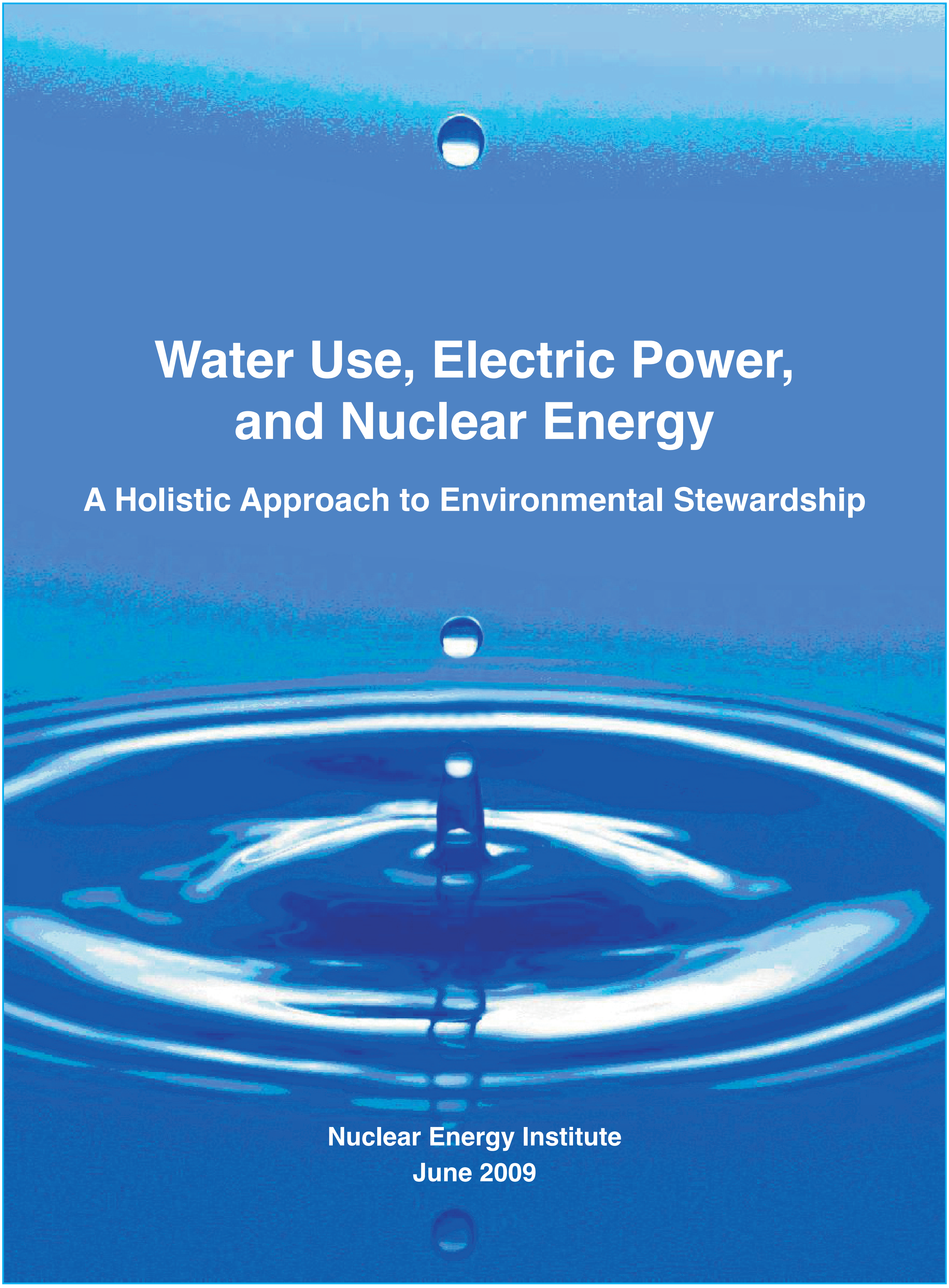

Water Use, Electric Power, and Nuclear Energy

A Holistic Approach to Environmental Stewardship

Nuclear Energy Institute

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Executive Summary

As an essential component of the global ecosystem, water sustains human, animal, and plant life. Within the human community, the availability of usable water determines overall health, economic well-being, and cultural development. There is a lot of water on our planet, but we use a lot of it also—for drinking, bathing, health care, and sanitation; for agriculture and raising livestock; for commercial uses, industrial processes, and mining; for recreation; and for electric power generation, both thermoelectric and hydroelectric, and other renewables as well.

Usable water and large-scale electricity generation are interdependent. To manage this interdependence responsibly, a range of issues, themselves interrelated, should be taken into account. Within the energy sector, these issues include the potential environmental impacts of thermoelectric power plant cooling systems, the environmental footprint of various energy sources, and their reliability and economics when generating electricity. These issues, in turn, impact the broader issues of sustainable development, climate change mitigation, and drought alleviation.

This study identifies and clarifies the relationships among water use, electricity generation, and nuclear energy. Understanding these relationships is critical to prudent decision-making and, in turn, standard of living and quality of life, both for present and future generations.

Holistic Environmental Management

A holistic approach to environmental stewardship will require balancing the relationships among all relevant environmental issues and making responsible trade-offs appropriate to the unique characteristics of each ecosystem where a thermoelectric power plant is located.[1]

What has come to be called the "water-energy nexus" is more encompassing than simply the relationship between water use and electricity generation. As an example, nuclear energy consumes more water than several other energy sources for electricity generation. However, when operating, it produces no greenhouse gases, which contribute to climate change. Therefore, nuclear energy mitigates the water shortages and drought conditions caused by climate change. As another example, nuclear energy, though not a renewable energy source, is more eco-friendly in certain ways than renewables, such as wind power and solar energy. This is because nuclear energy requires a fraction of the land to generate the same amount of electricity, thus preserving habitat.

Consumption

Water use consists of two distinct processes: withdrawal and consumption. Thermoelectric power generation is among the smallest consumptive uses of freshwater by any economic sector, at 3 percent of total consumption—about one-half of residential consumption. Thermoelectric power plants withdraw more water than any other economic sector, but they return 98 percent of the water they withdraw back to its natural sources.

Among energy sources, certain renewable energy systems exceed thermoelectric power plants in water consumption. Thermoelectric power plants—fueled by coal, natural gas, oil, and nuclear energy—generate 90 percent of the electricity in the United States.

Sustainable Development

Both water and electricity are necessary for economic progress. Economic development, along with environmental preservation, are the twin pillars of sustainable development. Large-scale usable water production and large-scale electricity generation are interdependent. While large-scale electricity production requires water for cooling, usable water production requires substantial amounts of electricity for pumping and purification. Each makes the other possible, and we cannot have one without the other.

All clean energy sources—nuclear energy and renewables—will be required for sustainable development, that is, to ensure economic progress and environmental preservation, including climate change mitigation. Clean energy sources must be deployed in an environmentally responsible manner, taking into account their environmental benefits, potential environmental impacts, and their differing electricity generation attributes.

Environmental Preservation

Environmental preservation must be considered comprehensively, in terms of the entire ecosystem. For responsible environmental management, it is therefore essential to consider the entire environmental footprint of energy sources.

Because an ecosystem is a network of relationships among human, animal, and plant life, habitat and climate, water use management must take into account the potential impacts on all elements of the ecosystem.

Nuclear power plants have the smallest environmental footprint of any energy source, making nuclear energy the most eco-efficient of all energy sources in terms of energy produced in relation to potential environmental impact. Nuclear energy generates the most electricity per amount of land required for operations; nuclear energy, along with wind power, has the lowest life-cycle impact on wildlife; and nuclear energy's life-cycle CO_2 emissions are comparable to renewables.

Thermoelectric power plant cooling systems are usually either once-through or closed-cycle (cooling towers or cooling ponds). They have varying potential impacts on water quantity, such as consumption; on water quality, such as discharge temperature and impurity concentrations; and aquatic life, such as impingement and entrainment from withdrawal. Choosing which system to deploy should, therefore, reflect the specific water availability, water temperature, aquatic life, and habitat of the local ecosystem.

Numerous field studies at thermoelectric power plants demonstrate that the loss of individual members of aquatic species is actually very small compared to the total number of fish of that species in the waterbody. Scientific study, in turn, shows that cooling water systems actually do not have an adverse impact on aquatic life in terms of population abundance over time.

Multiple environmental protection programs are undertaken by federal, state, and local governments and electric utilities. These include licensing, permitting, monitoring, mitigation, and restoration. These programs reduce the potential impact of thermoelectric power generation on the immediate ecosystem where the power plants are located.

Economics

Thermoelectric power plants are designed to use as little water as possible for optimal performance, because excess water intake would detract from process efficiency and cost effectiveness. Cooling water intake structures are designed to impinge and entrain as little marine life as practicable for cooling system operational efficiency.

The more expensive the water cooling mechanism is to operate, the more expensive the electricity produced by the power plant. Since electricity is required to process and transport usable water, the more expensive the electricity, the more expensive it will be to obtain water for residential, commercial, industrial, and agricultural use.

The more electricity required to operate power plant cooling systems, the more operating plants are needed on the grid to produce the same amount of electricity to respond to customer needs. More operating plants will increase the cost of electricity, increase the cost of water, and potentially incur additional environmental impacts.

Climate Change and Drought Mitigation

Climate change is one of the most pressing environmental issues of our time. Scientific studies of climate change demonstrate that impacts will vary from one geographical location to another. These studies show that one of the potential consequences is increasing water shortages and drought conditions in various regions of the United States, and around the world.

Carbon-free energy sources are essential to mitigating climate change. Nuclear energy, as an energy source that does not emit greenhouse gases during operations, can mitigate climate change, and, in turn, the water shortages and drought conditions that climate change is causing.

In addition, carbon-free energy sources will be essential for the large-scale implementation of such climate-change adaptation measures as desalination to increase water availability and alternative energies for fossil-fuel displacement in the transportation sector through electric and fuel cell vehicles.

Using nuclear energy as a power source can provide economical, emission-free electricity or process heat for desalination. Nuclear energy can generate large-scale electricity continually, steadily, and in sufficient quantities to provide the baseload generation required to sustain a stable electricity grid, in concert with renewables, to power a clean energy economy.

Regulation

Environmental regulations are an important means of preserving the environment. We must ensure that regulations, by focusing on one component of the ecosystem to the exclusion of all others, do not work against environmental preservation itself. This may be the case with Clean Water Act Section 316(b) Phase I and Phase II regulations.

Clean Water Act Section 316(b) Phase I establishes *national* standards for new plant cooling system operation, and Phase II establishes *national* standards for aquatic life impingement and entrainment for existing plant cooling systems. For more than three decades, the Environmental Protection Agency and the states have employed *site-specific* solutions to implement federal and state law regarding the operation of cooling water intake structures, managing potential environmental impacts for *comprehensive* ecosystem conservation.

If a state is unable to develop effective *site-specific* solutions for cooling system environmental performance, then it will have additional difficulty developing effective climate change adaptation strategies for local and regional ecosystems. If a state is unable to manage potential environmental impacts *comprehensively*, taking into account *all* elements of the ecosystem, then even those elements selected for protection, such as aquatic life, may ultimately be endangered by the overall ecosystem consequences of regulations solely focused on them.

In *Entergy Corp. v. Riverkeeper, Inc., et al.*, the U.S. Supreme Court reversed a federal appeals court decision limiting the use of site-specific cost-benefit analysis to determine the best technology available to minimize adverse environmental impacts. This reversal may encourage a return of federal and state legal interpretation of the Clean Water Act to its historic focus on appropriate site-specific analysis and comprehensive environmental impact analysis informing technology decisions.

Research and Development

As climate change is expected to introduce or exacerbate drought conditions in various parts of the United States, the electric power industry, sometimes in partnership with Department of Energy national laboratories, is funding and participating in research, development, and demonstration projects to reduce or eliminate freshwater use in thermoelectric power plant cooling systems.

Some electric power plants have already deployed advanced water-saving cooling system strategies, such as recycling degraded water, and planned new plant projects are integrating water-conservation approaches and technologies in their cooling systems.

I. Water Use in the United States

Water Consumption versus Water Withdrawal

Water use consists of two processes that can occur separately or in sequence: *water consumption* and *water withdrawal*. Water consumption occurs when water either ceases to exist as a liquid, through evaporation, or when water is degraded through contamination so that it is not fit to be returned directly to its original source. Water withdrawal occurs when water is removed from a source—it may subsequently be consumed and not returned to its original source, or it may be returned to the original source in practically the same condition as when it was withdrawn, that is, discharged in compliance with applicable environmental law.[2]

The distinction between water consumption and water withdrawal is crucial to any discussion about water use. For instance, one type of cooling system for electric power plants may withdraw substantially more water than another, but it may consume substantially less. Another energy source may withdraw no water at all, but still consume water, as in hydroelectric power plant reservoir evaporation.

Water and Numbers: Personal and Food-Related Water Consumption

Because water is relatively abundant, and because usage is so great, the scale of water use can be difficult to comprehend. Personal and food-related water use offer an effective way to get a sense of this scale, as they are familiar activities.

For instance, in the United States, each person consumes on average 11.6 gallons of water a day for showering. When we consider that every U.S. household takes on average two showers a day,[3] that number increases to 2.7 billion gallons of water per day for the entire country.[4]

Food-related water use data is similar. Producing one hamburger made of beef that weighs a quarter of a pound requires 616 gallons of water,[5] before it is cooked and without a roll. If McDonald's sells just one hamburger to the 52 million customers whom it serves in 100 countries daily,[6] about 32 billion gallons of water a day are consumed to produce meat for this item alone.

Water data is most useful when considered in context and in comparison, across sectors and uses, and according to a similar timeframe. Otherwise, the magnitude of any single number in isolation may distract us from the true value that water provides our world in terms of standard of living and quality of life.

Water Consumption by Economic Sector

Water is used in thermoelectric power generation—the process employed by power plants fueled by coal, natural gas, oil, or nuclear energy to produce electricity on a large scale. The water is heated to steam by burning fuel, in the case of coal, natural gas, and oil, or fissioning fuel, in the case of nuclear energy. The steam drives a turbine that generates electricity, and, subsequently, the steam must be cooled down to be recycled through the process again as water.

Electric power generation, although a visible source of water withdrawal, is among the smallest consumptive uses of freshwater by economic sector. According to the U.S. Geological Survey, thermoelectric power generation accounts for only 3.3 percent of freshwater consumption in this country, about the same percentage as the industrial sector (3.4 percent) and raising livestock (3.2 percent). The residential sector accounts for 6.7 percent of freshwater consumption, while the commercial and mining sectors are the least, at 1.3 percent and 0.8 percent, respectively. The largest consumption of freshwater is for irrigation, at 81.3 percent.[7]

Residential consumption of freshwater is more than double the consumption of freshwater for electric power generation. The residential sector consumed 6.68 billion gallons per day of freshwater in 1995.[8] By contrast, the thermoelectric power sector consumed 3.3 billion gallons per day of freshwater in 1995. In that year, the thermoelectric power sector also consumed an additional 0.4 billion gallons per day of saline water.[9]

To put residential and thermoelectric power water consumption in perspective, a typical nuclear plant in the United States supplies 740,000 homes with all of the electricity they use while consuming 13 gallons of water per day per household in a once-through cooling system, and 23 gallons per day per household in a wet cooling tower system. By comparison, the average U.S. household of three people consumes about 94 gallons of water per day for indoor and outdoor residential uses.[10]

Water Consumption by Energy Source

For energy sources, water consumption is calculated in terms of the amount of water consumed to produce a standard measure of electricity generated—a megawatt hour. This makes possible comparisons across different energy sources. Some forms of renewable energy consume quantities of water comparable to large-scale energy sources.

Nuclear energy consumes 400 gal/MWh with once-through cooling and 720 gal/MWh with wet cooling towers. Coal consumes somewhat less, ranging from about 300 gal/MWh for plants with minimal pollution controls with once-through cooling to 714 gal/MWh for plants with advanced pollution control systems and wet cooling towers. Natural gas consumes even less, at 100 gal/MWh for once-through, 370 gal/MWh for combined-cycle plants with cooling towers, and none for dry cooling.[11]

Hydro's typical water consumption is 4,500 gal/MWh, due in large part to evaporation from reservoirs. Solar thermal consumes 1,040 gal/MWh, and geothermal ranges from 1,800 to 4,000 gal/MWh.[12] Biomass is similar to coal, ranging from 300 to 480 gal/MWh for wet cooling systems.[13] Lower is solar photovoltaic at 30 gal/MWh.[14] Wind is lowest at 1 gal/MWh.[15]

Withdrawal: A Potentially Misleading Measure of Water Use

The distinction between withdrawal and consumption is important when evaluating potential ecosystem impacts. According to the United States Geological Survey, thermoelectric power plants, as a group, withdrew the most water of all economic sectors in 1995—189 billion gallons per day of fresh and saline water, but they returned 98 percent of that water back to its natural sources. By contrast, residential withdrawals were 26 billion gallons per day, but only 74 percent was returned, resulting in consumption about twice that of thermoelectric power plants. Withdrawals for irrigation were 134 billion gallons per day, second to the thermoelectric power sector, but only 20 percent of that water was returned, making irrigation by far the single largest consumer of water resources.[16] Accounting in part for the low consumption figure for thermoelectric power sector, research some years later in 2001 found that about 69 percent of thermoelectric power plants are equipped with once-through cooling systems.[17] Once-through cooling consumes considerably less water than wet cooling towers.

II. Power Plant Cooling Technologies and Environmental Preservation

Types of Power Plant Cooling Technologies

Electricity generation through thermoelectric, or steam turbine, power plants represents the most efficient and economical way to produce electricity on a large scale.[18] About 90 percent of U.S. electricity is produced by thermoelectric plants powered by coal, natural gas, oil, and nuclear energy, while hydroelectric power produces 7 percent, and other renewables, such as wind, solar, biomass, and geothermal, 3 percent.[19] Nuclear power plant generation has the added benefit of being emission free, preventing annually the emission of approximately 1.1 million short tons of nitrogen oxides, 3.4 million short tons of sulfur dioxide, and 682 million short tons of carbon dioxide that would have been produced if fossil fuels were used in place of nuclear.[20] In total, about 74 percent of U.S. emission-free electricity is produced by nuclear energy, the rest by hydro and other renewables.[21]

The engineering of a present-day thermoelectric power plant requires a cooling water system. A fuel source heats water to steam to drive a turbine generator that produces the electricity. Steam exhaust from the turbine is condensed back to water and recycled to the steam generator or boiler to begin the process anew. Cooling water flows through the heat exchanger, or condenser, absorbing the heat of the steam, which cools it down to water again.

A cooling water system provides the condenser with low-temperature water to cool the steam. The vast majority of thermoelectric power plants employ one of two types of cooling water systems. In a *once-through* or *open-cycle* system, cooling water is withdrawn from a natural water source, such as a lake, river, or ocean, or a constructed water source, such as a reservoir. The water passes through the condenser and is then returned back to its original source in a continuously flowing process, with the heat being transferred to the aquatic environment.

In a *recirculating* or *closed-cycle* system, cooling water is pumped from the condenser to a wet cooling tower, where the heat of the water transfers to the ambient air through evaporation.[22] The resulting lower temperature cooling water is then returned back to the condenser. Minerals and sediment building up in the water that remains from the evaporative process for recirculation could potentially clog the cooling system. The "blowdown" process controls these concentrations by discharging a portion of the recirculating water in the cooling tower to a water source and replenishing it with fresh "make-up" water.[23] The amount of water that evaporates in the tower is also replenished. As an alternative to a wet cooling tower, recirculating cooling systems may use cooling ponds for the same purpose of heat transfer through natural evaporation.[24]

Cooling Technologies and Potential Ecosystem Impacts

To evaluate the potential impacts of the various thermoelectric power plant cooling technologies on the ecosystem, we must first consider the potential impacts on the immediate ecosystem—the habitat where the plant is located. Then we must view those as part of the potential impacts on the comprehensive ecosystem—the global habitat, including climate. Potential immediate ecosystem impacts include *water quantity*, in terms of loss of water through consumption; *water quality*, in terms of the temperature of the water returned, the concentration of the chemical constituents of the water due to evaporation, and any impurities that might have been added; and *aquatic life* *impact*, in terms of the functioning of the mechanical water uptake apparatus and the effect of the discharge plume on behavior.

Water quantity. On balance, in terms of water consumption, once-through systems have substantially less potential environmental impact than recirculating systems. Once-through cooling systems involve a continuous flow of water to and from the water source, with withdrawal and replacement occurring simultaneously. Very little water is actually consumed—on average, only about 1 percent of the water withdrawn is consumed.[25] Recirculating systems, predominantly wet cooling towers, withdraw much less water than once-through systems, but they consume substantially more, as they depend on the evaporation of water for cooling. On average, about 70 to 90 percent of the water withdrawn is consumed.[26] Thus, recirculating systems tend to consume approximately twice as much water as once-through cooling systems.[27]

Despite their higher water consumption rate, recirculating cooling systems actually withdraw only a very small quantity of water relative to the overall size of the waterbodies on which they are located, and, in turn, consume even less. For instance, the Alvin W. Vogtle Electric Generating Plant, located on the Savannah River in Burke County, Georgia, and consisting of two 1,215-MW nuclear reactors with cooling towers,[28] withdraws about 1 percent of the average annual flow of the river while providing electricity to about 1.5 million homes. The NRC has received a license application to construct and operate two more 1,100-MW reactors with cooling towers at the site. If the two units are added, the four reactors combined will withdraw about 2 percent of the average annual river flow and produce electricity for about 2.9 million homes.[29]

Similarly, if the V. C. Summer Nuclear Station, located on the Broad River in Jenkinsville, South Carolina, and consisting of one 1,000-MW nuclear plant with a cooling tower,[30] becomes the site of two additional 1,117-MW reactors with cooling towers, according to a license application filed with the NRC, the new reactors would withdraw 1 percent of the normal flow of the river, 2.9 percent of the lowest annual mean flow, and 7 percent of the flow on the lowest day every 10 years.[31]

Water quality. The two main factors by which water quality is measured are temperature and impurities. Thermoelectric power plants operate according to standards regulating "conventional pollutants," "toxic pollutants," and "thermal pollution" set by the U.S. Environmental Protection Agency or a state.

