A primer on the water dependencies and impacts of coal, natural gas, and uranium as sources of electricity

Energy-Water Nexus Mapping Project
Seth Sheldon and Pam Solo
Civil Society Institute
1 Bridge St. #200
Newton, MA 02458

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ABBREVIATIONS

ADAMS	Agencywide Documents Access and Management System
AEA	Atomic Energy Act of 1954
AEO	Annual Energy Outlook
BACT	Best Available Control Technology
bgd	billion gallons per day
BTU	British Thermal Unit
BWR	boiling water reactors
CARMA	Carbon Monitoring for Action
CBM	coal bed methane
CCR	coal combustion residuals
CCS	carbon capture and sequestration
CDR	carbon dioxide recovery
CSP	concentrating solar power
CWA	Clean Water Act
CWIS	cooling water intake structure
DHS	Department of Homeland Security
DOE	U.S. Department of Energy
EEI	Edison Electric Institute
EIA	Energy Information Administration
EnPA	Energy Policy Act of 2005
EPA	U.S. Environmental Protection Agency
GDEIS	Generic Environmental Impact Statement for In-Situ Leach Uranium Milling Facilities
GHG	greenhouse gas
gpm	gallons per minute
GW	gigawatt
HLRW	high-level radioactive waste
HSA	Homeland Security Act
ISL	in-situ leaching
LAER	lowest achievable emissions rates
LCA	life-cycle analysis
LLRWPA	Low-Level Radioactive Waste Policy Act
LNG	liquefied natural gas
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSDS	Material Safety Data Sheets
MW	megawatt
MWh	megawatt·hour
NEI	Nuclear Energy Institute
NETL	National Energy Technology Lab
NG	natural gas
NGA	Natural Gas Act
NGCC	natural gas combined cycle
NGO	non-governmental organization

NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Lab
NSPS	New Source Performance Standards
NSR	New Source Review
NWPA	Nuclear Waste Policy Act
NWUIP	National Water Use Information Program
PC	pulverized coal
ppm	parts per million
ppt	parts per thousand
PWR	pressurized water reactors
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
SSEB	Southern States Energy Board
TENORM	technologically enhanced naturally occurring radioactive materials
TMDL	total maximum daily load
UMTRCA	Uranium Mill Tailings Remediation Control Act
USGS	U.S. Geological Survey
WQS	water quality standards
WWTP	wastewater treatment plants

Executive Summary

The current U.S. energy paradigm favors the use of hydrocarbon and uranium fuel sources in thermoelectric power plants for the production of electricity. A substantial portion of the energy debate centers on economic costs and carbon emissions reductions, but a potentially greater risk is that ever-increasing electricity demands are coupled with escalating water demands.

Common energy industry goals include minimizing the economic impacts of state and federal regulatory changes, maintaining electricity supply reliability, recovering costs, and negotiating a diverse energy policy landscape by coordinating their efforts with government agencies. In fact, the energy industry shares a politically complex relationship with federal energy and water research labs and legislators. Many of the laws meant to govern the energy industry are written by former energy industry representatives and policy makers who have a vested interest in weakening environmental and health legislation for the benefit of individual industries. There are only a handful of federal laws meant to minimize the negative impacts of energy production, and government oversight of the water needs and impacts of the coal, natural gas, and nuclear energy is generally lacking. All three sectors have substantial water requirements and degrade water resources in some way at every stage of their fuel's life cycle.

The coal, natural gas, and nuclear industries are regulated by many of the same laws and government agencies, have similar water requirements, and degrade the environment in similar ways. The Department of Energy (DOE) and its various research laboratories, the Department of the Interior (DOI), the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Homeland Security (DHS) are the most visible federal entities responsible for measuring and managing energy and water activity in the U.S.

Among the most important laws for all three industries are the Clean Water Act, the Safe Drinking Water Act, the Homeland Security Act, and the Energy Policy Act of 2005.
Of particular relevance to the natural gas industry are the Toxic Substances Control Act of 1976 and the Emergency Planning and Community Right-to-Know Act. Both laws have been criticized for being ineffectual by exempting "trade secret" drilling and hydraulic fracturing chemicals from being disclosed to and tested for safety by the EPA. Three important pieces of regulation are specific to the nuclear energy industry and meant to limit the amount of public exposure to radioactive wastes: the Uranium Mill Tailings Remediation Control Act, the Low-Level Radioactive Waste Policy Act, and the Nuclear Waste Policy Act. Each of these laws was not written with the intent of minimizing the energy industry's water needs,

and they do not fully address all negative environmental impacts. Overall, they fall short of integrating water and energy management.

