored as a polygon, and tabular information such as the region name was linked. Next, values for projected water consumption were added to the tables in preparation for analysis of the combined water consumption among the separate layers.

Regions in each layer varied in size and shape. To estimate the combined water demand, it was assumed that water consumption within regions was uniformly distributed. For example, it was assumed that water consumption for coal production in each Coal Supply Region was uniformly distributed in that region. The water consumption values were divided by the region areas to yield density values of water consumption per unit area. To determine the combined water consumption, the GIS "union" function was used with the set of layers being analyzed. This function combines the boundaries among all the layers, subdividing them where they overlap and preserving the table information. Each unique area among all the layers becomes a separate polygon in the output layer with the table information from each contributing layer. The GIS automatically calculated the area of the new polygons in the output layer. Each water consumption density value was then multiplied by the updated area of its corresponding polygon to determine an estimated total. The totals for each region type were then summed to determine the total water consumption within each polygon. This resulted in the total water consumption layer depicted in Figure 2-1.

The total water consumption layer was analyzed and summarized for year 2005 reported values and 2030 projections, and for specific energy sectors. Values were also aggregated by U.S. Census Regions, such as in Figure 2-2, which shows the regional distribution of estimated water consumption for all biofuels (corn-based and cellulosic ethanol and biodiesel) for 2005 and 2030, by using the GIS “summary” function to combine the polygons and total water consumption statistics for each U.S. Census Region.

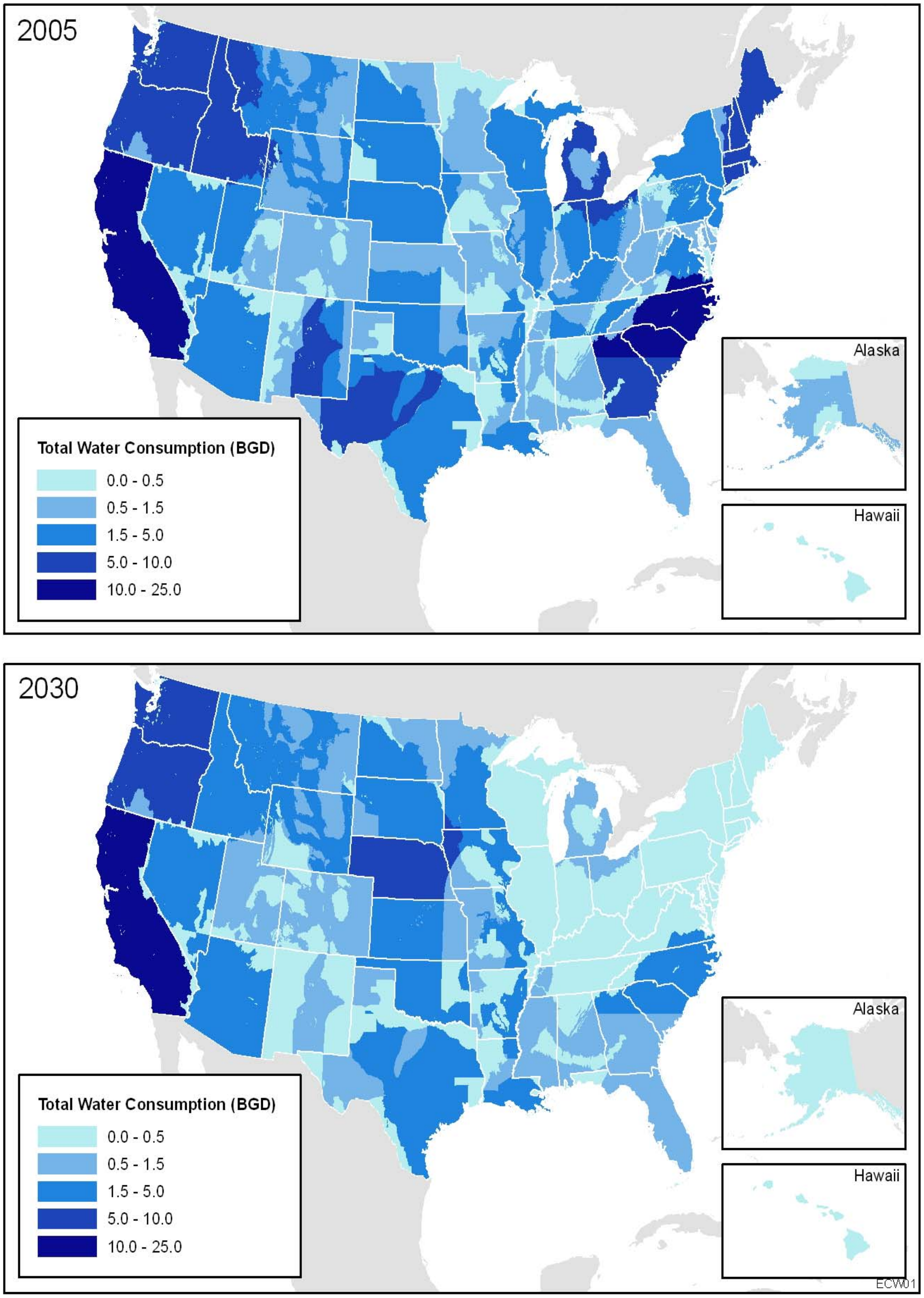

FIGURE 2-1 Comparison of Water Consumption Projections for All Sectors, 2005 and 2030

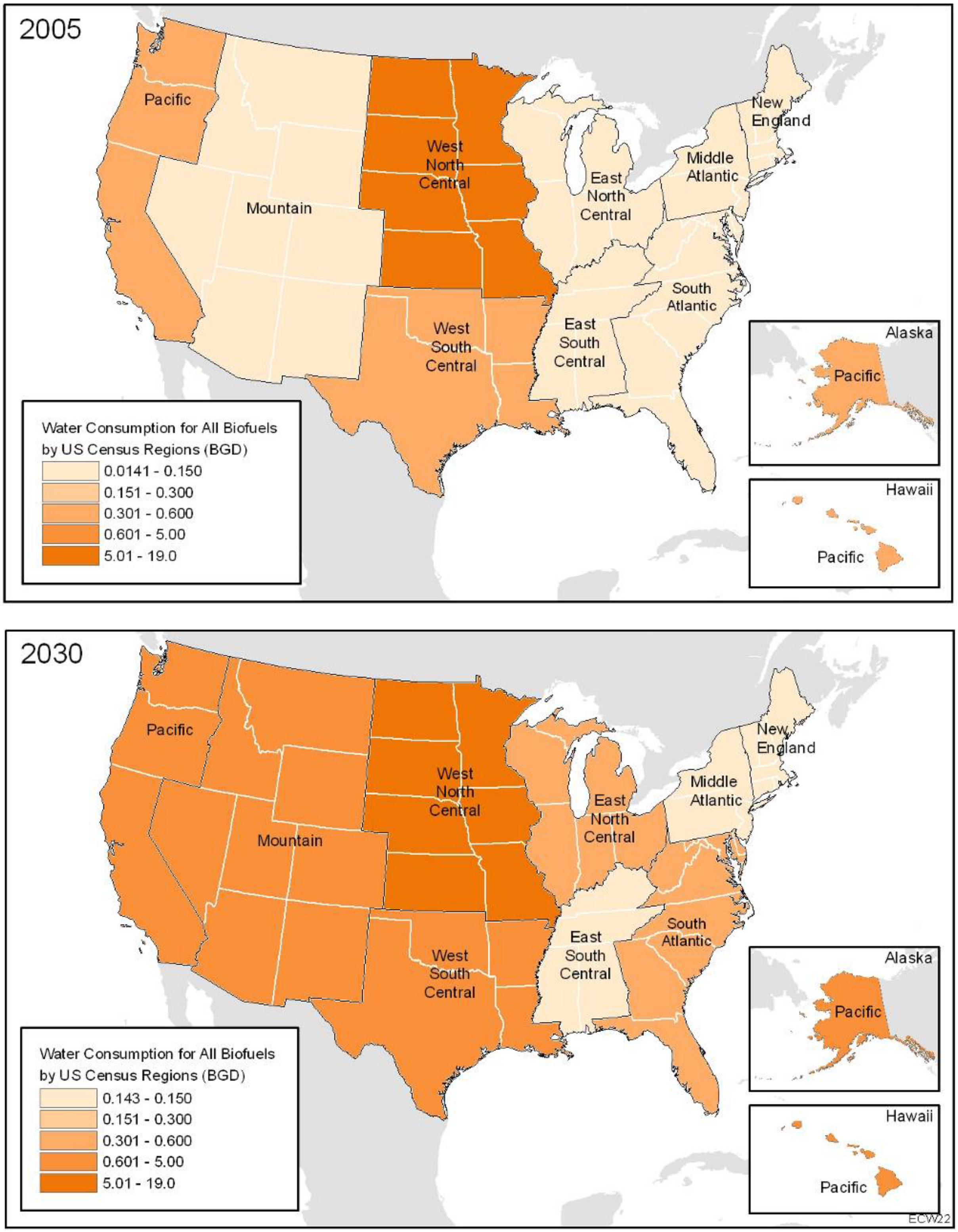

FIGURE 2-2 Estimated Water Consumption for Biofuels Production by Region, 2005 and 2030

3 WATER DEMAND PROJECTIONS FOR ENERGY SECTORS

Water consumption for all energy-producing sectors (Table 3-1) is projected to nearly triple—from about 12 bgd in 2005 to about 31 bgd in 2030. By far the most significant contributor to these consumption estimates is the production of biofuels (ethanol and biodiesel). In 2005, biofuels production consumed an estimated 7.4 bgd (62% of total consumption for energy production); by 2030, it is projected to consume an estimated 26.3 bgd (84% of total consumption for energy production) (Figure 3-1). In 2030, roughly 72% (18.9 bgd) of the total water consumption for biofuels is for ethanol and 28% (7.4 bgd) is for biodiesel.

After biofuels, the next highest water-consuming energy-production sectors are oil refining, gas plant operations (about 1.5 bgd [11%] each), and crude oil production (about 1.3 bgd). The water consumption estimates for crude oil production were developed under the assumption that all of the water used in enhanced oil recovery is freshwater. However, a significant, but unknown, portion of this consumed water is not freshwater, but produced water (i.e., water that is pumped up from an oil well together with oil, gas, or other hydrocarbons).

Figure 3-2 shows the dramatic increase in water consumption expected by energy production over the time period. It grows faster than any other sector, and it is higher than that for any other sector except irrigation.

At the regional level, the energy-production sector with potentially the most significant impacts on water consumption is ethanol. Over the projection period, nearly 99% of the water consumed for corn-based ethanol is projected to occur in the West North Central U.S. Census Region, with relatively small amounts in several other regions. For cellulosic ethanol, most of water consumption (about 99%) occurs in the Pacific Region, with the remainder in the South

TABLE 3-1 Energy Sectors for Which Water Demands Are Estimated

Energy Sector	Components
Coal	Mining
	Transportation (slurry pipeline)
Oil	Crude oil exploration and production, including enhanced oil recovery (water flooding, and thermal steam and CO_2 injection)
	Liquids from unconventional sources (coal to liquids, oil shale)
	Refining
Gas	Conventional production (gas processing, pipeline transport, and other plant operations)
	Unconventional production (tight sands and gas shale)
Biofuels	Biodiesel
	Ethanol (corn-based and cellulosic)
Hydrogen	Production
Thermoelectric[a]	Power generation

[a] Projections are taken from NETL (2007).

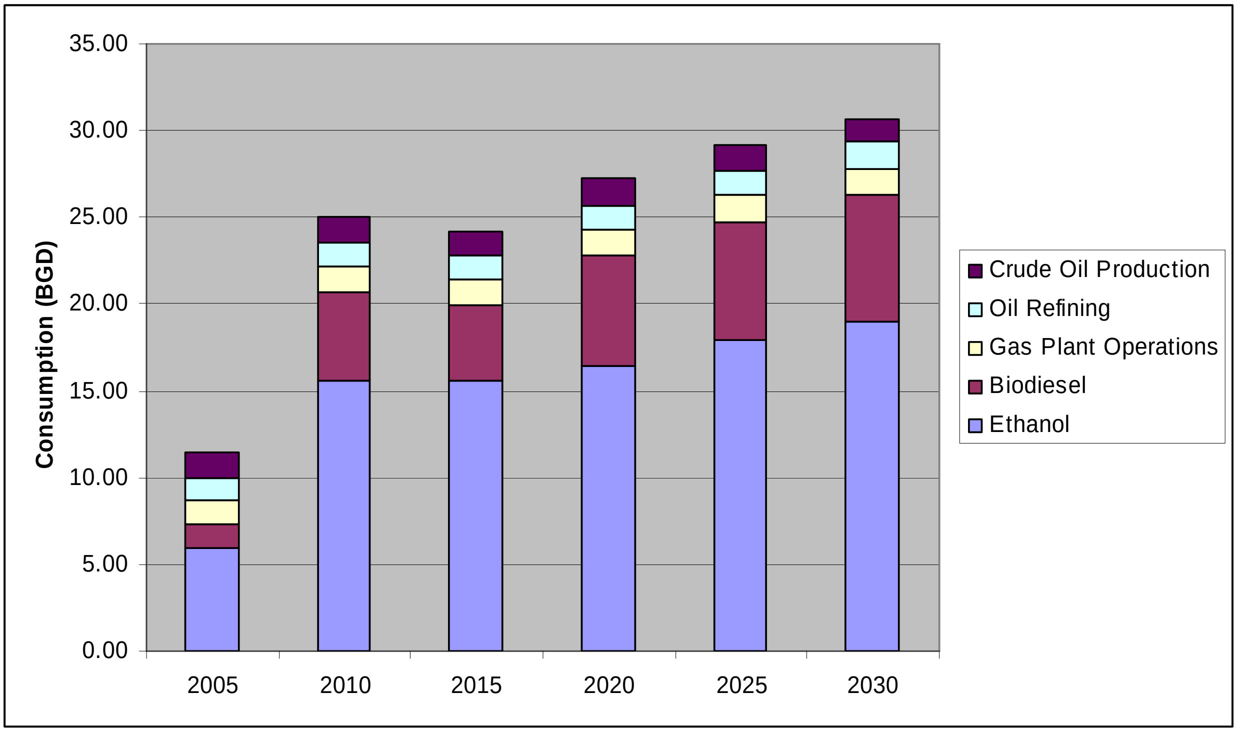

FIGURE 3-1 Projected Water Consumption for Highest Water-Consuming Energy Sectors

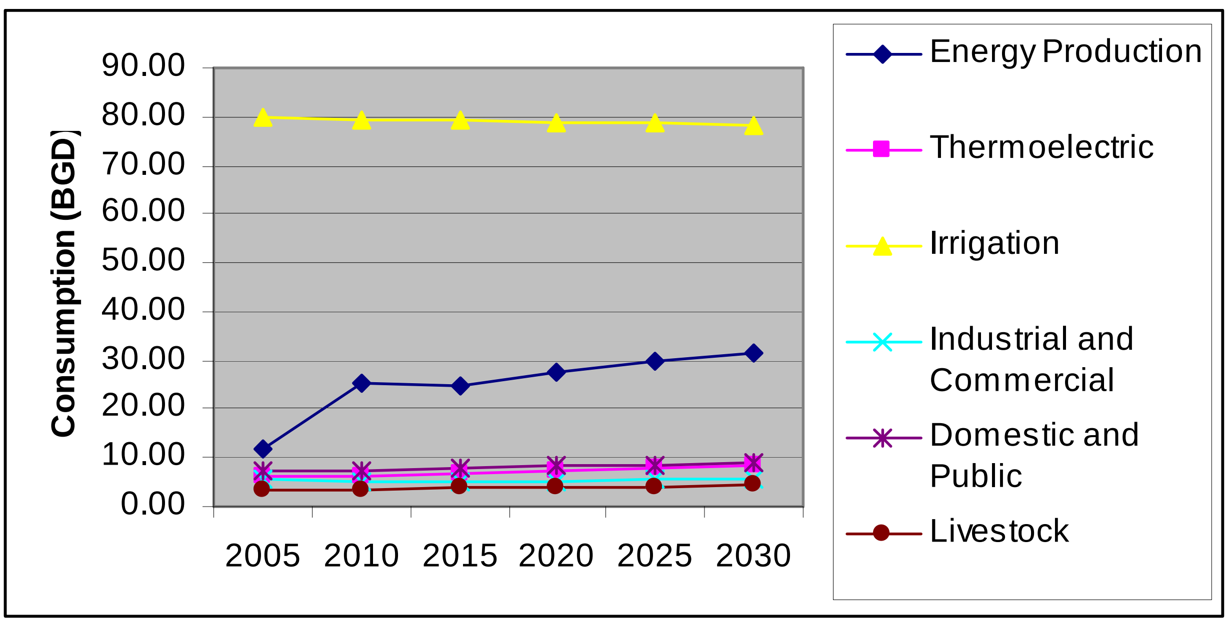

FIGURE 3-2 Projected Water Consumption Estimates, Energy and Nonenergy Sectors (Sources: Brown 1999 for industrial/commercial, irrigation, domestic/public, and livestock data; NETL 2007 for thermoelectric data)

Atlantic Region. While both regions are expected to produce about 0.12 billion gal of cellulosic ethanol by 2030, water consumption is greater in the Pacific because of the need to irrigate. Estimated water consumption for biodiesel production increases from about 1.5 bgd in 2005 to about 7.4 bgd in 2030. The regions with the highest projected consumption are the Pacific and West South Central Regions, where consumption in 2030 is projected to be about 3.0 bgd and 2.0 bgd, respectively.

Production of unconventional fuels, which consumes large amounts of water on a per-British thermal unit (BTU) basis, is not expected to be a major water consumer by the end of the projection period. Nonetheless, some of the unconventional fuel resources to be developed (e.g., shale oil) are in areas such as Colorado, Utah, and Wyoming, where water resources are limited.

Although water consumption for conventional gas production is projected to decrease slightly after 2020, the projected consumption for 2030 is still roughly 13% higher than in 2005. More significantly, the increase in water consumption for certain regions is much greater. For example, in the Rocky Mountain Region, projected water consumption for conventional gas production increases by nearly one-third—from 0.32 bgd in 2005 to about 0.43 bgd in 2030. Figure 3-3 compares estimated regional water consumption by all energy producing sectors in 2005 and 2030.

The remainder of this chapter addresses each of the energy sectors listed in Table 3-1. Each of these sections identifies how water is used and describes the sector-specific findings in terms of expected future demand projections at the national and regional levels. Factors that could change water demand, potential concerns, and noteworthy trends are discussed, and the assumptions used to estimate water demand projections are identified.

3.1 COAL

Water demand for coal occurs during mining and transportation via slurry pipeline. Projections for each are described in the following sections.

3.1.1 Mining

Coal mining and reclamation of mined land are water intensive, with the amount of water needed depending on the method used to mine the coal and the extent of coal washing required. During mining operations, water is used for cooling and lubricating cutting and drilling equipment and for suppressing dust during mining and hauling activities. Coal washing, which is conducted to increase the heat content and partially remove sulfur, is typically used with eastern and interior coals. Western coals are generally found in homogeneous seams with low sulfur content and, therefore, do not generally require washing. According to NETL (2006), roughly 80% of the coal mined in Appalachia and in the Interior is washed. The amount of water used in the reclamation and revegetation of surface mines varies with coal properties, mining waste disposal method, and mine location.

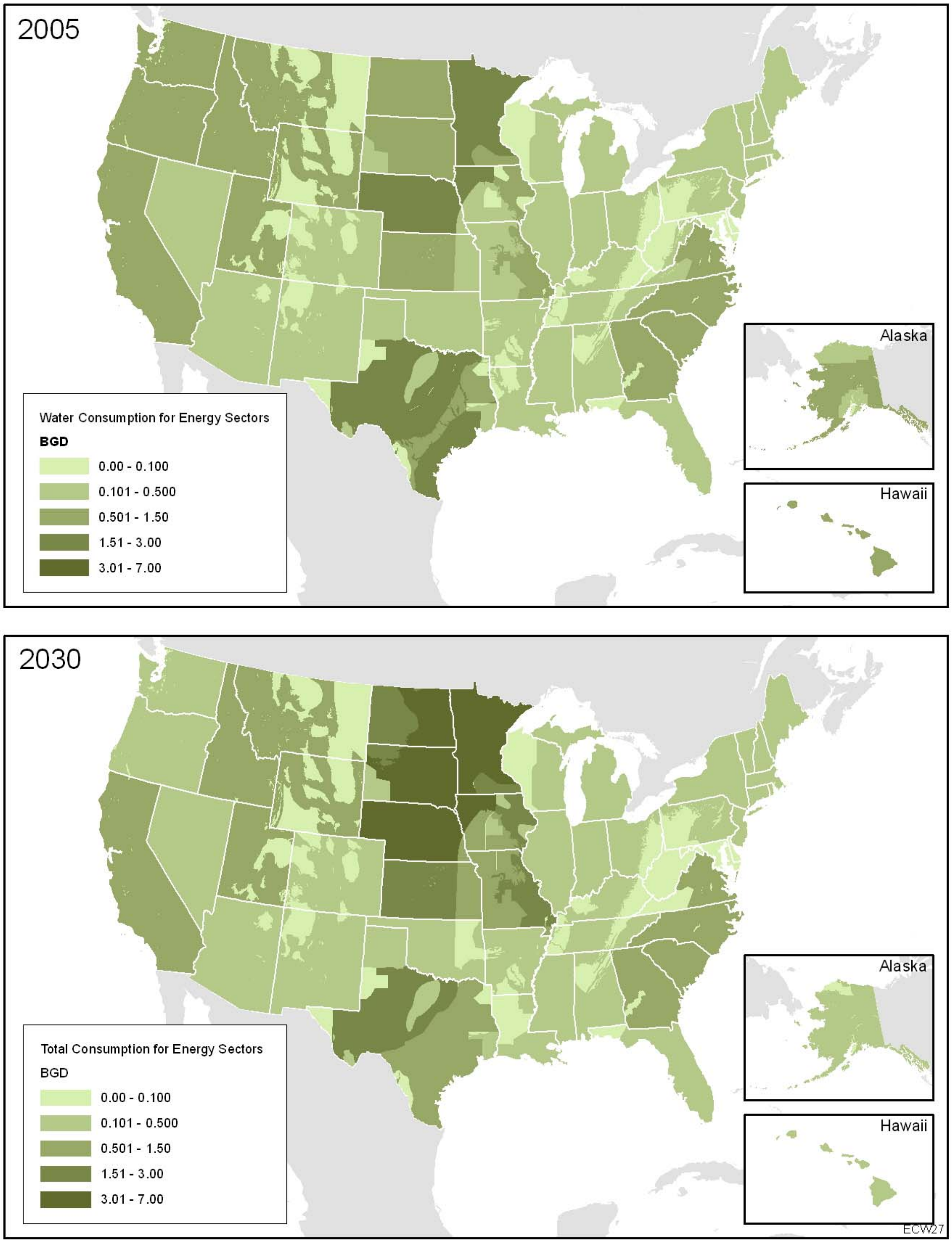

FIGURE 3-3 Comparison of Water Consumption Projections for Energy Sectors, 2005 and 2030

3.1.1.1 Findings

In the AEO 2007 reference case (EIA 2007a), coal production increases at an average rate of 1.1% per year to 2015, in response to increasing coal use for electricity generation at existing plants and construction of new coal-fired plants. Between 2015 and 2030, production increases by 1.8% per year as substantial amounts of new capacity are added. Western coal production increases steadily over the 2005–2030 period, and much of this growth is in the Powder River Basin. Appalachian production declines over the period due to resource depletion and increasing production costs, while Interior coal production increases slightly due to new coal-fired generating capacity in the Southeast (EIA 2007a) (Figure 3-4).

Water consumption for coal mining is projected to increase from about 200 million gallons per day (mgd) in 2005 to about 261 mgd in 2030. Although more coal is mined in the West over the projection period than in the Appalachian and Interior Regions, projected water consumption is highest in the Appalachian Region (Figure 3-5). This higher water consumption is largely because 90% of Appalachian coal is assumed to be from underground mining, which uses more water on a per-ton basis, and because most of the coal is washed, whereas none of the western coal is assumed to require washing. Figure 3-6, which shows projected water consumption by Coal Supply Region, indicates that the areas with the highest projected water consumption by 2030 are Northern and Central Appalachia, Eastern Interior, and Wyoming Coal Supply Regions. Figure 3-7 compares regional water consumption estimates for coal mining in 2005 with those in 2030 and shows the general increases in all regions except the Central Appalachian Coal Supply Region.

3.1.1.2 Projection Assumptions

According to Gleick (1994), estimates of the average amount of water consumed in underground coal mining range from 3 to 20 cubic meters (m^3) of water per 10^{12} Joule (thermal) (J(th)) of energy in the coal. Surface-mined land sometimes requires reclamation (i.e., restoration to an approximation of the original contour and vegetation). In these cases, water is used to establish vegetation on the reclaimed land. For surface mining, water consumption is estimated to be about 2 $m^3/10^{12}$ J(th) if no revegetation is required; if revegetation is required, estimated water consumption is about 5 $m^3/10^{12}$ J(th). These estimates include water used for disposing of mining wastes. Water used for suppressing dust for health and safety reasons in underground mining helps account for the higher water consumption estimates for underground mining than for surface mining.