Once-through systems have a greater potential environmental impact, in terms of water quality. They discharge a much larger quantity of cooling water to the water source after it has been heated to a temperature higher than when it was withdrawn.

To reduce this potential impact, many plants with once-through cooling systems use "discharge canals" up to a few miles long to cool the water before it reaches the waterbody. The canals enable natural processes to dissipate heat from the water, including evaporation into the air; heat "radiation," transfer, to the air; and convection, from wind. If discharging water into a reservoir, these plants may also use an "after-bay," a section of the reservoir that holds the heated water over a broad surface area to facilitate cooling before it is discharged into the waterbody proper.

Water discharged from recirculating systems is usually also warmer than when it was withdrawn. However, compared to once-through cooling systems, there is considerably less of it; it is discharged intermittently, from every few days to one to two week intervals; and it is cooler. In fact, depending on the season and time of day, water discharged from recirculating systems may be no warmer, or somewhat cooler, that the waterbody into which it is flowing. As it is "blowdown" water, the discharged water from a recirculating system is mostly collected from the cooling tower basin, away from the heat dissipation occurring above.

On the other hand, tower "blowdown" water discharged from recirculating systems will contain more concentrated amounts of impurities, and dissolved and suspended solids, resulting from the evaporative process in the cooling tower, than discharge water from once-through cooling systems.[32] These discharges observe nationwide limits set by regulations.

Aquatic life. There are two potential impacts to aquatic life, mostly to early life stages of aquatic species, from the *uptake* of water by once-through and recirculating systems. These are *impingement*—when aquatic life gets stuck on the screens meant to prevent them from being drawn into the cooling system of the plant; and *entrainment*—when early life stages of fish and shellfish that pass through the screening structure circulate through the cooling system. The primary potential impact from the *discharge* of water is the effect of temperature, as substantial temperature differences may decrease dissolved oxygen, alter the development of aquatic life, and affect mobility and patterns of migration.[33]

Numerous field studies and regular monitoring indicate that the loss of individual members of aquatic species from impingement and entrainment is actually very small. Typical is a five-year study conducted in compliance with environmental regulations at the North Anna Power Station in Virginia,[34] which consists of two 900 MW nuclear reactors with once-through cooling systems drawing from and discharging into Lake Anna.[35] For impingement, the study finds that, of the six species that account for 99 percent of all fish impinged, only 0.02 percent to 1.4 percent by weight of the "standing crop"—the localized population of fish of comparable age—of the six species, respectively, in Lake Anna, are impinged per year on average.[36]

For entrainment at the North Anna Power Station, the study finds that, among the five species entrained the most at the larval stage of development, the number of potential adult fish of these five species lost to entrainment ranges from 0.01 percent to 4.13 percent per year on average of their species' respective standing crops in Lake Anna. For Lake Anna, and numerous other facilities, "overall, the abundance and quality of the fishery has remained healthy and balanced despite increased fishing pressure and shoreline development."[37]

Because the number of individual fish, and eggs and larvae that would have matured to adulthood, lost through impingement and entrainment is actually very small compared to the total number of fish of that species in the waterbody, scientific study has found, in turn, that cooling water systems actually do not have an adverse impact on aquatic life. Several significant biological factors account for this result. First, the reproductive strategies of aquatic life in these water bodies tend to be either "periodic," spawning large numbers of eggs many times during adulthood, or "opportunistic," dispersing offspring widely throughout the habitat.

Second, fish reproductive strategies reflect substantial rates of natural mortality, with the result that losses of early life stages of fish typically associated with entrainment and impingement are negligible compared to natural forces. Factors other than impingement and entrainment that affect the abundance of fish populations include short-term environmental fluctuations, long-term environmental change, predation by burgeoning native species, introduction of exotic (invasive) species, and over-harvesting, both commercial and recreational.

Third, population growth of these aquatic life species tends to be "density-dependent," relying on such factors as food and predators, which limit survival. In such a case, limited mortality may improve the remaining population's survival, because there are more life-sustaining resources available to those individuals.

A fish population produces substantially more eggs than are required to maintain the population, and substantially more juveniles than can be accommodated by the habitat's available life-sustaining resources that would enable them to live and grow to adulthood. The relatively small number of individuals lost to impingement and entrainment are readily replaced by ongoing, highly fecund, reproductive behavior until the optimal population equilibrium, the "carrying capacity," allowed by habitat resources is reached.[38]

The results of a recent comprehensive biological impact study of the Indian Point Energy Center demonstrate these aquatic ecosystem processes. Indian Point is located on the Hudson River at Buchanan, New York, where reactors Unit 2, at 1,026 MW, and Unit 3, at 1,041, have a once-through cooling system. The study tracked the abundance of 21 fish species from 1974 to 2005, utilizing studies performed under the direction and supervision of the New York State environmental regulatory authority.

The study found that impingement and entrainment did not have a significant effect on regional fish populations. It concluded that species with relatively high susceptibility to entrainment were no more likely to decline in abundance during the study period than species with relatively low susceptibility to entrainment, and certain species particularly subject to entrainment had substantially increased during the study period.[39]

Overall ecosystem. When considering the ecosystem as a whole within which humans and animals and plants live—and thermoelectric power plants operate—an additional potential environmental impact arises: water availability, especially in relation to drought. If water and electricity are essential for human life, and water for all living things, then the need for an adequate water supply must be balanced against the need to protect fish and shellfish. Indeed, a decrease in the quantity of water in the ecosystem itself may have a significant impact on aquatic life.

Ecological balancing. Once-through cooling systems may pose certain potential challenges to aquatic life but consume very little of the water that comprises their habitat. Recirculating cooling systems may not substantially decrease potential aquatic species impact—because the once-through system potential impacts are so small—but they do consume more of their habitat, as well as the human water supply, particularly in periods of drought. These facts suggest that a reasonable balance between the deployment of both kinds of cooling systems is desirable in relation to the specific ecosystems at which a given thermoelectric power plant is or will be operating.

For instance, where the water—amount, level, flow—of a natural waterbody is more of a concern, a once-through cooling system may be more appropriate, as it consumes much less water. Where water temperature is more of a concern, however, a recirculating system may be more desirable because it discharges less water and at a lower temperature. Where water level is less of a concern, but aquatic life more so, for commercial and recreational purposes as well as ecosystem preservation, a recirculating system may be preferred.

Environmental Protection and Compensatory Measures for Cooling Systems

One way to balance competing uses of water resources, natural and man-made, is to reduce the potential impact of the use itself and thus lessen what effects need to be balanced. There are five environmental protection programs that, taken together, reduce the potential impact of thermoelectric power generation on the immediate ecosystem, that is, the aquatic habitat where the plant operates—licensing, permitting, monitoring, mitigation, and restoration in relation to the cooling system technology employed.

Licensing. An effective environmental program for water use relies on a sound determination of what the particular potential impacts of a specific plant cooling system are. For nuclear power plants, to obtain a license to build and operate a nuclear plant, or to renew that license, the plant operator must submit to the U.S. Nuclear Regulatory Commission an Environmental Report, prepared in accordance with the National Environmental Policy Act, that defines in detail anticipated potential environmental impacts of the plant, including those to aquatic life and bodies of water. The NRC reviews, investigates, and verifies the report, and then develops an Environmental Impact Statement for that plant, which specifies what features of the environment have to be monitored and what mitigative and restorative measures must be taken to protect the immediate ecosystem.[40] These environmental requirements are developed through a consultation process between the plant operator and the applicable federal and state environmental agencies where the plant will operate.[41]

Permitting. The National Pollutant Discharge Elimination System permitting process makes the environmental requirements for water discharges specific to the particular characteristics of the ecosystem where the plant will operate.[42] For instance, the NPDES permit will cite specific temperatures for thermal limits. Under the Clean Water Act, the EPA is authorized to implement the program, and has authorized most NPDES permit issuing to state environmental agencies. Some 45 states have complete or partial NPDES permitting authorization. In this way, permit requirements are aligned with the individual characteristics of the local ecosystem where the power plants are located. Thermoelectric power plants are required to complete a Daily Monitoring Report and submit the results at the end of each month to the EPA or its state environmental agency, noting if thermal limits, for instance, have been exceeded. If so, the EPA or state environmental agency may initiate an investigation to determine cause and penalties.[43]

NPDES permitting observes a five-year cycle. When the plant operator applies for renewal, the EPA or state environmental agency may revise the terms of the permit. Regulators will consider whether the "technology-based standard" for environmental protection has changed. The regulator will also account for any changes in environmental regulations since the last permit was issued, such as "water quality-based standards."

Monitoring. Regarding water quantity and quality, thermoelectric power plants routinely monitor water source levels, temperature, and flow; water intake volume; temperature of discharged water; and levels of polluting substances in the effluent. Regarding aquatic life, plants monitor the species, number, and survival rate of fish and shellfish that are being impinged and entrained by the plant's cooling system. If the plant is exceeding permitted limits, the plant operator will make the necessary adjustments, either short-term operational changes, or long-term enhancements.

Mitigation. Thermoelectric power plant operators install, operate, and maintain fish protection measures at cooling water intake structures to minimize impingement and entrainment of aquatic life. These measures have been researched and tested and are regularly monitored for effectiveness and practicality. The deployment of a particular measure depends on the species in the habitat and their life stages, the design and operating characteristics of the plant, the geographic location, the immediate environment, and the kind of water source, among other factors.

Some of these measures include *physical barriers* that prevent fish from entering the intake structure, such as stationary screens of various designs and materials, including fish nets and microfiltration fabric. These barriers are often equipped with flushing structures to free the fish if necessary and passageways for fish to return to their habitat. *Collecting systems*, such as "traveling" (rotating) screens of fine-mesh, gather smaller and early-stage aquatic life as well as mature fish and transfer them to buckets or baskets for return transport. *Diversion systems* direct fish away from the intake structure, and include angled traveling screens, or louver systems that alter flow direction and velocity. *Behavioral deterrents* involving light or sound are also used.[44]

Restoration. Up to this time, plant operators have undertaken a variety of restoration activities. These include supplementing fish populations through restocking the water sources; restoring fish passageways; creating wetlands; constructing artificial habitats, such as reefs; establishing or restoring submerged aquatic vegetation beds; and protecting habitats through direct purchase or partnering with another organization for this purpose.[45]

Comparative Economics of Cooling Technologies and the Implications

Some aspects of environmental stewardship and the economics of operating a thermoelectric power plant are actually mutually supportive. Power plants are engineered to use only as much water as is necessary for optimal performance, because excess water intake would detract from process efficiency and the cost-effectiveness of the plant. Likewise, power plant water intake structures are designed to impinge and entrain as little aquatic life as practicable, from an operational perspective, because fish and shellfish will clog the intake structures, rendering them inoperable, and, when entrained, will make the operation of the condenser less efficient, and, again, pose the potential for clogging.

The economics of electricity generation, cooling technologies, and usable water consumption are all interdependent. The more expensive the water cooling mechanism, the more expensive the electricity the plant produces. Certain water cooling technologies are less efficient and require more electricity than others, making the plant less efficient and increasing its electricity consumption—the electricity required to operate it—making the electricity it produces more expensive. Since electricity is required to produce usable water, the more expensive the electricity, the more expensive it will be to obtain water for residential, commercial, industrial, and agricultural use.

Power plant and cooling technology efficiencies have a direct environmental consequence as well. The more electricity required for power plants to generate electricity, the more operating plants are needed on the grid to produce the same amount of electricity. More operating plants will also increase the cost of electricity, increase the cost of water, and potentially incur additional environmental impacts.[46]

The most efficient and economical cooling technology for a thermoelectric power plant is the once-through or open-cycle system, because the cool water for the cooling system is provided by an environmental water source, where the water is naturally cool. A recirculating system involving wet cooling towers is more expensive to operate because the water for the cooling system is artificially cooled. The water must be pumped through the cooling tower, and the cooling process is less efficient. A natural draft cooling tower relies on the heat differential between the relatively warmer air in the tower and the cooler air outside to draw ambient air through the structure, but a mechanical draft tower uses a fan or fans to move the air through the tower, increasing operational costs. Also, a wet cooling tower increases the capital cost of constructing the plant, as it is an additional, and substantial, structure.

A dry recirculating cooling system does not use water at all to cool the steam in the condenser back down to water. Instead, air blown by fans causes a transfer of heat from the condenser to the ambient air. Compared to wet cooling towers, however, dry cooling towers involve higher operating costs, require more electricity, occupy a larger footprint, have lower performance, and entail higher capital costs. According to the EPA, a dry cooling tower entails capital costs as much as three times higher than a wet cooling tower, and operating costs ten times more expensive.[47]

In the United States, as of 2007, about 42.7 percent of thermoelectric generating capacity used once-through cooling systems, 41.9 percent used wet cooling towers, 14.5 percent cooling ponds, and only 0.9 percent dry recirculating systems. Only a few new natural gas combined-cycle power plants, one coal plant, and no nuclear plants, use dry cooling.[48] Regarding U.S. nuclear power plants, 60 reactors use a once-through cooling system, 35 reactors use wet cooling towers, and 9 reactors use hybrid systems—a combination of once-through and cooling tower systems, environmental conditions determining which is used at any given time.[49]

III. Water, Electricity, and Sustainable Development

Interdependence of Electricity Generation and Water Supply

Usable water and electricity are necessary for each other to exist at all on a large-scale. A developed country such as the United States readily demonstrates an inescapable fact—electric generation and water production are interdependent. We cannot have one without the other if both are to be available to the vast majority of the population. Large-scale electric generation requires water for cooling of equipment, and electricity is required for pumping, filtration, and purification to produce and deliver usable water. Electricity is required at every stage of water production, from extraction, conveyance, and treatment to distribution to wastewater collection.

Nationwide, about 80 percent of municipal water processing and distribution costs are for electricity. About 4 percent of U.S. electric power generation is used for water supply and wastewater treatment.[50]

Electricity consumption for supply of freshwater by public agencies is estimated at about 30 billion kWh for the year 2000.[51] Total U.S. electricity to satisfy freshwater demand and wastewater treatment in 2000 for all sectors was 123 million MWh in 2000.[52]

As time goes on, the interdependence of electricity generation and usable water will probably be the single most important factor in managing this country's portfolio of energy sources in relation to its water resources. The amount of reliable and affordable electricity that we generate will directly affect our supply, quality, reliability, and cost of usable water. In addition, to the degree that climate change affects drought, the energy sources of most value will inevitably be those that are carbon-free.[53] The federal government has recently acknowledged energy-water interdependence and initiated programs to address its implications.[54]

Water and Electricity Essential for Economic Progress

While a minimum supply of usable water can sustain life, more abundant supplies can significantly improve standards of living by making possible advanced agriculture, industry, and large-scale electricity generation. Correspondingly, electric power is required for the same agricultural and industrial advancement, in fact, for any economic, medical, and cultural progress, at any stage of development. In reality, electricity has come to be an essential service for public health and safety.

Data reveals a correlation between average electricity consumption per person and the stages of human development as measured by the United Nations Human Development Index. The Index tracks human development in terms of a long and healthy life (life expectancy at birth), knowledge and education (adult literacy rate and school enrollment), and a decent standard of living (gross domestic product per capita). The dividing line between developed and developing countries is 4,000 kWh per person per year. Countries in the high human development category have the highest consumption of electricity per person, such as Sweden (15,424 kWh) and the United States (13,351 kWh); countries with medium human development have less, such as China (1,585 kWh) and India (457 kWh); and countries with low human development have the least, such as Nigeria (97 kWh) and Ethiopia (33 kWh).[55]

The critical role that electricity has played in the development of the U.S. economy is dramatic. Today about 60 percent of our country's gross domestic product derives from industries and services whose primary energy source is electricity, whereas in 1950 only 20 percent was the case. Approximately 60 percent of new U.S. capital spending is on information technology equipment that runs on electricity. All of the fastest growing technology and communications sectors of the U.S. economy rely on electricity.[56]

Sustainable Development: Economic Progress and Environmental Preservation

Sustainable development has come to be the recognized international standard for human interaction with the world's natural resources, such as water. The United Nations developed the classic definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[57]

Subsequently, the United Nations made it clear, in a series of Principles regarding sustainable development, that economic progress and environmental preservation must proceed concurrently:

> *Principle 3*. The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.
> *Principle 4*. In order to achieve sustainable development, environmental protection shall constitute an integral part of the developmental process and cannot be considered in isolation from it.
> *Principle 5*. All States and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development.[58]

According to these principles, applicable to both developed and developing nations, water resources should be used for economic growth and, simultaneously, be protected and preserved. That economic growth is a requirement points to electricity as a key man-made resource. Thus, both water and electricity play a fundamental role in sustainable development. For this reason, management of the environment will have to take their interdependence into account.

Comparative Economics of Energy Sources in Relation to Environmental Preservation

Sustainable development will require clean energy sources that are also economical to deploy and operate. Considering the economics of nuclear power plants in relation to their environmental benefits, nuclear energy is the lowest cost producer of reliable, large-scale electricity. At the same time, the generation of nuclear energy and renewable energy sources, except biomass, is emission-free, producing no air pollutants or greenhouse gases during operations. In 2008, the average electricity *production cost* for nuclear energy was 1.87 cents per kilowatt-hour; for coal plants, 2.75 cents; for natural gas, 8.09 cents; for petroleum, 17.26 cents.[59]

In terms of the current *levelized cost* of electricity—the lifecycle cost of electricity generation over the facility's lifetime, including capital (construction, refurbishing), O&M (operations and maintenance), fuel costs (if any), and decommissioning—Lazard calculates that wind energy is lowest, at a range of $44 to $91 per megawatt hour, compared to natural gas combined cycle, at $73 to $100, and nuclear energy, at $98 to $126. These figures do not reflect potential carbon emissions costs assessed under a regional or national carbon reduction regime, which would increase the costs for natural gas.

However, the cost for wind is artificially lowered by subsidies from the federal government, which include production tax credits, investment tax credits, and accelerated asset depreciation. If wind did not receive government subsidies in the form of federal tax relief, its levelized cost would be at a range of $89 to $150 per megawatt hour, making it the most expensive energy system for electricity generation when compared to natural gas combined cycle and nuclear energy.[60]

Considering new electricity generation anticipated to be deployed and operating by 2015, the Electric Power Research Institute calculates that the levelized cost of nuclear energy would be $73 per megawatt hour, wind $91 at 32.5 capacity factor, and solar thermal $175. With new electricity generation anticipated to be deployed and operating by 2025, EPRI calculates that nuclear energy would be $64 per megawatt hour, wind $71 at 42% capacity factor, and solar thermal still at $175.[61]

IV. Comprehensive Management of the Environment

Ecosystem: Interaction and Interrelationship of All Living Things

Responsible water use management requires taking into account the potential impacts of water withdrawal and consumption on the entire fabric of life and environment—that is, on the ecosystem. An ecosystem is the interaction and interrelationship of all living things with each other and with their inanimate environment. Ecosystems can be local, regional, national, continental, and global.

While one approach to the environment is to consider humans as separate from the global ecosystem and acting upon it, that approach can lead to unforeseen consequences, such as the unrestrained production of greenhouse gases that many scientists believe has exacerbated climate change. In an age when scientific research increasingly acknowledges this relationship, it would appear more constructive to consider human activity as part of the broad range of animate behavior that makes use of the environment to sustain life.

Balancing Human Water Use Within the Ecosystem

Because an ecosystem is a network of relationships, any alteration can affect many other relationships. In interacting with our environment, therefore, humans find ourselves in a position where we need to balance ecosystem imperatives. We must balance the need to preserve natural water sources and the need to protect animal life with the need for electricity and the need for usable water essential to human life. There will be potential impacts. But even animals affect the environment. One species' endeavor to survive—as predators, or competitors for the same food resources or living space in the habitat—is another's environmental impact. Unlike animals, however, humans can substantially mitigate potential impacts, either by minimizing the original impact or compensating for it through restoration.

In an ecosystem approach to water use, the environmental consequences of withdrawing and consuming water would to be considered as a whole—on the air and land as well as water source, that is, on habitat and climate; on animals, both aquatic life and terrestrial life; and on humans, in relation to the importance of the need for the specific use of the water.[62]

From an ecosystem perspective, balancing the potential environmental impacts of water use for thermoelectric power generation, for instance, would take into account, not only potential impacts on aquatic life, but also on the air, in terms of air pollution and climate change, and on the land, in terms of greenfield preservation, habitat for terrestrial life, and intensity of use, that is, the amount of land required relative to the amount of electricity produced. Not to consider the ecosystem as a whole in terms of energy source management can lead to self-destructive consequences, however well intentioned.[63]

Potential Ecosystem Impacts in Terms of Environmental Footprint and Life-Cycle Emissions

When considering the potential environmental impact of large-scale energy sources for producing electricity that require water for cooling, two measures put in perspective their relative ecosystem values: environmental footprint during operations and potential life-cycle impacts.