Energy industry representatives have a tendency to downplay water requirements and impacts by selecting individual steps in what are complex, long term, and large-scale processes. Water is used in every stage of the process of creating electricity from coal, natural gas, and uranium. It is used in **extraction** (e.g. mining, drilling, fracking), **treatment** (e.g. milling, refining, conversion, enrichment), **transport** (e.g. slurry production, river channel maintenance, dust suppression, pipe testing), **electricity generation** (i.e., thermoelectric facility cooling, maintenance), and **waste removal** (e.g. scrubbing, blowdown, carbon capture and storage).

The life-cycle view of water used to produce energy offers a fuller picture for the comparison of technologies and fuel types. From "cradle to grave," coal for electricity requires, on average, between 660-26,000 gallons of water per megawatt·hour (gal/MWh) depending on power plant cooling technology type. Natural gas for electricity requires between 607-22,700 gal/MWh depending on drilling technology and power plant type. Nuclear sources of electricity require, on average, between 1,030-31,700 gal/MWh of energy produced. For comparison, solar photovoltaics require about 357 gal/MWh, wind energy sources require about 61 gal/MWh, and Midwestern biomass sources require about 530 gal/MWh. Values reported are for withdrawals (i.e., water that must be available), rather than consumption.

Meanwhile, surface and groundwater are negatively impacted at each stage, *even when industry personnel are abiding by environmental laws*. During extraction, aquatic habitats and drinking water sources are exposed to mine tailings and contaminated brines that are rich in heavy metals, salts, and radioactive isotopes, while heavy equipment traffic degrades small watersheds. Treatment of each fuel source typically consumes large amounts of fresh water, straining ecosystems and removing it from use by other sectors such as agriculture, sanitation, and recreation. Electricity generation is a particularly water-intensive stage, and its high water withdrawal and consumption rates lead to lower fish stocks, degraded downstream habitats due to thermal plumes, and, in the case of nuclear plants, radioactive leaks. The final stage—and one that is often dismissed out of hand by anti-environmentalists—is waste removal. Leaching of coal ash and gas well brine into groundwater from poorly lined holding ponds, and accidental spills into surface waters take a toll on human and environmental health.

The emphasis on carbon capture and storage (CCS) technology as a climate change mitigation strategy may be misplaced in areas where water is scare or is likely to become scarce. For modern coal- and natural gas-fired power plants, the installation of CCS technology at preexisting facilities nearly *doubles* the amount of water needed for operation. Neither the coal nor the natural gas life-cycle water withdrawal figures quoted earlier account for increased water use due to CCS.

Direct costs to human health for each of the energy sources are difficult to measure and poorly understood. Multiple studies have recently verified the high costs to human health associated with burning coal to produce electricity. No such studies exist for measuring the true costs of unconventional natural gas production. The risks and impacts of nuclear energy development are made apparent on an anecdotal basis during and after reactor melt downs (e.g. Three-Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011), but such events are uncommon enough that most risk models are inadequately suited to handle the implications. Other impacts are more widespread, but are even more difficult to quantify, such as public exposure to low levels of contaminants, long term habitat degradation, increased morbidity, and the risks associated with decreased fresh water supplies.

Water-for-energy use and impacts vary from geographic region to region. These differences underscore the need for more location-based and plant-specific research. A 2006 report from the DOE states that future water issues will have a national scope, but will be driven by regional issues. In the West, the fossil fuel and nuclear energy sectors will be faced with water rights issues and sporadic drought. In the East, Clean Water Act regulations and local droughts will strain electricity generation systems.

Many publically accessible online tools exist that provide information about the U.S. energy industry and about individual facilities. Governmental databases provide information for interested individuals out of legislative obligations, while independent public interest firms provide resources out of a desire to slow—and perhaps reverse—the rate of fossil fuel and uranium-based energy production in the U.S. None of the databases and informational tools is well advertised, and only a few offer user-friendly and engaging interfaces. Indeed, the single greatest problem with existing power plant and environmental databases is that they are not in the mainstream and are being used by only a fraction of the population. Consequently, opportunities abound for improving and aggregating existing data sets into cohesive informational units and digital outreach tools. The deficiencies of existing public databases may be indicative of the large energy and water knowledge gaps that exist between Regulators, the Regulated, and the Public.