Refining the coal includes washing, beneficiation (to remove the nonfuel contaminants), and thermal processing. Refining is conducted to separate coals of different qualities and to increase the thermal performance of the fuel. The refining process typically consumes about 4 $m^3/10^{12}$ J(th).

Appendix B shows how the water consumption values, in $m^3/10^{12}$ J(th) provided by Gleick (1994), are used to derive the coefficients for the coal sector used in this report. It also shows the assumptions used in the conversions.

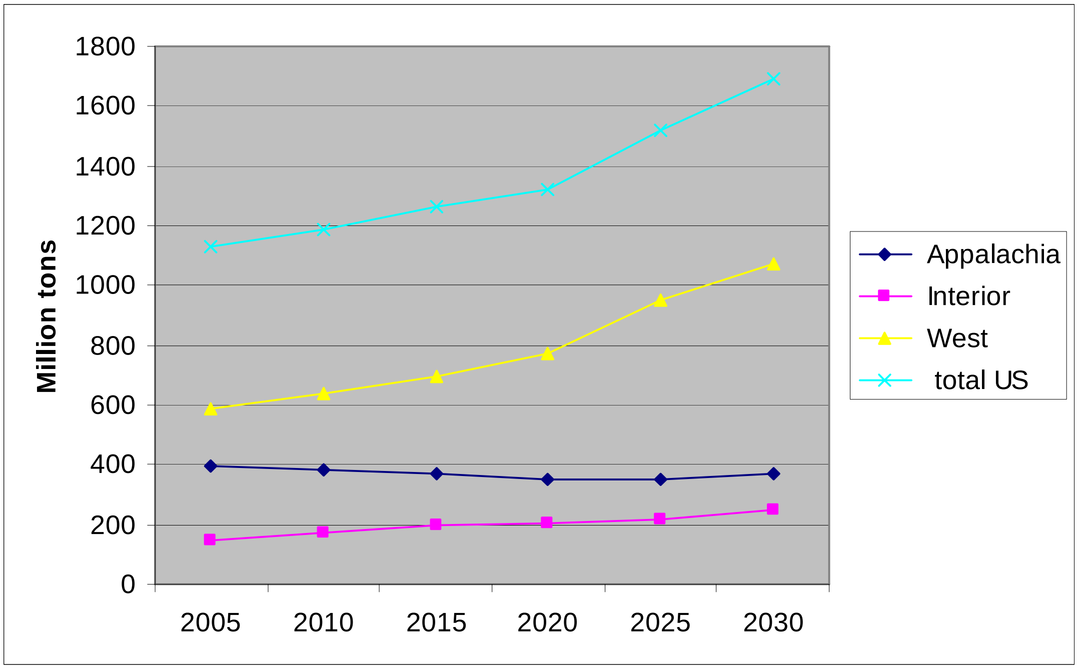

FIGURE 3-4 Projected U.S. Coal Production, 2005–2030 (Source: EIA 2007a)

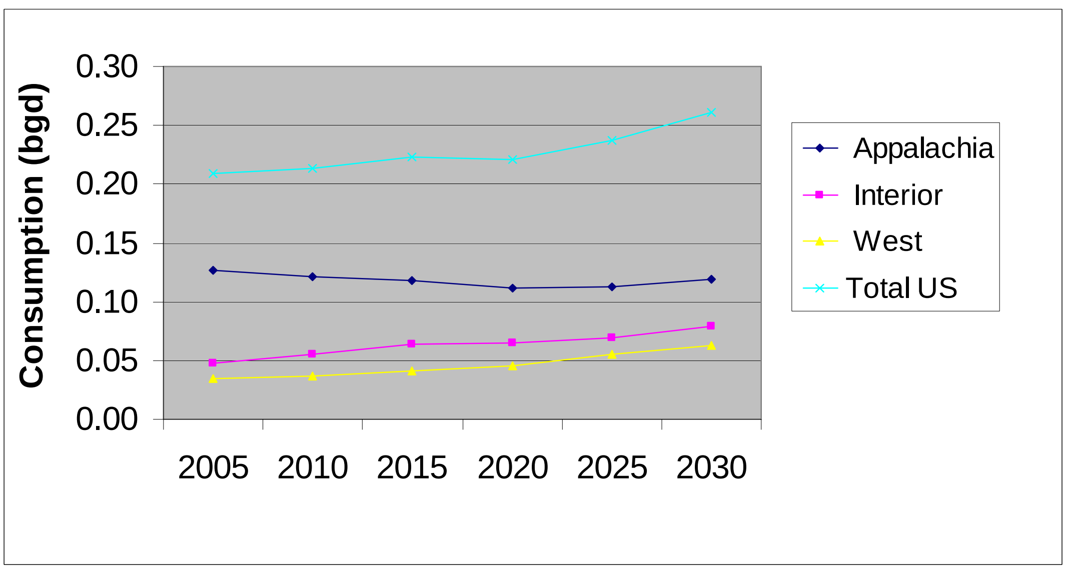

FIGURE 3-5 Projected Water Consumption for Coal Mining, 2005–2030

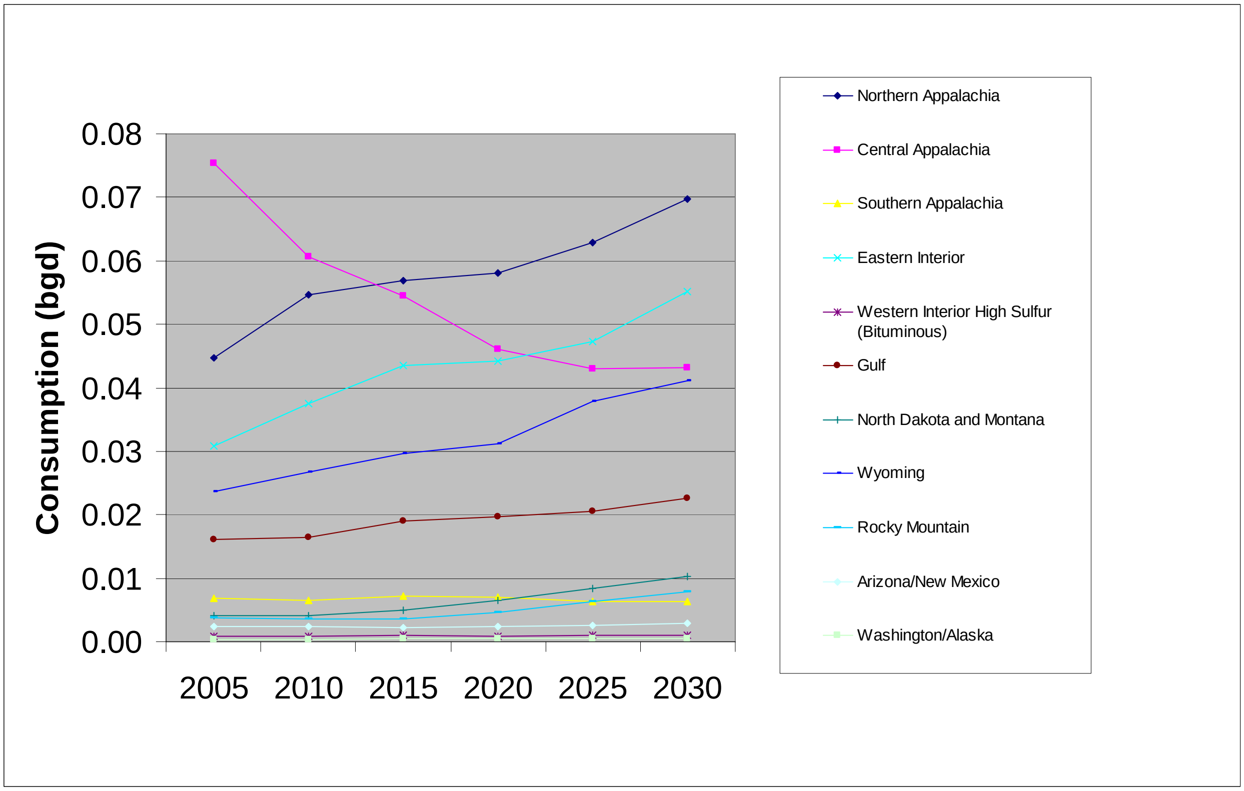

FIGURE 3-6 Projected Water Consumption for Coal Mining by Coal Supply Region

3.1.2 Coal Slurry Pipelines

Coal transportation via slurry pipeline moves large quantities of coal suspended in water. Typically, the volume of coal equals the volume of water. In the West, water for suspending the coal is supplied by wells that pump water from groundwater aquifers; recharge of such aquifers is negligible relative to the rate of withdrawal (Gleick 1994). When the coal is removed from the slurry at the power plant, some of the water is treated and used for other plant operations, such as plant cooling. Total consumptive water use for pipeline transport is estimated at 40–85 $m^3/10^{12}$ J(th) (Gleick 1994).

3.1.2.1 Findings

U.S. water consumption for coal slurry pipeline transport is projected to increase from about 0.05 bgd in 2005 to about 0.09 bgd in 2030 (Figure 3-8). This amount is roughly equal to about one quarter of that consumed in coal mining in 2005 and to about one-third of that consumed by coal mining in 2030. Figure 3-8 also shows that the greatest projected increases in water consumption by coal slurry pipelines between 2005 and 2030 are in the Eastern Interior and North Dakota Montana Coal Supply Regions.

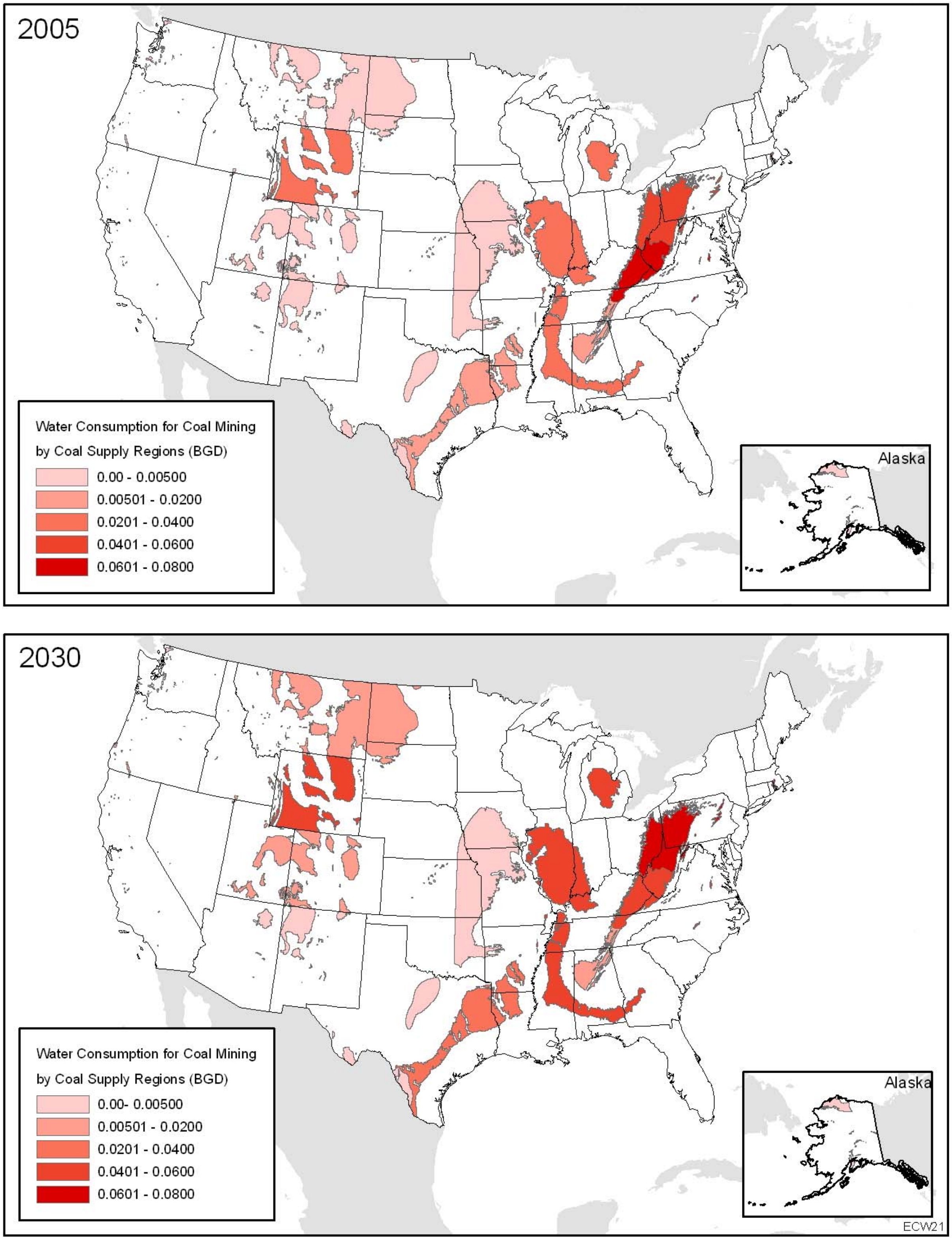

FIGURE 3-7 Comparison of Water Consumption Estimates for Coal Mining, by Region, 2005 and 2030

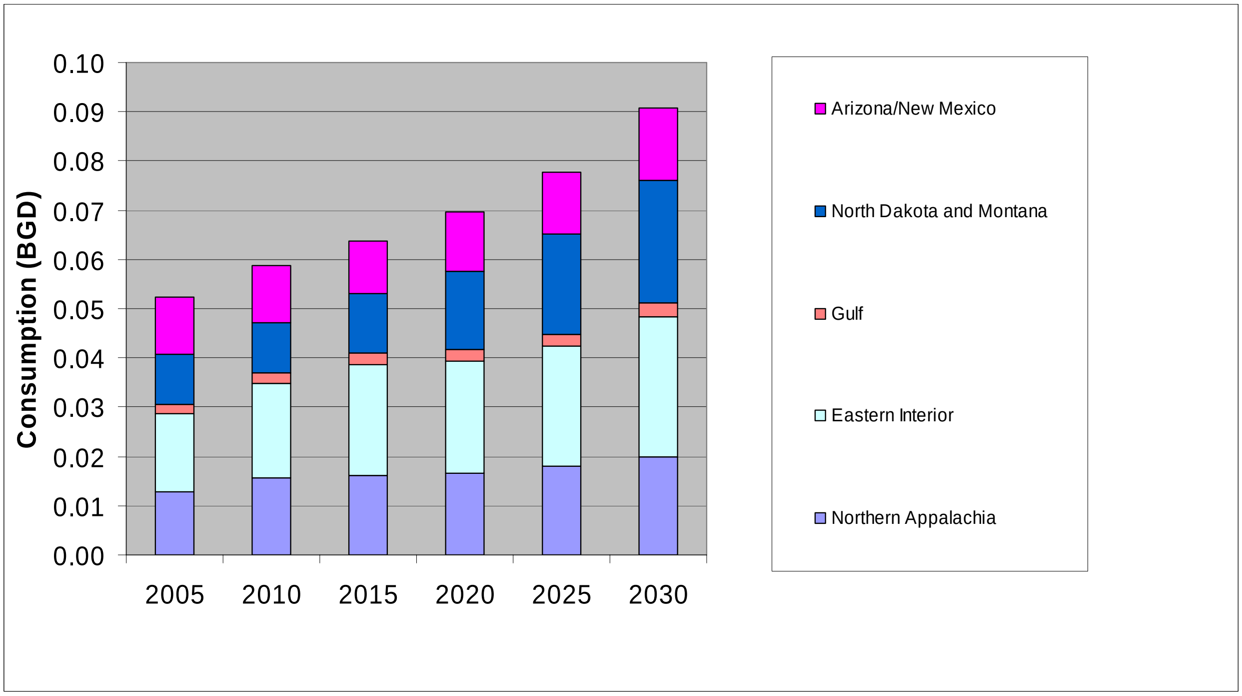

FIGURE 3-8 Projected Water Consumption for Slurry Pipelines

In the West, the relative amounts of water for transport compared with those for mining are much higher than the national average. Throughout the projection period, the amount of water consumed for slurry transport in the West is roughly 60% of that used for mining. In the Appalachian Region, the amount of water used for slurry pipeline transport is estimated at about 10% of that used for coal mining in 2005 and about 17% in 2030 (Figure 3-9).

3.1.2.2 Projection Assumptions

The AEO 2007 (EIA 2007a) does not project amounts of coal transported by slurry pipeline. However, EIA (2006) reports current-year data on the amount of coal distributed by state of origin and mode of transport. To project the amounts of coal transported by slurry pipeline in the future, the state-level amounts shipped by slurry pipeline in 2006 were first aggregated to Coal Supply Region (the same regions for which EIA projects coal production). The five-year growth rates in coal production for each of these regions were then calculated using the AEO 2007 projection data. To estimate the amount of coal shipped by slurry pipeline by region for each of the five-year periods between 2005 and 2030, the region/period-specific growth rates were multiplied by the appropriate regional estimates of 2006 slurry shipments. To estimate projected water consumption for coal slurry pipeline, these estimated shipment tonnages were multiplied by the estimated water-consumption rate for slurry pipeline transport and converted to billion gallons per day (see Appendix B).

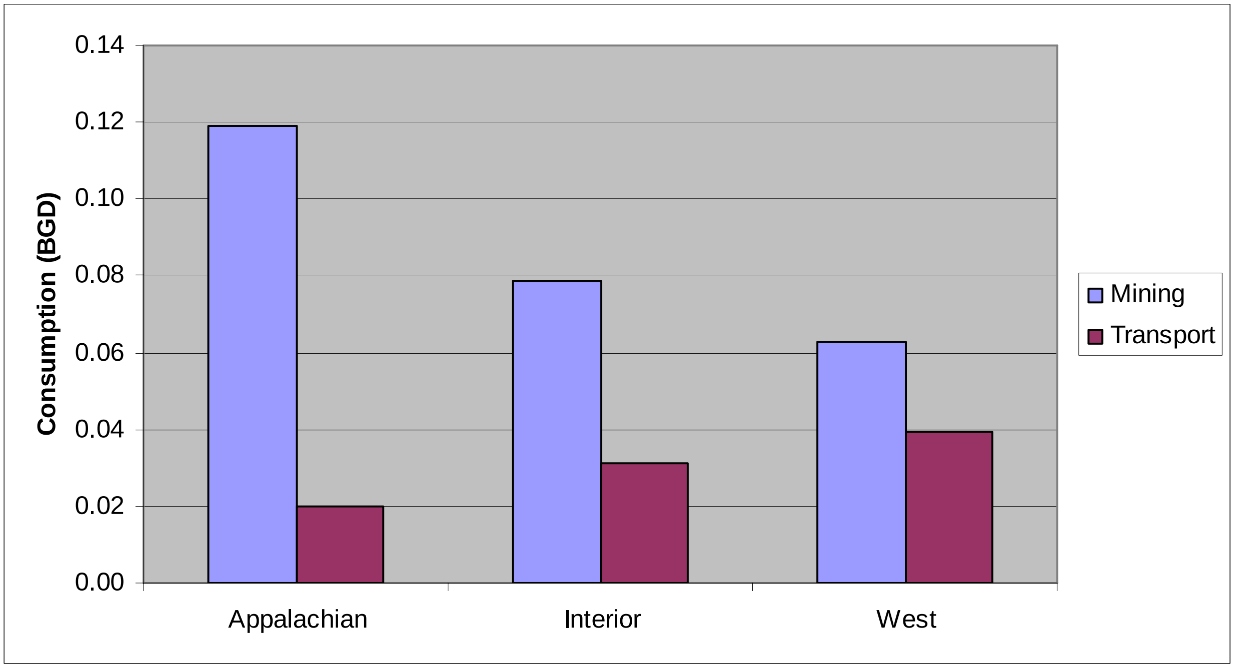

FIGURE 3-9 Projected Water Consumption for Coal Mining and Slurry Transport, 2030

3.2 OIL

This section describes water demand for the following oil-related production and processing categories: crude oil exploration and production, including enhanced oil recovery (water flooding, thermal steam, and CO_2 injection), the processing of liquids from unconventional sources (coal to liquids and oil shale), and refining.

3.2.1 Exploration and Production

During the exploration and production of crude oil, water is consumed in the drilling process and in treating the oil prior to use. According to Gleick (1994), water consumption for onshore exploration is about 0.01 $m^3/10^{12}$ J(th), and for extraction and production it is between 2 and 8 $m^3/10^{12}$ J(th). It should be noted that oil production results in the simultaneous production of large quantities of water, and that as a well ages, the percentage of oil decreases while the percentage of produced water increases. Because this produced water is saline at most wells, its potential uses are limited.

As the largest onshore crude oil reservoirs in the United States are depleted, secondary and tertiary methods are used to increase the percentage of oil recovered from these wells. These enhanced oil recovery methods increase water requirements. Secondary recovery uses water flooding to increase the flow of oil to the wells. According to Gleick (1994), roughly 600 $m^3/10^{12}$ J(th) of water are consumed during water flooding, and one-third of U.S. oil production uses water flooding recovery methods.

For tertiary recovery, thermal steam injection and CO_2 injection are the most widely used enhanced oil recovery methods. According to Gleick (1994), thermal steam injection consumes 100–180 $m^3/10^{12}$ J(th) of water, and CO_2 injection consumes 640 $m^3/10^{12}$ J(th) of water. An extrapolation of the results from biannual oil industry surveys conducted in 2004 and 2006 (Moritis 2006) indicates that, in 2005, roughly 0.324 mgd were produced using thermal recovery and roughly 0.222 mgd were produced using CO_2 injection. These amounts represent (at the national level) about 9% and 6%, respectively, of total U.S. onshore oil production in 2005. Because EIA reports oil production at the oil and gas supply model region, the state-specific tertiary recovery amounts (for both thermal and CO_2 injection) were allocated to the appropriate oil and gas model supply regions to obtain the region-specific percentages that these enhanced oil recovery methods contribute to total oil production in the respective regions. For example, in the West Coast Region, about 48% of the crude oil produced in 2005 used thermal recovery, while little if any oil was produced using this method in the other regions. For CO_2 recovery, the Southwest produced about 20% of its oil using CO_2 injection, and the Rocky Mountain Region produced about 7% of its oil using this method.

3.2.1.1 Findings

The amount of water consumed for crude oil exploration and production is expected to decline slightly over the projection period, from 1.5 bgd in 2005 to 1.3 bgd in 2030, in response to the general decline in oil production over the period. Figure 3-10 shows that, on a regional basis, the water consumption levels remain fairly steady over the period, except in the Rocky Mountain Region, where consumption is expected to increase by about 0.9 bgd or 50%, and in Alaska, where consumption is expected to decrease, again in response to oil production projections.

These findings may underestimate the projected water demand for exploration and production, because they assume that the percentages of oil produced using the various recovery methods (primary, secondary, and tertiary) remain constant over the projection period. It is likely, however, that the percentage of oil produced using the relatively low-water-consuming primary method will decrease over time, while the amounts produced using the higher-consuming methods will increase. It is also likely that these higher-water-consuming methods will be used in drier parts of the country, where much of the growth in oil production is expected. On the other hand, actual freshwater consumption may be less than projected because most operators rely on the reinjection of saline produced water rather than fresh surface water or groundwater for enhanced oil recovery. Data on the relative amounts of freshwater versus produced water used for enhanced oil recovery are not readily available.