Environmental footprint is the potential impact of an operating electricity generating facility on all aspects of the environment. Focusing on nuclear energy, nuclear power plants during operations probably have the smallest environmental footprint of any large-scale energy source. In terms of air emissions, nuclear plants are "emission-free" when they are operating to generate electricity for the power grid. They produce no air pollutants, such as nitrous oxide (NOx), which contributes to ground-level ozone formation, or sulfur dioxide (SO_2), which contributes to acid rain. When operating, coal plants produce both; natural gas plants produce NOx but not SO_2. Likewise, nuclear plants produce no carbon dioxide (CO_2), whereas coal plants do, and natural gas plants produce about half the amount of CO_2 as coal plants.[64]

Considering land use, nuclear plants are the most eco-efficient of any energy source, producing more electricity per amount of land required for operation. Renewable energy sources occupy substantially more land because they are more diffuse. In the case of wind, the turbines deflect and slow down wind flow; so they must be spaced accordingly. To produce the electricity equivalent of a 1,000-megawatt nuclear plant, a wind farm would have to be about 150,000 to 180,000 acres and a solar photovoltaic park 54,000 acres. By contrast, the Millstone Units 2 and 3 nuclear power plants in Connecticut have an installed capacity of over 1,900 megawatts of power on a 500-acre site designed for three nuclear plants.[65]

Land use serves as an indicator for the impairment or loss of habitat for wildlife and plant life, and potential impacts on the human community as well. Current energy development plans and renewable portfolio standards passed into law at the state level will alter the national energy mix and resulting land use. Projections indicate that, by 2030, wind energy will require 27.8 square miles to generate one terawatt-hour of electricity per year; solar photovoltaic, 14.2 square miles; natural gas, 7.1 square miles; coal, 3.7 square miles; and nuclear energy, only 0.9 square miles.[66]

Life-cycle CO_2 emissions analysis evaluates the total emissions that result from the manufacturing, construction, operation, fueling, dismantling, and disposing of a given type of generating facility over the course of its useful life. Many studies have found that nuclear energy's life-cycle CO_2 emissions are comparable to renewable energy sources, such as wind and hydropower, and far less than those of coal- or natural gas-fired plants. These studies have been developed by such independent institutions as the International Energy Agency and the University of Wisconsin, among others.[67]

Regarding the potential life-cycle impacts of electricity generation facilities on wildlife, a recent study by the New York State Energy Research and Development Authority and the Environmental Bioindicators Foundation determined that wind power and nuclear energy have the lowest potential impact on wildlife, followed by hydropower, natural gas, oil, and coal. The life-cycle stages included were resource extraction, fuel transportation, facility construction, power generation, transmission and delivery, and decommissioning. The effects on wildlife considered were physical injury or mortality, chemical injury or mortality, disruption of normal behavior, and destruction and alteration of habitat.[68]

In fact, because nuclear energy has such a small environmental footprint, the grounds at or near nuclear power plants provide attractive habitats for animals and plants. Nuclear plant owners actively support a broad range of ecology programs, including endangered species and wildlife protection, land and seashore preservation, wetland recovery, water protection, tree planting, nature park and trail maintenance, and environmental education. At last count, the 104 operating U.S. nuclear power plants sponsor some 221 ecology programs, many award winning.[69]

V. Climate Change and Drought Mitigation Through Nuclear Energy

Water Availability and Operation of Thermal and Hydro Power Plants

Given the central importance of water and electricity to standard of living and quality of life, water consumption and drought are always concerns. Because of the interdependence between electricity generation and usable water production, not only the supply of water itself from natural sources available for treatment and use, but also the availability of water from those sources for electricity generation *to process water* may be affected. In addition, the higher temperature level of lakes and rivers that often accompanies drought can have a potential impact as well on water supply and electricity generation.

The second largest source of emission-free electricity in the United States—hydroelectric power, at 22 percent[70]—experiences the most impact from drought conditions compared to other energy sources. Hydroelectric power production depends directly on rainfall and snowfall—the less precipitation, the less electricity produced because less water flows through the dams. Indirectly, hydroelectric power production may be reduced during drought conditions because plant operators may deliberately curtail dam water flow from reservoirs to provide adequate water supply for residential, commercial, industrial, and agricultural needs. The reduction in water release must be balanced, however, with minimum release schedules required to maintain downstream ecosystems and other recreational and commercial uses.

Though it is unusual, thermoelectric power plants will also reduce production so that they can continue operating during extreme temperature and abnormal drought conditions. Permits vary from state to state, but thermoelectric plants are generally required to discharge water within an upper temperature limit, in relation to the temperature of the natural waterbody, or as an absolute limit regardless of the waterbody temperature. If the plant's water source is a river, then the discharge temperature limit may be set in relation to water temperature upstream and downstream and according to the river's flow rate.

To respond to temperature in extreme weather conditions, operators will track weather reports for cloud cover (for temperature moderation) and wind speed (for evaporative cooling) as well as monitor real-time temperature of waterbody and discharge water. In addition, they will consult on-site meteorological towers, historical data, river flow, and ambient temperature. They will then perform complex calculations based on this data and reduce plant output, when necessary, to remain within environmental requirements prescribed by their permits.[71] On the other hand, thermoelectric power plants typically do not reduce output for water-level or water-flow of the water source. They ordinarily are permitted, according to EPA guidance, around low-flow conditions according to a formula that identifies as a permissible limit the lowest seven days over a 10-year period.[72]

Climate Change and Drought

Scientific studies of climate change have predicted, as one of the consequences, increasing periods and duration of drought conditions around the world,[73] as well as in various regions of the United States. Alterations in climatic conditions are not uniform, however, and some areas of this country may experience an increase in precipitation and less frequent dry spells. But others will experience challenges to water supply due to decreasing rainfall, higher temperatures of ambient air and lakes and rivers increasing evaporation, diminishing snowpack and melts earlier in the year causing floods initially but lower summer water levels later, and rising sea levels that diminish the quality of coastal fresh water sources as salt water intrudes further inland.

Climate change modeling for the United States indicates that Western states will experience increasingly intense drought conditions and the Great Lakes will see predominantly lower water levels that will have a regional impact on water supply. On the other hand, the major computer models differ regarding the Southeast. The Canadian Centre for Climate Modeling and Analysis predicts a higher degree of warming and lower soil moisture due to increased evaporation, while the Hadley Centre of the United Kingdom simulates less warming and a significant increase in precipitation of 20 percent by 2100.[74] The anticipated relationship between climate change and drought recently prompted U.S. water utilities to take preparatory action.[75]

Nuclear Energy and Climate Change Mitigation

Since the electric generation sector, as a whole, is responsible for substantial greenhouse gas emissions, energy sources that do not emit greenhouse gases and air pollutants during operations, such as nuclear energy and most renewables, are essential for mitigating climate change. Nuclear energy is especially important because, during operations, it is an emission-free source of large-scale, reliable, low-cost energy. The United Nations Intergovernmental Panel on Climate Change has determined that "Total life-cycle emissions of GHG per unit of electricity produced from nuclear power are . . . similar to those for renewable energy sources . . . . Nuclear power is therefore an effective GHG mitigation option, especially through license extensions of existing plants enabling investments in retro-fitting and upgrading."[76] According to the United Nations Industrial Development Organization (UNIDO), "It is likely that countries with the economic means to invest in nuclear technology will increasingly turn to this solution as a means of reducing their dependence on fossil fuels, achieving energy security and reducing greenhouse gas emissions."[77]

Among emission-free sources of energy, nuclear energy does have one advantage over renewables in terms of climate change mitigation—steady output of electricity. Nuclear power plants operate continually, 90 percent of the time, with no production of greenhouse gases involved during this period of operation. In this way, nuclear plants help to maintain the stability of the U.S. electric power grid as they generate baseload power to serve customary, around-the-clock electricity demand.

By contrast, renewable sources are *intermittent* in electricity production, operating only when the wind blows or the sun shines, and *variable*, producing frequently changing amounts of electricity, depending on wind speed and sun intensity. Consequently, wind turbines produce electricity about 30 percent of the time and solar photovoltaic panels and solar thermal plants about 20 percent of the time.[78] This means that wind and solar must be "backed up" by other energy sources to "balance" a loss of, or fluctuation in, generation, that is, to provide electricity immediately when production from renewable facilities suddenly drops.[79] Otherwise the electricity grid will fail and a blackout will occur.[80] These back-up facilities are fossil plants, usually natural gas—some running constantly in readiness at a low level—and natural gas plants produce about half of the greenhouse gas emissions of a coal plant.[81]

To be sure, no single technology can, by itself, slow and reverse increases in carbon emissions. A diverse portfolio of technologies and strategies will be required.[82] Nevertheless, many independent studies demonstrate that meaningful reductions in the world's greenhouse gas emissions will not be achieved without a substantial component of nuclear generation capacity. These studies have been developed by such organizations as the International Energy Agency, Pacific Northwest Laboratory, McKinsey & Company, Cambridge Energy Research Associates, the U.S. Energy Information Administration, and the Electric Power Research Institute.[83]

In addition to reducing the greenhouse gas emissions of the electric power sector, nuclear energy has the potential to help reduce the considerable carbon emissions of the transportation sector as well. Plug-in hybrid gasoline-electric automobiles are already a popular alternative technology to conventional hydrocarbon-based vehicles, because they have the potential to produce less greenhouse gases. Their effectiveness as a climate change mitigation strategy, however, depends upon their obtaining emission-free electricity from the power grid. It will take a substantial amount of electricity to power these plug-in hybrids, if they are widely adopted, and, as an emission-free, large scale generation source, nuclear energy is ideal for this task.[84] Also, if hydrogen fuel cell vehicles and the related fuel delivery infrastructure are developed, nuclear energy can provide an emission-free, low-cost energy source to produce the required hydrogen through cogeneration at nuclear facilities.[85]

Nuclear Energy and Drought Mitigation

Given that drought conditions can be attributed to climate change, any technology or strategy that is capable of addressing climate change can, at the same time, address diminishing water supplies. Expanding energy sources that do not produce greenhouse gases, such as nuclear energy and most renewables, will, over time, help mitigate climate change and, in turn, mitigate the drought conditions it causes. This link between climate change and water supply makes such emission-free energy sources as nuclear energy critical to environmental preservation, sustainable development, and quality of life around the world.

Nuclear Energy and Desalination

Using nuclear energy as a power source can be an important strategy to alleviate the effects of drought. Nuclear energy can provide economical, emission-free electricity or process heat for desalinating seawater and brackish groundwater to increase water availability.[86] According to the United Nations Intergovernmental Panel on Climate Change, "Increased future wastewater use and desalination are likely mechanisms for increasing water supply in semi-arid and arid regions . . . . The cost of desalination has been declining, and desalination has been considered as a water supply option for inland towns."[87] The United Nations Industrial Development Organization notes that "nuclear power is increasingly being considered as a viable energy source for thermal desalination plants, particularly in countries that have local uranium reserves. The advantages include fuel price stability and the long-term availability of the fuel . . . ."[88] Global desalination plant capacity, as of 2007, was about 40 million m3, mostly using fossil energy, and located primarily in the Middle East and North Africa.[89]

In terms of economics, studies conducted by the International Atomic Energy Agency (IAEA) have found that "the use of nuclear energy for electricity and potable water production is an attractive, technically feasible and safe alternative to fossil energy options."[90] In fact, a relatively small number of nuclear plants could have powered all desalination plants in operation in 2002: "An approximation of the market potential can be obtained by considering a 600 MW nuclear reactor operating in the cogeneration mode and producing about 500,000 m^3 of water per day. For such water production about 20 percent of the electrical capacity of the plant will be used. The total existing world desalination capacity (about 26 million m^3) could therefore be powered by about 50 such reactors."[91] In the most recent study, IAEA concludes that "Whatever the nuclear reactor, the desalting capacity and the site-specific conditions, nuclear desalination is by far economically the most interesting option as compared to the gas turbine, combined cycle plant . . . ."[92]

Desalination plants have been built in every state of the United States. About half of the plants are small, constructed to serve specific industrial needs. Seawater desalination represents only 8 percent of installed capacity in the United States, compared to 60 percent worldwide. U.S. desalination capacity to date is very small when compared to total U.S. water use: the daily production of 1.5 billion gallons per day represents less than 0.4 percent. But the desirability of the desalination option is growing: between 2000 and 2005, online desalination capacity increased by about 41 percent.[93]

In fact, the National Research Council recently concluded that desalination of seawater and brackish groundwater "offers the potential to substantially reduce water scarcity . . . particularly in water-scarce regions, in localities experiencing rapid population growth, or where users are able and willing to pay for high-quality, reliable new supply."[94] To be sure, energy is the largest single variable cost for a desalination plant, and has ranged from one-third to more than half of the cost of produced water.[95] The National Research Council concludes, however, that "the costs of producing desalinated water . . . is no longer the primary barrier to implementing desalination technology, because there have been significant reductions in desalination production costs. Meanwhile, the costs of other alternatives for augmenting water supplies have continued to rise, often making desalination more attractive in a relative sense."[96]

Significantly, addressing potential greenhouse gas emissions resulting from desalination energy requirements, the National Research Council recommends that "energy sources other than fossil hydrocarbons can provide energy for desalination and thus avoid or significantly reduce greenhouse gas emissions. Technologies such as nuclear, . . . hydroelectric, . . . wind, . . . and solar photovoltaic . . . are providing input to the electrical grid . . . and are not associated with the generation of greenhouse gases."[97]

VI. Cooling Technologies and Environmental Law: Ecosystem Diversity and Water Management

New Plant Cooling Systems: Clean Water Act Section 316(b) Phase I

The Clean Water Act, formally the Federal Water Pollution Control Act, was enacted into law by Congress in 1948, and has been frequently amended.[98] The 1972 amendments changed the enforcement approach to surface water discharges from *water quality standards*—regulating the amount of pollutants in a given body of water, to *effluent limitations*—regulating the amount of pollutants being discharged from a particular point source.[99] Section 316, however, preserves the focus on aquatic life in the water bodies receiving the water, in a standard that states: "the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts."[100]

The U.S. Environmental Protection Agency first published, then withdrew, regulations implementing Section 316(b) in 1976.[101] In 1995, to resolve a lawsuit filed by environmental groups, the EPA entered into a consent decree obligating it to create 316(b) regulations in three phases. Phase I addresses new facilities of all kinds, including thermoelectric power plants.

The Phase I regulation, published in 2001, establishes a single, nationwide standard for new plant water cooling intake structures, that is, "national technology-based performance requirements." It identifies "a closed-cycle, recirculating cooling water system"—wet cooling towers or cooling ponds—specifically as the best technology available, and its performance as the standard that new plant cooling system water withdrawal must meet in terms of intake capacity. In addition, Phase I specifies a velocity standard as well.[102]

Because closed-cycle cooling systems are already more expensive to build and operate than once-through cooling systems, and because any alternative cooling system to the closed-cycle systems, such as dry cooling, would be even more expensive, Section 316(b) Phase I, in effect, requires utilities constructing new plants to deploy only wet cooling towers or cooling ponds. In turn, because cooling ponds are more expensive to build and operate than wet cooling towers, Phase I, in effect, requires utilities developing new plants to resort to wet cooling towers.[103]

Local Ecosystem Preservation and Site-Specific Solutions

The ecosystems most important to water use environmental evaluations are local and regional. These ecosystems vary considerably—from communities of the West Coast and the Southwest to the Great Plains and Great Lakes to the Southeast and New England. Thermoelectric power plant cooling water technologies—once-through and wet cooling tower—in turn, have varying potential impacts on water quantity, water quality, and aquatic life. The choice of deployment of one or the other of these systems can, therefore, be correlated with local ecosystem needs in terms of site-specific drought, water temperature, water chemistry, aquatic life, and habitat conditions, and, more broadly, with the varying effects of climate change.

The EPA's original regulations implementing Section 316(b) were "remanded," sent back, to the EPA by a federal court for procedural reasons in 1977. When the EPA withdrew the regulations, it left intact a separate provision, which had not been remanded, that directs permitting authorities—state environmental agencies—to use their "best professional judgment" to determine the best technology available for each facility on a case-by-case basis.[104] This provision, in effect, enabled the EPA and the states for some 30 years to conform thermoelectric power plant water use permitting to the specific needs and conditions of the particular waterbody where the plant was located. For this purpose, the EPA, in 1977, issued draft guidance for evaluating the potential impact of cooling water systems on aquatic life for use in site-specific permitting decisions.[105] The EPA and the states addressed potential facility impacts at the time of construction.

With Section 316(b) Phase I regulations, however, local decisions regarding the appropriate choice of cooling water system for local ecosystem preservation are no longer possible. Site-specific environmental considerations, in terms of animal life (such as the species of aquatic life present, their population and behavior), have no bearing anymore. Nor do other environmental considerations beyond aquatic life that may be important to a locality or region, in terms of habitat (such as drought). In turn, selecting a cooling technology as the most advantageous, locally, for climate change adaptation is no longer possible.[106]

Although Phase I states that the regulations may have "benefits . . . at population, community, or ecosystem levels" as well as effecting a "decrease in expected mortality or injury to aquatic organisms," Phase I's environmental value at the ecosystem level appears to be only a secondary objective, and viewed solely in terms of aquatic life.[107] Phase I simply adopts the premise, not actually demonstrated, that reduced intake capacity and velocity will result in less impingement and entrainment—wet cooling towers withdraw less water, at a slower speed; so they impinge and entrain less aquatic life. Phase I then assumes that impingement and entrainment mortality will have an adverse environmental impact on aquatic life, when scientific study demonstrates that this mortality is so small relative to respective populations of aquatic species in the waterbody that their abundance is not affected by cooling systems.

Existing Plant Cooling Systems: Clean Water Act Section 316(b) Phase II

The Phase II regulation, published in 2004, addresses large thermoelectric power plants built before 2002.[108] Phase II "establishes national performance requirements," specifically, "performance standards for the reduction of impingement mortality and, when appropriate, entrainment." Rather than adopting a single "best technology available," EPA based the performance standards on the effectiveness of a selected group of mitigation technologies that together represent the best technology available, including wedgewire screens, filter barrier systems, barrier nets, and modified screens and fish return systems. EPA also based the performance standards on the type of waterbody in which the intake structure is located, the volume of water withdrawn by a facility, and the facility capacity utilization rate.[109] The resulting national performance standards consist of "ranges of reduction"—reducing from a power plant's baseline estimate, "calculation baseline," impingement mortality by 80-95 percent and entrainment by 60-90 percent.[110]

Phase II presents five alternatives for compliance. Four allow one or a combination of approaches to meet the national performance standard. These include employing various aquatic life control technologies that comprise the best technology available group; plant operational adjustments, such as reducing intake volume to that comparable to a closed-cycle cooling system and reducing intake velocity to a specific minimum; and restoration measures. The fifth compliance alternative allows a plant to request a site specific determination of best technology available for minimizing potential environmental impacts if the cost of complying with the national performance standards is significantly greater than the potential environmental benefits at that plant.[111]

In response to lawsuits from a variety of sources,[112] a federal appeals court reviewed the Phase II regulation and issued a ruling in January 2007. The ruling "prohibited EPA from allowing any site-specific consideration of costs and benefits in determining what intake technology best minimizes adverse environmental impacts." The ruling also "prohibited consideration of restoration efforts that reduce or eliminate the environmental impacts of impingement and entrainment in assessing whether an existing intake 'minimizes adverse environmental impact.'"[113] Finally, the court implied that the EPA should consider mandating retrofitting of all existing plants to use closed-cycle cooling.[114]

In April 2008, responding to formal requests from the electric utility industry, the United States Supreme Court announced that it would review the federal appeals court decision regarding the prohibition of cost-benefit analysis, but not other aspects of the federal appeals court ruling, including the prohibition of restoration measures.[115]

The Supreme Court rendered its decision in April 2009. The Court concluded that "the EPA permissibly relied on cost-benefit analysis in setting the national performance standards and in providing for cost-benefit variances from those standards" on a site-specific basis. The Court observed that "the EPA's current practice is a reasonable and hence legitimate exercise of its discretion to weigh benefits against costs that the agency has been proceeding in essentially this fashion for over 30 years."[116] The federal court of appeals must now modify its decision and instructions to the EPA to make them consistent with the decision of the Supreme Court. The EPA will then issue revised regulations.

Ecosystem Conservation and Comprehensive Environmental Management

Although the Phase II regulation sets a national standard for existing power plants, as did Phase I for new plants, Phase II incorporates some flexibility for site-specific conditions. Specifically, it designates an assortment of technologies as the best available technology, giving plant owners a choice according to local conditions. Also, it employs cost-benefit analysis to determine the installation of technologies on a case-by-case basis, again enabling utilities to consider local conditions. The federal appeals court decision calls into question the former, greatly restricting, if not eliminating, the ability of utilities to take into account local ecosystems.

Phase II also follows, and intensifies, the focus on aquatic life, present in Phase I, by introducing specific impingement and entrainment standards.[117] This is because Phase II, like Phase I, again assumes, without inquiry and contrary to scientific study, that the very small mortality from impingement and entrainment causes an environmental impact. The federal appeals court ruling exacerbates this limited and scientifically unsupported environmental perspective by implying that closed-cycle cooling systems are an optimal technology available for existing plants, and by prohibiting restoration as an environmental protection measure.

An ecosystem is the interrelationship of human, animal, and plant life, and habitat and climate. Responsible environmental management would adopt a comprehensive perspective that includes all elements of the ecosystem. Otherwise, even those being considered to the exclusion of all others, such as aquatic life, may in the end be harmed by the very regulations intended to protect them.

In view of climate change and the drought that is one of its consequences in many parts of the country, impingement and entrainment may not be the most significant challenges to aquatic life. The reduction of the aquatic habitat—the loss of water itself—may be an overriding concern.

Measures intended to protect the individuals of a species may endanger the entire species, and others as well.

Specifically, the Phase II federal appeals court decision, and the Phase I regulation, both assume that, because closed-cycle systems withdraw significantly less water, they reduce impingement and entrainment, and, in turn, environmental impact, when, in fact, scientific study demonstrates that once-through cooling systems do not adversely impact fish populations, and thus, there is no adverse environmental impact. Closed-cycle cooling systems, on the other hand, consume more water, thus contracting, to however limited a degree, the habitat of the aquatic life that are not impinged or entrained.

Environmental conditions and potential impacts vary. A once-through cooling system that consumes very little of the water it withdraws, fitted with aquatic life protection intake structure technologies, or accompanied by restoration measures that replace in the natural water source a comparable number of aquatic life individuals of the species affected, may be the ideal climate change adaptation strategy, particularly for local and regional ecosystems in the United States concerned about water consumption. In this way, both the aquatic life populations and aquatic habitat would be preserved.

Unfortunately, Phase I effectively prevents deployment of once-through cooling systems on new plants. The Phase II federal court ruling, in addition to favoring closed-cycle cooling systems, prohibits restoration measures, and the Supreme Court did not review that part of the decision. The consequences of losing restoration as a strategy for environmental preservation will be significant, both for the human and animal communities.

VII. Climate Change Adaptation: Future Power Plant Cooling Technologies

Existing Plants: Recycling Degraded Water

As climate change is expected to introduce or exacerbate drought conditions in various parts of the United States, the electric power industry is pursuing effective adaptation strategies—researching, developing, commercially demonstrating, and deploying power plant cooling system technologies that use less water, less freshwater, or no freshwater at all.

One strategy for freshwater conservation is the recycling of "impaired" or "degraded" water—freshwater from waterbodies, groundwater, or municipally supplied water that has subsequently been used and contaminated to the point that it needs to be processed before further use or return to a lake or river. This strategy is expected to play a significant role in water conservation in the future. A number of thermoelectric power plants may even be co-located at facilities or operations that produce degraded water.