GENERAL INTRODUCTION

In section 979 of the Energy Policy Act of 2005, Congress mandated that the U.S. Department of Energy release a two-part report exploring the interdependencies of our energy and water systems, no later than two years from the date of enactment [42 U.S.C. 15801]. Part I, released in 2007, offers a review of present research initiatives. Part II, which was meant to offer "recommendations for future actions" by the Federal government to address the concerns raised in Part I, was never released by the DOE. Given 1) the complex relationship between Federal energy research labs and the coal, natural gas, and nuclear industries, and 2) the substantial and ever-increasing water demands of each of those industries, it is possible that the second report may never be released to the public for what it reveals about the energy and water security risks associated with a research funding agenda that favors hydrocarbon and uranium fuel sources. More likely, the proposed research approach—a wholesale reorganization of the way we measure and manage our water resources, which begins to recognize water's vital nature—is a substantial threat to the status quo, and therefore unappealing to federal energy regulatory agencies.

What follows is a three-part summary of the connections between water and the coal, natural gas, and nuclear energy industries. Each section presents information on the following topics: the state of energy-water nexus research, relevant legislation, acting organizations, water dependencies, water impacts, and existing databases and tools.

Coal

RESEARCH AREA

Using coal for energy production is water-intensive at nearly every stage of the process. Various government agencies are tasked with identifying and minimizing the vulnerabilities associated with inadequate energy and water systems management, but they are not the sole participants in the debate surrounding coal use. The government agencies must contend with powerful coal industry lobbies and representatives as well as outspoken environmental advocates. The agendas of the groups vary widely, and research in individual sectors is driven by legislation and popular trends.

Generally, governmental energy agencies are charged with policymaking, regulation, and enforcement of energy and environmental legislation. Non-governmental organizations (NGOs) and non-profits do their best to uphold governmental and corporate accountability in light of imperfect laws. Coal energy companies try to maximize profits, to minimize legislation-related impacts on consumers, and to comply with environmental laws, although it is rare that they do all three to the satisfaction of independent review agencies (e.g. environmental non-profit agencies).

Legislation and a related court case

Several pieces of legislation and regulations are directly relevant to water use by the coal industry [Feeley et al. 2006]:

- **The Clean Water Act (CWA)** provides the U.S. Environmental Protection Agency (EPA) with the authority to protect waters of the U.S. from degradation from industrial, residential, and agricultural pollution [EPA et al., 2011]. An amendment to the CWA disallows the use of once-through cooling at new coastal thermoelectric facilities [Dennen et al., 2007]. No new once-through cooled power plants have been built in the U.S. in decades, although they represent a substantial percentage of the current electrical capacity. In a recent Supreme Court case, *Entergy Corp vs. Riverkeeper*, the Justices upheld the decision of the lower court to allow the EPA to conduct cost-benefit analyses when determining whether older power plants must replace their once-through systems with closed-loop cooling systems.
- **CWA §303(d), Water quality standards and implementation plans**. These require states to develop ranked lists of impaired waters, even after the installation of pollution control technology. Water quality standards (WQS) are set by each state, and state environmental agencies must establish the total maximum daily

load (TMDL) of pollutants for the waters and develop implementation plans for improving the impaired waters.

- **CWA §316(a), Water thermal discharge requirements.** Sets maximum discharge temperatures for effluents.
- **CWA §316(b), Cooling water intake structures.** Sets technology standards for minimizing fish mortality at the point of water withdrawal. A permit that satisfies the CWA §316(b) requirements is called a Cooling Water Intake Structure (CWIS) permit.
- As of February 2006, new fossil-fuel fired electric utility steam generating units must meet the **New Source Performance Standards** (NSPS), which require the installation of the best available control technology for reducing emissions but not water use [Woods et al., 2007]. As we shall see, additional coal scrubbing for reduction in harmful emissions increases water use, as does carbon capture and sequestration.
- **Safe Drinking Water Act (SDWA), Protection from contaminants.** Sets limitations on the amount of certain pollutants in drinking water sources—including those sources which are drawn upon and discharged into by thermoelectric facilities and mining operations. It requires the EPA to develop treatment requirements to remove contaminants from public drinking water supply systems. The EPA sets testing schedules and publishes acceptable testing techniques [EPA et al., 2011].