3.2.1.2 Projection Assumptions

To estimate regional oil production, the EIA's AEO 2007 regional projections were adjusted to reflect estimated amounts of oil produced by primary recovery and enhanced (secondary and tertiary recovery) according to the following steps:

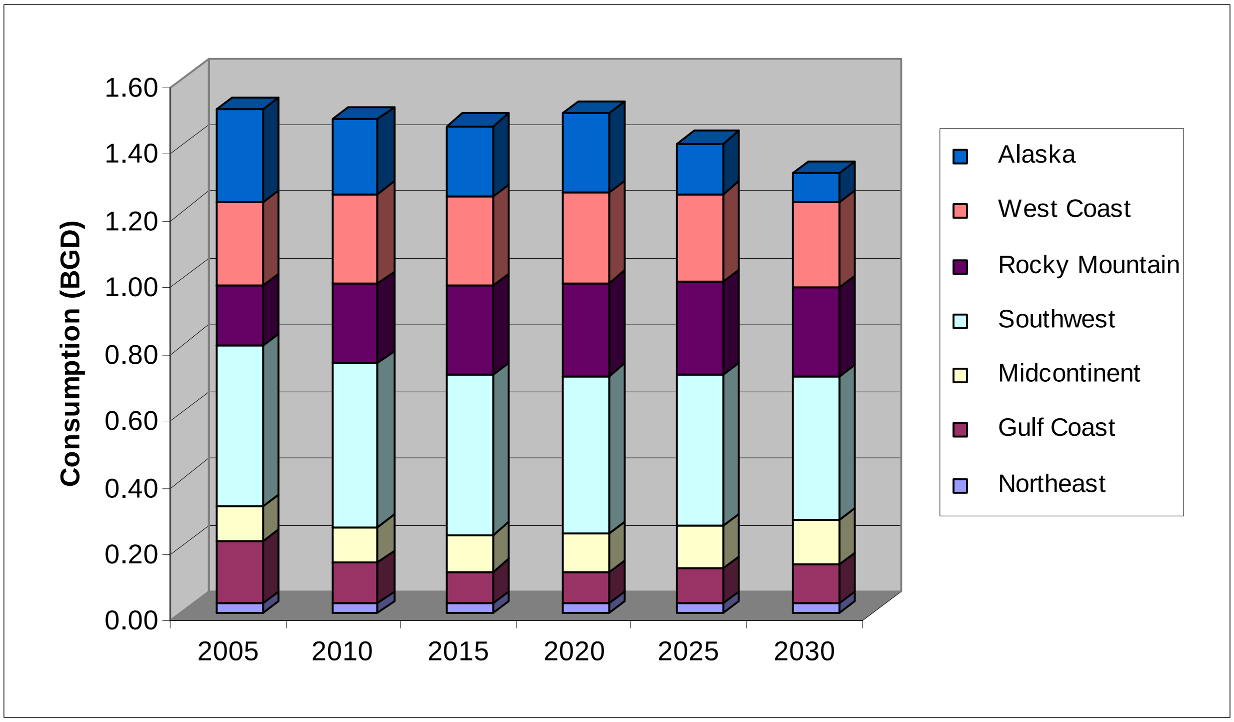

FIGURE 3-10 Projected Water Consumption for Crude Oil Production, 2005–2030

- Absent information that would indicate otherwise, it was assumed that the 33% of oil produced in each region would use secondary recovery (water flooding).

- Absent information that would indicate otherwise, it was assumed that the relative percentages of thermal steam and CO_2 injection derived from Moritis (2006) and the EIA base-year projections would apply to each of the projection years.

The amounts of crude oil produced by each recovery method were projected according to the following steps:

- For tertiary recovery, the region-specific percentages of oil produced using thermal and CO_2 recovery methods were applied to the AEO 2007 (EIA 2007a) regional projections of total oil production in the projection years.

- For secondary recovery, it was assumed (from above) that 33% of the oil produced in each region uses water flooding, and this 33% was applied to the AEO 2007 regional projections of total oil production in the projection years.

- For primary recovery, it was assumed that the amount produced in each region was equal to the total amount projected in AEO 2007 less the amounts produced with secondary and tertiary recovery; this percentage was applied to the AEO 2007 regional projections of total oil production in the projection years.

To estimate the amount of water consumed in each region and for each recovery method, the recovery-specific water consumption coefficient (converted to appropriate units) was multiplied by the amount of oil produced by the respective recovery method. The derivations of the coefficients and the assumptions are in Appendix C.

3.2.2 Liquids Production from Unconventional Sources

Unconventional oil and liquids production includes coal liquefaction (coal to liquids), oil shale, and gas to liquids. According to AEO 2007 (EIA 2007a), the amount of unconventional oil and liquids produced will depend on oil prices. The AEO 2007 reference case projects coal liquefaction beginning in 2015 and oil shale production in 2030 (in the high oil price scenario only). Water demand for these two categories is discussed below. EIA projects gas-to-liquids production only in its high oil price scenario, and in that case suggests that such production would likely occur on the North Slope of Alaska and would compete with the Alaska Natural Gas Transportation System for available natural gas resources. This report does not address gas to liquids.

3.2.2.1 Coal to Liquids

Coal liquefaction requires process water, boiler feed water, and cooling water. NETL (2006) reports that for a direct liquefaction plant using Illinois No. 6 coal, about 70% of the water would be used for cooling, and that of this amount, most of the cooling water would be recirculated, and about 3–5% would be lost to evaporation, leaks, and blowdown. NETL reports that this loss of cooling water is the most significant factor in total overall water consumption. Some process water and boiler feed water is consumed, but these components use much less water than cooling (roughly 10% each of total water demand). The amount of water required for liquefaction depends on factors such as plant design, type of gasifier, coal properties, temperature, and humidity. In reporting on a 1998 study of advanced Fischer-Tropsch Technology (Bechtel 1998), NETL (2006) found that, on average, an estimated 7.3 gal of water are required to produce 1 gal of liquid from eastern coals, and about 5.0 gal are required to produce 1 gal of liquid from western coals. The locations of future coal-to-liquids (CTL) plants are not known but are assumed to be near coal supply sources. For purposes of projecting regional water demand from CTL production, it was assumed that roughly two-thirds of the CTL production would be in the Rocky Mountain Region and one-third in the Northeast. This reflects the projected allocation of coal production in the later part of the projection period and the locations where CTL producers have expressed interest in locating plants.

The AEO 2007 reference case projects a growth in CTL production from zero in 2005 to about 440,000 barrels/day in 2030 as a result of the higher prices projected for traditional fuels and the support for alternative fuels provided in the Energy Policy Act of 2005 (EPAct).

Findings. The estimated water consumption for coal liquefaction is projected to increase from zero in 2005 to about 106 mgd in 2030. This rapid increase (by an order of magnitude in the 15 years between 2015 and 2030) mimics the rapid increase in coal liquefaction that appears in the AEO 2007 reference case. Reflecting the assumed regional distribution of coal liquefaction plants, water consumption is projected to be highest in the Rocky Mountain and Northeast Oil and Gas Supply Model Regions (Figure 3-11).

Projection assumptions. To reflect the differences in water consumption between coal liquefaction from western and eastern coals, EIA's CTL reference case projections (provided at the national level) were allocated to the Rocky Mountain Region (two-thirds) and the Northeast (one-third). The water-demand coefficient of 5 gal of water/gal liquid was used for the Rocky Mountain (western) coals and 7.3 gal of water/gal liquid for the Northeast (eastern) coals.

3.2.2.2 Oil Shale

Two types of technologies are generally discussed for oil shale development: (1) surface or deep mining with aboveground processing (retorting) and (2) in-situ processing. Surface processing consists of oil-shale mining and ore preparation, pyrolysis of oil shale to produce kerogen oil, and processing of kerogen oil to produce refinery feedstock. This method requires

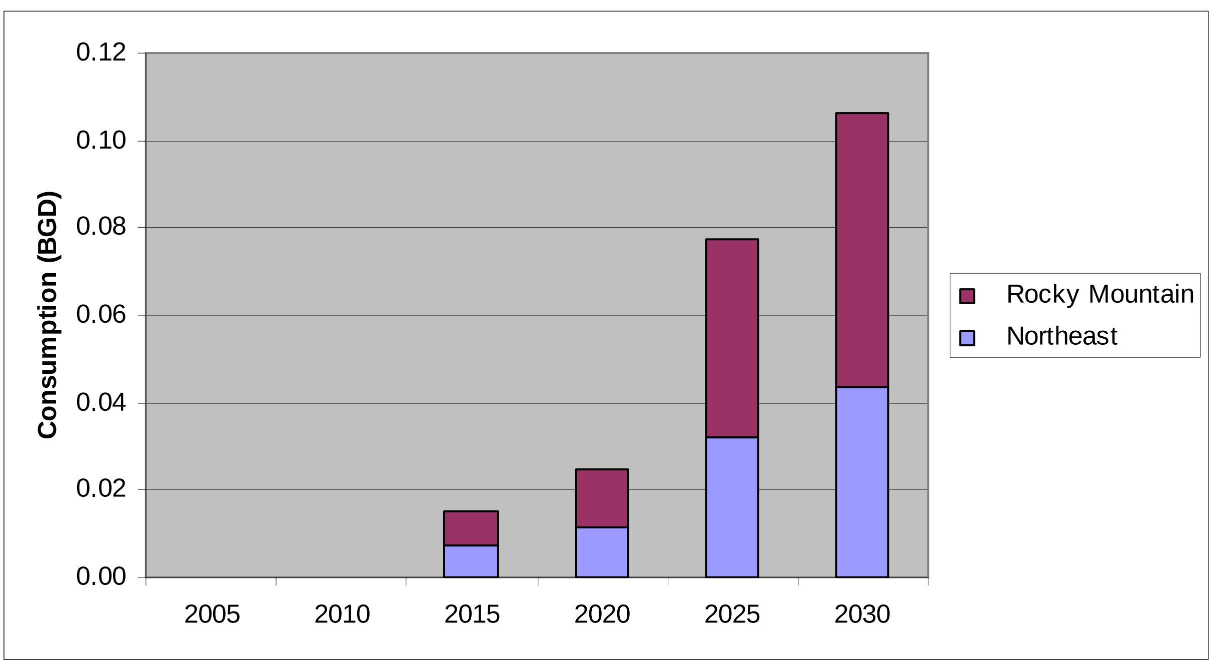

FIGURE 3-11 Projected Water Consumption by Region for Coal to Liquids Production

an estimated 2.6 to 4 barrels (bbl) of water per barrel of shale oil produced for mining and drilling operations, cooling of equipment, transport of ore and processed shale, dust control, cooling of spent shale from the retort, wetting of spent shale prior to disposal, fire control, and irrigation for revegetation (BLM 2007).

The in-situ process would be used for deeper, thicker deposits that are not amenable to mining methods. With this technology, the resource is heated in its natural setting and water (estimated at 1 to 3 bbl/bbl shale oil produced) would be used for hydrofracturing, steam generation, water flooding, quenching of kerogen products at producer holes, cooling of productive zones in the subsurface, cooling of equipment, and rinsing of oil shale after the extraction cycle (BLM 2007).

Findings. The AEO 2007 projects oil shale production of 405,000 bbl/day in 2030 (but only in the high oil price scenario). Because the surface process is further along in the development stage than is the in-situ process, this analysis assumes that the 405,000 bbl/day would be produced using surface techniques and that an average of 3.3 gal of water (midpoint between 2.6 and 4 gal) would be required. Using these estimates, water demand for oil shale in 2030 is projected to be about 56 mgd.

It should be noted that not only is oil shale development a water-intensive process, but the areas of highest shale oil resource concentrations are in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming—areas where water demand is high and water resources are limited. The *Proposed Oil Shale and Tar Sands Resource Management Plan Amendments to Address Land Use Allocations in Colorado, Utah, and Wyoming and Final Programmatic Environmental Impact Statement* (PEIS) presented scenarios illustrating projected water demand and consumption by various sectors in these states (BLM 2008). For example, in the Colorado Basin, consumptive water use in 2030 is projected to range between 1.34 and 1.38 million ac-ft/yr (roughly 1.2 bgd) with about 4% for municipal and industrial and self-supplied uses, 40% for agriculture, and 55% for export. The PEIS also reports projected amounts of water available and percentages of state share available for development in the Upper Colorado Basin. In 2030, the estimated percentages of water available are 4% for Colorado, 9% for Utah, and 23% for Wyoming. However, as explained in the PEIS,

> "Although a certain amount of water is calculated to be available in Wyoming and Utah and to a lesser extent in Colorado, this does not imply that the water is readily or physically available for development. Oil shale basins and STSAs [Special Tar Sand Areas] are situated in much smaller areas, as compared to the size of the hydrologic Upper Colorado River Basin by which the water availability was calculated. In addition, hydrologic basins enriched with surplus water resources are not necessarily coincident with the oil shale basins and STSAs. Storage infrastructures and delivery systems have to be built to capture water for use. Also, water rights and water storage rights (for reservoirs) have to be transferred or purchased before the water can be used for development, as most of the water and storage rights have been claimed in the Upper Colorado River Basin. Finally, water use for the development must meet different state and federal regulations, including requirements to protect instream flows for

endangered Colorado River fishes in the basin. All in all, whether enough water is available for development depends on the results of intensive negotiations between various parties, including water right owners, state and federal agencies, and municipal water providers as well as the developers." (BLM 2008).

3.2.3 Refining

The refining process converts crude oil into different forms of liquid fuel. According to Gleick (1994), traditional refining facilities in industrialized countries withdraw about 325 $m^3/10^{12}$ J(th) of crude oil input and consume about 23 to 65 $m^3/10^{12}$ J(th). Most of the consumptive loss (about 70%) is through evaporative cooling, about a quarter is boiler feed water, and the remainder is for other in-plant uses. Changes in fuel formulation and improved techniques for restructuring organic molecules have increased water consumption requirements to between about 60 and 120 $m^3/10^{12}$ J(th). This is because the process used to upgrade the quality of the product (hydrogenation) uses hydrogen, which is obtained by dissociating water (Gleick 1994).

3.2.3.1 Findings

Water consumption at refineries is expected to increase over the projection period from about 1.3 bgd in 2005 to 1.5 bgd in 2030. Most of the demand in 2030 is projected for the Gulf Coast (0.68 bgd) and the Midwest and West Coast PADDs (about 0.29 bgd in both cases). Most of the growth is expected in the Gulf Coast and Rocky Mountain PADDs (Figure 3-12), reflecting projected refinery capacity increases. These amounts could increase somewhat if new hydrocracking capacity is added (which uses more water than traditional refining processes), but since more than 90% of existing capacity already has hydrocracking capacity, those increases are not likely to be large. Other factors affecting projected water demand include increasing efficiencies of refineries and other technological improvements that could reduce water demand, and the quality of crude imports, which would affect the amount of refining necessary.

3.2.3.2 Projection Assumptions

To estimate the amount of water consumed by refinery operations, the EIA's 2007 Refinery Capacity Report (EIA 2007b) was used to identify refineries that use the more water-intensive hydrocracking, hydrotreating, reformulation processes. For each state and PADD—the regional level at which EIA reports refinery capacity—the percentage of capacity in 2007 that was associated with those refineries that included the higher water-consuming processes was calculated.[1] Overall, about 93% of U.S. refining capacity is at refineries that use the higher-water-consuming practices. On a regional basis, the percentage ranges from about 85%

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1 EIA (2007a) produces future capacity estimates in its supplemental AEO 2007 tables, but not state-level estimates.

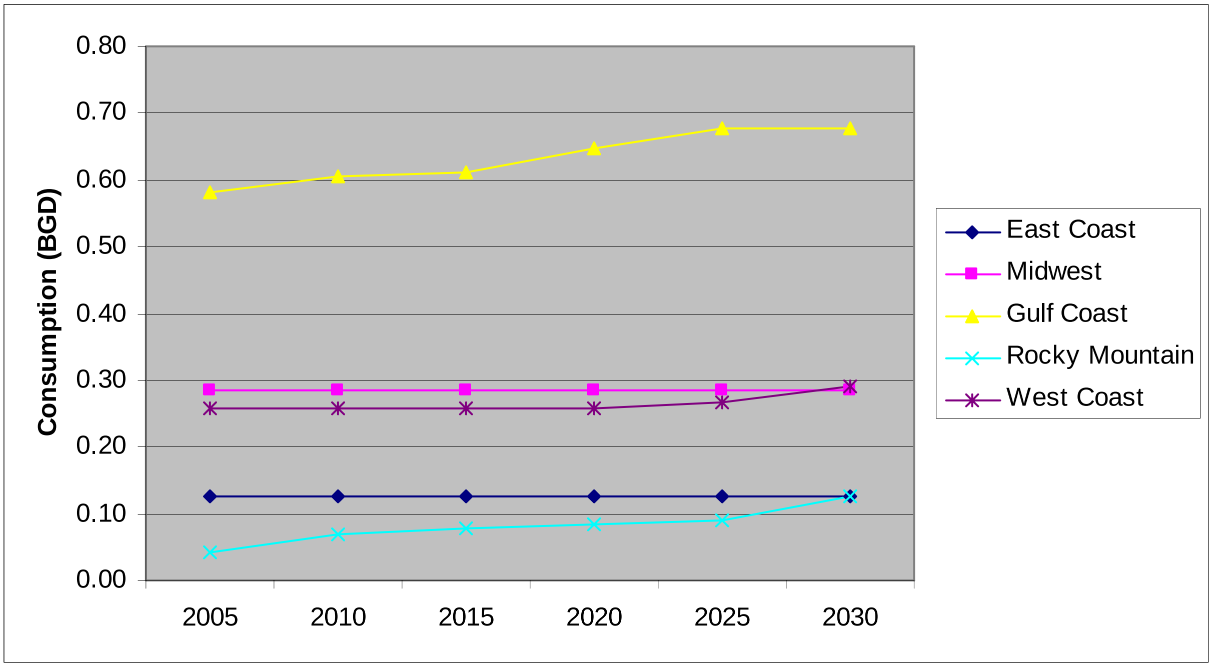

FIGURE 3-12 Projected Water Demands for Refining, by PADD

(PADD 5—West Coast) to 100% (PADD 4—Rocky Mountain). Future water consumption at the PADD and national levels was then projected by allocating the projected PADD-specific refinery capacities according to the PADD-specific shares of capacity using (1) the higher-water-consuming hydrogen-related processes and (2) the lower-water-consuming traditional processes. The hydrogen-process-related share was then multiplied by the high-water-consumption coefficient and the nonhydrogen-process share by the low-water-consumption coefficient to obtain water consumption estimates for the two processes. Appendix C shows the derivation of the high and low coefficients. The two were then summed to get a PADD-specific water-consumption estimate for each of the projection years.

3.3 GAS

Water demand projections are estimated in this section for both conventional and unconventional gas production.

3.3.1 Conventional Gas Production

Water demands for conventional production include those for gas processing, pipeline transport, and other plant operations. Unlike oil exploration and production, which uses water for drilling, flooding, and treating, exploration and production of natural gas uses water only for the preparation of drilling fluid and, therefore, consumptive use is negligible.

3.3.1.1 Gas Processing

Gas processing is conducted in the field at a gas plant prior to pipeline transport. Processing removes acid gases, water, and excess hydrocarbon liquids. Water is used for cooling purposes, and the estimated average consumption rate is 6 $m^3/10^{12}$ J(th) (Gleick 1994).

The AEO 2007 (EIA 2007a) projects national-level natural gas dry production in trillion cubic feet (TCF) per year, and it was assumed that 100% of this production is processed. It also projects onshore dry gas production at the oil and gas supply model region level, and offshore production for the Gulf, Atlantic, and Pacific offshore regions. It was assumed that gas processing activities for gas produced offshore occur onshore in the regions closest to the offshore production area. For example, gas produced in the Gulf would be processed in the Gulf Coast Oil and Gas Supply Model region.

Findings. The estimated amount of water consumed during gas processing increases from about 0.085 bgd in 2005 to about 0.097 bgd in 2020, and then declines slightly to about 0.096 bgd in 2030. These estimates reflect the trends in gas production and processing projected in the AEO 2007, which in turn reflect discoveries and cost. According to EIA, a large proportion of the conventional natural gas resource base in the onshore lower 48 states has been discovered. Discoveries of new conventional natural gas reservoirs are expected to be smaller and deeper, and thus more expensive and riskier to develop and produce. Accordingly, total lower 48 onshore conventional natural gas production declines in the AEO 2007 reference case from 6.4 TCF in 2005 to 4.9 TCF in 2030. These trends are reflected in water consumption for gas processing. On a regional basis, processing (and hence water consumption) declines over the projection period in the Gulf Coast and increases in Alaska, reflecting the increased role projected for Alaskan gas. Water consumed by gas processing in Alaska is expected to increase from an estimated 0.002 bgd in 2005 to 0.010 bgd in 2030 (Figure 3-13).

Projection assumptions. To estimate base and future year water consumption for gas processing, the coefficient cited above (converted to appropriate units; see Appendix E) was multiplied by the annual gas production estimates from AEO 2007.

3.3.1.2 Pipeline Transport

Hydrostatic testing is a method used to detect leaks in pipes. In a hydrotest, the section of pipe to be tested is filled with high-pressure water that is used to identify and record leaks. It is possible to recycle some of this water, particularly if the lines to be tested are in close proximity, thereby minimizing water transport costs. According to Gleick (1994), about 3 $m^3/10^{12}$ J(th) of water are consumed during hydrostatic testing.

Findings. As with gas processing, the water consumed in pipeline transport reflects the amount of gas produced. Thus, projected water consumption increases from 0.0083 bgd in 2005 to 0.0131 bgd in 2015, and then declines slightly to 0.0127 bgd by 2030.

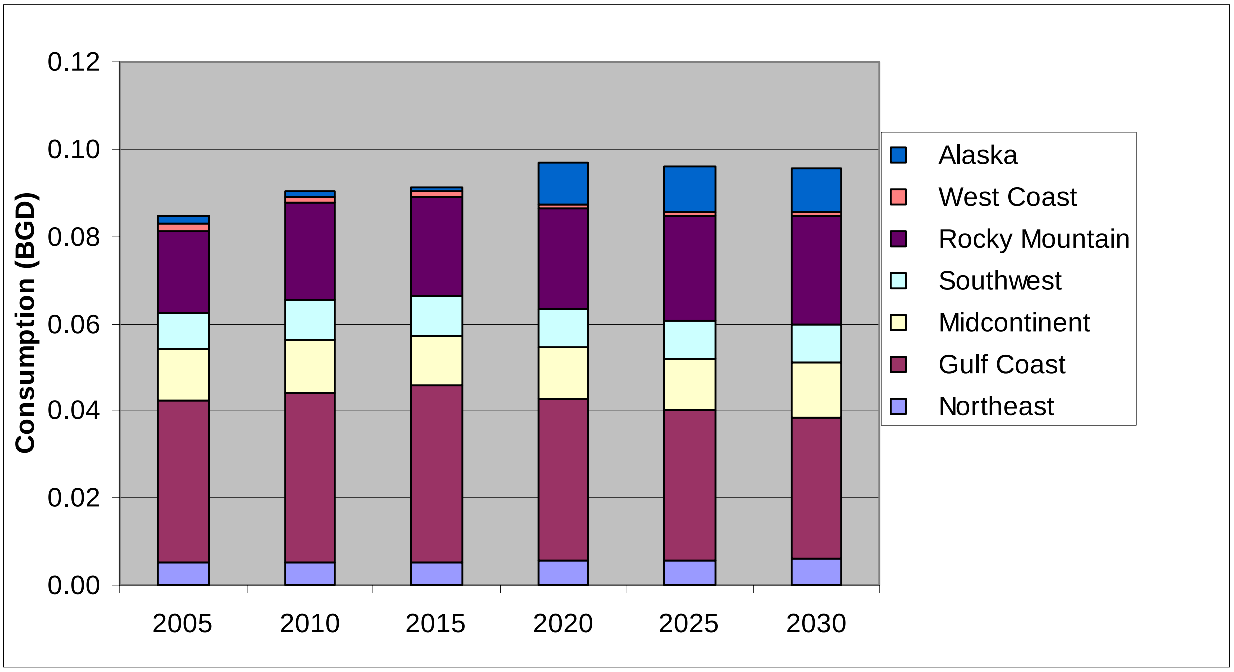

FIGURE 3-13 Projected Water Consumption by Gas Processing, 2005–2030

Projection assumptions. It was assumed that all natural gas that is processed is transported via pipeline. It was also assumed that imported natural gas is transported by pipeline. For the first component (gas processed), the same regional projections that were used for gas processing were used. For the second component (imports), the percentage allocations used for the first component to the national-level import projections provided in AEO 2007 were applied.

3.3.1.3 Other Plant Operations

Other natural gas plant operations for which water is consumed include plant service, potable water requirements, and boiler make-up water. Gleick (1994) estimates that consumptive water use for these other plant operations is 100 $m^3/10^{12}$ J(th). (See Appendix E for conversion assumptions.) By assuming that plant operations apply to all processed gas, the same projections and allocations were used for plant operations as for natural gas processing.

Findings. The projected amounts of water consumed for other plant operations follow the same pattern as those for processing and transport (i.e., an increasing amount between 2005 and 2020, and then a slight decline to 2030). However, the amount of water consumed for plant operations is two orders of magnitude higher than that for processing or transport (Figure 3-14).

It should be noted that although water consumption for conventional gas production decreases slightly after 2020, the projected consumption for 2030 is still roughly 13% higher than in 2005. More significantly, the increase in water consumption for certain regions is much greater. For example, in the Rocky Mountain region, projected water consumption for conventional gas production increases by nearly one-third—from 0.32 bgd in 2005 to about 0.43 bgd in 2030 (Figure 3-15).

3.3.2 Unconventional Natural Gas Production

Unconventional sources of natural gas in the United States include coalbed methane, tight sands (from low-permeability sandstone), and gas shale (from shale formations). Because coalbed methane is a net producer of water, no water consumption projections are made.

3.3.2.1 Tight Sands

Most unconventional gas resources are in tight sands, which are sand reservoirs of low permeability interbedded with clays and shale over intervals as thick as 5,000 meters (16,400 ft). To produce gas at volumes that are economical, reservoirs with low permeability must be treated; a typical method is hydraulic fracturing. Fracturing (or “fraccing”) increases the available surface area by creating fractures that are held open by the propping agents in the “frac” fluid. With hydraulic fracturing, very large volumes of freshwater that have generally been treated with friction reducers, biocides, scale inhibitors, and surfactants—and contain sand as the propping agent—are pumped into the formation. The fractures increase surface area, which further increases desorption and the mobility of the gas. The result is more efficient recovery of a larger volume of the gas in place.