Power plant owners have always minimized water use as much as is practicable, for economic as well as environmental reasons. Beyond ensuring conventional cooling system efficiencies, some utilities have already deployed such advanced cooling system strategies as recycling degraded water.

Recycling municipal wastewater. Palo Verde Nuclear Generating Station is the first, and only, nuclear power plant in the world to use recycled ("reclaimed"), partially treated ("secondary effluent") municipal wastewater for its cooling system requirements.[118] Palo Verde is located in a desert environment in Tonopah, Arizona, 55 miles West of Phoenix: the only nuclear plant in the United States that is not sited on a large waterbody.[119] Palo Verde is the largest power plant of any fuel type in the United States as measured by electricity production, and the second largest power plant in this country when measured by capacity.[120] Palo Verde's three reactors have been using recycled municipal wastewater for their nine cooling towers since they began producing electricity for the U.S. electricity grid in 1985, 1986, and 1987, respectively.[121]

Palo Verde's on-site Water Reclamation Facility, with a capacity of 90 million gallons per day, continues the wastewater treatment process begun by the municipalities[122] through enhanced filtration ("tertiary treatment"). After treatment, the water is pumped into two storage reservoirs with a combined capacity of one billion gallons, enough for a 10-day total cooling systems supply during the summer months. The plant cooling systems are designed to cycle this reclaimed water 15 times, but the plant is currently achieving over 29 cycles. After use, the water is disposed of in two evaporation ponds, 250 and 220 acres each, at 30 feet deep. A third evaporation pond of 180 acres was completed in 2008. The lined ponds will hold all sediment from the cooling process until the plant is decommissioned.[123]

Recycling mine pool water. Coal mining operations that create underground openings for coal extraction result in inflows of unwanted ground water. This water is contaminated by minerals at the coal seam. Mine operators often remove this water from the active mining areas and store it in abandoned portions of the mine.[124] This pooled water continues to rise after the mines are closed, resulting in acid mine drainage that can pollute rivers and streams. The U.S. Bureau of Mines has estimated that Pennsylvania's Anthracite Region discharges over 200 billion gallons of water annually from active and abandoned mineshafts, tunnels, and pits.[125]

Limerick Generating Station is the first, and only, nuclear power plant to make use of mine pool water for its cooling system.[126] The two-reactor plant is located on the Schuylkill River in Montgomery County, Pennsylvania, 21 miles northwest of Philadelphia, and produces enough electricity for two million homes.[127] Because of regional climate conditions, the Schuylkill River can only provide water for the plant's cooling system about six months of the year. A variety of remote creeks and reservoirs previously provided water the remainder of the year, some augmented by diverted water from the Delaware River.

Beginning in 2003, Limerick began to use water for cooling from two additional sources: the Still Creek Reservoir at Tamaqua and the Wadesville Mine Pool at Pottsville, which, unlike most mine pools, is non-acidic. Water from these sources is released into the Schuylkill River upstream of the plant to augment flow during shortages, and held during surplus availability. These sources currently supply 40 percent of Limerick's cooling water requirements. The amount of released mine water varies greatly from year to year based on weather conditions, which determine need. In 2005, the total volume of mine pool water discharged was 852.5 million gallons; in 2006, 91.05 million gallons; and in 2007, 521.4 million gallons. This strategy has reduced the plant's consumption of freshwater from the natural waterbodies and increased flows in the rivers that comprised the previous dry season water withdrawal network.[128]

New Plants: Hybrid Cooling Technologies

Certain companies that are planning to build new nuclear power plants have developed "hybrid" cooling systems for these new facilities that combine either one type of cooling system with another or with water treatment technology in order to conserve freshwater resources. Should these utilities decide to proceed with construction, these innovative cooling system approaches will be deployed.

Recirculating wet cooling with dry cooling. One of the proposed new reactors for the North Anna Power Station—Unit 3—would be equipped with a wet-dry hybrid cooling system. During periods of relative water surplus, the reactor would use a series of closed-cycle wet cooling towers. This is the Energy Conservation mode. When Lake Anna, the plant's water source, goes below a certain level, a series of dry cooling towers would replace or supplement the wet cooling towers. This is the Maximum Water Conservation mode. During periods of water shortage, under favorable weather conditions, the entire heat load would be dissipated through dry cooling. Under the most unfavorable conditions—when the reactor is at full power and the atmosphere is hot and humid—the dry cooling towers are designed to dissipate one-third of the heat first. Then the water would pass through the wet cooling towers, which would be activated to handle the remaining heat.[129]

Recirculating cooling system with desalination. The proposed new reactor at Calvert Cliffs Nuclear Power Plant, located in Lusby, Maryland—Unit 3—would have two cooling systems equipped with wet cooling towers. The primary Circulating Water Supply System, with one cooling tower, would serve the plant turbine's condenser that cools steam back to water. This system would draw water from the Chesapeake Bay. The safety-related Essential Service Water System, with four cooling towers, would provide cooling water to the Component Cooling Water System heat exchangers and the emergency diesel generators. It would be used for normal operations, refueling, shutdown/cooldown, anticipated operational events, and in case of an accident. Water for this system would be supplied by an on-site desalination plant drawing water from the Chesapeake Bay, eliminating the need to use groundwater sources, conserving the area's freshwater supply.[130]

Research and Development: Advanced Alternative Cooling Technologies

The thermoelectric power industry, sometimes in partnership with DOE national laboratories,[131] is funding and participating in a variety of research and development, and commercial demonstration, projects intended to create new water-saving or water-eliminating cooling system technologies and to improve the efficiency and cost-effectiveness of existing reduced-consumption recirculating cooling systems and dry cooling systems.

In 2007, EPRI developed an Advanced Cooling Technology Roadmap incorporating current and proposed advanced cooling system research projects. This comprehensive R&D program catalogues, by cooling system type, the industry's wide-ranging efforts to address the potential environmental impacts of power plant cooling systems.[132]

Once-through cooling systems. The objective of research on once-through cooling systems is to minimize aquatic life impingement and entrainment. Technologies include barrier nets; fish impingement, capture, and return systems; subsurface water intakes; intake flow reduction; and fish-friendly hydro turbine designs.

Recirculating cooling systems. Research on closed-cycle cooling systems is intended to reduce freshwater consumption, reduce electricity requirements, and use degraded water in cooling towers. Projects include water recovery from cooling tower plumes; the relationship between cooling tower design and degraded water treatment; and tower rain zone recovery and environmental impact reduction.[133]

Dry cooling systems. Research on dry cooling systems is focused primarily on the air-cooled condenser and is intended to improve fin design and wind tolerance. Projects include review of compact heat exchanger data, analysis of fin designs, analysis of attached and detached wind barriers,[134] forced draft fan design modifications, and wind enhanced designs for air cooled condensers.

Hybrid cooling systems. The purpose of research on hybrid cooling systems is to develop rigorous design and operating performance criteria and guidelines for system selection and optimization.[135]

■

Notes

Executive Summary

[1] This conclusion regarding the water-use and energy-deployment decision-making process is similar in scope to that of World Economic Forum and Cambridge Energy Research Associates (CERA), *Thirsty Energy: Water and Energy in the 21st Century*, 2008: "Water and energy are inextricably linked with other global issues, including climate change and energy security. A holistic approach to energy and water management considers all of these issues and looks for creative solutions that optimize all of these parameters. Some energy technologies with low CO_2 emissions are large users of water, and technologies that may enhance energy security may be harmful from a water security standpoint. Thus, an optimized solution may involve tradeoffs among the various factors." (p. 42)

I. Water Use in the United States

Water Consumption versus Water Withdrawal

[2] These definitions correspond to those proposed in Peter H. Gleick, *The World's Water 1998-1999: The Biennial Report on Freshwater Resources* (Washington, D.C.: Island Press, 1998), p. 12, and reiterated in Peter H. Gleick, *The World's Water 2000-2001: The Biennial Report on Freshwater Resources* (Washington, D.C.: Island Press, 2000), p. 41.

Water and Numbers: Personal and Food-Related Water Consumption

[3] American Water Works Association Research Foundation and Aquacraft, Inc. (Peter W. Mayer, et al.), *Residential End Uses of Water*, 1999, pp. 99-102, 167.

[4] The number of households in the United States, 114,384,000, is from U.S. Census Bureau, *Current Population Reports*; 2006 (released March 27, 2007).

[5] Water Education Foundation and Marcia Kreith, *Water Inputs in California Food Production*, 1991, p. 5. The California Beef Council sponsored a study that excluded rainwater and yielded slightly just over 100 gallons of water per hamburger. See Carl Bialik, "How Much Water Goes Into a Burger? Studies Find Different Answers," *The Wall Street Journal*, January 11, 2008, and United States Geological Survey, 'Water Science for Schools: Water Used to Grow Common Foods—How much water does it take to grow a hamburger?", http://ga.water.usgs.gov/edu/sc1.html (April 15, 2008).

[6] McDonald's Corporation, "About McDonald's," http://www.mcdonalds.com/corp/about.html (April 15, 2008).

Water Consumption by Economic Sector

[7] U.S. Geological Survey (Wayne B. Solley, et al.), *Estimated Use of Water in the United States in 1995*, 1998, pp. 6, 48-9, 40-1, 36-7, 28-9, 44-5, and 32-3. Percentages are derived from the individual sector data tables rather than the summary percentage chart (Figure 7) on p. 19. The USGS *1995* study is the most recent to include both consumption and withdrawal data. In the subsequent study, U.S. Geological Survey (Susan S. Hutson, et al.), *Estimated Use of Water in the United States in 2000,* 2004, "not reported were consumptive use," nor "irrigation conveyance loss" (p. 3). In addition, in the *2000* study, "domestic [residential] use refers to self-supplied withdrawals only. For self-supplied domestic water, the source usually is a well. . . . Public-supply deliveries to domestic users and consumptive use were not reported" (p. 16). To put this in perspective, in the *1995* study, public-supply water deliveries constituted

87 percent of residential sector water withdrawal (p. 25). According to USGS, the forthcoming *2005* study also omits consumption.

[8] U.S. Geological Survey (Wayne B. Solley, et al.), *Estimated Use of Water in the United States in 1995*, 1998, pp. 6, 24-5.

[9] U.S. Geological Survey (Wayne B. Solley, et al.), *Estimated Use of Water in the United States in 1995*, 1998, pp. 6, 48-9.

[10] This calculation assumes a 1,000 megawatt nuclear plant operating at 90 percent capacity factor per year, the industry average of the time that a plant is actually operating compared to its operating 100 percent of the time. Average U.S. household electricity consumption is from EIA, *Survey of Residential End-Use Electricity Consumption*, 2001. Nuclear plant water consumption per megawatt/hour is from EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, p. viii. Residential water consumption per person is from U.S. Geological Survey, *Estimated Use of Water in the United States in 1995*, 1998, p. 24. Number of persons in an average U.S. household is from U.S. Census Bureau, *Current Population Reports*; reports consulted were from 1995, 2003, and 2006.

Water Consumption by Energy Source

[11] Nuclear, coal once-through with minimal pollution control, and natural gas once-through water consumption data is from EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, p. viii. Water consumption data for conventional (subcritical pulverized) coal plants with advanced pollution control equipment and wet cooling towers, and combined-cycle natural gas plants with wet cooling towers is from U.S. Department of Energy, National Energy Technology Laboratory (NETL) (G. J. Stiegel, J. R. Longanbach, M. D. Rutkowski, M. G. Klett, N. J. Kuehn, R. L. Schoff, V. Vaysman, J. S. White), *Power Plant Water Usage and Loss Study*, August 2005, revised May 2007, p. xiii.

Nuclear power plants are designed to operate at lower temperatures and pressures than coal plants. Consequently, they need more heat, and produce more steam, to generate a megawatt hour of electricity. More steam requires more water for cooling. Therefore, nuclear plants consume more water than coal plants per unit of electricity produced. Natural gas plants are able to operate at somewhat higher temperatures and pressures than coal plants, and thus consume even less water. In addition, they do not operate, as coal plants must, more extensive pollution control and process equipment that consume water and decrease efficiency. These include equipment to reduce air emissions, such as "scrubbers"—flue gas desulfurization (FGD) apparatus for SO_2 emissions reduction.

Southern Illinois University (Ben Dziegielewski and Thomas Bik), *Water Use Benchmarks for Thermoelectric Power Generation*, August 15, 2006, combines coal and natural gas plant data into a fossil fuel category, while nuclear power plants are considered separately. The study finds that fossil fuel plants with once-through cooling systems consume 200 gal/MWh; with recirculating systems with cooling ponds, 700 gal/MWh; and with recirculating systems with wet cooling towers, 700 gal/MWh. Nuclear power plants with once-through cooling systems consume 400 gal/MWh, with recirculating systems with cooling ponds, 500 gal/MWh; and with recirculating systems with wet cooling towers, 800 gal/MWh (p. VII-2).

The Southern Illinois University study analyzed data during the period 1996-2004 from Form EIA 767, Steam Electric Plant Operation and Design Report, on which USGS water surveys are also based. Utilities are required to submit this form annually to the U.S. Energy Information Administration under Section 13(b) of the Federal Energy Administration Act of 1974. The study supplemented this data with non-statistical information gathered from site visits and a national survey of plant managers on how plant managers respond to the Form EIA-767 and on factors influencing water use at power plants (pp. III-1, 3). (Form EIA-767 was not collected in 2006, and beginning 2007, it was replaced by Form EIA-860 and Form EIA-923. See Energy Information Administration, Form EIA-767 Database, at http://www.eia.doe.gov/cneaf/electricity/page/eia767.html (August 12, 2008).

Virginia Tech, College of Natural Resources, Virginia Water Resources Research Center (Rachelle Hill and Tamin Younos), *The Water Cooler: The Intertwined Tale of Energy and Water*, April 2008, adopts gallons per BTU as a "standard unit" of "water use" for electric power generation facilities, when other studies use gallons per megawatt hour. The unit of gallons/BTU introduces *process efficiency* into the comparison of energy system water use, as the relative efficiency of these energy systems is measured by heat rate, which is BTU/MWe, that is, the amount of heat produced divided by the amount of energy. Consequently, gallons/BTU does not indicate the amount of water consumed in terms of the *product* the various energy systems generate—electricity, which is measured in megawatt hours. Moreover, the heat rate, or BTUs produced, does not necessarily affect the *economics* of the system, as a less efficient system, such as nuclear energy, is, nevertheless, less expensive to operate per megawatt hour, due to cheaper fuel, when compared to natural gas or coal, for example.

[12] Peter H. Gleick, "Water and Energy," Annual Reviews, *Annu. Rev. Energy Environ.*, 1994, 19:284.

[13] EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, p. viii

[14] Peter H. Gleick, "Water and Energy," Annual Reviews, *Annu. Rev. Energy Environ.*, 1994, 19:284. The main use of water in solar energy is to wash off the solar panels to maximize sun capture. See "Renewable Energy: A Solar-Motivated Land Rush Hits the Southwestern Deserts," *ClimateWire*, June 24, 2008.

National Renewable Energy Laboratory (NREL) (P. Torcellini, N. Long, and R. Judkoff), *Consumptive Water Use for U.S. Power Production*, Technical Report NREL/TP-550-33905, December 2003, calculates and reports water consumption data according to two categories: thermoelectric power plants and hydroelectric power plants. This study finds hydroelectric consumption to be 18,000 gal/MWh (p. 4). As the study explains, "Reservoirs and dams are built for many reasons, including electric power production, flood control, water storage, and recreation. . . . There is no easy way to disaggregate on a national level the end uses for hydroelectric dam water into irrigation, flood control, municipal water, and thermoelectric power plant cooling. . . . Water flowing through the turbines and into the river is not considered consumptive because it is still immediately available for other uses. However, the increased surface area of the reservoir, when compared to the free flowing stream, results in additional water evaporation from the surface. A Free Water Surface Evaporation (FWSE) map was used to calculate the amount of water evaporated off the reservoirs" (p. 2).

[15] American Wind Energy Association, "Wind Web Tutorial: Wind Energy and the Environment" (formerly "The Most Frequently Asked Questions About Wind Energy"), "How much water do wind turbines use compared with conventional power plants?" at http://www.awea.org/faq/wwt_environment.html#How%20much%20water%20do%20wind%20turbines%20use%20compared%20with%20conventional%20power%20plants (July 21, 2008). This figure represents an AWEA calculation based on data provided by Fluidyne Corp. in 1996 and assumes that wind turbine blades are washed four times annually.

U. S. Geological Survey (Kimberly H. Shaffer and Donna L. Runkle), *Consumptive Water-Use Coefficients for the Great Lakes Basin and Climatically Similar Areas*, Scientific Investigations Report 2007-5197, 2007, studies water consumption in about one-fourth of the country—the regions of the Great Lakes, New England, Mid-Atlantic, Ohio River, Tennessee Valley, and Upper Mississippi—in the categories of domestic and public supply, industrial, thermoelectric power, irrigation, livestock, and commercial. This study is part of the National Assessment of Water Availability and Use Program that will eventually encompass the entire nation. At present, the data is geographically limited to the Great Lakes area.

Withdrawal: A Potentially Misleading Measure of Water Use

[16] U.S. Geological Survey (Wayne B. Solley, et al.), *Estimated Use of Water in the United States in 1995*, 1998, p. 48-9, 24-5, and 32-3. Regarding irrigation, 61 percent of water withdrawn is consumed, and 19 percent is lost during conveyance. In terms of *freshwater* withdrawals, thermoelectric power plants withdrew 131 billion gallons per day in 1995, making this sector *second* in total freshwater withdrawals to irrigation, whose total withdrawal of 134 billion gallons per day consisted entirely of freshwater.

[17] DOE NETL (Thomas J. Feeley, III, et al.), *Department of Energy/Office of Fossil Energy's Water-Energy Interface Research Program*, April 2006, p. 4.

II. Power Plant Cooling Technologies and Environmental Preservation

Types of Power Plant Cooling Technologies

[18] The National Academy of Engineering cited electrification as the most important of the top "20 engineering achievements that have had the greatest impact on quality of life in the 20th century," and highlighted developments in steam generator turbine technology in the early decades of the twentieth century in the "Electrification Timeline." See the NAE News Release, "National Academy of Engineering Reveals top Engineering Impacts of the 20th Century: Electrification Cited as Most Important," Feb. 22, 2000, and the "Electrification Timeline" at http://www.greatachievements.org?id=2971 (April 15, 2008).

[19] According to 2006 data from Global Energy Decisions and the U.S. Energy Information Administration.

[20] Emissions avoided by nuclear power are calculated using regional fossil fuel emissions rates from the Environmental Protection Agency and plant generation data from the U.S. Energy Information Administration. Total emissions are calculated from data from the Environmental Protection Agency.

[21] According to 2007 data from Global Energy Decisions and U.S. Energy Information Administration.

[22] There are two primary types of wet cooling towers. A "natural draft" cooling tower pumps the cooling water to the top, where it descends to be cooled by the upward natural flow of air. To enhance cooling, a medium inside the tower, "fill," retards or interrupts the flow of the water to increase its surface area exposed to the air. A "forced draft" or "mechanical" cooling tower adds fans that circulate the air through the tower.

[23] EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, pp. 3-1 through 3-7; DOE NETL (Thomas J. Feeley, III, et al.), *Department of Energy/Office of Fossil Energy's Water-Energy Interface Research Program*, April 2006, pp. 2-4.

[24] There are two types of cooling ponds. Cooling ponds routinely called reservoirs or lakes are technically "waters of the United States" or "waters of the state" if the streams flowing into and out of them are navigable, as defined by the Clean Water Act (see the *Code of Federal Regulations* at 33 C.F.R. Part 328). These bodies of water contain aquatic life and are subject to the full range of applicable federal environmental law and regulations. Cooling ponds that are separate from navigable waterways are considered industrial facilities and are termed, technically, "industrial water impoundments," or "industrial cooling impoundments." These bodies of water usually do not contain aquatic life. They may be replenished using ground water, and they may periodically draw water from, or discharge water into, waters of the United States to maintain a usable and safe water level. Industrial water impoundments, in themselves, are subject to fewer federal and state regulations than waters of the United States. If they draw or discharge water from waters of the United States, then the intake and discharge structures and activities would be subject to the full range of applicable federal and state regulations. From a regulatory perspective, cooling systems that use constructed lakes or reservoirs that are waters of the United States or waters of the state are considered once-through even if they are recirculating systems.

Cooling Technologies and Potential Ecosystem Impacts

[25] EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, p. 3-1.

[26] DOE NETL (Jeffrey Hoffmann, et al.), *Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts*, June 2004, p. 2.

Recirculating systems for the advanced reactor designs that are currently being considered for prospective new nuclear plant construction are at the low end of this range. For instance, the two Westinghouse AP1000 reactors for the William States Lee III Nuclear Station in Cherokee County, South Carolina, would consume 69 percent of the water withdrawn by each unit from the Broad River. See the data provided in the Water Balance Summary chart in Duke Energy, *Application for a Combined License for William States Lee III Nuclear Station Units 1 and 2*, Part 2, *Final Safety Analysis Report*, December 2007, p. 2.4-1.

[27] Texas Water Development Board, University of Texas at Austin (C. King, I. Duncan, M. Webber), *Water Demand Projections for Power Generation in Texas*, April 30, 2008, pp. ix, 4.

[28] Southern Nuclear Operating Company, "Plant Vogtle," at http://www.southerncompany.com/southernnuclear/vogtle.aspx (Dec. 16, 2008)

[29] Southern Nuclear Operating Company, "Nuclear Energy Is a Beneficial and Prudent Use of Our Water Resources," Op-Ed Article, October 2008 (unpublished)

[30] SCE&G, *V.C. Summer Nuclear Station*, at http://www.sceg.com/NR/rdonlyres/0065CB41-32BC-490A-9469-AA2B48053D28/0/VCSummerNuclearStation.pdf (Dec. 16, 2008).

[31] "SCE&G Exec: Building 2 Reactors Makes Sense," *The State* (Columbia, S.C.), Dec. 8, 2008.

[32] EPRI, *Water & Sustainability*, Vol. 3 *U.S. Water Consumption for Power Production*, 2002, pp. 3-3.

[33] Jan G. Laitos and Joseph P Tomain, *Energy and Natural Resources Law* (St. Paul, Minn.: West Group, 1992), pp. 185-6.