There are a series of pending regulations due from the EPA that are meant to clarify existing legislation [EEI, 2010]:

- A proposal for the implementation of 316(b) (water intake structure) requirements was due in February of 2011.
- The EPA is supposed to establish whether cooling towers are the preferred technology for coal-fired power plants.
- A proposal for how coal combustion residuals (CCRs) will be regulated was due in June of 2011. CCRs may be given a “special” hazardous waste designation, or may be listed as a beneficial use, and therefore exempt from existing regulations. Many states, ash recyclers, industry groups, and congress people are opposed to stricter CCR regulations. Stricter regulations would lead to ash pond closures, the need for additional disposal capacity, and a reduction in beneficial uses, such as concrete production, but would also increase governmental scrutiny of hazardous waste handling and CCR-related human health impacts [EEI, 2010].

Government research

The U.S. Department of Energy (**DOE**), the National Energy Technology Lab (**NETL**), the National Renewable Energy Lab (**NREL**), **Sandia** National Labs, **Argonne** National Lab, the EPA, the Energy Information Administration (**EIA**, part of the DOE), and the U.S. Geological Survey (**USGS**), are all heavily involved in energy-water nexus research. Most published reports use a 15-40 year timeline and are based on only a few survey-based data sets. The analyses also tend to be conservative, as the agencies must maintain an ongoing dialogue with coal industry reps and their critics. For example, Fischer et al. (2009) found that the EIA tended to underestimate capacity building by about 2% or more in its Annual Energy Outlook (AEO) reports [Fischer et al., 2009; Elcock, 2010].

An earlier study by the NETL presented a series of models meant to evaluate water use at coal-fired thermoelectric facilities, based on the assumption that all future facilities would use recirculating cooling technology (most faculties currently use once-through cooling technology),[1] and would draw half of their water from municipal waterworks and the other half from groundwater (most facilities withdraw from rivers and lakes). The NETL's assumptions would necessarily lead to a less alarming picture of future water withdrawals [Woods et al., 2007].

Specific coal industry goals

A recent presentation by the Edison Electric Institute (EEI), the association of shareholder-owned electric companies in the U.S., outlines the following energy industry goals, neatly summarizing complex and numerous interests. Faced with an uncertain legislative future, the energy industries are focused on the following points [EEI, 2010]:

- Minimize economic impact of transition (to stricter environmental standards)
- Continue improving environmental record
- Strive for better coordination with EPA on air, water, and waste
- Maintain or increase reliability
- Maintain or increase fuel diversity
- Development and deployment of new technology
- Capital acquisition and cost recovery
- Negotiating a diverse political landscape

Energy developers view the present as an ideal time to build new capacity due to low commodity prices, and many utilities believe we are at the beginning of a major investment cycle.

WATER DEPENDENCIES

[1] The distinction between recirculating and once-through cooling systems is described in a later section.

One of the difficulties that face energy and water nexus researchers is vocabulary. The specific terms used to describe the most common parameters of interest are far from standardized, but it would be fruitless to present Energy's water dependencies without any frame of reference.

Terminology

The USGS makes distinctions between water *use*, *withdrawal*, and *consumption*:

- **Use**: includes withdrawals, delivery, consumptive uses, wastewater releases, reclaimed wastewater, returned flows, hydroelectric power use and others
- **Withdrawal**: the amount of water extracted from natural resources
- **Consumption**: amount of water withdrawn that evaporates, is transpired, incorporated into products or crops, consumed by humans and livestock, or otherwise removed from the immediate water environment [Dziegielewski & Bik, 2006]

The DOE and NETL often use the terms *demand*, *internal recycle*, and *raw water usage*:

- **Raw water usage**: amount of water coming from a natural or municipal source [Woods et al., 2007]
- **Internal recycle**: amount of water continuously reused in a process
- **Demand**: total water needed for an industrial process; made up of raw water usage plus recycled water

Cooling technologies employed at thermoelectric facilities are classified as either *wet* or *dry*. Wet cooling is further divided into *open-* or *closed-loop*.