Most of the water used for fracturing is returned as “flowback” early in production, with the remainder coming out with the produced water of the formation over time. Because the flowback water is highly mineralized, operators capture the water in frac tanks and transport it to centralized facilities for down-hole disposal in deep formations. It is not typically recycled, because water high in total dissolved solids can cause scaling to form in the well bore and in the formation, which can decrease productivity, and because handling water high in dissolved solids can cause soil and potable groundwater contamination (GTI 2007). Research is underway to evaluate the feasibility of treating and recycling flowback waters.

Findings. Water consumption for tight gas production is projected to increase slightly over the projection period from about 0.0018 bgd in 2005 to about 0.0020 bgd in 2030. Most of the water consumption is expected in the Rocky Mountain and Gulf Coast areas (Figure 3-16).

Projection assumptions. According to McCallister (2000), just over half of the estimated 31.8 TCF of proved tight gas reserves are in the Rocky Mountain Oil and Gas Supply Region, while three-fourths of the current production is split between the Rocky Mountain and Gulf Coast Regions (Slutz 2007) (Table 3-2). Future production of tight gas will be governed by innovations in extraction technologies, regulatory climate, and natural gas prices. The EIA projects production of tight gas to increase slightly from 5.4 TCF in 2005 to 5.9 TCF in 2030. To reflect the possibility that future production may shift toward those areas with greater proved reserves, future gas production was allocated as shown in Table 3-2.

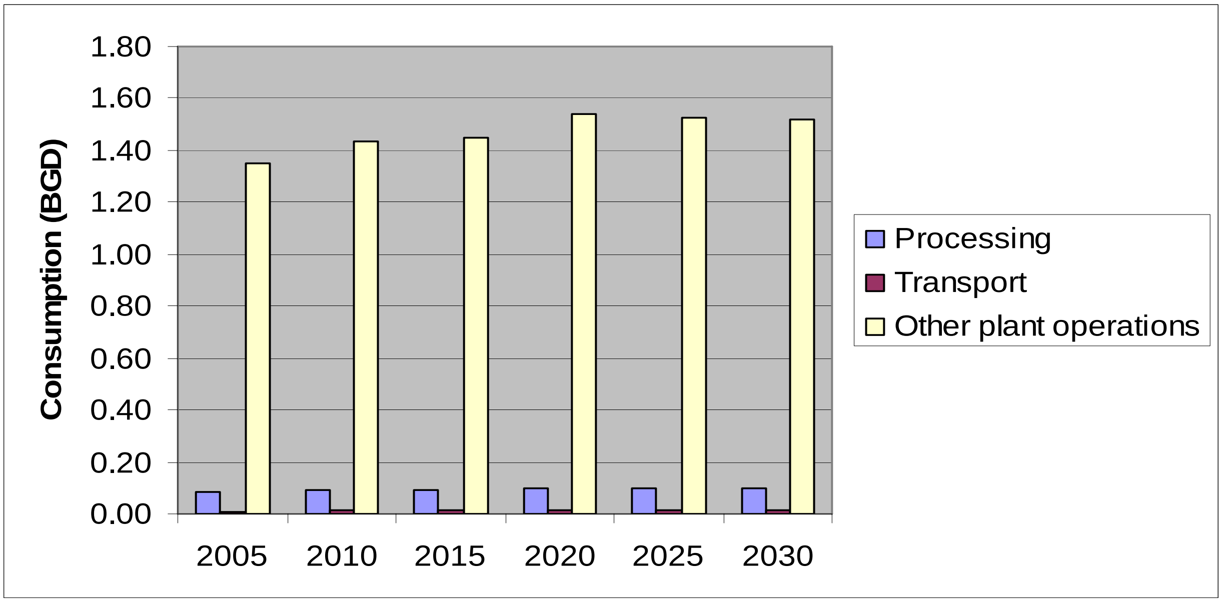

FIGURE 3-14 Projected Water Consumption for Conventional Gas Processing, Transportation, and Other Plant Operations

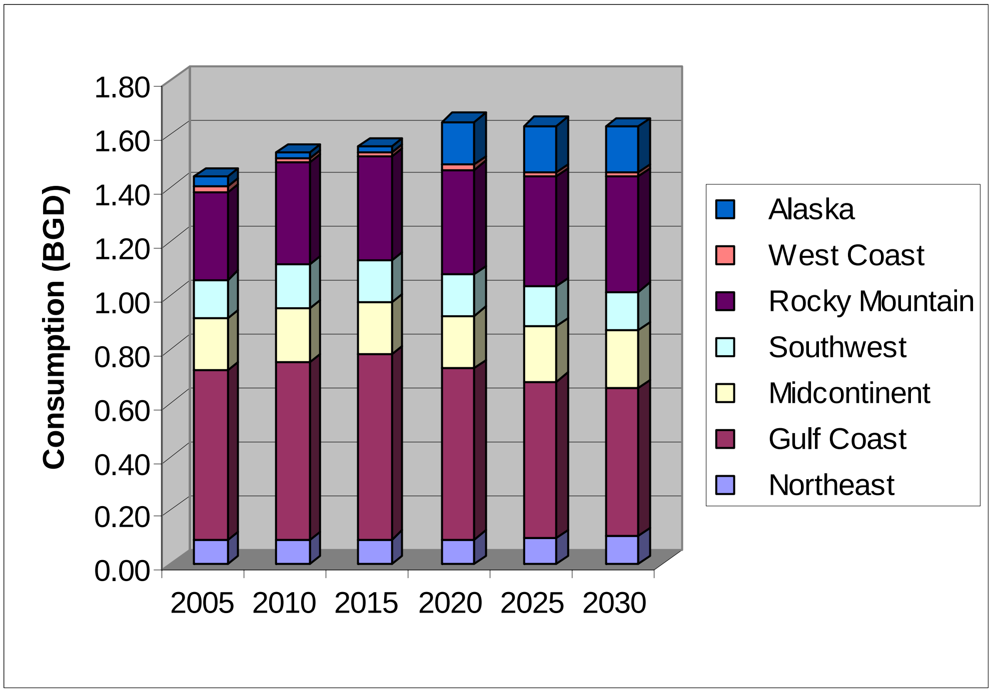

FIGURE 3-15 Projected Regional Water Consumption for Gas Processing, Transportation, and Other Plant Operations

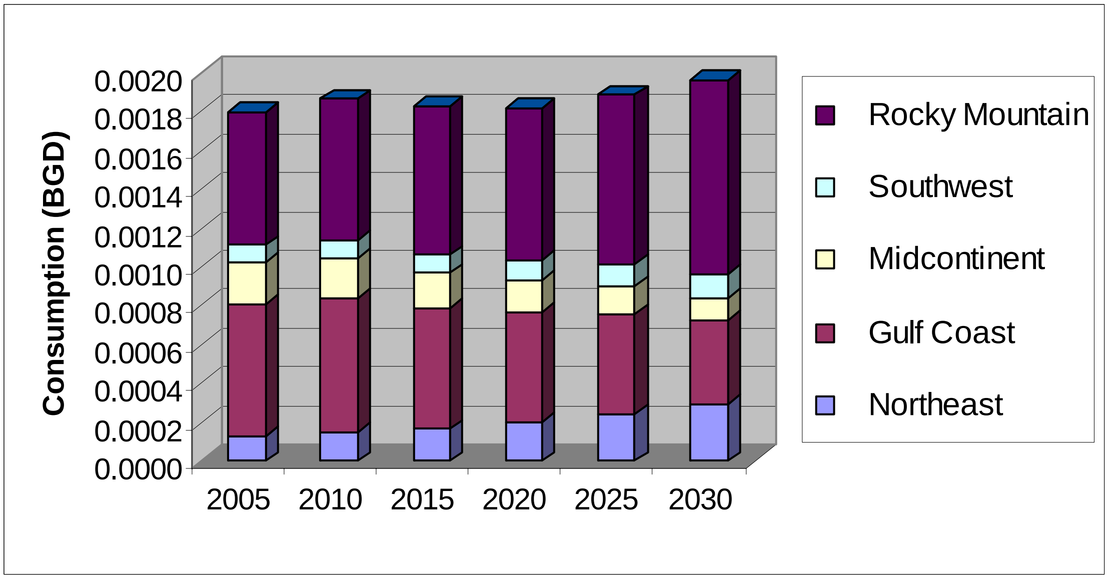

FIGURE 3-16 Estimated Water Consumption for Tight Gas Production, 2005–2030

TABLE 3-2 Regional Shares of Tight Gas Production

	Current Production[a] (%)	Proved Reserves[b] (%)	Projected Production (%)					
			2005	2010	2015	2020	2025	2030
Northeast	7	15	7	8	9	11	13	15
Gulf Coast	38	22	38	37	34	31	27	22
Midcontinent	12	6	12	11	10	9	8	6
Southwest	5	6	5	5	5	6	6	6
Rocky Mountain	38	51	38	39	42	43	46	51
Total	100	100	100	100	100	100	100	100

[a] Slutz (2007)

[b] McCallister (2000)

The procedures for drilling and producing tight gas and shale gas are similar. Lacking water consumption data specific to tight gas, it was assumed that the estimate of water use per TCF derived for shale gas—1.21×10^8 gal/TCF (see Section 3.3.2.2)—also applies to tight gas.

3.3.2.2 Gas Shale

Recovery of gas from shale is difficult because of the shale's low permeability. As with tight gas formations, favorable production rates are achieved by fracturing the formations. Shale wells may be refractured multiple times during their producing years.

Findings. Estimated water consumption for gas shale development is expected to nearly triple over the projection period, from about 0.275 million gpd in 2005 to about 0.766 million gpd in 2030. Over the projection period, slightly more than half of the water consumption is projected to occur in the Southwest, with the remainder primarily in the Northeast (Figure 3-17).

Although the overall water consumption projections for unconventional gas production may appear small relative to other uses, they are likely to be quite localized, and many of the tight gas resource areas overlap with the gas shale areas, which may also overlap with other energy resource production areas.

Projection assumptions. A recent assessment of freshwater use in the Fort Worth Basin/Barnett Shale Natural Gas Play (GTI 2007) provided data on wells drilled and water used for gas shale development in Texas. With these data and the results of a study by Truestar (2006) that estimated the average cumulative production from initial fracture stimulation to be about 0.0012 TCF per well and an average well production life of 20 years, the average amount of water consumed for gas shale production was estimated to be about 1.21×10^8 gal/TCF (see Appendix F).

According to Slutz (2007), a little more than half of the gas shale production comes from the Southwest Oil and Gas Supply Region, and about 41% from the Northeast Oil and Gas Supply Region. However, because roughly 93% of the 3.7 TCF of proved reserves of gas shale is located in the Northeast Oil and Gas Supply Model Region, and the remainder is in the Southwest (McCallister 2000), it is possible that the regional distribution of production may shift to the Northeast in the future. This possibility has been reflected in the regional allocation of future gas shale production shown in Table 3-3.

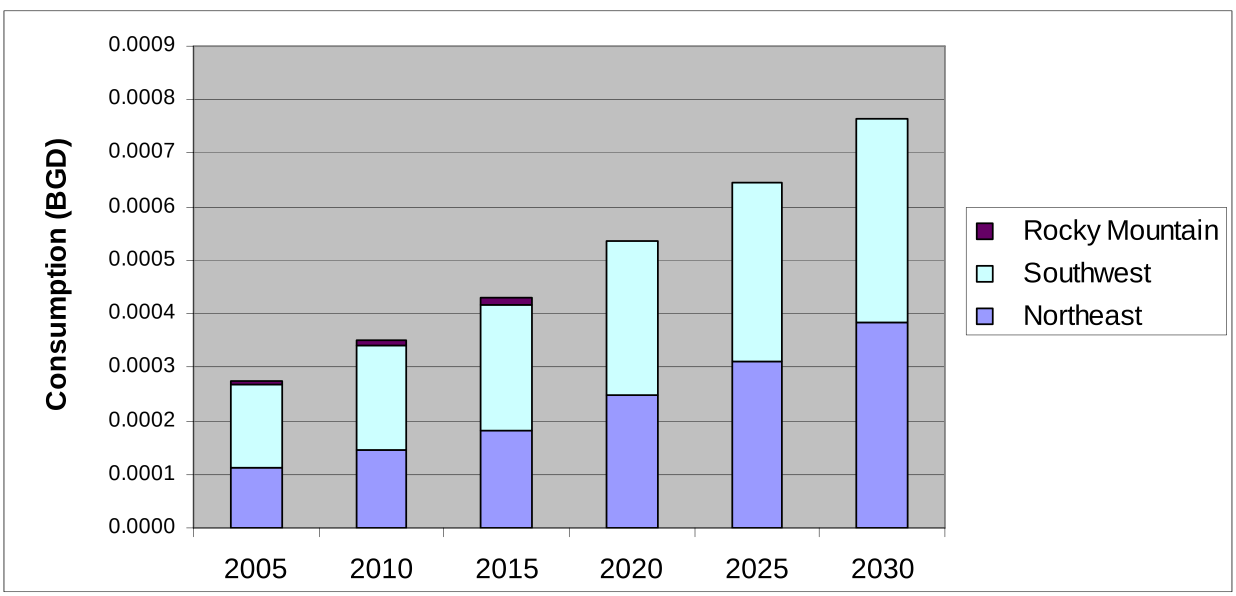

FIGURE 3-17 Projected Water Consumption for Gas Shale Development

TABLE 3-3 Shares of Gas Shale Production by Region

	Current Production[a] (%)	Proved Reserves[b] (%)	Projected Production (%)					
			2005	2010	2015	2020	2025	2030
Northeast	41	93	41	41	42	46	48	50
Southwest	56	7	56	56	55	54	52	50
Rocky Mountain	3	0	3	3	3	0	0	0
Total	100	100	100	100	100	100	100	100

[a] Slutz (2007)

[b] McCallister (2000)

3.4 BIOFUELS

This section considers water demand for three types of biofuels: biomass for power generation, biodiesel fuel for transportation, and ethanol for transportation. Each is described in the following subsections.

3.4.1 Biomass for Power Generation

The EIA identifies four types of biomass used for power generation: agricultural residues, forestry residues, urban wood waste/mill residues, and energy crops. Of these, only the energy crops could be considered to generate net water demand; all of the residue fuels are simply by-products of products or processes for which water consumption would be allocated to the first use. For example, all of the water demand associated with commodity crops would be for growing the crops for food; no additional water would be consumed to produce the residues that remain. On the other hand, the production of energy crops—which include hybrid poplar, hybrid willow, and switchgrass, and are grown on cropland acres currently cropped, idled, or in pasture, and in the Conservation Reserve Program—would consume water. The EIA assumes that that energy crop production will be limited to areas that require no irrigation (Haq 2002). Haq explains that there is a natural rain gradient in the United States, and that land to the West of the gradient generally requires irrigation for crop production. Because irrigation may have significant environmental penalties, all states in the Rocky Mountain and Western Plains Regions are assumed to be excluded from energy crop production. While land in the East could be used to grow energy crops, those crops would not require irrigation. Because of these factors, this study does not project water use associated with the production of energy crops for biomass used for power generation. It can be argued that the rainwater that would be used by the plants would not be available to recharge groundwater and could, therefore, contribute to reduced groundwater flows. However, it is beyond the scope of this study to estimate the quantities of water that would be no longer available for such groundwater recharge.

3.4.2 Biodiesel Fuel

Biodiesel is a renewable diesel substitute with early commercial market development in the United States. The predominant feedstock is surplus soybean oil, which is generated as a coproduct in the soybean meal industry. Biodiesel can be produced from other feedstocks, including vegetable oils, tallow and animal fats, and restaurant waste and trap grease. There are no significant differences in the processing of the numerous biodiesel feedstocks. In 2005, biodiesel production was about 92 million gal. Water consumption for the irrigation of soybean crops depends on the location, but it far outweighs that for production.

Findings. According to the AEO 2007, biodiesel production is expected to increase to about 430 million gal in 2030. As explained below, different estimates of water consumption per gallon of fuel produced were used depending on the region. Estimated water consumption for biodiesel production increases from about 1.5 bgd in 2005 to about 7.4 bgd in 2030, and the regions with the highest consumption are the Pacific and West South Central regions, where 2030 consumption is projected to be about 3.0 bgd and 2.0 bgd, respectively (Figure 3-18).

Projection assumptions. According to NREL (1998), the water used for soybean agriculture is about 550 liters per kilogram (L/kg) of soybeans, and for converting the soybeans to biodiesel fuel, the water use is about 0.55 L/kg. It was assumed that the fuel is converted in the same location as it is grown. A bushel of soybeans weighs about 52 pounds (Kansas Soybean Association 2008). Because the conversion process requires a bushel of soy per gallon of fuel (DOE 2006), water use for agriculture is about 3,470 gal/gal of biodiesel; for processing, it is about 3.5 gal/gal. The Department of Energy (2006) also suggests that water use for irrigated soy production in the United States ranges from about 1,600 to 9,000 gal/bbl depending on location, with eastern areas at the lower end of the range and western areas at the higher end. To reflect this range in water consumption, the projections in this study use the region-specific water consumption assumptions shown in Table 3-4.

3.4.3 Ethanol

In the transportation sector, ethanol is the most widely used liquid biofuel in the world. In the United States, nearly all ethanol is blended into gasoline at up to 10% by volume to produce a fuel called E10 or "gasohol." In 2005, total U.S. ethanol production was 3.9 billion gallons, or 2.9% of the total gasoline pool. Ethanol is produced by fermenting sugars. It can be produced from any feedstock that contains plentiful natural sugars or starch that can be readily converted to sugar. Today the most prevalent feedstock in the United States is corn.

With additional processing, plants and other biomass residues (including low-cost resources such as urban wood waste, forestry residue, paper and pulp liquors, and agricultural residue) can be processed into fermentable sugars to yield significant quantities of fuel-quality ethanol, generically termed "cellulosic ethanol." Cellulosic ethanol currently is not cost-competitive with gasoline or corn-based ethanol, and no large-scale cellulosic ethanol production facilities are operating or under construction. However, technological breakthroughs could make cellulosic ethanol a viable economic option for expanded ethanol production in the future.

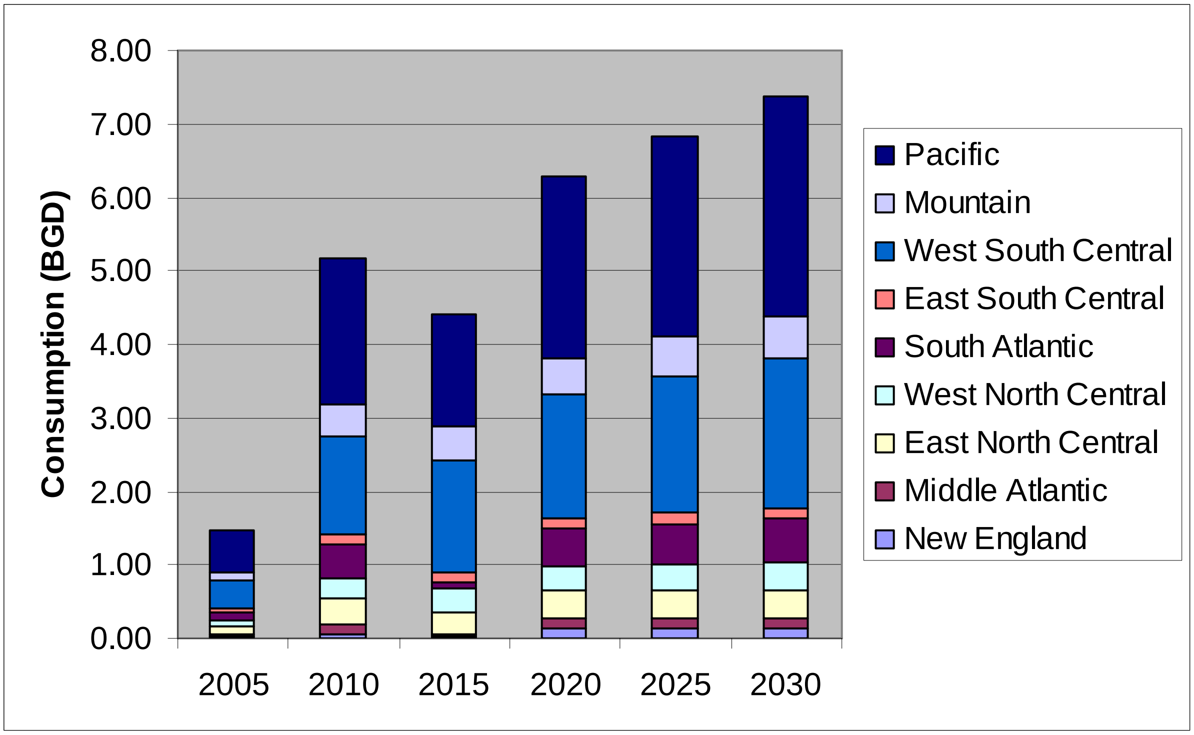

FIGURE 3-18 Projected Water Consumption for Biodiesel Production

TABLE 3-4 Regional Water Consumption Assumptions for Biodiesel Production

Region (U.S. Census Region)	Water Use Assumption (gal water/gal biodiesel produced)
New England	1,600
Middle Atlantic	1,600
East North Central	3,500
West North Central	3,500
South Atlantic	3,500
East South Central	3,500
West South Central	9,000
Mountain	9,000
Pacific	9,000

The EPAct provides financial incentives, which, in the AEO 2007 (EIA 2007b) reference case, are projected to bring the first cellulosic ethanol production facilities on line between 2010 and 2015, with a total capacity of 250 million gal/yr. Also, the AEO 2007 reference case projects a tripling of corn-based ethanol use to 13.6 billion gal by 2030. These assumptions are embodied in the projections of water demand for ethanol in this study. However, the Energy Independence and Security Act of 2007 (EISA), signed on December 19, 2007, extends and increases the renewable fuel standard (RFS), which requires minimum annual levels of renewable fuel in U.S. transportation fuel, set by the EPAct and increases the portion of cellulosic-based ethanol production. The previous RFS was 5.4 billion gal for 2008, rising to 7.5 billion gal by 2012. (In the AEO 2007 reference case, ethanol demand is projected to exceed the applicable RFS between now and 2012, because of ethanol's use in meeting federal gasoline specifications and as an octane enhancer.) The new standard starts at 9.0 billion gal in 2008 and rises to 36 billion gal in 2022, of which 16 billion gal are to be cellulosic ethanol. Starting in 2016, all of the increase in the RFS target must be met with advanced biofuels, defined as cellulosic ethanol and other biofuels derived from feedstocks other than corn starch. In addition, the new law requires the DOE to research and develop strains of biofuels that would reduce water and soil needs; and the DOE, EPA, and the Department of Agriculture to report to Congress every three years on the environmental impacts of renewable fuels mandates, including impacts on water supplies. With the implementation of these provisions, the mix of crops and the technologies used to produce ethanol may cause the water demands to differ from those projected in this study.

3.4.3.1 Water Use

Corn-based ethanol uses water for irrigation and processing. Irrigation requires an estimated 785 gal water/gal ethanol produced (Aden 2007), but not all corn requires irrigation. Today, it is estimated that less than 10% of the field corn used for ethanol is irrigated. As more land is used, however, the amount requiring irrigation is expected to increase. For this study, it was assumed that none of corn grown in the East will require irrigation and that all of the corn in the West will require irrigation at the rate of 785 gal water/gal ethanol produced. Water use for processing has been declining over time, from about 6 gal to 4 gal water/gal ethanol between 1998 and 2005 (IATP 2006). Newer processing plants consume about 3 gal water/gal ethanol produced. Most of this water is used for energy—about 60% in the cooling tower, and about 20% to feed the boiler. The remaining 20% is absorbed into the ethanol itself (Adams and Zink 2007). In this study, to reflect improvements in water efficiency over time, the assumed average water use for processing was 5 gal/gal for 2005–2010, 4 gal for 2015–2020, and 3 gal for 2025–2030.

Water consumption for cellulosic ethanol is expected to be significantly less than that for corn-based ethanol. Many cellulose sources require no irrigation, and those that do are expected to require less water than does corn. It was assumed that cellulosic ethanol produced in the East will require no irrigation and that the irrigation water requirements for cellulose produced in the west will be half that for corn-based ethanol. Current technology for cellulosic ethanol processing uses about 6 gal water/gal ethanol produced (Aden 2007). Technology improvements are expected to reduce this demand to less than 2 gal water/gal ethanol. To reflect these expected improvements, this study uses the 6 gal water/gal fuel estimate for the 2005–2020 period and the 2 gal water estimate for 2025–2030 period.

Findings. With the AEO 2007 reference case scenario, projected water consumption for corn-based ethanol production increases from about 5.9 bgd in 2005 to 18.8 bgd in 2030; for cellulosic ethanol, projected water consumption increases from zero in 2005 to about 0.1 billion gallons in 2030 (Figure 3-19).

Over the projection period, nearly 99% of the water consumed for corn-based ethanol occurs in the West North Central U.S. Census Region, with relatively small amounts in several other regions. Figure 3-20 shows projected water demand for corn-based ethanol in regions other than the West North Central U.S. Census. These demands are small relative to those for corn-based ethanol in the West North Central U.S. Census Region, but not necessarily small relative to other uses in these regions.