[34] Virginia Power, *Impingement and Entrainment Studies for North Anna Power Station, 1978-1983*, prepared by the Water Quality Department, Richmond, Virginia, May 1985. The study's results are presented in Dominion, *North Anna Early Site Permit Application*, *Revision 9*, September 2006, at http://adamswebsearch2.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML062580096.

[35] Lake Anna is technically a reservoir, and the major part of it is referred to as the North Anna Reservoir. It was created through the construction of the Lake Anna Dam on the North Anna River above the North Anna Dam for the purpose of providing water for the North Anna Power Station cooling systems. It is "waters of the United States" because the North Anna River, a navigable body of water, flows into and out of it.

[36] Dominion, *North Anna Early Site Permit Application*, *Revision 9*, September 2006, pp. 3-5-44, 3-5-47-8 for impingement, and pp. 3-5-49 to 3-5-50 for entrainment.

[37] Dominion, *North Anna Early Site Permit Application*, *Revision 9*, September 2006, p. 3-5-53.

The study points out that the more robust a fish population is—the greater the number of individuals—the more likely it is for individuals to be impinged or entrained, because there are more available. Fish populations tend to find an equilibrium based on the given life-sustaining resources per individual that the habitat provides. Individuals lost to animal predators, such as larger fish and diving or wading birds, as well as to humans, through commercial and recreational fishing, scientific study, and technology such as power plants, tend to be replaced until the optimum equilibrium is reached again (p. 3-5-48).

For an example of an aquatic life impact assessment of a once-through cooling system on a river, a "riverine" ecosystem, see the latest NPDES water use permit application of the Salem Generating Station, located on an island in the Delaware River, at the Estuary, in Lower Alloways Creek, New Jersey. Salem consists of two nuclear reactors with a capacity of 1200 MW each, which began operations in 1976 and 1981, respectively. "Available data on the composition of the finfish community in the vicinity of Salem from 1970 through 2004 were analyzed using widely-accepted techniques for measuring species richness. . . and species density . . . . This analysis showed that finfish species richness in the vicinity of Salem has not changed since the startup of Salem, and that finfish species density has increased. During trawl surveys conducted from 1999 through 2004, 27 additional finfish species were collected that had not previously been collected during PSEG's field surveys. . . . The majority of species have increased in abundance since 1998 or have experience rates of mortality due to Salem during this period that are much too low to have caused measurable reductions in abundance." From PSEG, *Salem Generating Station NJPDES Permit Renewal Application*, February 1, 2006, Section 5, *Adverse Environmental Impact*, p. 159. A convenient summary of the 14-volume application is Section 1, *Memorandum in Support of Renewal Application*. Plant information is from PSEG Nuclear, "The Salem Generating Station," at http://www.pseg.com/companies/nuclear/salem.jsp (August 7, 2008).

[38] For a discussion of population dynamics, see National Research Council, Commission on Life Sciences, Committee on the Applications of Ecological Theory to Environmental Problems, *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies* (Washington, D.C.: National Academy Press, 1986), pp. 28-35.

[39] LWB Environmental Services, Inc. (L.W. Barnthouse), AKRF, Inc. (D. G. Heimbuch), Van Winkle Environmental Consulting (W. Van Winkle), and ASA Analysis & Communications, Inc. (J. Young), *Entrainment and Impingement at IP2 and IP3: A Biological Impact Assessment*, January 2008, pp. 1-2, 5-19, 78-79. Information on Indian Point Energy Center is from Entergy, *Entergy Statistical Report & Investor Guide 2007*, p. 52.

Environmental Protection and Compensatory Measures for Cooling Systems

[40] Additionally, for nuclear power plants, groundwater measures, air measures, and terrestrial measures may be addressed in the Facility Operating License, Appendix B, Environmental Protection Plan, as required.

[41] For example, see the NRC's *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (NUREG 1437) at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/ and *Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site* (NUREG 1815) Final Report at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1815/.

[42] The NPDES permit addresses the quality of discharged water, and is managed by the state environmental agency authorized to oversee water quality. Water quantity, in terms of withdrawals, is addressed through state and local water authorities, water planning groups, and state environmental agencies authorized to oversee water resources, water appropriations, and water rights. The U.S. Army Corps of Engineers has jurisdiction over activities affecting navigable waters and wetlands. For operating plants, these may include dredging a waterbody in the vicinity of the cooling tower intake structure, and for new plant construction, building a dock to receive shipment of large components by barge, or building a roadway across wetlands to transport the components to the construction site.

[43] For detailed information on the National Pollutant Discharge Elimination Program, see the page of the EPA Web site, "NPDES Permit Program Basics" at http://cfpub.epa.gov/npdes/home.cfm?program_id=45, where the following are accessible: *Water Permitting 101*, *Protecting the Nation's Waters Through Effective NPDES Permits: A Strategic Plan*, "NPDES Permitting for Environmental Results," "Water Quality and Technology-Based Permitting," "Overview of the Water Quality Standards-to-Permits Process," "U.S. State Information," "State and Tribal Program Authorization Status," and the chart, "State Program Status," and the map, "State NPDES Program Authorization."

[44] For a detailed description of mitigation measures—either developed and deployed, or in experimental stages—and their effectiveness, now numbering close to 30 different kinds, see EPA, *Technical Development Document for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities*, November 9, 2001, Chapter 5, "Efficacy of Cooling Water Intake Structure Technologies," and Attachment A, "CWIS Technology Fact Sheets;" EPRI, *Fish Protection at Cooling Water Intakes*, December 1999; and EPRI, *Fish Protection at Cooling Water Intake Structures*, December 21, 2007.

[45] For a survey of the wide range of restoration activities that thermoelectric power plant operators undertake, see EPRI, *Enhancement Strategies for Mitigating Potential Operational Impacts of Cooling Water Intake Structures*, June 2003.

Comparative Economics of Cooling Technologies and the Implications

[46] For instance, DOE calculated the consequences of converting more efficient once-through cooling systems to less efficient wet cooling towers: "The U.S. Department of Energy pointed out to EPA that existing fossil-fuel facilities converting from once-through cooling water systems to wet-cooling towers would produce 2.4 percent to 4.0 percent less electricity even while burning the same amount of coal. For at least one nuclear power plant, which provides 78 percent of the electricity consumed by the State of Vermont, the energy penalty associated with converting to cooling towers was estimated to be 5.3 percent. Expressed differently, DOE estimated that nationally, on average 20 additional 400-MW plants might have to be built to replace the generating capacity lost by replacing once-through cooling systems with wet cooling towers." From U.S. Environmental Protection Agency, *National Pollution Discharge System—Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities*, *Federal Register*, 69 Fed. Reg. 41,605 (2004).

[47] U.S. Environmental Protection Agency, *National Pollutant Discharge Elimination System: Regulations Addressing Cooling Water Intake Structures for New Facilities*, *Federal Register*, 66 Fed. Reg. 65,283, 65,284 (2001).

As explained in Duke Energy, *Application for a Combined License for William States Lee III Nuclear Station Units 1 and 2*, Part 3, *Environmental Report*, December 2007, "Since dry towers do not rely on the process of evaporative cooling as does the wet tower, larger volumes of air must be passed through the tower compared to the volume of air used in wet cooling towers. As a result, dry cooling towers need larger heat transfer surfaces and must be larger in size than comparable wet towers" (p. 9.4-4). Moreover, a dry cooling tower requires substantially more energy to operate compared to a wet cooling tower. "Because of the larger volume of air required for heat rejection, fan horsepower requirements for the ACC [air-cooled condenser] are typically 3 to 4 times higher than wet towers. This would significantly decrease the net electrical output of the unit" (p. 9.4-5). The COL is available on the NRC Web site at http://www.nrc.gov/reactors/new-reactors/col/lee.html.

[48] DOE/NETL (Thomas J. Feeley, III, et al.), "Water: A Critical Resource in the Thermoelectric Power Industry," *Energy*, 33 (2008) [rev. January 12, 2007], p. 2; Platt's, *North American Energy Business Directory*, *World Electric Power Plants Database*, McGraw-Hill Companies, Inc., 2005; DOE/NETL (Thomas J. Feeley, III, et al.), *Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program*, 2006, p. [4].

[49] This data is from Scientech, 2008.

III. Water, Electricity, and Sustainable Development

Interdependence of Electricity Generation and Water Supply

[50] EPRI, *Water & Sustainability*, Vol. 4 *U.S. Electricity Consumption for Water Supply & Treatment*, 2002, p. 1-2.

[51] EPRI, *Water & Sustainability*, Vol. 4 *U.S. Electricity Consumption for Water Supply & Treatment*, 2002, p. 2-4.

[52] EPRI, *Water & Sustainability*, Vol. 4 *U.S. Electricity Consumption for Water Supply & Treatment*, 2002. DOE, *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, 2006, p. 26.

[53] Municipal water utilities are already taking actions that recognize the interrelationship of water treatment, electricity generation, and climate-change-induced water shortages. For instance, the Maryland-based Washington Suburban Sanitary Commission signed a ten-year contract to buy one-third of its electricity from a Pennsylvania wind farm, the largest percentage of renewable energy purchased by a local government agency to date, according to the EPA. The WSSC Laurel, Maryland, filtration plant supplies drinking water to about 1.8 million customers in suburban Washington, and the arrangement is expected to save WSSC $20 million a year. See "WSSC Deal a Huge Boost to Wind Power: Locking in Costs Could Save $20 Million a Year," *The Washington Times*, May 7, 2008.

[54] The National Science and Technology Council has issued a report recommending expanded research and more effective monitoring of water supply and use, and will develop a strategic plan for federal science and technology to support water availability and quality. See Executive Office of the President of the United States, National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality, *Science and Technology to Support Fresh Water Availability in the United States*, November 2004, pp. 9-15: "A very close linkage exists between the Nation's energy future and water future—water is crucial to the production of energy: different energy sources have different water needs. Conversely, many of the technologies for withdrawing, storing, or treating water consume large amounts of energy. Thus, the science of water availability and use is crucial to the planning of our nation's energy future" (p. 5).

The Department of Energy provided a report to Congress detailing energy sector water use and calling for integrated energy and water planning and management based on collaboration between federal, regional, and state agencies as well as industry. See U.S. Department of Energy, *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, December 2006, pp. 49-52: "Low water levels from drought and competing uses have limited the ability of power plants to generate power . . . Additionally, water levels in aquifers in many regions of the U.S. have declined significantly, increasing energy requirements for pumping . . ." (p. 13). This report was a joint effort between Sandia National Laboratories, as project lead, and Los Almos National Laboratory and the National Energy Technology Laboratory, as collaborators.

Sandia National Laboratories is developing a National Energy-Water Research and Development Roadmap to provide DOE and other federal agencies guidance in directing research, development, demonstration, and commercialization projects to ensure optimization of water use in energy generation and optimization of energy use in water production. See Sandia National Laboratories, "Energy-Water Roadmap Process" at http://www.sandia.gov/energy-water/roadmap_process.htm, and "Energy-Water Nexus Overview" at http://www.sandia.gov/energy-water/nexus_overview.htm (August 6, 2008): "Proposed restrictions on the use of water for power generation to protect fish and other aquatic organisms could result in increased costs of electricity or potential energy shortages. Because the energy required for treatment and delivery of water accounts for as much as 80% of its cost, an insufficient supply of affordable energy will have a negative impact on the price and availability of water." See also Sandia National Laboratories (R. Pate, M. Hightower, C. Cameron, W. Einfeld), *Overview of Energy-Water Interdependencies and the Emerging Energy Demands on Water Resources*, SAND 2007-1349C, March 2007: "Currently, electric power generation is one of the largest water withdrawal and use sectors in the U.S. . . . On the other hand, water resource development—distribution, treatment, and transmission—is one of the largest energy use sectors" (p. 1); and Mike Hightower and Suzanne A. Pierce (Sandia National Laboratories), "Commentary: The Energy Challenge," *Nature*, March 20, 2008, pp. 285-6.

For other national laboratory work, see U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory (NETL), *Water and Energy: Addressing the Critical Link Between the Nation's Water Resources and Reliable and Secure Energy*, Feb. 2004; and U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory (NETL) (E. Shuster and A. McNemar, and, from Research and Development Solutions, LLC, G. J. Stiegel and J. Murphy), *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*, DOE/NETL-400/2007/1304, Sept. 2007.

Finally, the Environmental Protection Agency has issued a National Water Program strategy responding to climate change that takes into account the reciprocal relationship between water conservation and energy conservation. U.S. Environmental Protection Agency, *National Water Program Strategy: Response to Climate Change*, September 2008: ""Water conservation through water use efficiency will be important not just to extend water supply, but also to reduce greenhouse gases. Reduced water consumption saves energy because less water is needed to be pumped and treated. On the other side of the water/energy equation, when energy use is reduced, water is saved because less is needed to operate power plants" (p. 29).

State governments are also beginning to recognize the interdependence between water and energy and the advantages of planning accordingly. A recent report sponsored by the Texas Water Development Board acknowledges that "electric power production and water usage are intimately related." Consequently, "any reduction in electricity demand will thus decrease the demand for water, and many times reducing water usage can reduce electricity generation." The report encourages "state planning agencies and government elected officials to consider water and energy planning and policy together," for instance, to "coordinate water and electricity infrastructure projects as much as possible." From Texas Water Development Board and University of Texas at Austin (C. King, I. Duncan, M. Webber), *Water Demand Projections for Power Generation in Texas*, April 30, 2008, pp. x, 64-5.

On the federal legislative front, in March 2009, Senator Jeff Bingaman (D-N.M.) and Senator Murkowski (R-Alaska) introduced the *Energy and Water Integration Act of 2009* (S. 531), authorizing six studies and programs: (1) NAS study of the intensity of water use in transportation and power generation; (2) DOE study of power plant energy and water efficiency; (3) Bureau of Reclamation water conservation and energy savings study; (4) Brackish Groundwater National Desalination Research Facility in Otero County, New Mexico; (5) EIA survey of water-related energy consumption, focusing on the acquisition, treatment, and delivery of water for agricultural, municipal, industrial, and domestic purposes; and (6) Doe Energy-Water R&D Roadmap. The Senate Energy and Natural Resources Committee held a hearing on the pending legislation on March 10. The testimony of Carl Bauer, Stephen Bolze, Michael Webber, Peter Gleick, and Lon House is available at http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Hearing&Hearing_ID=b8d13106-0dae-8b3e-696f-ccf8582f616b.

Water and Electricity Essential for Economic Progress

[55] United Nations Human Development Index data is from 2005. World Bank annual per capita electricity consumption (kWh) is from 2004.

[56] Peter W. Huber and Mark P. Mills, *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We Will Never Run Out of Energy* (New York: Basic Books, 2005), p. 18. As sources, the authors cite *Electricity in Economic Growth* (National Academy Press, 1986); Philip S. Schmidt, *Electricity and Industrial Productivity: A Technical and Economic Perspective* (Pergamon, 1984); and Sam H. Schurr et al., *Electricity in the American Economy: Agent of Technological Progress* (Greenwood, 1990).

Sustainable Development: Economic Progress and Environmental Preservation

[57] From United Nations, World Commission on Environment and Development, *Our Common Future*, Report to the United Nations General Assembly, August 4, 1987, commonly referred to as the Brundtland report.

[58] *United Nations Rio Declaration on Environment and Development*, 1992.

Comparative Economics of Energy Sources in Relation to Environmental Preservation

[59] Data is from Global Energy Decisions, as of June 2009, the most recent date for which information is available.

Fitch Ratings, an independent credit markets rating agency, made explicit the implications of the overall economics of various energy sources in a recent report, *Global Power/North America Special Report: Wholesale Power Market Update*, March 13, 2006: "The most likely and receptive sites for new nuclear plant construction are in the Southeast and Midwest. New nuclear plants and base-load power plants using new coal technologies are least likely to appear in the populous and energy-hungry Northeast or in California, regions that already have significantly higher energy prices than the Southeast and Midwest. For political or geological reasons, these regions are likely to rely either on gas-fired power facilities or costly investments for other resources, such as wind or solar. These differences will tend to favor lower energy prices in the Southeast and Midwest to the disadvantage of the Northeast and California" (p. 3).

[60] Lazard, *Levelized Cost of Energy Analysis*, Version 2.0, June 2008, Slide 2, "Levelized Cost of Energy Comparison," and Slide 5, "Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Incentives." This presentation was originally delivered at the National Association of Regulatory Utility Commissioners (NARUC) Summer Committee Meetings, June 20, 2008.

According to the American Wind Energy Association, wind power receives federal production tax credits and renewable energy credits that amount to about $35 per megawatt hour. See "PJM Eyes Making Wind Equal to Other Generation Resources," *Electric Power Daily*, May 20, 2009. Wind generation can also receive state and local tax credits, which are not included in the Lazard calculations. See, for instance, "A Mighty Wind: Oregonians Want Green Energy At Any Price, And That's What We're Getting," *WWeek* (Portland, Oregon) at wweek.com, March 11, 2009.

Contributing to the cost of wind is the cost of back-up generation—primarily fossil fuel generation—to compensate for renewables' intermittent and variable electricity production. The greater the percentage of renewable output constituting total electricity generation, the greater the cost for the required fossil fuel back-up. For instance, Frank P. Prager, Vice President, Environmental Policy, Xcel Energy, "said that Colorado planners calculate that if wind machines reach 20 percent of total generating capacity [in that state], the cost of standby generation will reach $8 a megawatt hour of wind. That is on top of a generating cost of $50 or $60 a megawatt-hour, after including a federal tax credit of $18 a megawatt-hour. By contrast, electricity from a new coal plant currently costs in the range of $33 to $41 a megawatt-hour, according to experts." As reported by Matthew L. Wald in "The Energy Challenge: It's Free, Plentiful and Fickle," *The New York Times*, December 28, 2006.

Likewise, Black & Veatch, a company involved in the construction of coal and gas plants and wind facilities, calculated that "A modern coal plant of conventional design, without technology to capture carbon dioxide before it reaches the air, produces at about 7.8 cents a kilowatt-hour; a high-efficiency natural gas plant, 10.6 cents; and a new nuclear reactor, 10.8 cents. A wind plant in a favorable location would cost 9.9 cents per kilowatt hour. But if a utility relied on a great many wind machines, it would need to back them up with conventional generators in places where demand ends to peak on hot summer days with no breeze. That pushes the price up to just over 12 cents, making it more than 50 percent more expensive than a kilowatt-hour for coal." As reported by Matthew L. Wald in "Cost Works Against Alternative and Renewable Energy Sources in Time of Recession," *The New York Times*, March 29, 2009.

[61] Electric Power Research Institute, *Program on Technology Innovation: Integrated Generation Technology Options*, Technical Update, November 2008, Table 1-4, "Representative Cost and Performance of Power Generation Technologies (2015)," p. 1-12, and Table 1-5, "Representative Cost and Performance of Power Generation Technologies (2025)," pages 1-13 and 1-14.

IV. Comprehensive Management of the Environment

Ecosystem: Interaction and Interrelationship of All Living Things

[no notes for this section]

Balancing Human Water Use Within the Ecosystem

[62] The balancing of potential environmental impacts will involve environmental priorities that are inevitably based on moral and ethical principles. For instance, the "working definition of sustainable water use" and the "Sustainability Criteria for Water Planning" proposed by Peter H. Gleick, P. Loh, S. Gomez, and J. Morrison implicitly observe an assumed and implied hierarchy of moral and ethical values. The definition reads "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it." The seven water use sustainability criteria are provided in a particular order. The first four are: "1. A basic water requirement will be guaranteed to all humans to maintain human health. 2. A basic water requirement will be guaranteed to restore and maintain the health of ecosystems. 3. Water quality will be maintained to meet certain minimum standards. These standards will vary depending on location and how the water is to be used. 4. Human actions will not impair the long-term renewability of freshwater stocks and flows." Originally published in Peter H. Gleick, et al., *California Water 2020: A Sustainable Vision* (Oakland, Calif.: Pacific Institute for Studies in Development, Environment, and Security, 1995); reprinted in Peter H. Gleick, *The World's Water 1998-1999: The Biennial Report on Freshwater Resources* (Washington, D.C.: Island Press, 1998), p. 18.

[63] For instance, in California, the Solar Shade Control Act requires that homeowners keep their trees from shading more than 10 percent of a neighbor's solar panels between 10 a.m. and 2 p.m. Recently, a Santa Clara County court ruled that a homeowner must cut down two redwood trees because they were blocking sunlight from reaching some of a neighbor's rooftop solar panels. Reported in "Sunlight Law Levels Trees," *The Washington Times*, Feb. 21, 2008, and "Trees Block Solar Panels, and a Feud Ends in Court," *The New York Times*, April 7, 2008.

On a larger scale, the private company Windforce proposed to the State of Maryland a project that required clearing 400 acres of forest on public land along Backbone Mountain in Garrett County to make room for 100 wind turbines. The Governor eventually blocked the project from proceeding. In both examples, to make way for a small-scale, intermittent and variable energy source that does not produce greenhouse gases, a natural greenhouse gas sequestration system, and habitat for terrestrial species, is to be, or would have been, eliminated. Reported in "Wind Power Proves Divisive: Energy Versus 'Green' Issues," *The Washington Times*, May 3, 2008.

In blocking the project, Governor Martin O'Malley said, "In the end, we could not justify the consequences that commercial wind would have on this land, this publicly held land. . . . . I also want to stress what this decision should not be misinterpreted to mean: this is not a rejection of wind power in the state of Maryland." On the other hand, Governor O'Malley supports the construction of a third emission-free nuclear reactor at Calvert Cliffs Nuclear Power Plant in Lusby, Maryland, that will double the electricity generating capacity of that site: "It is a huge moral challenge and it is a moral imperative given what massive new burning of coal will do to the planet if we don't develop better and cleaner technology, including safer and cleaner nuclear, which is . . . planned and talked about in terms of the third reactor." Reported in "'It Is a Moral Imperative': O'Malley Outlines Necessity for New Reactor in Lusby," *The Washington Post*, May 2, 2008.

To put the Windforce project in perspective, wind turbine electricity production capacity ranges between 0.7 MW and 2.5 MW. A wind farm of 100 turbines, then, would have a capacity of between 70 MW and 250 MW. By contrast, a nuclear power plant averaging 1,000 MW capacity can occupy a similar amount of land. Wind data is from American Wind Energy Association, "Wind Web Tutorial: Wind Energy Basics," "How many turbines does it take to make one megawatt (MW)?" at http://www.awea.org/faq/wwt_basics.html#How%20many%20turbines%20does%20it%20take%20to%20make%20one%20megawatt%20(MW) (August 7, 2008).