- **Wet cooling**: a cooling process that uses fresh or saline water for heat exchange. The water is usually *non-contact*, which means that it does not touch the heat exchange fluid
- **Open loop**: a type of wet cooling system that does not recirculate its water. In some cases, cooling ponds are used before the water is returned to its source. The amount of water withdrawn is roughly equal to, but always less than, the amount of water discharged. Open loop systems cause thermal pollution and generally require a lot of water to operate.

- **Closed loop**: a type of wet cooling system that uses cooling towers or evaporation ponds so that it can reuse most of the water that it has withdrawn. Closed loop systems generally withdraw much less water than open loop systems, but consume more. Thermal pollution is largely eliminated, but effluent pollutant concentrations are higher.
- **Dry cooling**: a type of cooling system that uses air rather than water to cool down the heat exchange fluid. Dry cooling systems are less efficient than wet cooling systems, are susceptible to reduced functionality during extreme heat, and are expensive to install.

A few other terms and units are useful for describing water needs and impacts:

- **Water use efficiency**: alternatively called *water use intensity* or *water use factor*, it describes the amount of water used (gallons, gal) per unit of energy (megawatt·hour, MWh), or as a rate in gallons per minute per megawatt (gpm/MW)
- **Thermal loading**: expressed as an increase in downstream temperature caused by the power plant discharge in either F° or C°.
- **Chemical loading**: usually expressed in parts per thousand (ppt) or parts per million (ppm) of a specific pollutant in a plant's effluent

Process of using coal as a fuel source

For coal, water is used at every stage in the process to create electricity. The stages include **fuel acquisition** (mining), **fuel preparation** (refining, or *beneficiation*), **plant/device construction**, **transportation**, **electricity generation**, **waste removal**, and **indirect water usage** (upstream uses)[2] [Fthenakis & Kim, 2010]. Precise estimates of thermoelectric water use at the national level do not exist [Dziegielewski & Bik, 2006], and only rough estimates of complete life-cycle water usage for coal energy are available.

Fuel acquisition

For coal that was mined underground, fuel acquisition is the second largest user of water behind power plant cooling for electricity generation. In the West, 90% of mines are surface mines, where very little water is used. In Appalachia, 65% of mines are underground [DOE & Sandia, 2006]. Water is used or withdrawn for the following purposes:

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[2] A full listing of upstream uses is beyond the scope of this summary. They include all water withdrawals that are indirectly associated with each of the other six stages.

- Underground coal cutting
- Dust suppression
- Reclamation and revegetation of mine area
- Dewatering of coal seams [DOE & Sandia, 2006]

Fuel preparation

Lower grade coals are washed to increase heat content by removing non-combustibles and to reduce sulfur levels. It takes about 30 gallons to wash one ton of coal. In the eastern U.S., about 80% of coal is washed.

Plant/Device construction

The amount of water used during the construction of a new coal-fired power plant varies. Although it is certainly a component of the total water use, its contribution per MWh of energy produced is minimal, due to the fact that construction and modification only occur a few times during a plant's lifespan.

Transportation

The two most significant water needs for the transportation of coal are withdrawals used for slurries and streamflow maintenance for barge traffic. The water withdrawn and mixed with coal for the production of pipeline transported slurries is not returned to its source [Dziegielewski & Bik, 2006; Elcock, 2010].

A less obvious water need is the maintenance of adequate river flows for barges. When water levels drop below a certain level, barge traffic is reduced. About 10% of all coal is transported by barge [DOE & Sandia, 2006].

Electricity generation

In 2000, about 2.762 billion MWh were generated by thermoelectric utilities, and 439 million MWh were generated by thermoelectric non-utility plants (i.e., industrial users that are not connected to the public grid) [Dziegielewski & Bik, 2006]. 44.6% of the energy generated in the U.S. (including hydroelectric) is coal-based [EEI, 2010], and 58% of all *thermoelectric* energy generated in the U.S. is coal-based [Feeley et al., 2006]. There is still ambiguity as to whether non-utility water withdrawals for energy are adequately accounted for by the USGS in their semi-decadal water accounting reports [Dziegielewski & Bik, 2006].