For cellulosic ethanol, most water consumption (about 99%) occurs in the Pacific U.S. Census Region with the remainder in the South Atlantic U.S. Census Region. While both regions are expected to produce about 0.12 billion gal of cellulosic ethanol by 2030, water consumption is greater in the Pacific because of the need to irrigate. Figure 3-21 compares the regional water consumption patterns for biofuels production in 2005 with those projected for 2030. It shows that while most of the production is expected to occur in the West North Central U.S. Census Region, nearly all of the regions can expect to experience increased water consumption for biofuels production by 2030.

As noted in the National Academies Report, *Water Implications of Biofuels Production in the United States* (NRC 2008), while the amount of water used in the processing of biofuels is small relative to that required for growing the plants, local effects could be substantial because

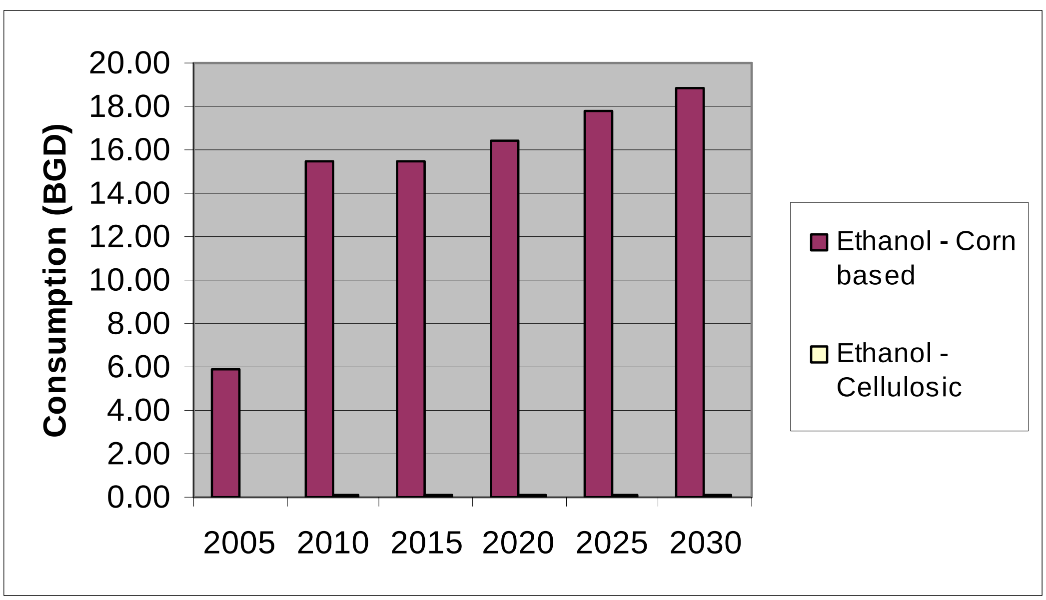

FIGURE 3-19 Projected Water Consumption for Ethanol, 2005–2030

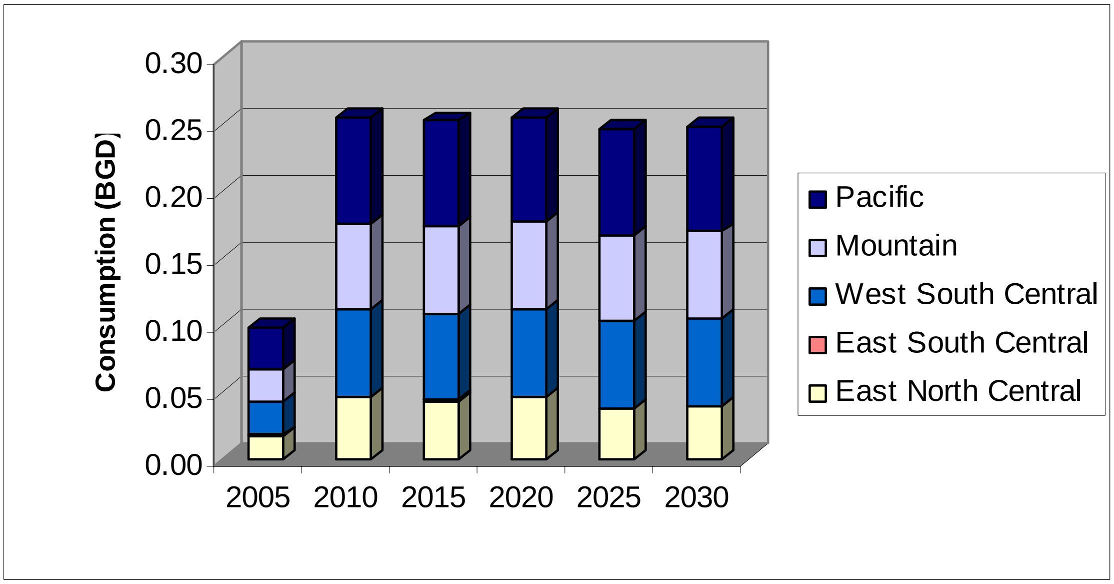

FIGURE 3-20 Projected Water Demand for Corn-Based Ethanol in Regions Other than the West North Central

water use is concentrated in smaller areas. For example, a biorefinery that produces 100 million gal ethanol/yr would use an amount of water that would supply a town of about 5,000 people. Irrigation demands will depend on the type and location of the crop gown. The National Academies report suggests that increased production of biofuels in the next 5 to 10 years will not alter the national, aggregate view of water use, but significant regional impacts can be expected where water resources are already stressed.

3.5 HYDROGEN

The term "hydrogen economy" describes a future American energy system in which hydrogen is used as a fuel for transportation and stationary power. Since the President's 2003 announcement of a large-scale research and development program, DOE has invested millions of dollars in the Hydrogen Fuel Initiative and developed a "Hydrogen Posture Plan," which is a coordinated plan for the Department's hydrogen and fuel cell programs required by the EPAct. AEO 2007 (EIA 2007a) projects that hydrogen will contribute about 0.004 quads of energy to the nation's total energy supply in 2030 (estimated at about 131 quads), and greater contributions of hydrogen are projected to occur after 2030.[2]

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2 The National Research Council (NRC 2004) estimates an ultimate demand for hydrogen possibly exceeding 100 billion kg annually after 2050 when the hydrogen economy is fully scaled up. This compares with the estimated 30 million kg that would be required to meet the 0.004-quad contribution to domestic energy supply projected in the AEO 2007 (EIA 2007a) for 2030.

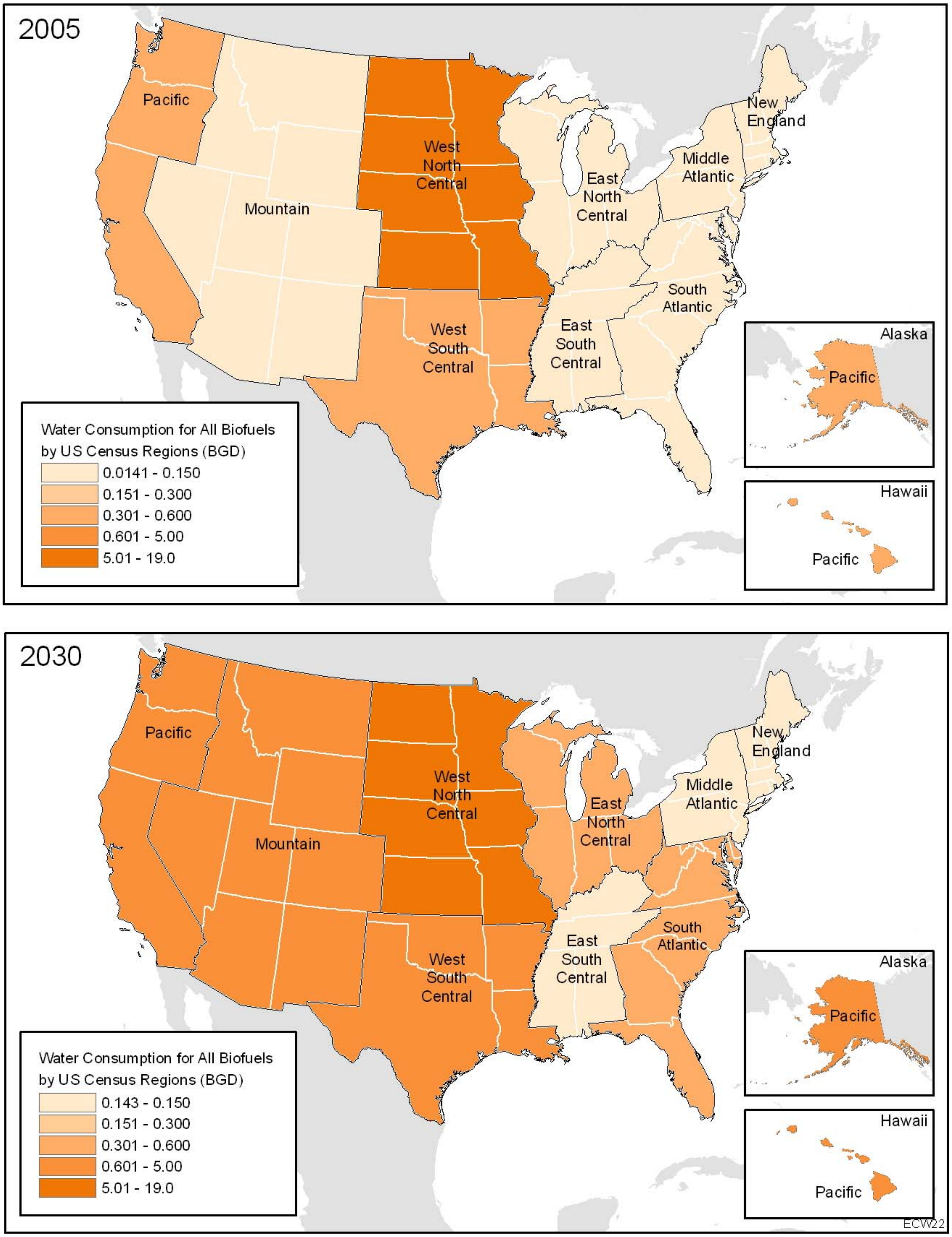

FIGURE 3-21 Comparison of Regional Water Consumption Estimates for Biofuels, 2005 and 2030

At least two studies have estimated water use for hydrogen production. Spath and Mann (2001) estimate that the water consumed during hydrogen production via natural gas steam reforming is about 18.8 L/kg (4.96 gal/kg) of hydrogen produced. Of this, about a quarter is consumed in reforming and shift reactions and the remainder in steam production. Webber (2007) has estimated that hydrogen production will, on average, withdraw approximately 1,100 gal of cooling water and will consume 27 gal of water as a feedstock and coolant per kilogram of hydrogen that is produced using an electrolyzer with an efficiency of 75%.

By 2030, projected water consumption for hydrogen production is estimated to range between about 420,000 and 2,280,000 gal/d, and projected water withdrawals would be about 93 mgd (Figure 3-22). Figure 3-23 shows the rapid growth in water consumption by U.S. Census Region over the study period. The areas with the greatest projected water consumption (assuming the consumption rate of 27 gal/kg of production) in 2030 are the South Atlantic (500,000 gal/d) and the Pacific (400,000 gal/d). The East North Central, Middle Atlantic, and West South Central regions each are estimated to consume about 300,000 gal/d in 2030. Because impacts can be localized, the dramatic increases in water consumption over a fairly short time period suggest that future hydrogen production locations may need to be evaluated for potential impacts on local water resources. Figure 3-24 compares the regional distribution of water consumption for hydrogen production in 2005 with that projected for 2030.

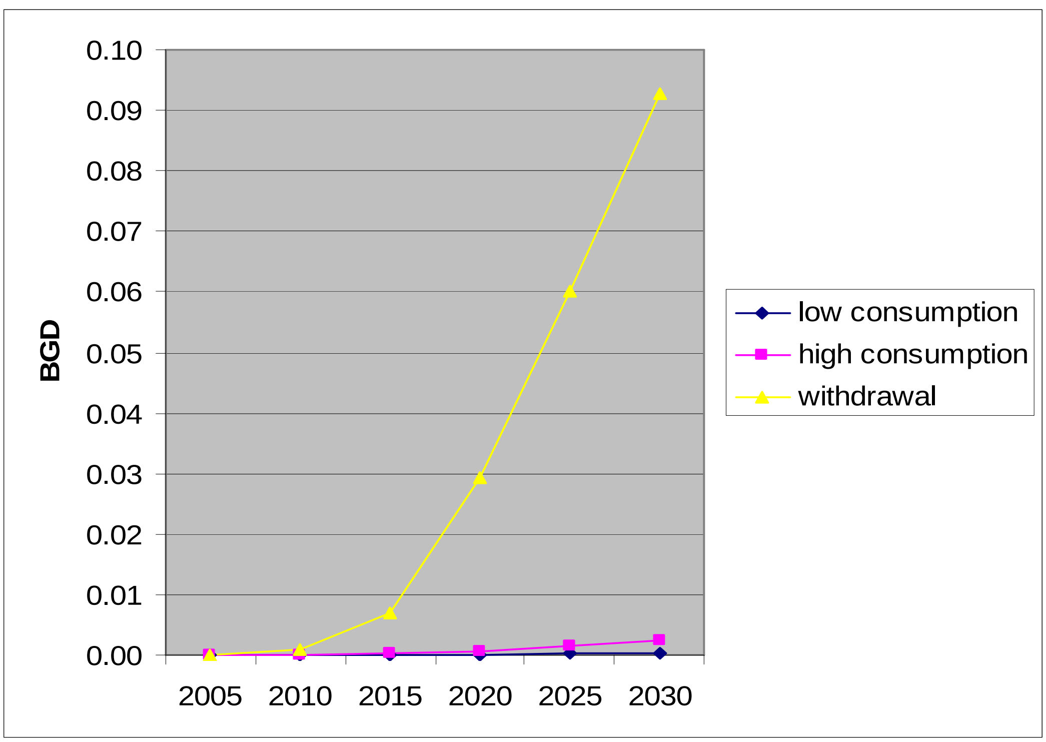

FIGURE 3-22 Projected Water Withdrawals and Consumption for Hydrogen Production, 2005–2030

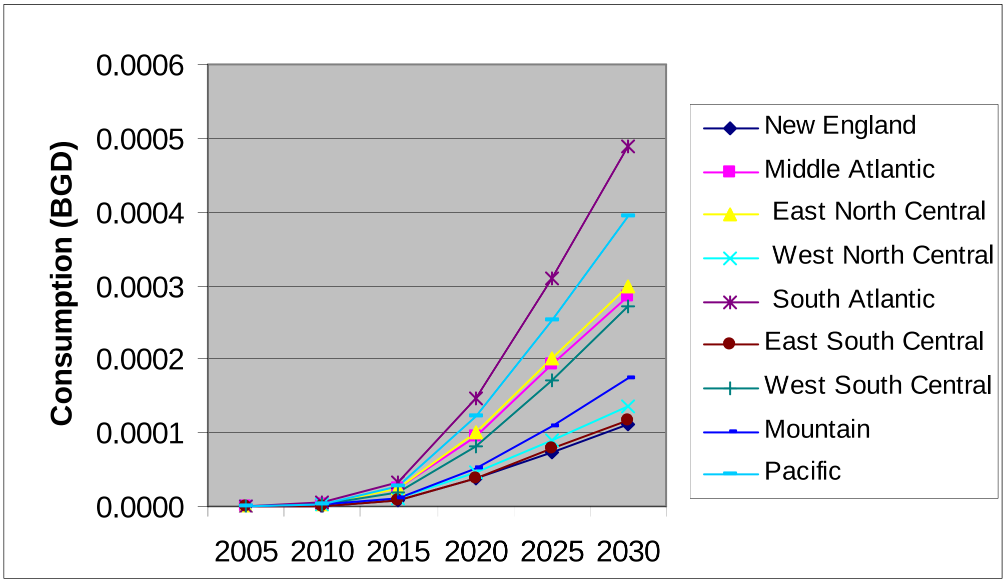

FIGURE 3-23 Projected Water Consumption for Hydrogen Production, by Region, 2005–2030

3.6 THERMOELECTRIC POWER GENERATION

NETL (2007) projects average national freshwater withdrawal and consumption for thermoelectric power generation for five cases using the AEO 2007 regional projections for capacity additions and retirements. The cases vary in terms of cooling assumptions, which are detailed in NETL 2007. Table 3-5 reproduces the estimated water consumption projections for each case.

Figure 3-25 shows regional consumption estimates for NETL Case 2, which assumes that all capacity additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. According to NETL, Case 2 “represents a plausible future cooling system scenario.” Accordingly, in this report, the estimated energy and nonenergy sector water consumption projections are compared with the water consumption projections from NETL Case 2. Regions with the highest projected water consumption in 2030 in Case 2 are the Electric Reliability Council of Texas and the Southeastern Electric Reliability Council, both of which are projected to consume more than 1.5 bgd (Figure 3-25.) Regions with the fastest projected growth in water consumption over the period are the Western Electricity Coordinating Council, the Florida Reliability Coordinating Council, and the Northeast Power Coordinating Council.

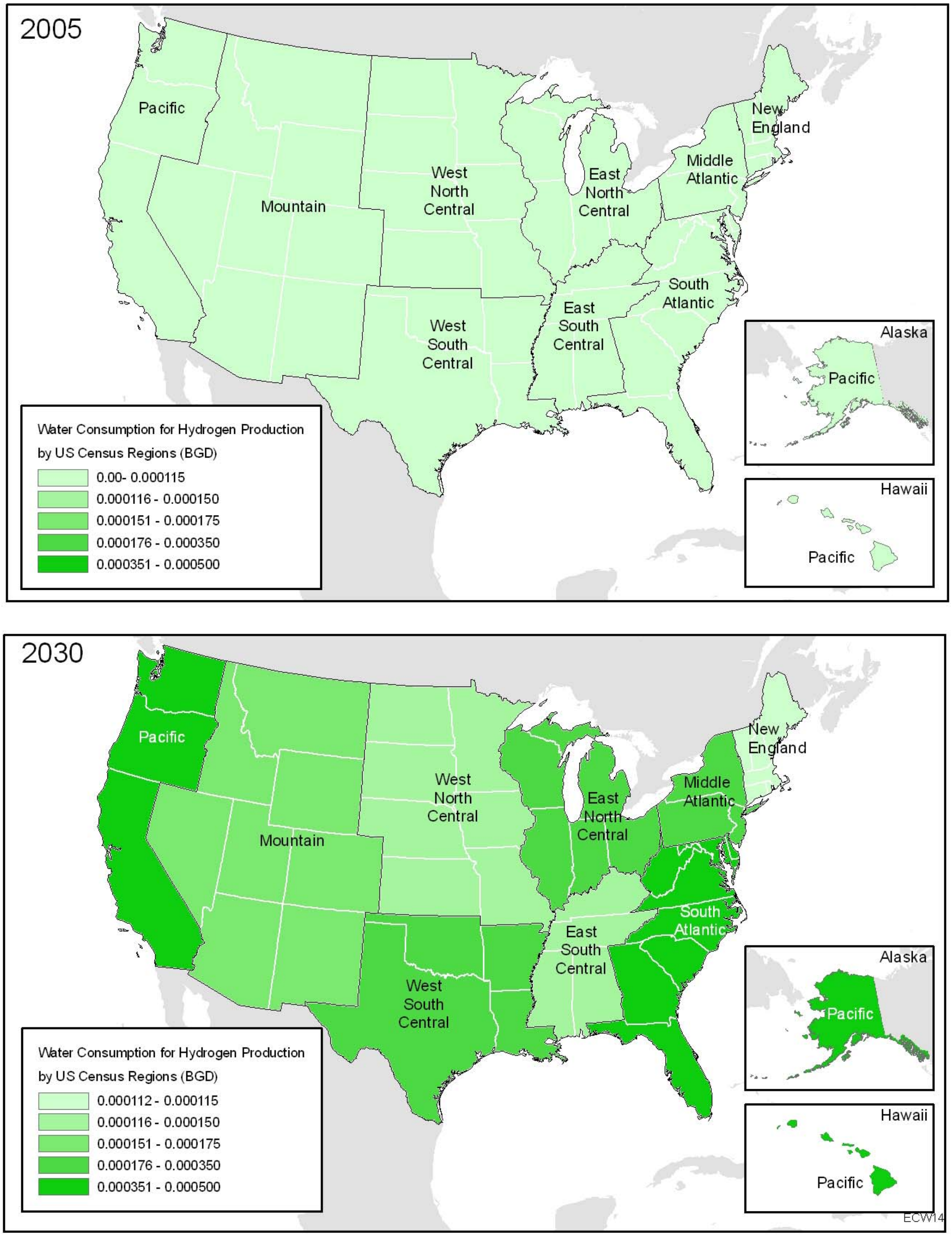

FIGURE 3-24 Comparison of Regional Water Consumption Estimates for Hydrogen Production, 2005 and 2030

TABLE 3-5 Projected Average National Freshwater Consumption for Thermoelectric Power Generation (bgd)

Case	2005	2010	2015	2020	2025	2030
1	6.1	6.3	6.6	7.0	7.5	7.9
2	6.1	6.3	6.7	7.2	7.7	8.2
3	6.1	6.3	6.6	7.2	7.6	8.1
4	6.1	6.3	6.6	7.0	7.4	7.8
5	6.1	6.5	7.0	7.8	8.4	9.1

Source: NETL (2007).

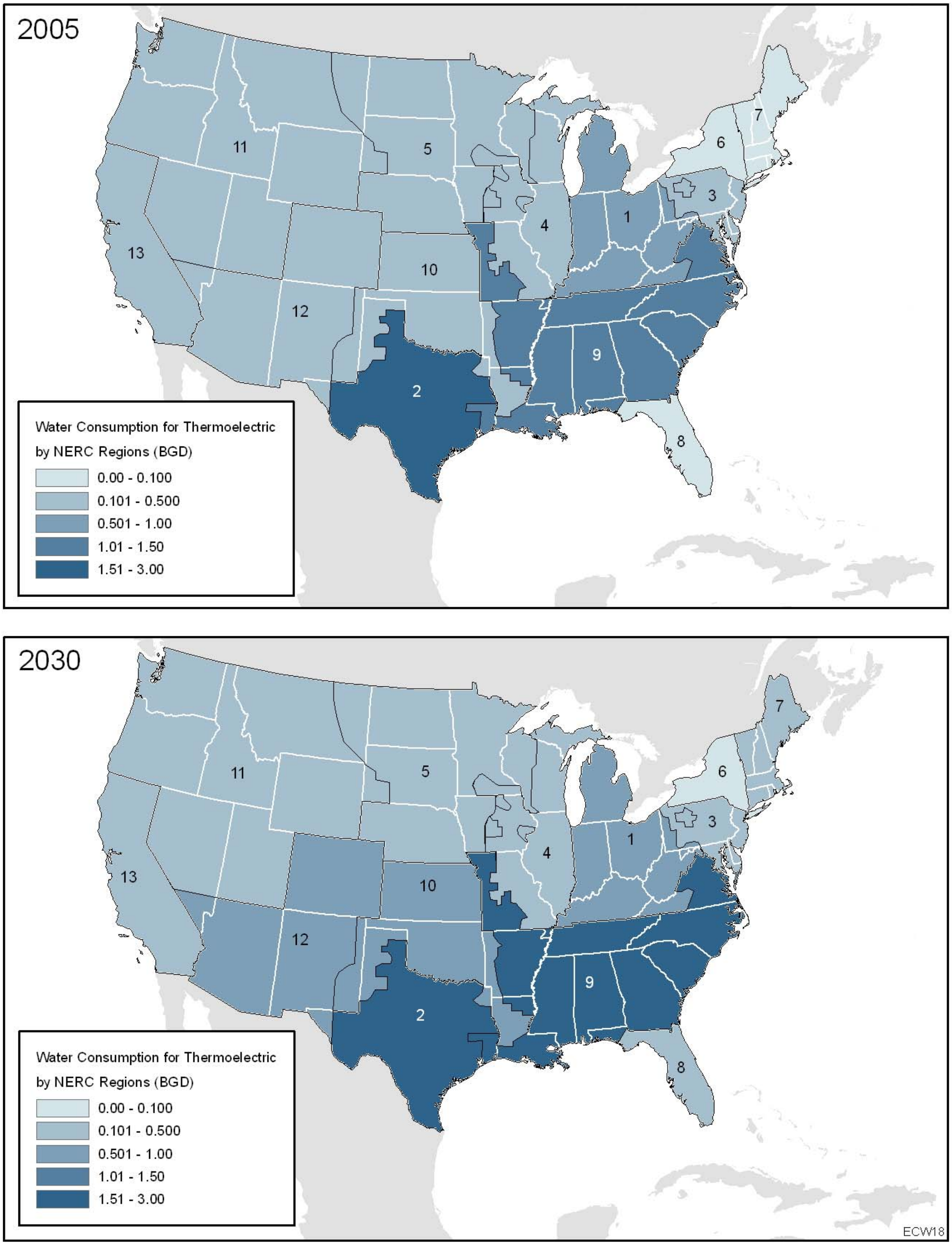

FIGURE 3-25 Comparison of Regional Water Consumption Estimates for Thermoelectric Power Production, 2005 and 2030 (Source: NETL 2007)

4 WATER DEMAND PROJECTIONS FOR NONENERGY SECTORS

Water demand estimates for nonenergy sectors in this report come from the USFS, which projected freshwater demands for aggregated demand categories in 10-year increments through 2040. The USFS provided these estimates in a technical document (Brown 1999) that supported the 2000 USFS assessment of renewable resources. The projections in this RPA study are based on extrapolations of historical USGS water use data and are provided at the national level and for the 21 WRRs. Table 4-1 shows the uses included in the various categories for which the USGS (and the USFS) provided water use estimates. The RPA projections were developed prior to the current energy situation and the recognition of the significant linkages between water and energy production (although the relationship between irrigation pumping and energy was identified). Neither the EPAct of 2005 nor the Energy Independence and Security Act of 2007 had been introduced, and, therefore, it is not surprising that the RPA projections did not highlight water use for energy production.