Compare this approach to greenhouse gas mitigation of cutting down trees to make way for renewables installations with that of the United Nations Environment Program, who, with the World Agroforestry Center (ICRAF), developed the "Billion Tree Campaign" worldwide tree planting initiative as a "response to the threat but also the opportunities of global warming, as well as to the wider sustainability challenges from water supplies to biodiversity loss." According to the UNEP, "Tree planting remains one of the most cost-effective ways to address climate change. Trees and forests play a vital role in regulating the climate since they absorb carbon dioxide—containing an estimated 50 percent more carbon than the atmosphere. Deforestation, in turn accounts for over 20 percent of the carbon dioxide humans generate, rivaling the emissions from other sources." UNEP announced that in eighteen months the program encouraged the planting of two billion trees around the world. See the UNEP news release, "Billion Tree Campaign to grow into the seven Billion Tree Campaign: Grassroots Initiative Hits Two Billion Mark—Target Raised to Over One Tree Per Person by Crucial 2009 Climate Convention Meeting," May 13, 2008.

Potential Ecosystem Impacts in Terms of Environmental Footprint and Life-Cycle Emissions

[64] With nuclear power plants, the physical process used to heat water to steam to turn the turbine generator to produce electricity—nuclear fission inside the reactor—does not produce air emissions. By contrast, coal, natural gas, or petroleum produce heat by burning the fuel—a chemical reaction—that does produce CO_2 and air pollutants.

[65] These calculations take into account the respective capacity factors of the energy sources—90 percent for nuclear, 20 percent for solar, and 30 percent for wind. Solar generation and land use data is from the DOE FAQ sheet, *Energy Efficiency and Renewable Energy.* Wind data is from the American Wind Energy Association, "Wind Web Tutorial: Wind Energy and the Environment" (formerly "The Most Frequently Asked Questions About Wind Energy"), "How much land is needed for a utility-scale wind plant?" at http://www.awea.org/faq/wwt_environment.html#How%20much%20water%20do%20wind%20turbines%20use%20compared%20with%20conventional%20power%20plants (July 21, 2008). For wind farms, the land physically occupied by turbines, access roads, and other equipment is 5 percent of the required land area, or, in the case of a 1,000 MW wind farm, 7,500 to 9,000 acres. The remaining land may be compatible with other uses, such as farming or ranching.

To consider a recent example of wind energy and land use, T. Boone Pickens company, Mesa Power LLP, announced plans to build a wind farm in the Texas panhandle over the next four years that will include 2,700 turbines over 200,000 acres. The 4,000 megawatt capacity facility, operating at 25 percent capacity factor, according to Mesa Power estimates, will have approximately the equivalent electricity production of one new 1,300 megawatt advanced nuclear power plant operating at 90 percent capacity factor. The NRC projects that such a plant will occupy just 640 acres, a fraction of a percent of the acreage for the wind farm. The Mesa Power wind project was reported in "Big Oil to Big Wind: Texas Veteran sets up $10bn Clean Energy Project," *The Guardian*, April 14, 2008. NRC data is from U.S. Nuclear Regulatory Commission, *Generic Environmental Statement for License Renewal of Nuclear Power Plants* (NUREG 1437 Vol. 1), 8. Alternatives to License Renewal, 8.3 Environmental Impacts of Alternative Energy Sources, 8.3.12 Advanced Light Water Reactor, at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v1/part08.html#_1_204.

[66] "A Demand for Land: The Land Area Needed for Renewable Energy is Greater Than for Traditional Energy-Production Sources—Land Use Intensity in 2030," *The Washington Post*, at http://www.washingtonpost.com/wp-dyn/content/graphic/2009/04/16/GR2009041600093.html (May 21, 2009).

In a paper currently in review at the journal *PLoS One*, The Nature Conservancy calculates that "under current law, the United States is due for at least 200,000 square kilometers [77,220 square miles] of new development for energy . . . about the size of Minnesota," most of that for renewables deployment.

Cognizant of this land use dilemma, environmental organizations, according to The Nature Conservancy, are working to "not just quantify the potential habitat impact of renewables, . . . but to find pragmatic solutions that will minimize the biodiversity impact of it's [sic: its] citing [sic: siting]." The Nature Conservancy proposes, as a viable approach to this reality, "Development by Design," which consists of three principles: "First you plan energy development, so you avoid hurting particularly sensitive species or habitats. Then, where development *will* occur, you minimize the spatial footprint of development, limiting environmental damage there as much as possible. Finally, whatever environmental damage does occur can be offset to some extent by encouraging those doing the development to pair it with conservation action to protect other parcels of land." In this way, environmental groups, according to The Nature Conservancy, "are trying to make sure renewable energy development happens the right way, rather than just fighting it because of its habitat effects." From The Nature Conservancy (Rob McDonald), "Energy Sprawl and U.S. Climate Policy," *Cool Green Science: The Conservation Blog of The Nature Conservancy*, April 16, 2009 at http://blog.nature.org/2009/04/energy-sprawl-and-us-climate-policy/.

See also "Renewable Energy's Environmental Paradox: Wind and Solar Projects May Carry Costs for Wildlife," *The Washington Post*, April 16, 2009.

California recently provided an example of the potential conflict between renewables development and environmental preservation of land and habitat, as reported in "Renewable Energy Sparks a Probe of a Modern-Day Land Rush," *The Los Angeles Times*, June 1, 2009. "A rush to stake claims for renewable energy projects in the California desert has triggered a federal investigation and prompted calls for reforms to prevent public lands from being exposed to private profiteering and environmental degradation. . . . The investigation comes amid debate over how best to control burgeoning renewable energy industries as they overwhelm the chronically understaffed and underfunded BLM [Bureau of Land Management] with an avalanche of applications."

"Environmentalists say the situation is a preeminent conservation issue . . . . Companies queuing up to develop solar farms say they want to replace imported oil and facilitate a national clean-energy economy. The environmental community also wants to ensure that scenic landscapes and ecosystems are not trampled in the process. . . . Hot spots of contention include 600,000 acres of former railroad lands between Mojave National Preserve and Joshua Tree National Park. The land was purchased with $40 million in private donations collected by the Wildlands Conservancy and $18 million in federal funds, then donated to the Department of Interior for conservation. Earlier this year, however, environmentalists were outraged to learn that the BLM was entertaining 19 applications for renewable energy projects on the donated lands."

[67] Franz H. Koch, International Energy Agency (IEA), *Hydropower-Internalized Costs and Externalized Benefits*, Implementing Agreement for Hydropower Technologies and Programs, Ottawa, Canada, 2000; Paul J. Meier, University of Wisconsin, Madison, *Life-Cycle Assessment of Electricity Generation Systems*

and Applications for Climate Change Policy Analysis, August 2002; W. Krewitt, et al., *ExternE—Externalities of Energy: National Implementation in Germany*, IER, Stuttgart, 1998; Central Research Institute of the Electric Power Industry (Japan), *Life-Cycle Analysis of Power Generation Systems*, March 1995; and AEA Technology-Environment, British Energy, *Environmental Product Declaration of Electricity from Torness Nuclear Power Station*, May 2005. See also the aggregating study, World Nuclear Association, *Energy Analysis of Power Systems*, March 2006.

[68] Nuclear energy was evaluated as lowest impact on wildlife in more categories than any other energy source other than wind power, including fuel transportation, facility construction, and facility decommissioning. Nuclear energy and wind were both evaluated as moderate impact in the categories of power generation and transmission and delivery. By contrast, coal, oil, and hydro were not evaluated as lowest impact in any category.

The results of this research have been reported twice. The final study is New York State Energy Research and Development Authority (Environmental Bioindicators Foundation, Inc., and Pandion Systems, Inc.), *Comparison of Reported Effects and Risks to Vertebrate Wildlife from Six Electricity Generation Types in the New York / New England Region*, NYSERDA Report 09-02, NYSERDA 9675, March 2009, page 3-1.

The research results had previously been reported in two presentations: Mark Watson, NYSERDA, *Environmental Impacts of Our Energy Choices*, at Community Wind Energy 2008, April 14, 2008; and Christian Newman, Pandion Systems, *To What Effect? A Comparison of Cumulative Wildlife Effects from Wind & Other Major Electricity Generation Types*, at WINDPOWER 2008, June 3, 2008. See also "Energy: Research Finds Wind Power Poses Least Risk to Wildlife," *Houston Chronicle*, June 4, 2008: "Wind and nuclear power plants have the lowest potential impact on wildlife among the major U.S. electricity sources, according to a report examining several decades of research."

The March 2009 results differ from the April and June 2008 results, with certain conventional energy source impacts increasing in degree and certain renewable energy source impacts decreasing in degree. The change in results, however, did not affect nuclear energy's relative standing as one of the two energy sources having the lowest potential impact on wildlife. Specifically, hydro power generation went from higher to moderate; nuclear resource extraction went from moderate to highest; natural gas fuel transportation went from lowest to moderate; coal decommissioning went from lowest to lower; oil facility construction went from lowest to lower, and, the only exception, oil power generation went from highest to higher.

In terms of energy source life-cycle bird fatalities, the NYSERDA study assessment that wind power and nuclear energy have the lowest wildlife impact is corroborated by Benjamin K. Sovacool (Energy Governance Program, Centre on Asia and Globlisation, Lee Kuan Yew School of Public Policy, National University of Singapore), "Contextualizing Avian Mortality: A Preliminary Appraisal of Bird and Bat Fatalities from Wind, Fossil-Fuel, and Nuclear Electricity," *Energy Policy*, 37 (2009), pp. 2241-2248. "Based on operating performance in the United States and Europe, . . . [t]he study estimates that wind farms and nuclear power stations are responsible each for between 0.3 and 0.4 fatalities per gigawatt-hour of electricity while fossil-fueled power stations are responsible for about 5.2 fatalities per GWh." (p. 2241).

The study goes on to say that "the estimate means that wind farms killed approximately 7,000 birds in the United States in 2006 but nuclear plants killed abort 327,000 and fossil-fueled power plants 14.5 million." (p. 2241) Since wind farms kill the same number of birds as nuclear plants per amount of electricity generated, nuclear energy bird fatalities totaled more than wind farm bird fatalities in 2006 simply because nuclear energy generated more electricity that wind power that year. If relative electricity generation were reversed in 2006, and wind produced 19.4 percent of the nation's electricity and nuclear only 0.7 percent, then wind farms would have killed 327,000 birds while nuclear energy 7,000. (U.S. electricity generation fuel shares from U.S. Energy Information Administration data as of April 2009.)

[69] NEI, *Powering the Future With Environmentally Sound Nuclear Energy: The Ecological Stewardship of the Nuclear Energy Industry*, 2003.

V. Climate Change and Drought Mitigation Through Nuclear Energy

Water Availability and Operation of Thermal and Hydro Power Plants

[70] According to 2007 data from Global Energy Decisions and U.S. Energy Information Administration.

[71] J.P. Morgan Securities Inc., Global Equity Research, *Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World*, April 1, 2008, p. 15, and Ceres and Pacific Institute (J. Morrison, M. Morikawa, M. Murphy, P. Schulte), *Water Scarcity and Climate Change: Growing Risks for Business and Investors*, Feb. 2009, p. 26, cite the shutdown in August 2007 of one of the three reactors at the Browns Ferry Nuclear Plant, operated by the Tennessee Valley Authority, due to water temperature, as evidence that the nuclear energy industry is vulnerable to water constraints.

According to Nuclear Regulatory Commission Region 2 Power Reactor Status Reports, Browns Ferry Unit 2 was at 0 percent power on August 17, August 18, August 19, and August 20. Units 1 and 3 were reduced to 85 percent power on August 16, and to 75 percent power on August 17. Unit 1 returned to 100 percent power on August 18, Unit 3 to 95 percent on August 19, and then to 100 percent on August 20. Unit 2 returned to 70 percent power on August 21.

To put this event in perspective, the average capacity factor for a nuclear power plant is 90 percent, which means that nuclear plants operate 90 percent of the time during the year. At 90 percent capacity factor, nuclear energy is the most reliable energy source for electricity generation in the United States. The next highest capacity factor, coal, at 60 percent, is considerably lower. Renewables are half, or less, of that.

The four days that Browns Ferry Unit 2 was not operating represent .01 percent of the potential 37,960 days that the 104 nuclear power plants in this country could be operating. These four days are accounted for as part of the 10 percent of the time that nuclear plants do not operate during the year.

[72] See U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Monitoring and Data Support Division, *Technical Guidance Manual for Performing Waste Load Allocations, Book VII: Permit Averaging Periods*, September 1984, and, for a general discussion, "Flow 101—Design Flows: Definitions and Methods," at http://www.epa.gov/waterscience/models/dflow/flow101.htm.

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[73] See the comprehensive report, United Nations Intergovernmental Panel on Climate Change, IPCC Working Group II, *Climate Change and Water*, IPCC Technical Paper VI (B.C. Bates, et. al.), June 2008.

[74] U.S. Climate Change Science Program, U.S. Global Change Research Program, National Assessment Synthesis Team (Jerry M. Melilo, et al.), *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, *Overview* and *Foundation*, especially, in the *Overview*, "Regions: Southeast" (p. 47 for modeling scenarios) and "Regions: West," and, in the *Foundation*, Chapter 5, "Southeast" (p. 138, 158-9 for modeling scenarios) and Chapter 8, "West"; U.S. Climate Change Science Program, Water Sector Assessment Team of the National Assessment of the Potential Consequence of Climate Variability and Change (Peter H. Gleick, et al.), *Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States*, September 2000; the National Academies, the National Academy of Science, the National Research Council, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*, February 2007; Cynthia Rosenzweig, et al., "Attributing Physical and Biological Impacts to Anthropogenic Climate Change," *Nature*, 453 (15 May 2008), pp. 353-7 [rev. 28 January 2008] (many of the authors of this study are the scientists who developed the United Nations Intergovernmental Panel on Climate Change study, *Synthesis Report of the IPCC Fourth Assessment Report*, November 2007); National Science and Technology Council, Committee on Environment and Natural Resources, *Scientific Assessment of the*

Effects of Global Climate Change on the United States, May 2008, especially Section V.4 Water Resources, pp. 148-9; Noah D. Hall, et al., "Climate Change and Freshwater Resources," *National Resources & Environment*, Vol. 22, No. 3, Winter 2008. The last paper notes, correctly, that "all of the traditional methods of getting more water require energy," but then, erroneously, states that "the largest carbon-neutral source of electricity in the United States presently is hydropower" (p. 34). In fact, the largest source of carbon-free electric power generation in the United States, during operations, is nuclear energy. From a life-cycle emissions perspective, neither hydropower nor nuclear energy, nor any renewable source of energy, for that matter, is carbon-neutral, but numerous life-cycle studies have found that nuclear energy is comparable in carbon emissions to all renewable sources.

[75] Eight of the largest municipal water agencies formed the Water Utility Climate Alliance to "improve research into the impacts of climate change on water utilities, develop strategies for adapting to climate change, and implement tactics to reduce their greenhouse gas emissions." Most, but not all, of the member water agencies are from the West: Denver Water, Metropolitan Water District of Southern California, New York City Department of Environmental Protection, Portland Water Bureau, San Diego County Water Authority, San Francisco Public Utilities Commission, Seattle Public Utilities, and Southern Nevada Water Authority. See Water Utility Climate Alliance, News Release, "Major U.S. Water Agencies Form New National Climate Alliance," February, 26, 2008; "Top Water Utilities to Study Climate Change," Reuters, February 26, 2008.

The formation of the alliance followed a call for the formation of a Western groundwater monitoring network by scientists at Scripps Institution of Oceanography in conjunction with the United States Geological Survey. See Scripps Institution of Oceanography, University of California at San Diego, "When the Well Runs Dry: Scripps Researchers Lead Call for Western Groundwater Monitoring Network," *Explorations*, February 2008

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[76] United Nations Intergovernmental Panel on Climate Change, Contribution of Working Group III to the Fourth Assessment Report, *Climate Change 2007: Mitigation* (Cambridge, England: Cambridge University Press, 2007), p. 269. This report also states, "Mitigation generally means significantly less coal, somewhat less natural gas and consistently more nuclear and biomass" (p. 222). "Even if the nuclear industry expands significantly, sufficient fuel is available for centuries" (p. 271).

[77] This statement by UNIDO is preceded by the following: "An interesting observation can be made by exploring the relationship between the carbon intensity of electricity production and the role of nuclear power in the electricity sector. In the group of twenty-five countries with the highest carbon intensity, only three countries have nuclear power in their electricity portfolios, each at a rather modest level. In the group of the next twenty-five countries, however, there are five countries with nuclear electricity, and in three of them, nuclear power provided around 30 percent of electricity in 2002." From United Nations, World Water Assessment Program, *Water: A Shared Responsibility—The United Nations World Water Development Report 2* (Paris: United Nations Educational, Scientific and Cultural Organization [UNESCO] and New York: Berghahn Books, 2006), Chapter 9, "Water and Energy," p. 323.

Likewise, the Nuclear Energy Agency of the Organization for Economic Cooperation and Development observes that "The United Nations Intergovernmental Panel on Climate Change concludes that CO_2 emissions, including those from electricity generation, must be halved to contain the consequences of climate change at a tolerable level. On a whole life cycle basis, nuclear energy is virtually carbon free. A combination of technologies is needed to meet this demanding target, but nuclear energy is the only carbon-mitigating technology with a proven track record on the scale required. Nuclear energy could make an increasing contribution to electricity generation, as well as to virtually carbon-free heat in the future; a potentially important development is global R&D aimed at producing hydrogen to fuel the transport sector, using nuclear heat." From NEA, OECD, *Nuclear Energy Outlook 2008*, p. 20.

[78] According to 2008 data from Global Energy Decisions and U.S. Energy Information Administration.

These numbers are the capacity factors for the various generation facilities. Capacity factor is a measure of operational efficiency. To be more precise, a capacity factor is the ratio of the total electricity that a facility produced during a year compared to the total potential electricity that would have been produced if the plant operated at 100 percent power during every hour of the year. It is essentially the percentage of electricity that a plant produced compared to the electricity that it could have produced operating constantly at peak output. Reasons for a generation facility not operating at 100 percent power during the year include designated use for peak demand periods only, scheduled refueling or maintenance outages, unscheduled shutdowns due to malfunctions, operating at reduced output or "power downs" for mechanical difficulties, and, in the case of renewables, intermittent performance of the energy source.

[79] According to the North American Electric Reliability Corporation (NERC), in the *2007 Long-Term Reliability Assessment, 2007-2016*, October 2007, "Wind and solar resource variability requires ancillary services such as voltage support, frequency control, increased base-load unit dispatch flexibility, and spinning reserves. In addition, many times their available generating capacity at time of peak is significantly less than their nameplate capacity varying with location. Those entities responsible for bulk power system reliability must take these unique characteristics and attributes into account to ensure wind and solar are reliably integrated into the system" (p. 13). "The intermittent nature of wind constitutes the major challenge to planning and operating bulk power systems with large amounts of wind generation. Wind generation's total capacity is not available at full output throughout the day and is unavailable most often mid-day when the peak internal demand occurs. . . . Therefore, to offset the impact of the intermittent nature of wind resources, higher planning/operation capacity margins are required to include supplemental generation (quick-start, gas-fired, or increasingly flexible and dispatchable base-load units) providing load and wind-following flexibility. Considerable bulk power system upgrades and design modifications are required to provide the ancillary services to deliver new wind energy and to support overall operational reliability, including load following, frequency response, voltage regulation, and other ancillary services; [and] increased reactive support accommodating remotely located wind resources" (p. 48). NERC ensures that the electric grid in North America is reliable. In 2007 the U.S. Federal Energy Regulatory Commission (FERC) granted NERC legal authority to enforce reliability standards with all U.S. owners, operators, and users of the bulk power system and made compliance with those standards mandatory. NERC also has authority over certain Canadian provinces.

A Canadian grid operator overseen by NERC, Alberta Electric System Operator, summarizes the challenges of integrating wind energy into the grid: "wind power has a number of attributes that make managing the reliability of the system significantly more challenging than managing the system with existing, predominantly thermal generation. These system challenges include: fast ramping wind conditions; limited flexibility of installed generation resources; limited interconnection capability; unpredictable wind (fuel source uncertainty); and output variability and low capacity factor (may be zero output at system peak). Essentially the energy supplied from wind generating facilities must be taken 'as delivered,' which requires the use of other dispatchable resources . . . to keep the supply and demand of electricity in balance." From Alberta Electric System Operator, "Reliability Considerations for Wind Power Integration in Alberta," *NERC News* (North American Electric Reliability Corporation), June 2008, pp. 7-8.

The U.S. Department of Energy, in *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, May 2008, actually makes the same point, though it characterizes the intermittency challenge by, at first, stating that wind energy is not actually being backed-up, and then proceeding to say that it needs to be:

"Wind energy has characteristics that differ from those of conventional energy sources. Wind is an *energy* resource, not a *capacity* resource. Capacity resources are those that can be available on demand, particularly to meet system peak loads. Because only a fraction of total wind capacity has a high probability of running consistently, wind generators have limited capacity value. Traditional planning methods, however, focus on reliability and capacity planning. Incorporating wind energy into power system planning and operation, then, will require new ways of thinking about energy resources" (p. 87).

"Thinking in terms of 'backing up' the wind is not appropriate because the wind capacity was installed to generate, low-emissions energy but not to meet load growth requirements. Wind power cannot replace the need for many 'capacity resources,' which are generators and dispatchable load that are available to be used when needed to meet peak load. If wind has some capacity value for reliability planning purposes, that should be viewed as a bonus, but not a necessity. Wind is used when it is available, and system reliability planning is then conducted with knowledge of the ELCC of the wind plant. Nevertheless, in some areas of the nation where access to generation and markets that spans wide regions has not developed, the wind integration process could be more challenging" (p. 88). (DOE defines ELCC, *effective load-carrying capability*, as "The amount of additional load that can be served at the target reliability level by adding a given amount of generation. For example, if adding 100 MW of wind could meet an increase of 20 MW of system load at the target reliability level, the turbine would have an ELCC of 20 MW, or a capacity value of 20% of its nameplate value" [p. 220]).