Dry cooling technology can be substantially more expensive to install at thermoelectric plants than wet cooling technology, and it is also limited by ambient temperature conditions. For individual plants, dry cooling systems generally account for about 6.5% of total plant build costs, whereas wet cooling systems usually only account for about 2% of plant build costs [Feeley et al., 2006].

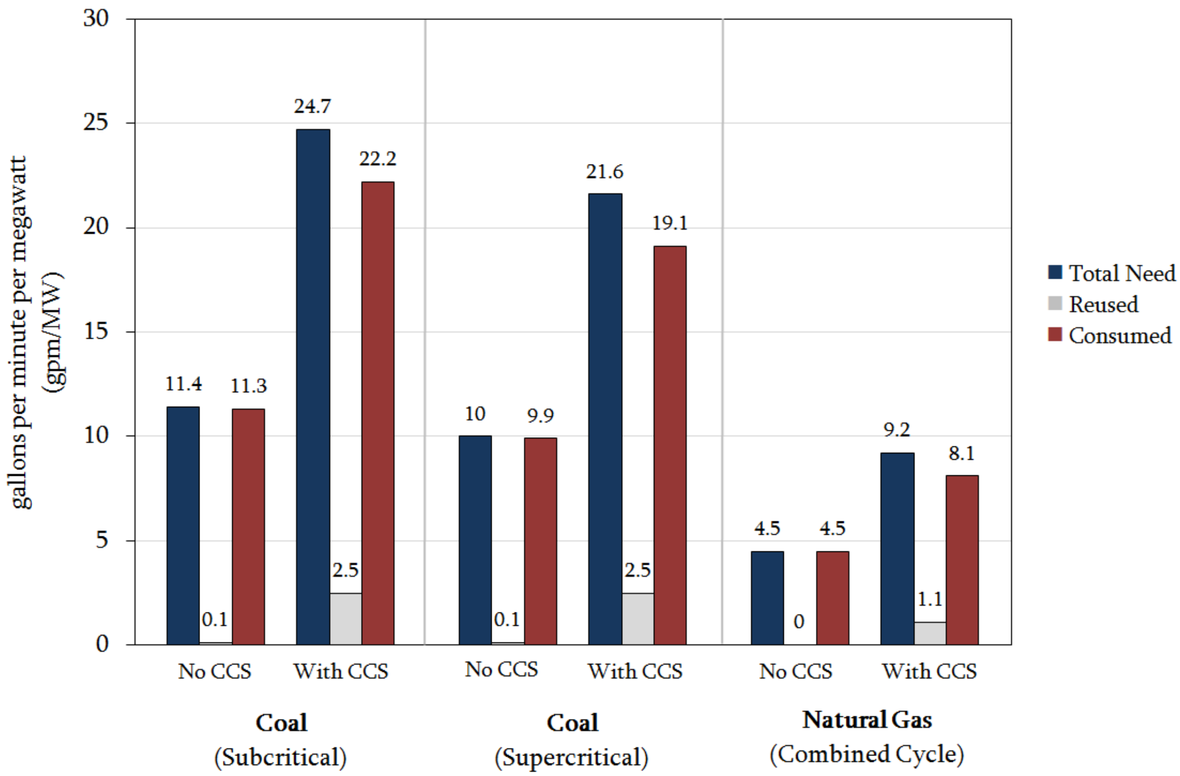
Wet cooling systems are by far the most common types of cooling systems in the U.S., due to the expense of air-cooled systems and the relative cheapness of water for industrial users. Old plants use old technology, and most coal units are in the 30-60 year old range [EEI, 2010]. Indeed, more than half of all thermoelectric plants employ once-through cooling, and the most common sources of water are rivers, followed by lakes. In some cases, saline sources, groundwater, or municipal sources are used. In all cases, water must be "reserved for generation" and is therefore inaccessible for other uses [Dziegielewski & Bik, 2006].

Waste removal

Water is used to facilitate the containment and removal of waste products such as coal ash, particulates (via "scrubbing"), coal slurry water, boiler and cooling tower "blowdown," and carbon dioxide (CO_2). Water dependencies for each of these types of waste materials vary substantially, but can be considerable—especially in the case of emissions scrubbing and CO_2 removal. The specific water-related impacts of handling these materials are covered in the Water Impacts section.