4.1 PROJECTION ASSUMPTIONS

The USFS based its water-use projections on historical water withdrawal and consumption information from USGS reports and demographic and other data projections that included population, civilian labor force, disposable income, gross national product, kilowatt hours generated, imported oil price, and electricity price. Estimates of future population and income provided by the Bureau of the Census and Bureau of Economic Analysis, and explicit assumptions about rates of change in other factors affecting water use developed specifically for the study, were used to develop water demand projections. In some cases (e.g., industrial and commercial withdrawal per dollar of income), the future rates of change follow past trends. In other cases (e.g., domestic and public use per capita), recent abrupt changes in trends have made trend extrapolation problematic, thus diminishing rates of change over time were used. (For details, see Brown 1999.)

For most sectors, projections of water consumption were made at the national level. These projections were then disaggregated to WRRs on the basis of the shares each region had of the 1995 total demand. Because irrigation was considered subject to more region-specific forces than other uses, the rates of change for acres irrigated were specified at the WRR level, and rates of withdrawal per acre were specified separately for the eastern and western portions of the country.

The historical data on which the projections are based are from 1960 through 1995, and the trends in water-use efficiency are assumed to continue into the future. Although the study projects water withdrawals rather than water consumption, the methodology description includes sector- and region-specific consumption factors (consumption as a percentage of withdrawal) for 1995 (Brown 1999). These consumption factors were applied to each region/sector combination (e.g., Upper Colorado/irrigation), as appropriate, to obtain consumption estimates for each projection year. The national-level results for total freshwater consumption by sector (water use category) are summarized in Table 4-2, shown graphically in Figure 4-1, and discussed in the following paragraphs. Unless otherwise noted, the following information is from Brown (1999).

TABLE 4-1 Water Use Categories Reported by USGS

Category	Water Use
Domestic and Public	*Domestic supply.* Indoor household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and outdoor purposes such as watering lawns and gardens. In rural areas, domestic supply is also used for livestock and dairy sanitation, evaporation from stock-watering ponds, cleaning, and waste disposal.
	Public supply. Water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for domestic, commercial, industrial, thermoelectric power, and public water uses.
Industrial and Commercial	*Industrial.* Fabrication, processing, washing, and cooling for industries such as chemical and allied products, food, mining, paper and allied products, petroleum refining, and steel.
	Commercial. Motels, hotels, restaurants, office buildings, other commercial facilities, and military and nonmilitary institutions. Water for commercial purposes may be obtained from a public-supply system or may be self-supplied.
	Mining. Extraction of naturally occurring minerals including solids, such as coal, sand, gravel, and other ores; liquids, such as crude petroleum; and gases, such as natural gas. Also includes uses associated with quarrying, milling, and other preparations customarily done at the mine site or as part of a mining activity.
Irrigation	Water that is applied by an irrigation system to assist in the growing of crops and pastures or to maintain vegetative growth on recreational lands such as parks and golf courses. Irrigation includes water that is applied for pre-irrigation, frost protection, chemical application, weed control, field preparation, crop cooling, harvesting, dust suppression, the leaching of salts from the root zone, and water lost in conveyance. In the arid and semi-arid parts of the Rocky Mountains and Pacific Coast, irrigation is required to cultivate most non-native vegetation. In the more humid areas in the North and South, irrigation helps increase the number of plantings per year and yield per crop, and it reduces the risk of loss during droughts.
Livestock	Livestock watering (drinking and sanitation), feedlots, dairy operations, and other on-farm needs. Depending on the data collection and presentation method, it may also include water used for aquaculture.
Thermoelectric	The USGS reports water withdrawal for thermoelectric use, and the USFS projects water demand for thermoelectric power. These estimates were included so that the consumption components will sum to the total. However, because water consumption for thermoelectric power use is described in detail in NETL (2007), in this report the NETL projections are used for comparing thermoelectric water demands with those of other energy sectors.

Source: USGS (2004).

TABLE 4-2 RPA Freshwater Consumption Projections by Sector (bgd)

Sector	2005	2010	2015	2020	2025	2030
Irrigation	79.98	79.50	79.20	78.90	78.66	78.42
Industrial and Commercial	5.35	5.33	5.32	5.31	5.40	5.48
Domestic and Public	7.26	7.56	7.89	8.22	8.53	8.84
Livestock	3.49	3.65	3.82	3.98	4.14	4.29
Thermoelectric	4.00	4.02	4.07	4.11	4.16	4.20
Total	100.08	100.07	100.29	100.52	100.88	101.24

Source: Brown 1999 for 2010, 2020, and 2030 data; data for 2005, 2015, and 2025 are interpolated.

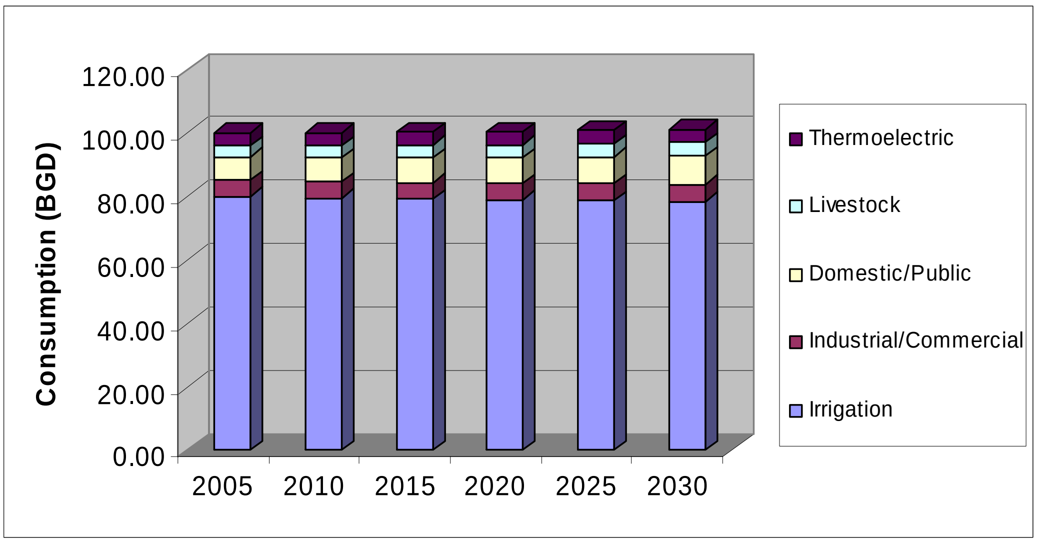

FIGURE 4-1 RPA Freshwater Consumption Projections by Sector (Source: Brown 1999 for 2010, 2020, and 2030 data; data for 2005, 2015, and 2025 are interpolated.)

In the RPA analysis, total water consumption is projected to increase over the period by about 1.16 bgd—from 100.08 bgd in 2005 to 101.24 bgd in 2030. The relatively small overall increase (about 1%) in water consumption over the 25-year period, despite projected population increases, results largely from assumed continued improvements in water-use efficiency expected in the municipal, industrial, and thermoelectric sectors. A reduction in total water consumption for irrigation between 2005 and 2030 of about 1.6 bgd also contributes to the relative overall stability in nonenergy-related water consumption. The largest increases in water consumption by nonenergy sectors are in domestic and public use (1.58 bgd—a 22% increase over the projection period) and livestock (0.8 bgd—a 23% increase over the period). Industrial and commercial water consumption is expected to increase by about 0.13 bgd (a 2.4% increase) over the 25-year projection period.

4.2 IRRIGATION

Although irrigation remains by far the largest consumer of water over the period (it is projected to consume, on average, about 79% of all water consumed by nonenergy uses), national-level water consumption for irrigation is projected to decrease from about 80.0 bgd in 2005 to about 78.4 bgd in 2030. The principal source of irrigation water is wells. Because irrigation sources must be pumped, energy use—particularly electricity—is high. As aquifers decline, increased pumping costs can reduce overall consumption increases. Technological advances in irrigation, such as "smart" sprinkler controllers, are expected to continue and contribute to the declining growth in irrigation water demand.

In addition to energy prices (particularly with respect to pumping) and irrigation technologies, factors affecting irrigation consumption include international markets for agricultural crops, changing tastes for livestock (nearly half of western irrigated land is used to produce feed and forage for livestock), federal agricultural policies, instream flow concerns, and precipitation variations. Because of the difficulties in attempting to account for all these factors, the approach used by Brown (1999) was to set withdrawals equal to irrigated acreage multiplied by withdrawal per acre. Past trends were extrapolated to estimate future acreage and withdrawal per acre. By applying the region-specific irrigation consumption factors noted above to Brown's projected withdrawal estimates, region-specific consumption estimates were projected, which were then summed to provide national irrigation consumption estimates. Between 2005 and 2030, water consumption for irrigation in the United States is projected to drop by about 2%. These projections could change with the implementation of the new "20 in 10" goal, which requires reducing U.S. gasoline usage by 20% in the next 10 years through increased renewable (biodiesel and ethanol) and alternative fuels by 2017.

4.3 DOMESTIC AND PUBLIC USE

After increasing for 30 years (although at decreasing rates), per-capita domestic and public water withdrawals dropped by 0.3% per year between 1990 and 1995. It was not known whether this decrease was too recent and small to induce a major shift in the prior trend, but several factors suggest a possible trend change. Thus, the USFS authors assumed that future per-capita withdrawal would remain constant at 121 gpd, equal to the midpoint between the 1990 and 1995 levels, and that national domestic and public withdrawals would increase at the same rate as population growth. As a consequence, water consumption for domestic and public use is expected to increase by 1.6 bgd between 2005 and 2030, essentially offsetting the drop in projected consumption for irrigation.

4.4 INDUSTRIAL AND COMMERCIAL USE

In the 1970s, water quality legislation imposed more stringent regulations on industrial dischargers, meaning that the dischargers either had to pay increased treatment costs required by municipal treatment systems or build costly treatment facilities themselves. To reduce these costs, industries implemented leak detection and repair and recycling, which reduce the volume of water needing treatment. The historical trend in industrial self-supplied water has fluctuated and has no significant association with gross national product. The types of industries that are heavy water users have shown mixed economic performance in the past.

In the RPA study, withdrawals for industrial and commercial use were projected on the basis of estimates of future population and income and assumptions about the rate of change in withdrawal per dollar of income. Withdrawal per dollar of income, which dropped from the 1960s to the 1990s, was assumed to drop at a gradually decreasing rate—from 2% to 1% per year—over the projection period. This assumption continues the past trends of converting to more efficient processes, increasing the levels of water recycling, and shifting from heavy industry to the generally less water-intensive service industries. Total industrial and commercial water consumption is projected to increase slightly, from about 5.4 bgd in 2005 to about 5.5 bgd in 2030—a 2% increase. Thus, the decreasing withdrawal per dollar largely compensates for the continued increases in population and per-capita income.

4.5 LIVESTOCK

Livestock watering needs are a function of demand for red meat, dairy products, and fish (assuming aquaculture is included in livestock watering). Livestock withdrawals were assumed to remain constant at the 1995 level of about 21 gpd per person. Total livestock water consumption in the United States is projected to rise from 3.5 bgd in 2005 to 4.3 bgd in 2030—a 23% increase over the projection period.

4.6 REGIONAL NONENERGY WATER DEMAND PROJECTIONS

Regional level projections show no dramatic changes in water consumption patterns over the projection period (Figures 4-2 and 4-3). General conclusions include the following:

- The WRRs with the highest projected water consumption for nonenergy-production sectors in 2030 are the California, Missouri Basin, Lower Mississippi, and Pacific Northwest WRRs (Figure 4-4). Many of these areas are in the Midwest or West, where water supply is of concern.

- WRRs with the highest projected growth in nonenergy sector water consumption between 2005 and 2030 are Lower Mississippi (23% increase), Tennessee (18% increase), and South Atlantic–Gulf (17% increase) (Figure 4-5).

- All WRRs project increases in consumption for livestock and domestic and public uses, a finding that is consistent with the assumptions of increasing population in all regions.

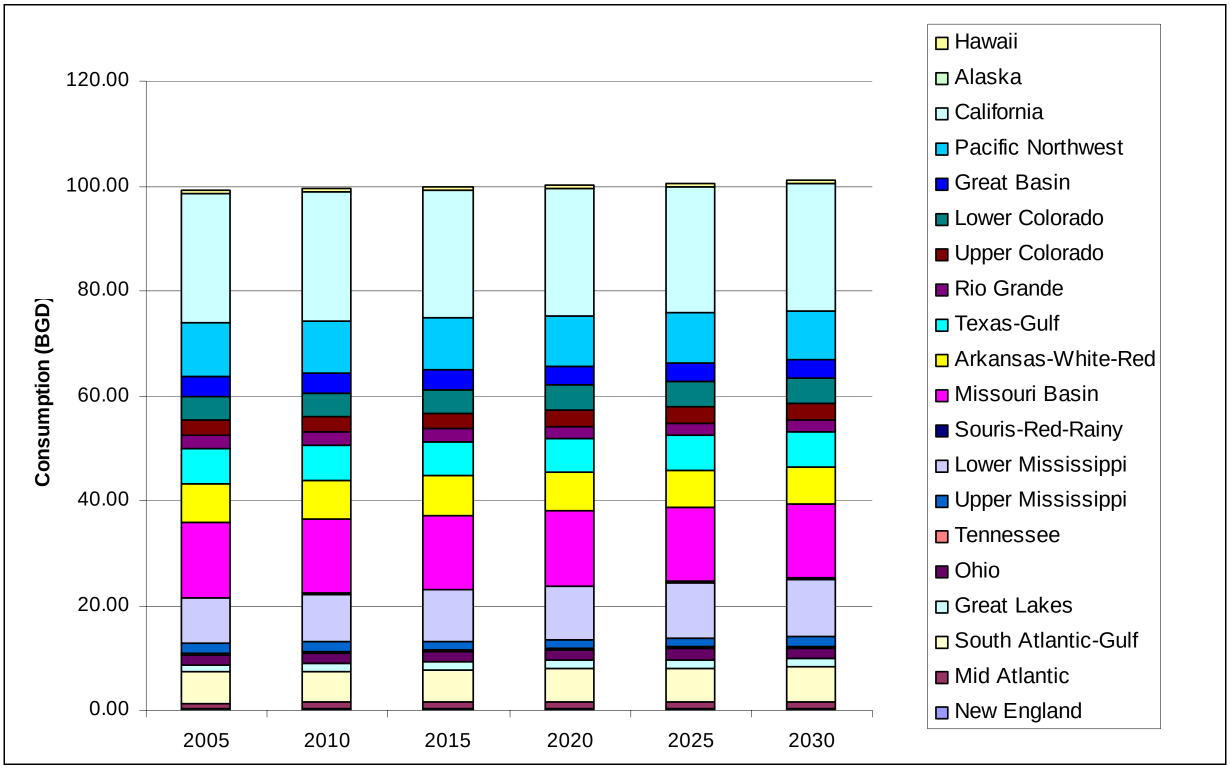

FIGURE 4-2 RPA Projected Water Consumption for Nonenergy Uses by Water Resource Region (Source: Brown 1999 for 2010, 2020, and 2030 data; data for 2005, 2015, and 2025 are interpolated)

- On a percentage basis, the increases in livestock and domestic and public consumption are most pronounced in the western regions and in the South Atlantic Gulf WRR, where the greatest population increases are projected.

- Water consumption is projected to remain steady or decline in nine WRRs for industrial and commercial use despite the expected increases in economic activity, because of the assumed increase in efficiency of industrial and commercial water use. In the other regions, population and per-capita income increases overwhelm the increasing efficiencies of water use to cause projected increases in industrial and commercial consumption ranging from about 5% to about 18% in the continental United States.

- Irrigation consumption is projected to increase in nine WRRs, decrease in nine, and remain constant in two. Only three regions are projected to experience substantial volume increases in consumption (the South Atlantic–Gulf, Lower Mississippi, and Upper Colorado), although in percentage terms, several other WRRs also show substantial increases (e.g., Tennessee, Ohio, Great Lakes).

Appendix G contains USFS-projected water consumption estimates by sector and WRR over the projection period.

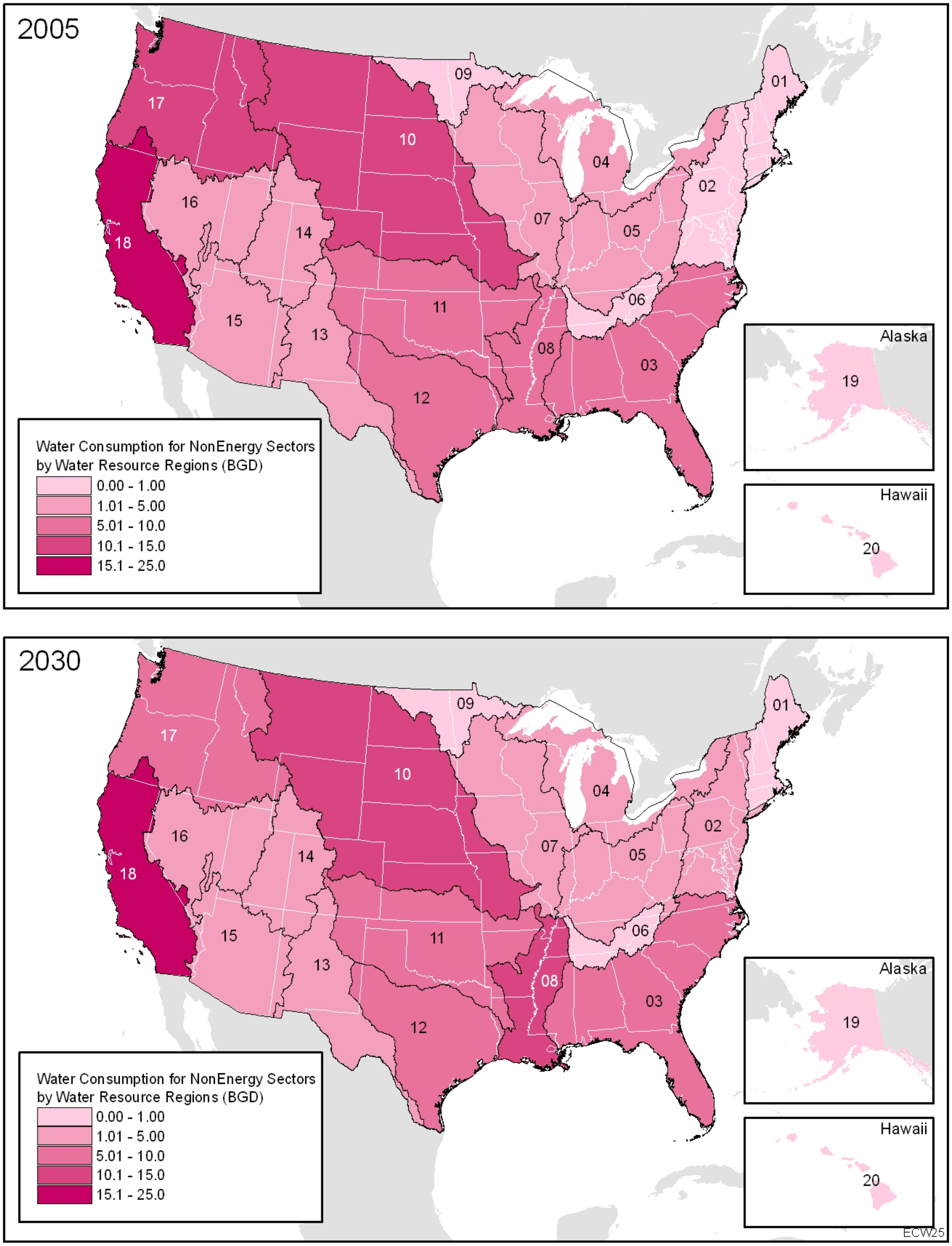

FIGURE 4-3 Comparison of Regional Estimates of Water Consumption for Nonenergy Sectors, 2005 and 2030

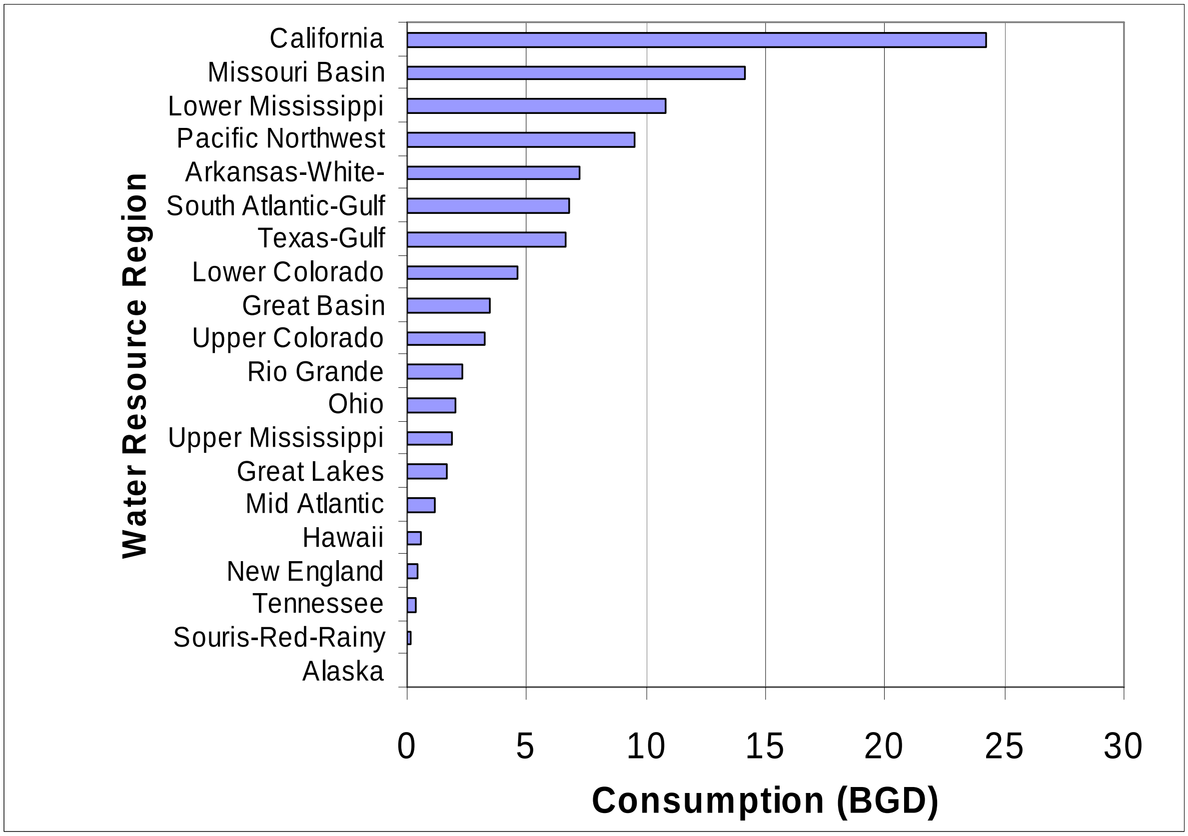

FIGURE 4-4 Projected Nonenergy Regional Water Consumption of Highest-Consuming WRRs, 2030 (Source: Brown 1999)

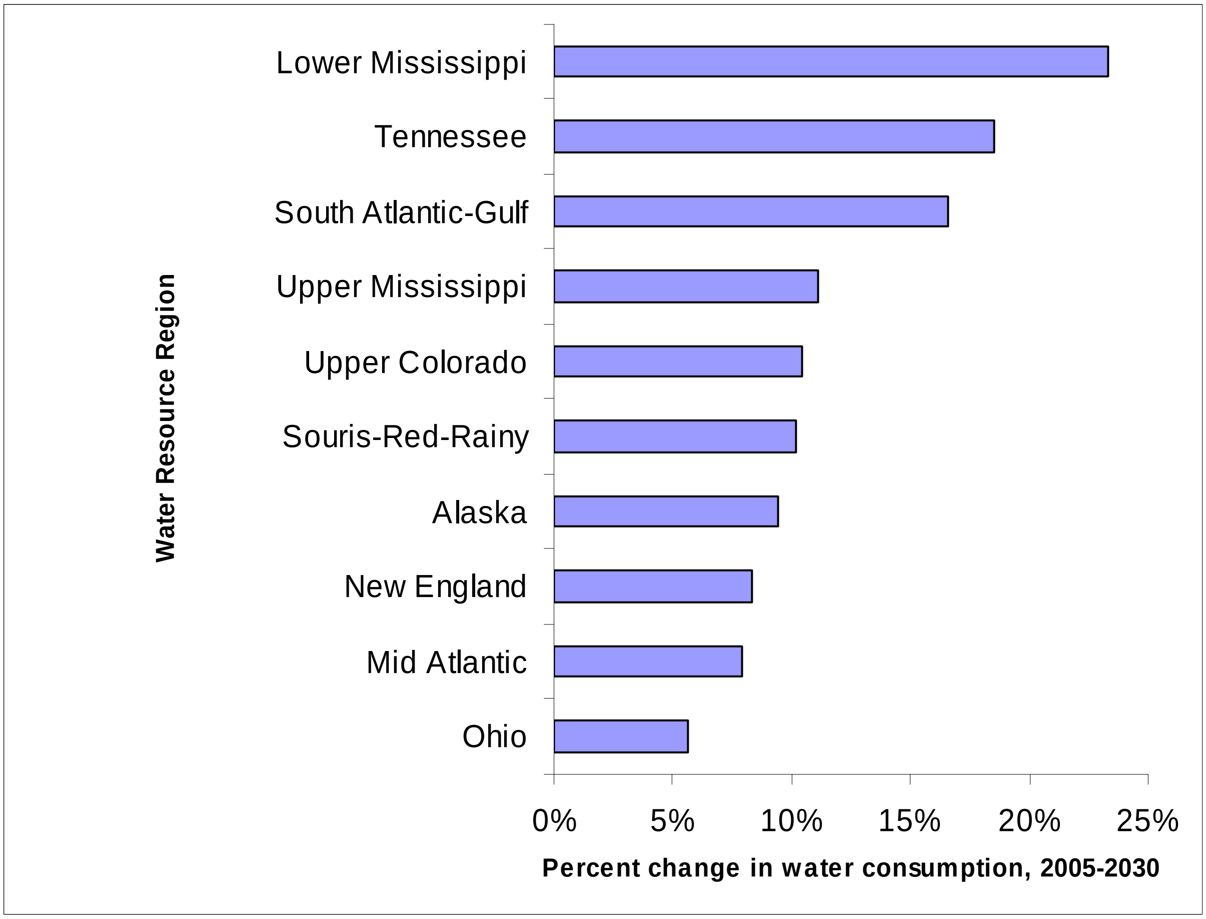

FIGURE 4-5 WRRs with the Highest Projected Percentage Increase in Nonenergy Water Consumption over the Projection Period (Source: Brown 1999)

5 CONCLUSIONS

On the basis of: (1) assumptions regarding future energy production from the DOE and water consumption coefficients from the literature; (2) NETL projections of water consumption by thermoelectric power generation; and (3) USFS projections of water use by nonenergy sectors, total domestic water consumption is projected to increase from about 114 bgd in 2005 to about 136 bgd in 2030—an increase of nearly 20% over the 2005–2030 period. Water consumption by energy-production sectors is projected to increase from about 12 bgd in 2005 to 31 bgd in 2030.