[80] Recently, the Electric Reliability Council of Texas (ERCOT) experienced the consequences of not anticipating and preparing adequately for a sudden 82 percent drop in wind generation. On February 26, 2008, ERCOT, noting a sudden drop in system frequency, had to implement emergency grid procedures and curtail load to avoid widespread outages when a sudden decrease in wind resulted in a large decline in wind electricity output. According to ERCOT, "the wind production dropped from over 1700 megawatts three hours before the event, down to 300 MW at the point the emergency procedures were activated." As ERCOT explained, "the frequency decline was caused by a combination of events including a drop in wind energy production at the same time the evening electricity load was increasing, accompanied by multiple power providers falling below their scheduled energy production. In addition, the drop in wind energy led to some system constraints in moving power from the generation in the north zone to load in the west zone, resulting in limitations of balancing energy availability." When the back-up natural gas plants failed to compensate for the power difference, ERCOT requested those industrial customers who had previously agreed to a reduction in electricity supply during emergency situations to reduce demand. This measure avoided any noticeable impact on residential customers. See the ERCOT News Release, "ERCOT Demand Response Program Helps Restore Frequency Following Tuesday Evening Grid Event," February 27, 2008; the *ERCOT Operations Report on the EECP Event of February 26, 2008*; and "Renewable Energy: Can a Growing Reliance on Fickle Winds Harm the Power Grid?," *ClimateWire*, June 20, 2008.

A few days after the event, Dottie Roark, an ERCOT official, noted that "In 2007, ERCOT issued 82 alerts telling market participants that responsive reserves were below the 2,500-MW requirement. Twenty-seven of those alerts were 'suspected to be strongly correlated to a drop in wind generation.'" Reported in "ERCOT Event Illustrates Wind Challenges to Grid Operation," *Electric Power Daily*, February 29, 2008.

The dilemma that wind energy's intermittency, and the need for fossil-fueled back-up, poses for regulated utilities—who have a fiduciary responsibility to provide reliable, economical, environmentally responsible electric power as determined by their public utilities commission—is explained by David Christian, an executive of Dominion, in testimony before the U.S. Senate Subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works, during a hearing entitled "Nuclear Regulatory Commission's Licensing and Relicensing Processes for Nuclear Plants," July 16, 2008: "I don't believe it to be true that renewables can supplant other baseload forms of electric power generation . . . . First, we'll take reliability. Everyone knows that wind only blows some of the time. We have an obligation to serve, and state regulation comes into play as well. Our customers demand electricity all the time, when requested. . . . Wind is typically anti-correlated to peak demand—that is to say, when you need it the most, it's there the least—which requires regulated companies who have an obligation to serve native load to simultaneously install gas-fired generation. And if you're going to install gas-fired generation to meet the requirements that we are under to serve that load, then you begin to get into capital inefficiencies" (at three hours into the hearing). As Jerry Taylor of the Cato Institute observes, "wind power is twice as expensive as natural gas-fired generation 'and probably more if you take out the subsidies,'" as quoted in "What is T. Boone Really up to? Legendary Investor Proposes Energy Plan that Leaves Critics in Doubt," *Electric Utility Weekly*, July 14, 2008.

In an overall assessment of the intermittent nature of wind energy electricity production and the need for back-up from other energy sources, Michael O'Sullivan, an executive from FPL Energy, said at the annual meeting of the American Wind Energy Association, *WINDPOWER 2008*, in Houston: "wind is a flawed product in the sense that it is intermittent, and is available only 30 to 40% of the time." As such, he said that wind energy is really "an energy displacement product." Reported in "DOE Goal of 20% from Wind Met with Skepticism from Industry," *Electric Power Daily*, June 3, 2008. FPL is the nation's largest wind energy utility, which will be operating 55 wind farms in 16 states totaling 6,300 MW of capacity by the end of 2008.

As an "energy displacement" product, wind substitutes, on an intermittent and variable basis, for energy sources used to power conventional electricity generation that is "dispatchable"—readily available for constant electricity production—during the period of time it is committed to operate, continually if for baseload, or as needed, if for peaking load.

[81] Taking into account the necessity for back-up energy, William Tucker analyzes the strategy of T. Boone Pickens' planned Mesa Energy LLP Texas wind farm, specifically, to use wind power to replace natural gas in electricity generation and use that natural gas to power more cars and buses: "not all generating capacity is interchangeable. Different power sources play different roles on the grid; so while some gas generators may see less use if wind power is added, the role of others will actually increase. . . . Bringing windmills online will probably mean cutting down production from some coal and combined-cycle natural-gas plants. Gas turbines, on the other hand, will become *more* important as wind is incorporated onto the grid. They will have to be on constant standby to raise and lower voltage with the wind's fluctuation," and "they do not have the efficiency of combined-cycle and are very expensive to operate." From "Tilting We Will Go? Windmills Are Not an Energy Policy," *National Review*, August 18, 2008, p. 3. Considering Pickens' energy strategy, Paul Driessen comes to a similar conclusion: "Since adequate wind is available only three to eight hours a day, we would also need more gas-fired generating plants that mostly run at idle, kicking in whenever the wind dies down." From "Blowing Hot Air on Wind Power," *The Washington Times*, August 4, 2008.

Presciently, in 2006, Matthew L. Wald reported William Bojorquez, Director of System Planning, ERCOT, noting that "power plants that run on coal or gas must 'be built along with every megawatt of wind capacity.'" Further, Frank P. Prager, Managing Director of Environmental Policy, Xcel Energy, which serves eight states from North Dakota to Texas, observed that "the higher the reliance on wind, the more an electricity grid would need to keep conventional generators on standby—generally low-efficiency plants that run on natural gas and can be started and stopped quickly. He said that in one of the states the company serves, Colorado, planners calculate that if wind machines reach 20 percent of total generating capacity, the cost of standby generators will reach $8 a megawatt-hour of wind. That is on top of a generating cost of $50 or $60 a megawatt-hour, after including a federal tax credit of $18 a megawatt-hour. By contrast, electricity from a new coal plant currently costs in the range of $33 to $41 a megawatt-hour, according to experts." From "The Energy Challenge: It's Free, Plentiful and Fickle," *The New York Times*, December 28, 2006. More recently, Jason Satsky, Director of the Energy Group, Credit Suisse, observed, of ERCOT's "not implementing a capacity market to spur investment in new baseload projects," that "'You're going to need a lot of other conventional types of generation to balance out all the wind that's being developed. Without a capacity market in place, it's a problem ERCOT, in particular, is going to have.'" Reported in "ERCOT Needs a Capacity Market: Executives," *Electric Power Daily*, April 6, 2009.

In fact, Edgar Gartner, in "Business Europe: Wind Fuels Gas," *The Wall Street Journal*, September 11, 2008, finds a correlation between the development of wind energy and the construction of new natural gas power plants in Europe: "Wind turbines generate electricity very irregularly, because the wind itself is inconsistent. Therefore wind turbines always need backup power from fossil fuels to keep the electricity grid in balance. Gas turbines are the best way to do this. They are able to respond quickly and push power production when wind generators stop suddenly. They can be turned on and off almost instantly, whereas traditional coal-fired plants need to be maintained in a very inefficient standby mode if they are to respond to large fluctuations in power demand.

"A proliferation of windmills, then, can become a windfall for gas sellers. Just look at the cases of Spain and Germany, Europe's leading producers of wind power. By the end of 2007 Spain had 14,700 MW of installed wind capacity, . . . producing 8.7 percent of the country's total power supplies. . . . Only last year, Spanish power providers added 6,400 MW of gas-turbine power capacity, taking the total installed capacity of gas turbines to 21,000 MW. Natural gas has become the main source of electricity generation in Spain. . . . In Germany, more than 20,000 wind turbines with a total capacity of 21,400 MW" are now operating. "Wind power's share of total electricity generation has risen in line with that of natural gas since 1990. Germany's gas consumption for power generation more than doubled between 1990 and 2007, and now represents 11.7 percent of the country's total power generation."

The Northwest Power and Conservation Council has initiated a project, codified in *The Northwest Wind Integration Plan*, March 2007, to integrate wind into the Pacific Northwest's electricity grid using primarily the region's abundant hydropower to balance—that is, provide "flexibility" for—wind's intermittent and variable output. The objective is for wind to "displace fossil fuel consumption." As the Plan states, however, "wind energy cannot provide reliable electric service on its own" (p. 9). While asserting that "wind energy is not fundamentally different from anything control area operators have to deal with when managing load variability," the Plan acknowledges that "one megawatt of new wind is significantly more variable and less predictable than one megawatt of new load" (p.19). In view of hydropower's ultimate limitations in providing sufficient grid flexibility, "existing and new combined-cycle gas-fired turbines (CCCTs) might also assist in meeting future flexibility requirements." In fact, "given that wind energy will make a very modest contribution to Northwest capacity needs, and the difficulty in siting new coal facilities, it is likely that gas turbines will play a major role in the future of the Northwest" (p. D-1).

[82] As the United Nations Intergovernmental Panel on Climate Change observes, "No one sector or technology can address the entire mitigation challenge. All assessed sectors contribute to the total." From UN IPCC, Contribution of Working Group III to the Fourth Assessment Report, *Climate Change 2007: Mitigation* (Cambridge, England: Cambridge University Press, 2007), p. 12.

Likewise, the Progressive Policy Institute, under the subtitle "Leave No Fuel Behind," states: "When it comes to clean energy, silver bullets are few and far between. The business of making solar panels, particularly in China, relies on a slew of toxic chemicals. The economic and environmental downsides of biofuels made from food products are coming to light. Renewable sources, while extraordinarily promising, are simply not yet capable of supplying energy in remotely the same quantities as coal, which presently provides 50 percent of U.S. electricity. Nuclear power generates electricity with no CO_2 emissions, but any expansion of this industry begs the question of where to store spent fuel. The truth of the matter is that cutting greenhouse gases by more than one-half by mid-century will require us to harness all of these energy sources." From the PPI Policy Report, *Finding Common Ground on Cap and Trade: Three Design Principles*, May 2008, p. 5.

[83] International Energy Agency, "450 Stabilization Scenario," World Energy Outlook, 2007; Pacific Northwest National Laboratory, Joint Global Change Research Institute, Global Energy Technology Strategy Program, Global Energy Technology Strategy: Addressing Climate Change—Phase 2 Findings, May 2007; McKinsey & Company, U.S. Greenhouse Gas Abatement Mapping Initiative, Executive Report, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?"*, December 2007; Cambridge Energy Research Associates, *The Great Divide: The Future of Clean Energy*, 2008; U.S. Department of Energy, Energy Information Administration, National Energy Modeling System (NEMS), *Energy Market and Economic Impacts of a Proposal to Reduce Greenhouse Gas Intensity with a Cap and Trade System* (SR/OIAF/2007-01), January 2007; *Energy Market Impacts of a Clean Energy Portfolio Standard: Follow-Up* (SR/OIAF/2007-02), January 2007; *Energy Market and Economic Impacts of S. 280, the Climate Stewardship and Innovation Act of 2007* (SR/OIAF/2007-04), July 2007; *Supplement to: Energy Market and Economic Impacts of S. 280, the Climate Stewardship and Innovation Act of 2007* (SR/OIAF/2007-

04), July 2007; *Energy Market and Economic Impacts of S. 1766, the Low Carbon Economy Act of 2007* (SR/OIAF/2007-06), January 2008; Electric Power Research Institute, EPRI Energy Technology Assessment Center, PRISM-MERGE Analysis, "The Power to Reduce CO_2 Emissions: The Full Portfolio," EPRI 2007 Summer Seminar Discussion Paper, August 2007; Princeton University, Princeton Environmental Institute, Carbon Mitigation Initiative: Robert Socolow, Roberta Hotinski, Jeffery B. Greenblatt, and Stephen Pacala, "Solving the Climate Problem: Technologies Available to Curb CO_2 Emissions," *Environment*, Vol. 46, No. 10 (Dec. 2004), pp. 8-19, and S. Pacala and R. Socolow "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, Vo. 305 (13 Aug. 2004), pp. 969-72; World Business Council for Sustainable Development, CO_2 Emissions Reduction Program, *Pathways to 2050: Energy and Climate Change*, November 2005, and *Facts and Trends to 2050: Energy and Climate Change*, August 2004. According to the Council on Foreign Relations, "nuclear power plays a strong role in almost every careful assessment of a world with deeply reduced greenhouse gas emissions"; from the report, *Confronting Climate Change: A Strategy for U.S. Foreign Policy* (2008), pp. 51-2.

[84] Recent developments regarding plug-in hybrid vehicles include a study that finds the widespread adoption of plug-in hybrids can reduce greenhouse gas emissions from vehicles by more than 450 million metric tons annually by 2050, the equivalent of removing 82.5 million conventional passenger cars from the road, as reported in the EPRI/Natural Resources Defense Council News Release, "EPRI-NRDC Report Finds Environmental Benefits of Deploying PHEVS: Analysis Cites Curb in Greenhouse Gas Emissions, Potential for Improved Air Quality," July 19, 2007, and the related news articles, "EPRI, NRDC Find Plug-in Hybrids Reduce GHG," *Electric Power Daily*, July 20, 2007, and "Plug-In Hybrids Can Deliver Big Greenhouse Cuts—Study," *Energy Daily*, July 23, 2007; the news article "Plug-In Cars Could Actually Increase Air Pollution," *USA Today*, February 26, 2008, notes the consequences if the electricity for plug-in hybrids is not supplied by emission-free energy sources; the news article "Plug-In Hybrids Could Require 160 New Plants," *Electric Power Daily*, March 13, 2008, points out the electricity generation requirements if plug-in hybrids are widely deployed and users recharge batteries at 5:00 p.m. as opposed to overnight.

In June 2008, the U.S. Department of Energy announced that it will provide funding of up to $30 million for three cost-shared plug-in hybrid vehicle demonstration and development projects intended to address barriers to achieving DOE's goal of making the vehicles cost-competitive by 2014 and ready for commercial production by 2016. See the DOE News Release, "DOE Announces $30 Million for Plug-In Hybrid Electric Vehicle Projects," June 12, 2008. In October 2008, DOE awarded Ford Motor Company a $10 million grant toward the total project cost of $20 million for the continued development of a demonstration fleet of 20 plug-in hybrid electric vehicles. Ford's partners in this project include the nuclear utilities Southern California Edison and DTE, the battery manufacturer Johnson Controls/Saft, and the Electric Power Research Institute (EPRI). See the Ford Motor Company News Release, "Ford Awarded $10 Million Energy Department Grant to Accelerate Development of Plug-In Vehicles," October 6, 2008.

As an indication of the increasing importance of electricity production to the transportation sector as a result of plug-in hybrids, two electric utilities that operate nuclear power plants, Southern California Edison and DTE Energy, have joined the U.S. Department of Energy's program, the FreedomCAR and Fuel Partnership, to help with research and development, and market introduction and acceptance, of alternative fuel vehicles. Previously comprised of U.S. automobile manufacturers and petroleum producers, the program is focusing on plug-in hybrids as well as hydrogen fuel-cell vehicles. The utilities will work with DOE on the vehicle charging interface with the electric power grid, the long-term impact of a national plug-in car fleet on electricity distribution, and the potential for "vehicle-to-grid" use of the cars, whereby the cars could serve as a distributed battery back-up system to the grid. See the DOE News Release, "U.S. Department of Energy Announces Two Utility Companies Join FreedomCAR and Fuel Partnership," June 20, 2008, and "Autos: Plug-In Promise Draws Utilities Into Federal Fuels Program," *Greenwire*, June 20, 2008.

As an additional development signaling the importance of electricity production to the transportation sector, General Motors is collaborating with 34 electric power utilities and EPRI on future plug-in vehicle codes and standards as well as grid capability. The collaboration includes nuclear utilities American Electric Power, Duke, Dominion, DTE Energy, Pacific Gas & Electric, Progress Energy, Public Service Electric & Gas, Southern California Edison, and Southern Company. See General Motors, News Release, "General Motors and Electric Utility Industry Launch Major Collaboration to Commercialize Plug-In Vehicles," July 22, 2008; "GM Teams With Dozens of Utilities on Plug-In Cars," *The Wall Street Journal*, July 22, 2008; and "GM, Utilities to Integrate Plug-In Vehicles with Grid," *Energy Daily*, July 22, 2008.

The future use of electricity as a transportation fuel to reduce fossil-fuel greenhouse gas emissions may be even more extensive. According to its 2008 mid-term business plan, Nissan will introduce a pure electric vehicle in the United States and Japan in 2010, and then mass-market electric vehicles to consumers globally in 2012. "Nissan projects that around one-third of all the cars it sells by 2050 could be hybrids or plug-in hybrids, over one quarter would be all-electric or powered by fuel cells, and the remainder powered by internal combustion. If this mix is representative of the global transport fleet at that time, electricity generation would have to expand by around 45% to accommodate the fuel switch." From "Energy and Environment: Cars to Drive Growth in Electricity," *World Nuclear News*, May 29, 2008.

[85] Hydrogen vehicles and the efficient, cost-effective production of hydrogen from an emission-free energy source such as nuclear energy have attracted intense interest during this decade. In the Energy Policy Act of 2005, the U.S. Congress established a target date of September 30, 2021, for the U.S. Department of Energy to complete construction and begin operation of a prototype Next Generation Nuclear Plant with hydrogen production or process heat facilities, or for the DOE to submit to Congress a report establishing an alternative date. The Next Generation Nuclear Plant project—initially sponsored by the DOE and its Idaho National Laboratory and later evolving into a public/private partnership—defines the NGNP as a very high-temperature, gas-cooled nuclear reactor capable of producing electricity, hydrogen through a cogeneration process, and high-temperature process heat currently produced by fossil fuels for commercial applications.

For a technical description of the NGNP project and reactor, see U.S. Department of Energy, Idaho National Engineering and Environmental Laboratory, *Next Generation Nuclear Plant—Design Methods Development and Validation Research and Development Program Plan*, September 2004. The NGNP industry alliance has produced the following: Areva, B&W, Entergy, General Atomics, PBMR, Shaw, Westinghouse, et al., *Response to U.S. Department of Energy Expression of Interest Request Regarding the NGNP*; and a white paper, "Next Generation Nuclear Plant: Building the Industry Alliance," January 2008.

In August 2008, the DOE and the U.S. Nuclear Regulatory Commission submitted to Congress the *Next Generation Nuclear Plant Licensing Strategy: A Report to Congress*, which describes the licensing approach, analytical tools, research and development activities, and estimated resources required to license the NGNP design by 2017 and begin operation of the prototype by 2021. See the report and U.S. Department of Energy, News Release, "DOE, NRC Issue Licensing Roadmap for Next Generation Nuclear Plant," August 15, 2008.

However promising this technology and the support it receives, demonstration and commercial deployment of the cogeneration reactor are perhaps decades away ("NGNP Development Cost Could Exceed $4 Billion," *Nucleonics Week*, January 3, 2008, and "DOE Estimates Cost of Next-Generation Nuclear," *Electric Power Daily*, December 14, 2007). Mass-market production of fuel cell vehicles may also take over a decade to begin. Consequently, some automobile manufacturers believe that plug-in hybrids are the more viable near-term technology for the transportation sector to reduce greenhouse gas emissions ("GM. Toyota Doubtful on Fuel Cells' Mass Use," *The Wall Street Journal*, March 5, 2008).

Nonetheless, a recent study by the National Research Council concludes that currently high hydrogen vehicle costs and the lack of a broad hydrogen distribution infrastructure can be overcome with continued government support for research and development and firm commitments from the automobile industry. The study projects that the total cost of hydrogen vehicles and fuel could be competitive with conventional vehicles by 2023. See The National Academies, National Research Council, *Transitions to alternative Transportation Technologies: A Focus on Hydrogen*, 2008.

Already, Honda has started production of its FCX Clarity, the world's first hydrogen-powered fuel-cell vehicle intended for mass production. Honda will manufacture 200 units through 2011, but will increase production volumes as hydrogen filling stations become more prevalent. Reported in "Latest Honda Runs on Hydrogen, Not Petroleum," *The New York Times*, June 17, 2008.

Also, in August 2008, nine automobile manufacturers teamed with the U.S. Department of Transportation, the U.S Department of Energy, the California Fuel Cell Partnership, and the National Hydrogen Association on the Hydrogen Road Tour, a nationwide show to demonstrate that hydrogen vehicle and fueling technologies are approaching commercial viability. The companies included BMW, Daimler, Ford, General Motors, Honda, Hyundai-Kia, Nissan, Toyota, and Volkswagen. The fleet of hydrogen automobiles, joined by hydrogen transit buses along the way, made 31 stops in 18 states, from Maine to California. Air Products and Chemicals, Inc. and Linde provided hydrogen fuel and mobile refueling stations. See U.S. Department of Transportation, News Release, "America Gets New Glimpse of Hydrogen Powered Future During Historic Two Week Road Tour Across the United States," August 11, 2008; and *Greenwire*, "Autos: U.S., Automakers Reaffirm Commitment to Hydrogen," August 15, 2008.

Nuclear Energy and Drought Mitigation

[no notes for this section]

Nuclear Energy and Desalination

[86] Most of the planet's water is, in fact, saline—about 97 percent of the Earth's water is ocean. Most of the remaining 3 percent, which is freshwater, is not easily accessible or geographically convenient—68.7 percent is frozen, in ice caps and glaciers, 30 percent is groundwater, and only 0.3 percent is surface water. From National Science and Technology Council, Committee on Environment and Natural Resources, *Scientific Assessment of the Effects of Global Climate Change on the United States*, May 2008, p. 145.

[87] United Nations Intergovernmental Panel on Climate Change, Contribution of Working Group II to the Fourth Assessment Report, *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Cambridge, England: Cambridge University Press, 2007), p. 181.

[88] United Nations, World Water Assessment Program, *Water: A Shared Responsibility—The United Nations World Water Development Report 2* (Paris: United Nations Educational, Scientific and Cultural Organization [UNESCO] and New York: Berghahn Books, 2006), Chapter 9, "Water and Energy," p. 311. The quotation continues, ". . . but these need to be balanced against the well-known drawbacks of high initial investment costs and the disposal of spent nuclear fuel."