Figure 5-1 shows the dramatic increase in water consumption expected by energy production over the time period. It grows faster than any other sector, and it is higher than that for any other sector except irrigation. As a percentage of total water consumption, that consumed by energy sectors is projected to increase from about 10% in 2005 to about 27% in 2030. The bulk of this increase comes from increased biofuels production. Thus, water consumption for biofuels production is projected to more than triple—from an estimated 7.4 bgd to an estimated 26.3 bgd—between 2005 and 2030.

By removing the biofuels component from the energy-production total, water consumption for the rest of the energy-production sectors is projected to be between that for livestock and industrial/commercial uses—that is, about 0.4 bgd more than in 2005, or about 5 bgd in 2030 (Figure 5-2).

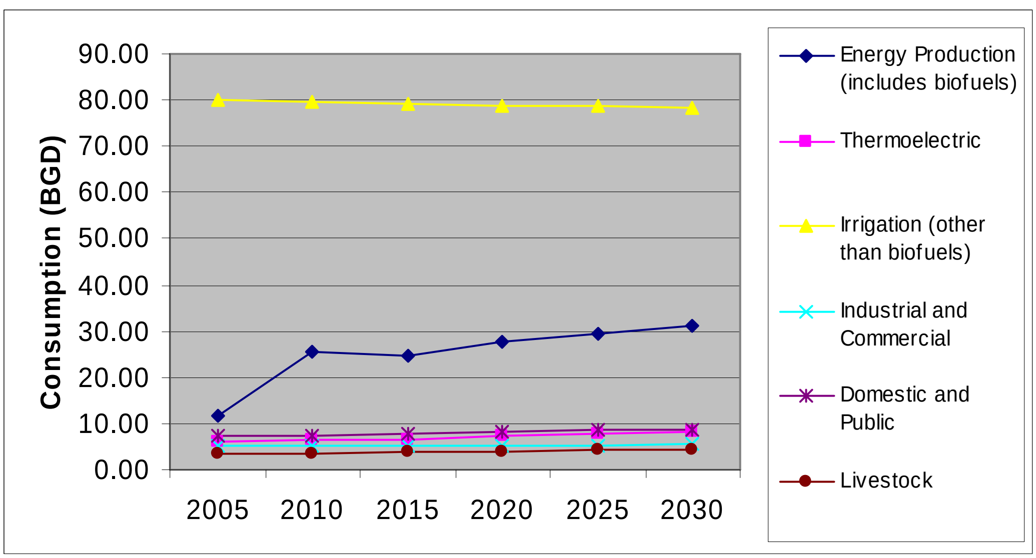

FIGURE 5-1 Projected Water Consumption Estimates for the Energy and Nonenergy Sectors (Sources: Brown 1999 for industrial/commercial, irrigation, domestic/public, and livestock data; NETL 2007 for thermoelectric data)

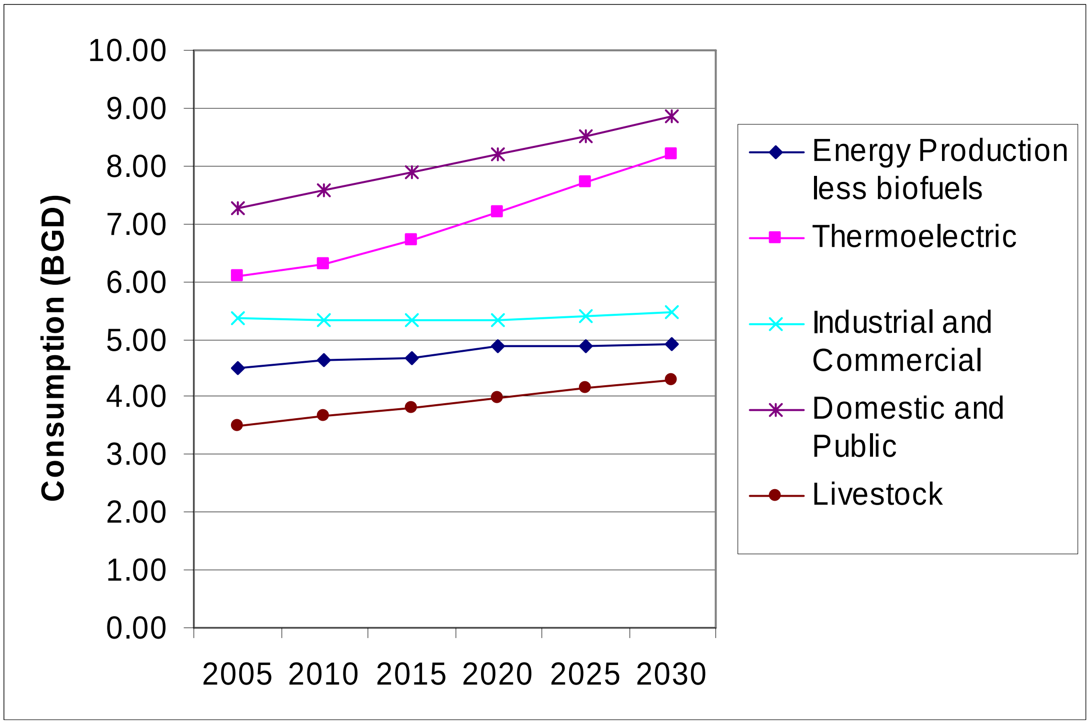

FIGURE 5-2 Projected Water Consumption Estimates, Energy Less Biofuels (Sources: Brown 1999 for industrial/commercial, irrigation, domestic/public, and livestock data; NETL 2007 for thermoelectric data)

5.1 CAVEATS

Several caveats must be recognized when considering the conclusions of this report. First, the data come from different sources that have different assumptions. For example, to obtain the total estimated 2030 water consumption, the NETL projections of thermoelectric water consumption were substituted for those provided in the USFS's RPA estimates. However, the assumptions used to produce the NETL projections of water consumption for thermoelectric power are likely different than those used in the RPA assessment. In addition, assumptions made in original source data may be inaccurate or subject to change. Examples of such assumptions include, but are not limited to, the following:

- The USFS projections assume that water-use efficiency improvements will continue in the municipal, industrial, and thermoelectric sectors throughout the projection period.

- The assumptions used in the AEO 2007 projections may change; indeed, the EIA projects energy supply for at least three different growth scenarios, and this study used the results of the middle range.

- The EIA assumes that energy crop production will be limited to areas that require no irrigation.

Second, there is likely overlap among some nonenergy sectors and some of the energy-production sectors. For example, water consumption for coal mining may be included in both the energy-production category (developed in this report) and the industrial category projected in the RPA report. Similarly, some of the water consumption for biofuels irrigation may be included in the irrigation estimates provided in the RPA assessment.

Third, in addition to the assumptions embedded in the original data sources, many of the calculations in this study required the use of additional assumptions. Examples of such assumptions include, but are not limited to, the following:

- No western coal is assumed to require washing.

- About one-third of the oil produced is assumed to have been recovered via water flooding (the percentage may be much higher).

- The relative percentages of thermal steam and CO_2 injection used for oil production identified in the base year are assumed to apply to each of the projection years;

- The estimate of water use derived for shale gas is assumed to apply to tight gas.

- None of corn grown in the East is assumed to require irrigation, and all of the land used in the West is assumed to require irrigation.

These assumptions were made on the basis of the best data and information available at the time of the analysis. They may be incorrect, and even if they are correct today, they may change with time.

The compounding of assumptions made in this report with those made in the original source data may weaken the robustness of the ultimate estimates and projections. An analysis of the effects of changing the assumptions used in this report is beyond the scope of this report. However, such effects could be estimated by conducting a series of sensitivity analyses on the assumptions (i.e., changing the assumptions by incremental amounts and determining the impact of these changes on the results). Such analyses could help identify the relative impacts of various assumptions on the results—not only within a given sector, but on the relative contribution of that sector to total water consumption at both the regional and national levels. The conduct of such a follow-up analysis is recommended.

Given these caveats, the conclusions presented here should be viewed merely as one possible indicator of potential trends and areas of concern regarding U.S. water consumption.

5.2 FINDINGS

Meeting projected 2030 energy demands in the United States will require the consumption of an additional 19 bgd of water beyond that consumed for all other uses, including thermoelectric. This 19 bgd is more than twice the amount of water projected to be consumed for domestic and public supply in 2030 and more than double the amount projected to be consumed for thermoelectric power generation in 2030.

Although biofuels production dominates the water consumption profile for energy-production sectors over the period (biofuels production is projected to consume about 26.3 bgd in 2030), other energy sectors are projected to consume significant amounts of water as well. As with biofuels, water consumption by these sectors is often concentrated in specific geographic regions. The following general conclusions are drawn regarding regional water consumption:

- Over the projection period, almost all of the water consumed for biofuels production occurs in the West North Central Region, with high amounts in the West and Southwest, and lower amounts in other parts of the county.

- Water consumption at refineries is expected to increase over the projection period from about 1.3 bgd in 2005 to 1.5 bgd in 2030. Most of the water consumption for oil refining in 2030 is projected for the Gulf Coast, Midwest, and West Coast PADDs.

- For thermoelectric power generation, the regions with the highest projected water consumption are the Electric Reliability Council of Texas (nearly 3 bgd) and the Southeastern Electric Reliability Council Region (about 1.5 bgd) (NETL 2007).

- Estimated water consumption for conventional gas production is projected to increase to about 1.6 bgd from 1.4 bgd in 2005. Most of this consumption is in the Rocky Mountain Oil and Gas Supply Region, where projected water consumption for conventional gas production is projected to increase by nearly one-third.

- Water consumption for unconventional gas sources is low relative to that for conventional gas sources, because the development of unconventional gas is projected to remain low by 2030. Most of the tight gas production is expected to occur in the Rocky Mountain and Gulf Coast Oil and Gas Supply Regions; most of the water consumption for gas shale production is expected to occur in the Southwest and Northeast Oil and Gas Supply Regions.

- The production of liquid fuels from coal and oil shale consume large amounts of water, but because fuel production estimates for these two energy sources remain relatively low over the period, projected water consumption is also relatively low. Site-specific water demands can be significant, however, particularly in areas where water supplies are limited.

- Because hydrogen contributes relatively little to the energy mix over the projection period, estimated national-level projected water consumption for this energy source is low. Nonetheless, in several areas, including the Pacific and West-South Central U.S. Census Regions and in Hawaii, water consumption for hydrogen production is expected to be high.

- By 2030, the regions projecting the highest water consumption for the combined uses of irrigation, industrial and commercial, domestic and public, and livestock are the California, Pacific Northwest, Missouri Basin, Arkansas White-Red, and Lower Mississippi WRRs.

- Projected water consumption for coal mining is relatively low, and the areas with highest projected consumption by 2030 are Northern and Central Appalachia, Eastern Interior, and Wyoming Coal Supply Regions.

- For many energy-producing sectors, water consumption on a per-BTU basis can be high, and because dramatic increases in water consumption can occur over a fairly short time period, impacts can be localized, suggesting that future production locations may need to be evaluated for potential impacts on local water resources.

These conclusions will vary depending on factors ranging from demographics to oil price, many of which can be neither predicted nor controlled. A key variable, and one over which there is control, is policy. As evidenced by the projected increases in water consumption associated with decisions to increase biofuels production, changes in energy policy can have dramatic effects on water consumption.

Policy makers will be expected to make decisions intended to increase energy supplies and reduce costs. Decisions such as those to establish commercial oil shale programs in the West can be expected to increase water demand significantly, because, at least with the current technologies, oil shale development is water intensive. Other options, such as increasing offshore drilling or opening offshore areas to renewable energy technology development, may have fewer impacts on water consumption.

Impacts on water consumption resulting from energy policies may be exacerbated or mitigated by water, agricultural land development, and other policies that may call for increased water reuse, recycling, and efficiency. Information on the impacts of such policy decisions on water supplies will be an important component of science-based decision making.

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APPENDIX A

MAPS SHOWING REGIONS FOR WHICH WATER DEMAND IS REPORTED

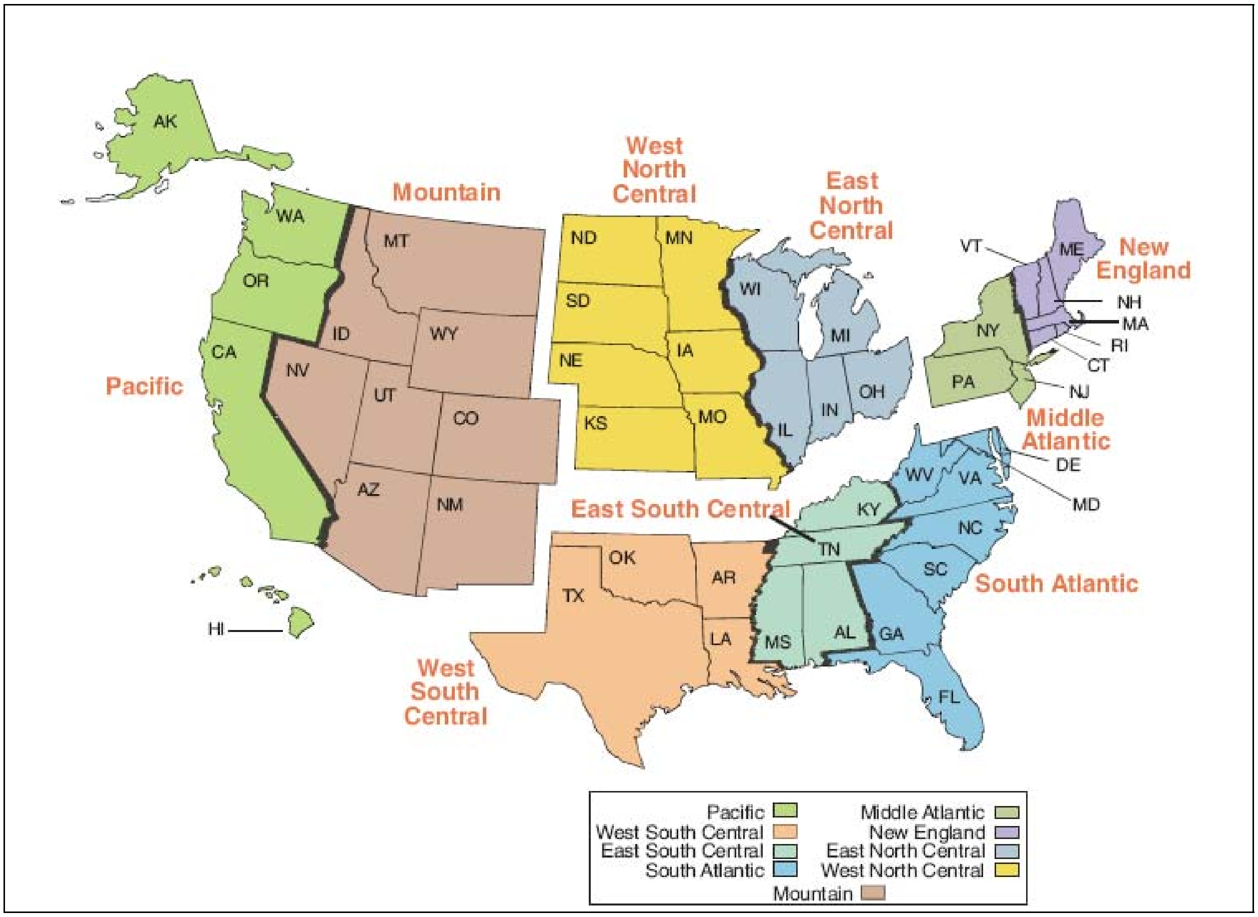


FIGURE A.1 U.S. Census Regions (Source: EIA 2007a)

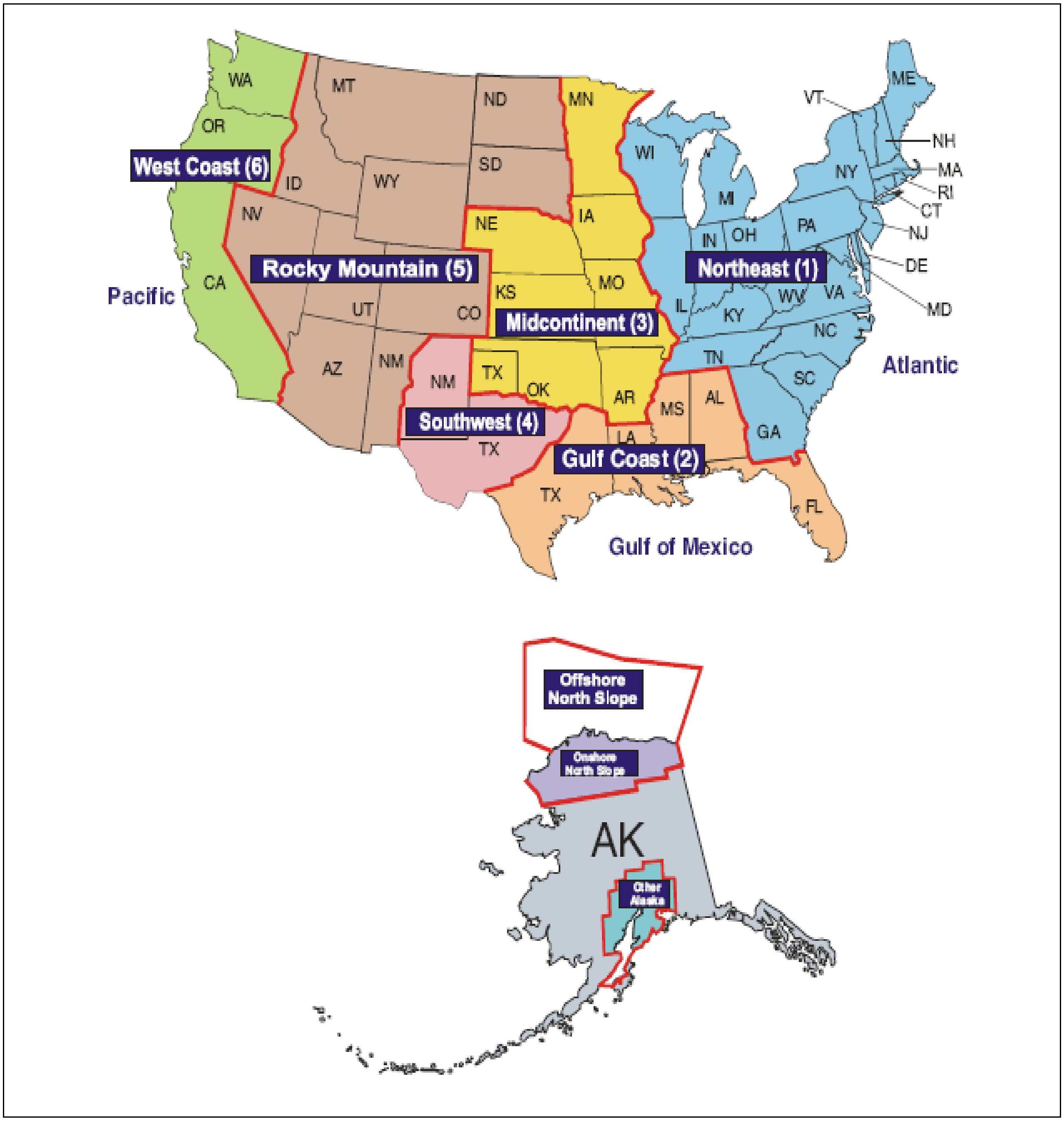


FIGURE A.2 Oil and Gas Supply Model Regions (Source: EIA 2007a)

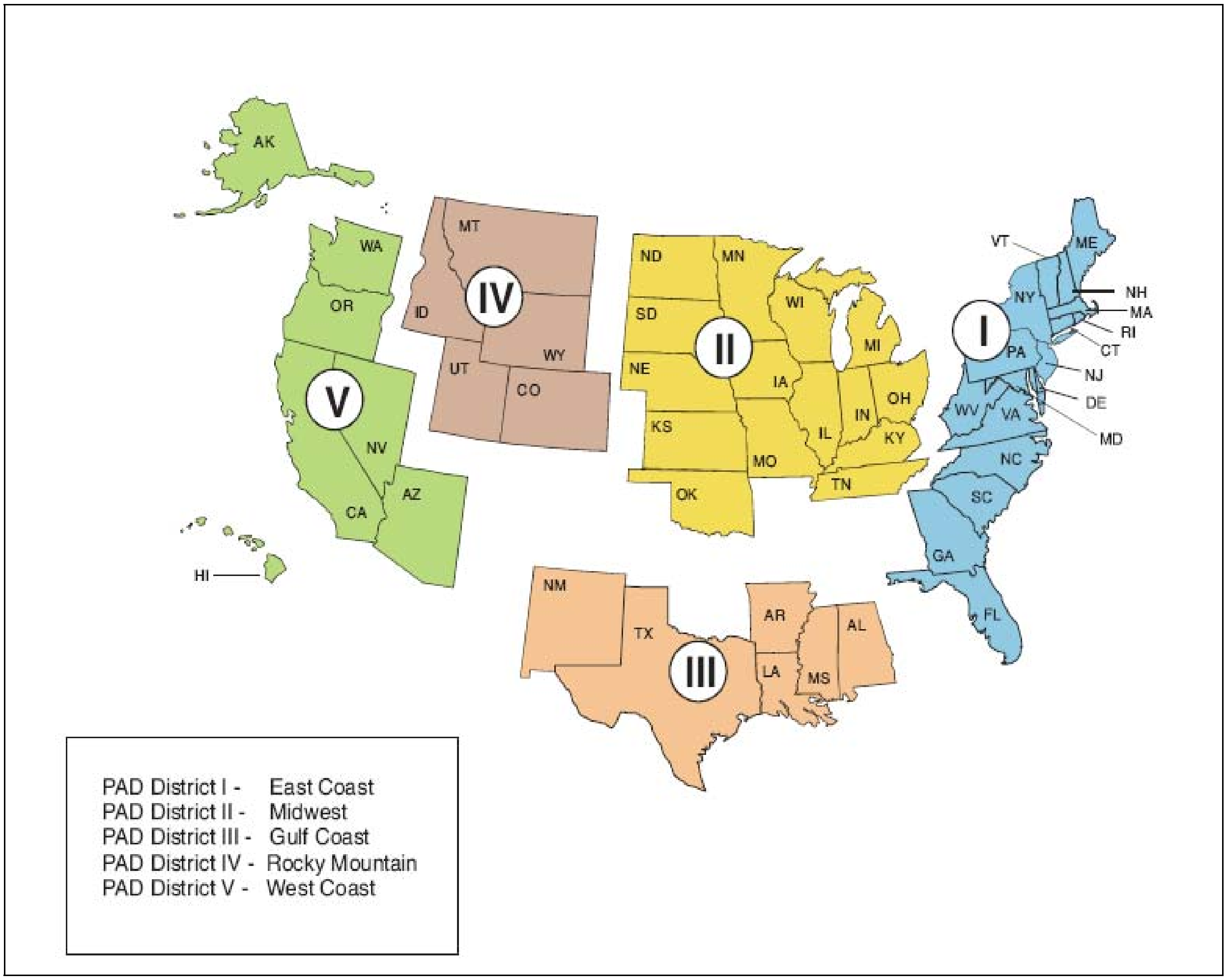


FIGURE A.3 Petroleum Administration for Defense Districts (Source: EIA 2007a)

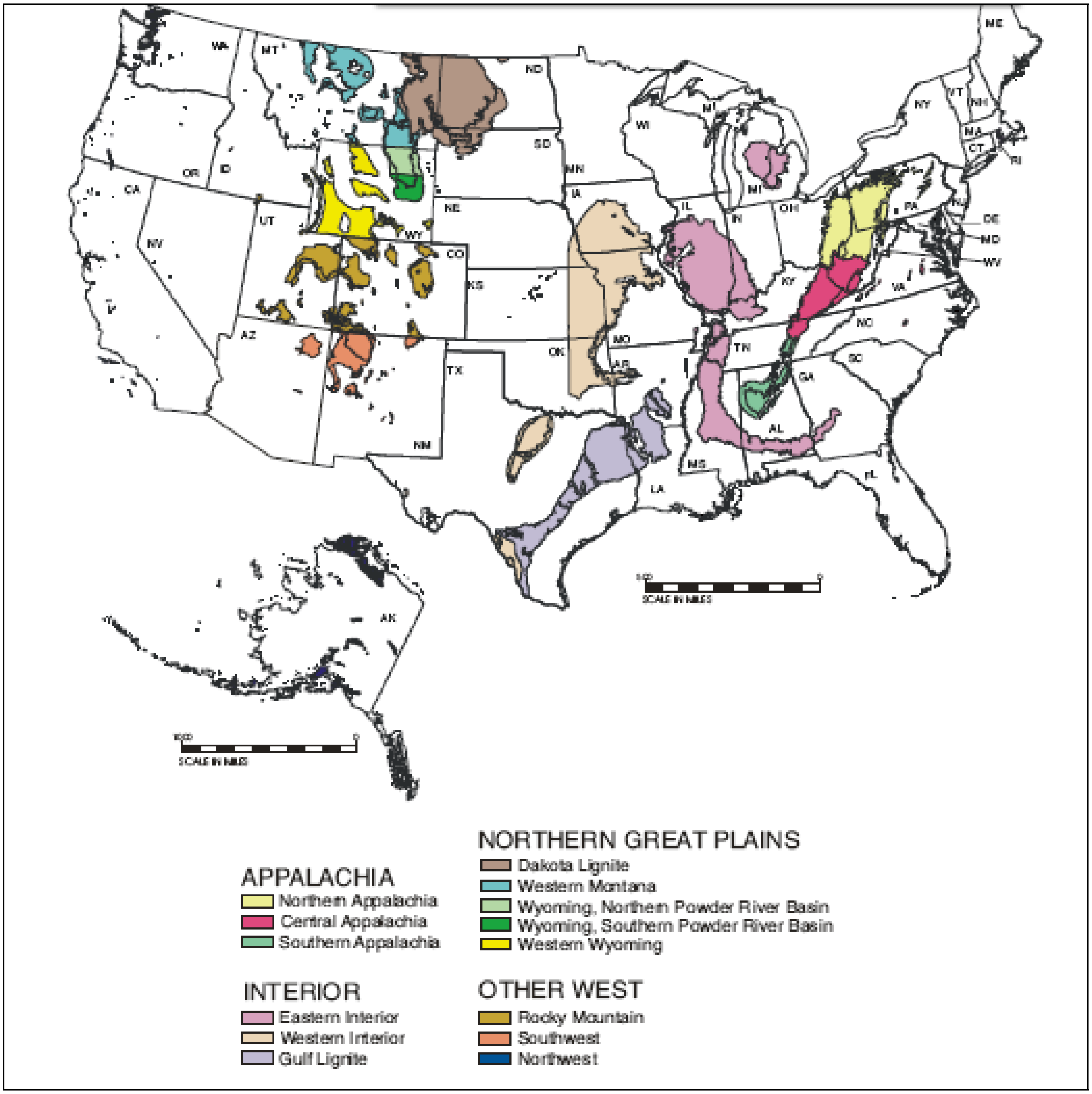
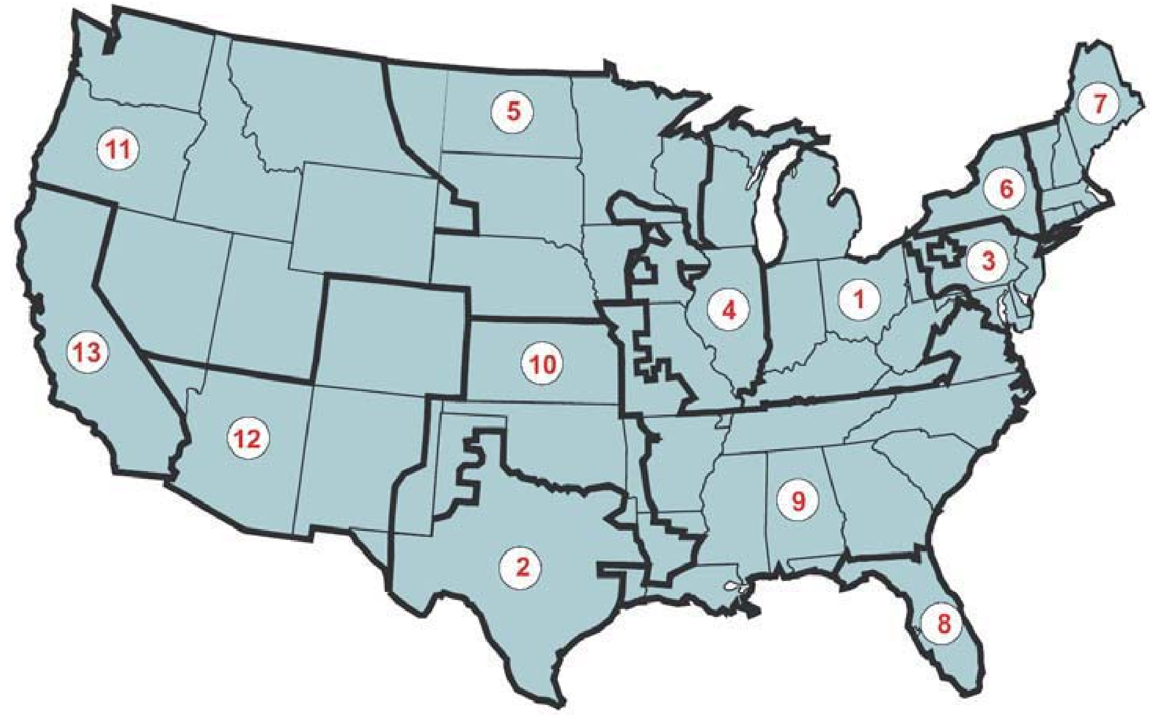
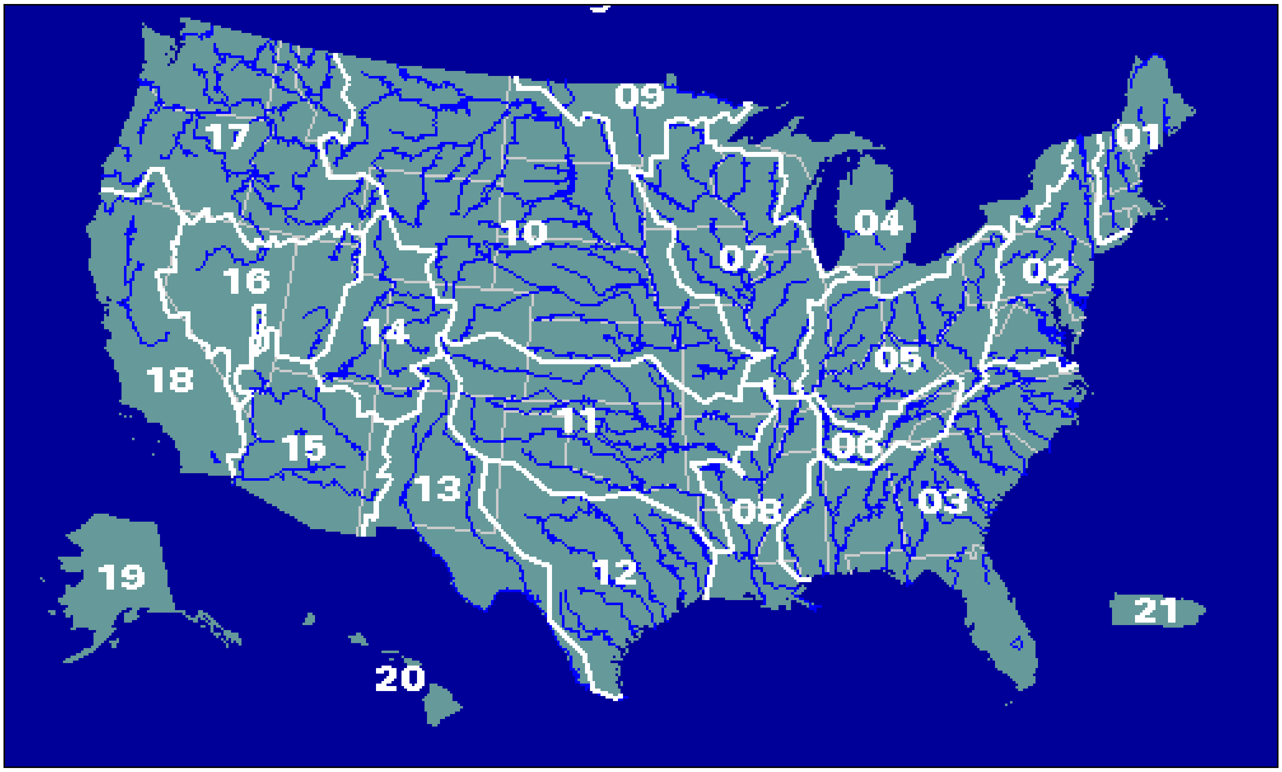


FIGURE A.4 Coal Supply Regions (Source: EIA 2007a)



1. East Central Area Reliability Coordination Agreement (ECAR)
2. Electric Reliability Council of Texas (ERCOT)
3. Mid-Atlantic Area Council (MAAC)
4. Mid-America Interconnected Network (MAIN)
5. Mid-Continent Area Power Pool (MAPP)
6. Northeast Power Coordinating Council/New York (NPCC/NY)
7. Northeast Power Coordinating Council/New England (NPCC/NE)
8. Florida Reliability Coordinating Council (FRCC)
9. Southeastern Electric Reliability Council (SERC)
10. Southwest Power Pool (SPP)
11. Western Electricity Coordinating Council/Northwest Power Pool (WECC/NWPP)
12. Western Electricity Coordinating Council/Rocky Mountains, Arizona, New Mexico, southern Nevada (WECC/RM)
13. Western Electricity Coordinating Council/California (WECC/CA)

FIGURE A.5 North American Electric Reliability Council (NERC) Control Regions (Sources: NETL 2007 and EIA 2007a)



Region 01 New England	Region 12 Texas-Gulf
Region 02 Mid-Atlantic	Region 13 Rio Grande
Region 03 South Atlantic-Gulf	Region 14 Upper Colorado
Region 04 Great Lakes	Region 15 Lower Colorado
Region 05 Ohio	Region 16 Great Basin
Region 06 Tennessee	Region 17 Pacific Northwest
Region 07 Upper Mississippi	Region 18 California
Region 08 Lower Mississippi	Region 19 Alaska (old numbering system)
Region 09 Souris-Red-Rainy	Region 20 Hawaii
Region 10 Missouri	Region 21 Caribbean
Region 11 Arkansas-White-Red	

FIGURE A.6 Water Resource Regions (Source: Brown 1999)

APPENDIX B

DERIVATION OF COEFFICIENTS USED TO PROJECT WATER DEMAND FOR COAL MINING AND COAL SLURRY PIPELINE TRANSPORTATION

Assumptions:

On average, a ton of coal produces 21 to 22 gigajoules (GJ) of energy (Elert 2006).
1 m^3 of water = 264.2 gallons
Assuming 1 ton = 22 GJ, then 1 ton = 22×10^9 J or 0.022×10^{12} J,
therefore, 1 ton/0.022 = 10^{12} J or 45.45 ton = 10^{12} J.
Then 1 $m^3/10^{12}$ J $\times$ 264.17 gal/m^3 = 5.81 gal/ton, and since EIA reports coal production in million tons per day, the factor to convert $m^3/10^{12}$ J to gallons per million tons will be 5.81×10^6.

The table below shows the conversions for the different types of coal mining.

10^{12} J(th) = 45.45 tons coal assuming 1 ton = 22 GJ
1 $m^3/10^{12}$ J(th) = 5.81 gal/ton

TABLE Water Use Coefficients for Coal Mining and Transport

Coal Mine Type and Assumption	Coefficient in $m^3/10^{12}$ J(th)[a]	Coefficient Converted to gal/ton	Notes
Surface mining—no vegetation	2	12	For 90% of western coal mined (90% is surface mined, and it is assumed that no revegetation is conducted)
Surface mining—revegetation (or reclamation)	5	29	For 10% of the coal mined in the Appalachian and Illinois Basins (10% of the coal in these basins is surface mined; assumed that revegetation would be required in all cases)
Underground mining—recycling of water	3	17	Assuming that 10% of the water used in underground mining is recycled and 90% is once-through (see below), a weighted average coefficient for underground mining would be 106 gal/ton
Underground mining—once through with no recycle	20	116	Assuming that 10% of the water used in underground mining is recycled and 90% is once-through (see below), a weighted average coefficient for underground mining would be 106 gal/ton

Water Use Coefficients for Coal Mining and Transport (Cont.)

Coal Mine Type and Assumption	Coefficient in $m^3/10^{12}$ J(th)[a]	Coefficient Converted to gal/ton	Where Coefficient Is Used
Refining/ beneficiation[b]	4	23	Assume 80% of eastern and interior coal is washed; assume 0% of western coal is washed (NETL 2006)
Transport by slurry pipeline	40–85	232–494	Assume that average water demand would be the midpoint between the range of estimates, or 363 gal/ton

[a] As reported in Gleick 1994.

[b] Includes washing, beneficiation to remove nonfuel contaminants, and thermal processing to separate coals of different quality and to increase the thermal performance of the fuel.

Note that using these coefficients and the million ton per year production numbers, the water demand is calculated in terms of gallons per year. These values are converted to billion gallons per day by multiplying by 2.74×10^{-12} (1 year/365 days)/10^{-9}.

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APPENDIX C

DERIVATION OF COEFFICIENTS USED TO PROJECT WATER DEMAND FOR OIL EXPLORATION AND PRODUCTION

Assumptions:

To convert m^3 water demand/10^{12} J(th):

1 m^3 = 264.2 gal
1 GJ = 10^9 J = 0.165 bbl of oil; therefore, 10^{12} J = 165 bbl of oil

Therefore, 1 $m^3/10^{12}$ J = 1.601 gal water/bbl oil

Water Use Coefficients for Conventional Oil Production

Recovery Method	$m^3/10^{12}$ J(th)[a]	Gal Water/bbl Oil
Conventional oil production (primary)	3–8	4.80–12.8
Midpoint	5.5	8.8
Enhanced oil recovery using water flooding (secondary)	600	961
Enhanced oil recovery using thermal steam (tertiary)	100–180	160–288
Midpoint	140	224
Enhanced oil recovery using CO_2 injection (tertiary)	640	1024

[a] As reported in Gleick (1994).

REFERENCE

Gleick, P., 1994, “Water and Energy,” *Annu. Rev. Energy Environ.* 19:267–299.

APPENDIX D

DERIVATION OF COEFFICIENTS USED TO PROJECT WATER DEMAND FOR OIL REFINERIES

Assumptions:

To convert m^3 water demand/10^{12} J(th):

$1\ m^3 = 264.2$ gal
$1\ GJ = 10^9\ J = 0.165$ bbl of oil; therefore, $10^{12}\ J = 165$ bbl of oil

Therefore, $1\ m^3/10^{12}\ J = 1.601$ gal water/bbl oil.

By calculating the midpoint of the estimated water consumption ranges provided by Gleick (1994) and multiplying those midpoints by appropriate conversion factors (see table below), an average water consumption coefficient of 70 gal/bbl of oil was derived for the traditional refineries, and an average coefficient of 144 gal/bbl of oil for the refineries that use hydrogenation processes (see table below). In the United States today, most refineries have processes that produce or use hydrogen.

Refinery capacity given in million barrels per day (EIA 2007c).

TABLE Water Use Coefficients for Oil Refining

	$M^3/10^{12}$ J(th)[a]	Gal Water/bbl oil	Use for
Traditional refinery processes	23–65	36–104	Traditional refining (about 7% of total capacity nationwide)
Midpoint	44	70	
Refinery processes that use hydrotreating, hydrocracking, or reformulation	60–120	96–192	Refinery capacity that uses the hydrogen-related processes (about 93% of total capacity nationwide)
Midpoint	90	144	

[a] As reported in Gleick (1994).

REFERENCE

Gleick, P., 1994, “Water and Energy,” *Annu. Rev. Energy Environ.* 19:267–299.

APPENDIX E

DERIVATION OF COEFFICIENTS USED TO PROJECT WATER DEMAND FOR GAS SECTORS

Gas Processing

Using the following conversion factors, the estimated consumption coefficient of 6 $m^3/10^{12}$ J(th) (Gleick 1994) converts to 1.7×10^9 gal/TCF.

1 m^3 = 264.2 gal
1 TCF = 1.05 EJ (exajoules or 10^{18} joules)

Hydrostatic Testing/Pipeline Transport

Using the following conversion factors, the value of 3 $m^3/10^{12}$ J(th) converts to 8.5×10^8 gal/TCF.

1 m^3 = 264.2 gal
1 TCF = 1.05 EJ (exajoules or 10^{18} joules)

Other Gas Plant Operations

Using the following conversion factors, the value of 100 $m^3/10^{12}$ J(th) converts to 2.7×10^{10} gal/TCF.

1 m^3 = 264.2 gal
1 TCF = 1.05 EJ (exajoules or 10^{18} joules)

(1 quad = 1 TCF)

REFERENCE

Gleick, P., 1994, “Water and Energy,” *Annu. Rev. Energy Environ.* 19:267–299.

APPENDIX F

DERIVATION OF COEFFICIENTS USED TO PROJECT WATER DEMAND FOR UNCONVENTIONAL GAS PRODUCTION

A recent assessment of freshwater use in the Fort Worth Basin/Barnett Shale Natural Gas Play (GTI 2007) provided data on wells drilled and water used for gas shale development in Texas. According to that assessment, in 2005 the drilling and completion of 713 wells required about 6,400 acre-feet of water; the drilling and completion of 1,504 wells in 2007 required about 13,000 acre-feet. Thus, on average, about 9 acre-feet (nearly 3 million gal) were required for each well. Over the 2005–2007 period, about 90% of the drilled wells were horizontal with an average water use of 9.4 acre-feet (3 million gal) per well, and about 10% were for vertical wells with an average water use of 6 acre-feet (1.96 million gal) per well. The percentage of horizontal wells increased over the period from 83% to 93%, and this trend is expected to continue. Of the water used, about 10% is for drilling the bore and about 90% is for completion (fracturing the formation).

According to a study by Truestar (2006), the average cumulative production from the initial fracture stimulation is about 1.25 billion ft^3 (0.0012 TCF) of gas per well, and the average well produces for an average of 20 years.

Using the 9 acre-feet per well average, over the 20-year well life, an average of 2.9×10^6 gal of water (1 acre-foot = 325,829 gal) would be used. On an annual basis, this would be an average of 145,000 gal/well. At 0.0012 TCF/well (from above), the average amount of water consumed is estimated to be 1.21×10^8 gal/TCF. On a daily basis, this would be 3.31×10^5gal/TCF (1.21×10^8/365). A number of factors (e.g., percentage of horizontal wells vs. vertical wells, depth of well, permeability of formation) will alter this multiplier, but for projecting future water demand, these particular factors are not known.

Because of the similarities in production of shale gas and tight gas, and the lack of data on water consumption for tight gas, the same coefficient, 1.21×10^8 gal water/TCF, was used for both shale gas and tight gas.

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GTI (Gas Technology Institute), 2007, *Fort Worth Basin/Barnett Shale Natural Gas Play: An Assessment of Present and Projected Fresh Water Use*, prepared by L. Peter Galusky, Texerra, April.

Truestar Petroleum Corporation, 2006, *Newark East Gas Field, Barnett Shale (Texas)*. Available at http://www.truestar-petroleum.com/texas.html. Accessed Jan. 18, 2008.

APPENDIX G

PROJECTED WATER CONSUMPTION FOR NONENERGY SECTORS, 2005 AND 2030 (bgd)

Water Resource Region		Irrigation		Industrial and Commercial		Domestic and Public Withdrawal		Livestock		Thermoelectric Power		Total	
		2005	2030	2005	2030	2005	2030	2005	2030	2005	2030	2005	2030
1	New England	0.13	0.13	0.07	0.07	0.15	0.18	0.02	0.02	0.02	0.02	0.39	0.42
2	Mid Atlantic	0.18	0.20	0.28	0.27	0.37	0.43	0.10	0.11	0.13	0.13	1.04	1.13
3	South Atlantic-Gulf	3.33	3.79	0.69	0.76	0.98	1.25	0.42	0.54	0.37	0.42	5.79	6.75
4	Great Lakes	0.31	0.36	0.51	0.49	0.25	0.28	0.05	0.06	0.45	0.45	1.58	1.64
5	Ohio	0.13	0.17	0.55	0.55	0.21	0.24	0.12	0.14	0.89	0.91	1.90	2.00
6	Tennessee	0.04	0.07	0.13	0.14	0.06	0.07	0.05	0.06	0.00	0.00	0.28	0.33
7	Upper Mississippi	0.47	0.55	0.27	0.27	0.35	0.41	0.23	0.28	0.38	0.39	1.70	1.89
8	Lower Mississippi	6.81	8.60	0.28	0.28	0.56	0.66	0.83	0.98	0.27	0.28	8.76	10.80
9	Souris-Red-Rainy	0.11	0.12	0.01	0.01	0.02	0.02	0.02	0.02	0.00	0.00	0.16	0.17
10	Missouri Basin	12.85	12.68	0.21	0.22	0.46	0.55	0.43	0.52	0.18	0.19	14.12	14.16
11	Arkansas-White-Red	6.44	5.86	0.18	0.19	0.40	0.48	0.42	0.50	0.17	0.18	7.61	7.21
12	Texas-Gulf	4.58	4.17	0.61	0.64	1.05	1.29	0.23	0.28	0.24	0.25	6.71	6.63
13	Rio Grande	2.12	1.87	0.10	0.11	0.19	0.24	0.04	0.05	0.02	0.02	2.47	2.28
14	Upper Colorado	2.69	2.96	0.02	0.02	0.04	0.05	0.01	0.02	0.14	0.16	2.91	3.21
15	Lower Colorado	3.56	3.51	0.34	0.38	0.46	0.61	0.04	0.06	0.06	0.08	4.46	4.65
16	Great Basin	3.25	2.96	0.17	0.20	0.19	0.26	0.02	0.02	0.03	0.03	3.66	3.46
17	Pacific Northwest	9.92	8.79	0.23	0.25	0.22	0.28	0.07	0.09	0.05	0.09	10.48	9.49
18	California	22.67	21.84	0.60	0.63	1.20	1.51	0.17	0.20	0.01	0.01	24.64	24.20
19	Alaska	0.00	0.00	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.03
20	Hawaii	0.44	0.38	0.04	0.05	0.09	0.11	0.00	0.00	0.00	0.00	0.58	0.55
United States		79.98	78.42	5.35	5.48	7.26	8.84	3.49	4.29	4.00	4.00	100.08	101.24

Source: Brown, T.C., 1999, *Past and Future Freshwater Use in the United States*, Technical Document Supporting the 2000 USDA Forest Service RPA Assessment, USDA Forest Service Gen. Tech. Rept. RMRS-GTR-39.

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