In our carbon constrained world, nuclear energy's life-cycle costs are competitive with natural gas and coal facilities, even in light of nuclear energy's relatively higher investment costs, given its relatively lower operating costs and a non-emitting environmental footprint. See, for instance, Florida Power & Light Company, *Petition to Determine Need for Turkey Point Nuclear Units 6 and 7*, Florida Public Service Commission Docket No. 070650, October 16, 2007, p. 11: "FPL's analysis shows that . . . the addition of new nuclear capacity is economically superior versus the corresponding addition of new [combine cycle] units required to provide the same power output . . . . In fact, in the only scenario in which nuclear is not clearly superior, the natural gas prices are significantly lower than they are today and there are zero future economic compliance costs for CO_2 emissions." Also, see the U.S. Energy Information Administration's modeling of *Senators Joseph Lieberman and John McCain's Climate Stewardship and Innovation Act of 2007* (S. 2180) at http://www.eia.doe.gov/oiaf/servicerpt/biv/fig2.html, which determined that the levelized costs of nuclear and biomass were the cheapest of all technologies once the price of carbon was above $10/ton.

Regarding used nuclear fuel, international scientific consensus has consistently found that deep geologic disposal is the most effective method of protecting public health and the environment. The volume of material requiring disposal is relatively small. For instance, all the used nuclear fuel produced by the U.S. nuclear energy industry in 40 years of operation—more than 50,000 metric tons—would, if stacked end to end, cover only an area the size of a football field to a depth of less than 10 yards. Also, used nuclear fuel can be recycled, and has been, for decades, in France, the United Kingdom, Russia, and Japan. Recycling introduces economic efficiencies, including recovering the considerable energy remaining in the used fuel and reducing the volume of material requiring disposal.

[89] Gamini Seneviratne, "Research Projects Show Nuclear Desalination Economical," *Nuclear News*, April 2007, p. 60.

[90] International Atomic Energy Agency, *Examining the Economics of Seawater Desalination Using the DEEP Code*, IAEA-TECDOC-1186, November 2000, p. 77.

[91] International Atomic Energy Agency, *Market Potential for Non-Electric Applications of Nuclear Energy*, Technical Reports Series No. 410, 2002, p. 6

[92] International Atomic Energy Agency, *Status of Nuclear Desalination in IAEA Member States*, IAEA-TECDOC-1524, January 2007, p. 2. The quotation continues, ". . . as long as gas prices remain higher than about 21 $/bbl, if nuclear can achieve capital costs at or below the 1500 $/kWh range." As of mid-2008, natural gas prices are nearly double this figure at the Henry Hub, according to data from the Intercontinental Exchange. Since 2005, capital costs have increased 69 percent, according to Cambridge Energy Research Associates IHS CERA Power Capital Costs Index, but for all generation facilities, even those that do not provide the added advantage of not emitting greenhouse gases as the world moves toward the economic impact of more stringent global and national carbon emissions reduction regimes. Specifically, according to the IHS CERA Index, since 2000, capital costs for coal plants have increased 78 percent, natural gas plants 92 percent, and nuclear plants 130 percent. See IHS, News Release, "Construction Costs for New Power Plants Continue to Escalate: IHS CERA Power Capital Costs Index," May 27, 2008.

[93] The National Academies, National Research Council, *Desalination: A National Perspective*, 2008, pp. 17-18. One example of this trend is the California Coastal Commission's approval of the Carlsbad desalination plant, which will be the largest in the Western hemisphere. Construction is expected to begin in 2009, with the plant operational in 2011. The $300 million project will produce 10 percent of San Diego's water supply from the Pacific Ocean, enough drinking water for 300,000 people. More than a dozen other desalination plants are under consideration in the state. Reported in "Panel Approves Plan for Desalination Plant," *San Francisco Chronicle*, August 7, 2008.

[94] The National Academies, National Research Council, *Desalination: A National Perspective*, 2008, p. 1.

[95] Peter H. Gleick, *The World's Water 2006-2007: The Biennial Report on Freshwater Resources* (Washington, D.C.: Island Press, 2006), p. 69.

[96] The National Academies, National Research Council, *Desalination: A National Perspective*, 2008, p. 2.

[97] The National Academies, National Research Council, *Desalination: A National Perspective*, 2008, pp. 116-7.

VI. Cooling Technologies and Environmental Law: Ecosystem Diversity and Water Management

New Plant Cooling Systems: Clean Water Act Section 316(b) Phase I

[98] The full text of the Federal Water Pollution Control Act is conveniently available online from the California Water Resources Control Board at http://www.waterboards.ca.gov/water_laws/docs/fedwaterpollutioncontrolact.pdf.

[99] U.S. Environmental Protection Agency, *Water* [*The Challenge of the Environment: A Primer on EPA's Statutory Authority*] at http://www.waterboards.ca.gov/water_laws/docs/fedwaterpollutioncontrolact.pdf, accessible from *Federal Water Pollution Control Act Amendments of 1972: Documents* at http://www.epa.gov/history/topics/fwpca/.

[100] The location of Section 316 in the *United States Code* is 33 U.S.C. 1326.

[101] In the *Federal Register*, 41 Fed. Reg. 17,387 (1976)

[102] According to the Phase I regulation, companies building new thermoelectric power plants have a choice of two alternatives. Under Track 1, which establishes both "national intake capacity and velocity requirements," plant developers "must reduce your intake flow, at a minimum, to a level commensurate with that which can be attained by a closed-cycle recirculating cooling water system." Plant developers must also observe a specified "maximum through-screen design intake velocity." Track 2 allows plant developers to "demonstrate that the technologies employed will reduce the level of adverse environmental impact from your cooling water intake structures to a comparable level to that which you would achieve were you to implement the requirements" for intake capacity and velocity of Track 1. See U.S. Environmental Protection Agency, *National Pollutant Discharge Elimination System: Regulations Addressing Cooling Water Intake Structures for New Facilities*, *Federal Register*, 66 Fed. Reg. 65,256, 65,340-1 (2001) and *Code of Federal Regulations*, 40 C.F.R. Parts 9, 122, 123, 124, and 125.

[103] A cooling pond of the industrial water impoundment type must be quite substantial in size to serve a power plant's cooling needs. Even if the purchase expense could be accommodated, the necessary land may not even be available, or the available land may not be of the appropriate configuration. In addition, the construction cost would be significantly higher than a wet cooling tower because of potential excavations costs, and because environmental regulations usually require that the entire bottom of the pond be covered with a water impermeable layer, either impermeable soil or artificial surface. Finally, the resulting operating cost of the plant is higher because a cooling pond is less efficient than a wet cooling tower—radiant solar heating increases the waterbody's temperature, in addition to the incoming cooling system water's process thermal heating. By comparison, solar heating of a cooling tower is substantially less.

Local Ecosystem Preservation and Site-Specific Solutions

[104] See, in the *Federal Register*, 44 Fed. Reg. 32,854, 32,956 (1979); and in the *Code of Federal Regulations*, 40 C.F.R. 401.14.

[105] U.S. Environmental Protection Agency, Office of Water Enforcement, Permits Division, *{Draft} Guidance for Evaluating the Adverse Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500*, May 1, 1977.

[106] The State of Nebraska indicates the range of individual site-specific ecosystem conditions that are relevant to local environmental preservation in the selection of a cooling system technology, citing actual situations, in a document related to Phase II: "For example, in some waterbodies, the major fish species that would incur impingement and entrainment mortality is invasive. In those waterbodies, the state's

best means of maintaining the native aquatic organisms at that site is by writing permits that prescribe once-through cooling technologies. Similarly, in states containing waterbodies with essentially minimal aquatic life, the Second Circuit's decision would require technology to protect aquatic organisms that are not present. Proper maintenance of a waterbody may also result in an NPDES permit that requires thermal discharges to regulate the waterbody temperature. For instance, thermal discharges from electric generating facilities in Florida have been critical to the wellbeing and survival of the manatee populations, where agricultural irrigation wells and diversion channels disrupted the way that springs had previously moderated river-water temperature. Finally, in western and drought-stricken areas, where water supplies are scarce, states must be allowed to consider technologies that ensure that the minimal water necessary is consumed [references omitted]." From State of Nebraska, Amicus Curiae Brief on a Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Riverkeeper, Inc., et al.*, July 21, 2008, pp. [4-5].

The United Nations Intergovernmental Panel on Climate Change specifically recommends that any potential climate change mitigation measure be evaluated according to site-specific ecosystem conditions with relation to water supply impacts: "Implementing important mitigation options such as afforestation, hydropower and bio-fuels may have positive and negative impacts on freshwater resources, depending on site-specific situations. Therefore, site-specific joint evaluation and optimization of (the effectiveness of) mitigation measures and water-related impacts are needed." From IPCC, IPCC Working Group II, *Climate Change and Water*, IPCC Technical Paper VI (B.C. Bates, et. al.), June 2008, p. 130.

[107] U.S. Environmental Protection Agency, *National Pollutant Discharge Elimination System: Regulations addressing Cooling Water Intake Structures for New Facilities*, *Federal Register*, 66 Fed. Reg. 65,256 (2001). For instance, even at the waterbody level, the Phase I regulation is attempting to focus on aquatic life with insufficient available information: "The potential cumulative effects of multiple intakes located within a specific waterbody or along a coastal segment are largely unknown" (65,263). In addition, the Phase I regulation confuses habitat impairment that threatens the entire species with impingement and entrainment that affect, relative to total population, only a very small number of individuals: "EPA notes that the top four leading causes of waterbody impairment (siltation, nutrients, bacteria, and metals) affect the aquatic life uses of a waterbody. The Agency believes that cooling water intakes potentially contribute additional stress to waters already showing aquatic life impairment from other sources such as industrial discharge and urban stormwater" (65,263). Oddly, the regulation prefers wet cooling towers over once-through systems, when the discharge water of the latter potentially contains less impurity concentrations.

Existing Plant Cooling Systems: Clean Water Act Section 316(b) Phase II

[108] Phase III, not relevant here, addresses smaller existing power plants, new offshore and coastal oil and gas facilities, and existing manufacturing and industrial facilities.

[109] Facility capacity utilization rate is a measure of electricity production used to calculate the water volume that a power plant is actually withdrawing from the waterbody: "Capacity utilization rate means the ratio between the average annual net generation of power by the facility (in MWh) and the total net capability of the facility to generate power (in MW) multiplied by the number of hours during a year." From *Code of Federal Regulations*, 40 C.F.R. 125.93.

[110] U.S. Environmental Protection Agency, *National Pollution Discharge System—Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities*, *Federal Register*, 69 Fed. Reg. 41,590, 41,598-9 (2004), and *Code of Federal Regulations*, 40 C.F.R. 125.94 (b).

[111] U.S. Environmental Protection Agency, *National Pollution Discharge System—Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities*, *Federal Register*, 69 Fed. Reg. 41,685-7 (2004), and *Code of Federal Regulations*, 40 C.F.R. 125.94 (a)(1)-(5).

[112] Environmental groups and several Northeastern states, four power companies, a State energy association, and the Utility Water Act Group all sought review, on different grounds.

[113] This summary is from Utility Water Act Group, Petition of Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Riverkeeper, Inc., et al*., November 2, 2007, p. 12.

[114] The court stated that its "concern with the EPA's determination with respect to section 316(b) is further deepened by the Agency's rejection of closed-cycle cooling and selection of a suite of technologies as the basis for BTA"; the court expressed doubt as to whether a suite of technologies could "approach[] the performance of closed-cycle cooling"; and is remanding "for clarification . . . and possibly for a new determination of BTA." Quotations from Nuclear Energy Institute, Brief as Amicus Curiae on Petitions for a Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Riverkeeper, Inc., et al*., December 2007, pp. 9-10.

[115] In addition to the Utility Water Act Group Petition and the NEI Brief, other documents consulted on the Phase II regulation and the Second Circuit's decision include PSEG Fossil LLC and PSEG Nuclear LLC, Petition of Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Riverkeeper, Inc., et al*., November 2, 2007; Entergy Corporation, Petition of Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Environmental Protection Agency, et al*., November 2, 2007; Federal Respondents, Brief on Petition of Writ of Certiorari to the United States Court of Appeals for the Second Circuit, The Supreme Court of the United States, *Riverkeeper, Inc., et al*., February 2008; and Entergy Corp. and PSEG Fossil LLC and PSEG Nuclear LLC, Brief for Petitioners, The Supreme Court of the United States, *Environmental Protection Agency, et al.* and *Riverkeeper, Inc., et al*., July 14, 2008. See also "Supreme Court Mulls Taking Power Plant Cooling Water Case," *Electric Power Daily*, April 11, 2008; "Court Steps Into Utilities Case," Associated Press, April 14, 2008; U.S. Supreme Court to Hear Utility Lawsuit Against EPA Rule," *Nucleonics Week*, April 17, 2008.

[116] The Supreme Court of the United States, Opinion of the Court, *Entergy Corporation v. Riverkeeper, Inc. et al*., April 1, 2009, pp. 16, 14.

Ecosystem Conservation and Comprehensive Environmental Management

[117] One notable exception is when EPA decided not to adopt closed-cycle cooling systems as the best available technology. EPA notes that there would be an "energy penalty" incurred if a wet cooling tower replaced a once-through system, as the former consumes more energy to operate than the latter. This loss of energy production to the national grid would have to be provided by other generating facilities, leading to "other negative consequences," specifically, "non-water quality environmental impacts," most notably, in terms of clean air: "Because this deficit is predicted to occur during the summer months (when energy demand is highest), the net effect would be more consumption of fossil fuel, which in turn increases the emission of sulfur dioxide, NOx, particulate matter, mercury and carbon dioxide." From U.S. Environmental Protection Agency, *National Pollution Discharge System—Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities*, *Federal Register*, 69 Fed. Reg. 41,605 (2004).

Realistically, retrofitting existing power plants currently using once-through cooling systems with cooling towers may not be possible. The land to build a cooling tower may not be available, and if it were, an environmental impact is incurred in terms of land use and available habitat for wildlife. Further, regulated utilities, observing their fiduciary obligation, built condensers only as large as necessary—the lower the water temperature, the smaller the condenser. Since cooling towers are less efficient at providing cool water, condensers need to be larger to accommodate them. Thus, plants built for lower water temperatures have condensers too small for cooling towers, and to replace a condenser would be prohibitively expensive. Finally, regarding environmental protection, the EPA and the states have already approved existing plants' once-through cooling systems for meeting environmental regulations at the time they were built.

VII. Climate Change Adaptation: Future Power Plant Cooling Technologies

Existing Plants: Recycling Degraded Water

[118] The Martin Drake Power Plant, a coal-fired power plant in Colorado Springs, Colorado, also uses wastewater from a local treatment facility. See DOE/NETL (Thomas J. Feeley, III, et al.), *Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program*, 2006, p. [3].

[119] APS, "About APS," "Power Plants," at http://www.aps.com/general_info/AboutAPS_18.html (July 30, 2008), and PNM, "Palo Verde Nuclear Generating Station," at http://www.pnm.com/systems/pv.htm (July 30, 2008).

[120] U.S. Energy Information Administration, "100 Largest Electric Plant Net Generation, 2006" at http://www.eia.doe.gov/neic/rankings/rankbyplantgeneration.htm and "100 Largest Electric Plants" at http://www.eia.doe.gov/neic/rankings/plantsbycapacity.htm. Grand Coulee Dam is the largest U.S. power plant by capacity, but the seventh largest by electricity production.

[121] U.S. Energy Information Administration, "U.S. Nuclear Plants," Palo Verde," at http://www.eia.doe.gov/cneaf/nuclear/page/at_a_glance/reactors/palo_verde.html (July 31, 2008).

[122] Wastewater comes from the Tolleson Wastewater Treatment facility in Tolleson, Arizona, and the Phoenix Wastewater Treatment facility, which serves, in addition to Phoenix, Scottsdale, Mesa, Tempe, and Glendale. Palo Verde Nuclear Generating Station, *Water Reclamation Facility*, and information provided by APS, July 2008.

[123] Information on Palo Verde's cooling systems, Water Reclamation Facility, reservoirs, and cooling ponds is from Palo Verde Nuclear Generating Station, *Water Reclamation Facility*, supplemented and updated by information provided by APS, July 2008.

[124] U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (J.D. Byars, T.P. Mucho, R. L. Zick), *Discharge Water Handling and Treatment: Problems and Solutions at a Large Pittsburgh Seam Coal Mine*, NIOSHTIC-2 No. 20021270, Feb. 2001, p. 1.

[125] "The total volume of water discharged annually from active and abandoned mines in the anthracite region by pumping and drainage tunnels exceeds 200 billion gallons." From U.S. Department of the Interior, U.S. Bureau of Mines (S. H. Ash, et al.), *Water Pools in Pennsylvania Anthracite Mines*, Technical Paper 727, U.S. Government Printing Office, 1949. The authors cite George A. Roos, "Mine Drainage in the Anthracite Region," *Min. Cong. Jour.*, Vol. 31, No. 6, June 1945, pp. 32-34, 50.

[126] Six small fluidized bed combustion coal plants in the Anthracite region of Pennsylvania have been using mine pool water for cooling for about two decades. Their respective capacities range from 31 MW to 100 MW. Five of the six plants operate close-cycle cooling systems, while the sixth uses dry cooling supplemented by an auxiliary wet cooling tower. See Argonne National Laboratory, Environmental Science Division J.A. Veil and M.G. Puder), *Update on Use of Mine Pool Water for Power Generation*, ANL/EVS/R-06/6, September 2006, pp. 1, 3, 5.

[127] Exelon, Plant Fact Sheet, *Limerick Generating Station*, and "Power Generation," "Limerick Generating Station," at http://www.exeloncorp.com/ourcompanies/powergen/nuclear/limerick_generating_station.htm (August 4, 2008).

[128] Exelon, and Normandeau Associates, Inc. and URS Corporation, *2007 Interim Report for the Limerick Generating Station Water Supply Modification Demonstration Project and Wadesville Mine Pool Withdrawal and Streamflow Augmentation Demonstration Project*, December 2007, pp. 1-6, and *Interim Reports* for 2006 and 2005 (these reports were made to the Delaware River Basin Commission); Argonne National Laboratory, Environmental Science Division J.A. Veil and M.G. Puder), *Update on Use of Mine Pool Water for Power Generation*, ANL/EVS/R-06/6, September 2006, pp. 13-7.

As part of the river augmentation project, a fund was created to support restoration projects in the Schuylkill River Basin. The Exelon Schuylkill River Watershed Restoration Program fund is overseen by the Schuylkill River Heritage Area. Exelon contributes to the fund based on the quantity of consumptive cooling water that is not required to be augmented. Exelon continues to try to identify additional viable, environmentally advantageous water sources in the area.

New Plants: Hybrid Cooling Technologies

[129] U.S. Nuclear Regulatory Commission, *Environmental Impact Statement for an Early Site Permit (ESP) at the North Anna ESP Site* (NUREG 1811), Final Report, Vol. 1, Dec. 2006, pp. 3-9 to 3-10, at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1811/sr1811.html. Dominion is also planning to build a Unit 4 at North Anna, which will use dry cooling towers only.

[130] Unistar Nuclear, *Calvert Cliffs Nuclear Power Plant Unit 3 Combined License Application*, *Environmental Report*, Revision 2, March 2008, pp. 3.4-1 to 3.4-3, at http://adamswebsearch2.nrc.gov/idmws/ViewDocByAccession.asp?AccessionNumber=ML081021118; George Vanderheyden (Unistar Nuclear Energy, LLC), "Extraordinary Steps to Ensure a Minimal Environmental Impact," *Nuclear Plant Journal*, March-April 2008, p. 28.

Research and Development: Advanced Alternative Cooling Technologies

[131] The U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory (NETL), is engaged in a number of freshwater-use-reduction joint projects involving fossil fuel power plant cooling systems. See DOE NETL (Thomas J. Feeley, III, et al.), *Department of Energy/Office of Fossil Energy's Water-Energy Interface Research Program*, April 2006; DOE/NETL (Thomas J. Feeley, III, et al.), *Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program*, 2006; and DOE/NETL (Thomas J. Feeley, III, et al.), "Water: A Critical Resource in the Thermoelectric Power Industry," *Energy*, 33 (2008) [rev. January 12, 2007].

[132] Information about EPRI's research program is from Charles R. McGowin, "EPRI Advanced Cooling Technology Roadmap," a presentation delivered at the *EPRI Advanced Cooling Technology Workshop*, Charlotte, North Carolina, July 9, 2008. This and other presentations at the workshop are available at www.epri.com/advancedcooling.

[133] Inside a wet cooling tower, water vapor is produced through evaporation in the wet cooling process—tower water absorbs heat from the steam that will be recirculated as water back through the power plant to be boiled again to produce steam to drive the turbine. As the water vapor rises upward and exits at the top of the tower, it encounters the cooler temperature of the ambient air outside of the tower, which condenses a portion of the vapor into rain. This rainwater could be captured for reuse in the cooling tower.

The rain from the cooling tower plume contains concentrations of the chemical constituents of the water from the continuous evaporation and reuse of the water inside of the cooling tower. When this rain falls outside of the cooling tower, it may have an adverse impact on the foliage in the immediate vicinity.

[134] Wind conditions outside of a dry cooling tower can adversely impact the efficiency of the air cooling process inside. Barriers can prevent wind outside of the tower from affecting wind currents inside of the tower.

[135] In addition to these water-saving cooling system innovations, EDF is reconsidering assessing an experimental nuclear reactor developed and operated in France between 1980 and 1990, known as the CYBIAM reactor for "ammonia binary cycle," that is also intended to reduce water consumption. The reactor combines an initial water cycle that employs a conventional steam turbine, known as the Rankine cycle, which uses a water cooling system, and a second ammonia cycle employing a gas turbine, known as the Brayton cycle, which uses dry cooling. See the presentation on this subject on the EPRI water use Web site at www.epri.com/advancedcooling.

The next-generation of advanced nuclear reactors, known as Generation IV, are high-temperature gas-cooled reactors that do not use a steam cycle, are anticipated to withdraw and consume substantially less water than reactors in operation today and the Generation III reactors that the industry is currently making plans to build. Generation IV reactors are intended to generate electricity and produce process heat for such industrial uses as hydrogen production for transportation vehicle fuel as well as biofuel manufacturing, among other uses. A combination of cooling towers with process heat applications will significantly reduce the amount of heat a cooling system will need to dissipate.

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