To the extent that carbon dioxide gas is a waste material, **carbon capture and sequestration** (CCS) is yet another process that entwines coal and water. A 2007 study by the NETL estimated that adding CCS technology to an existing pulverized coal (PC) power plant increases water usage by a staggering 95%. The report also presents a graph that demonstrates this tradeoff between emissions reductions and water conservation (Figure 1) [Woods et al., 2007].

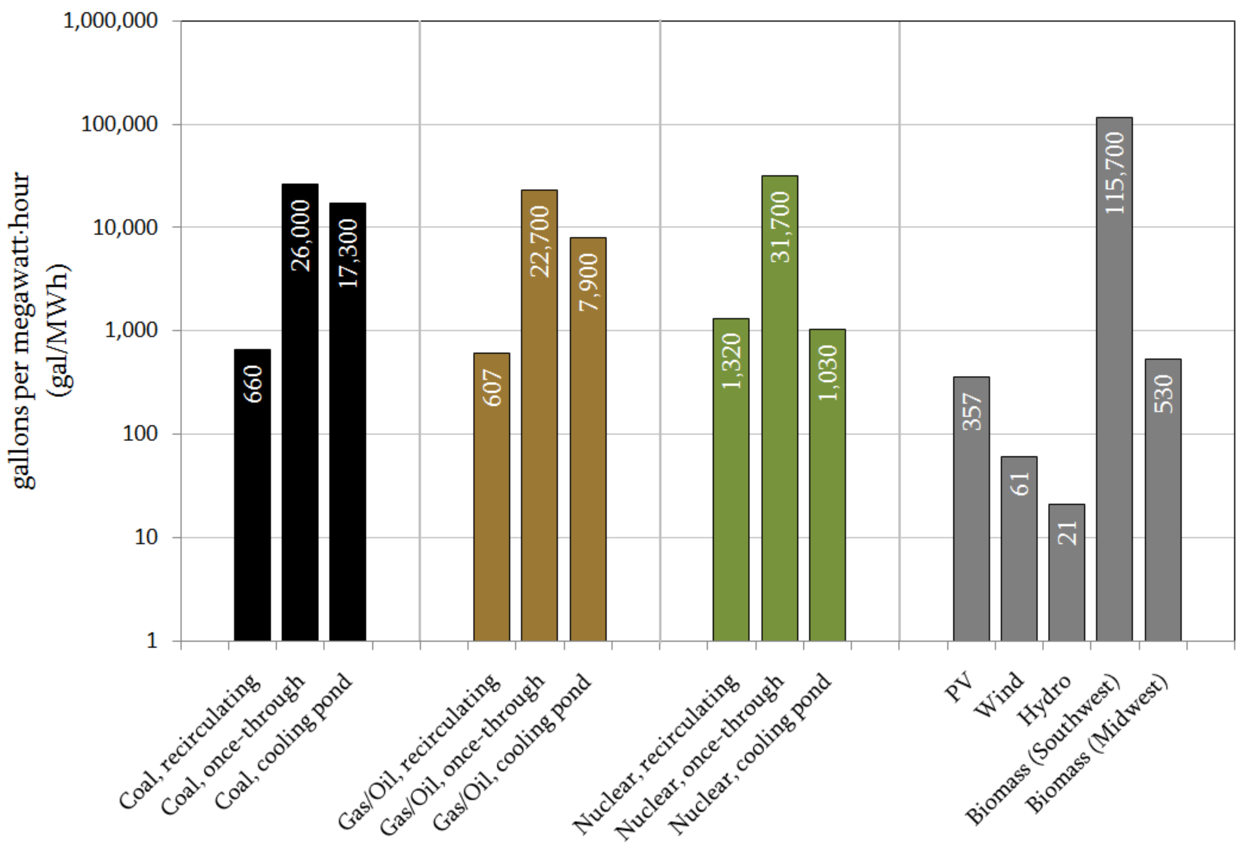
Figure 1. Water requirements per MW for coal- and natural gas-fired thermoelectric facilities, with and without CCS. Plants are assumed to use recirculating cooling systems. *Subcritical* and *supercritical* describe two different types of coal combustion technologies [Adapted from Woods et al., 2007].



Life-cycle view of water resource use

Life-cycle analysis (LCA) can be difficult for even the simplest systems, and coal-fired power plants are incredibly complex. Cooling mechanisms and subtler system differences can have a substantial impact on the accuracy of the assessment. Despite these challenges, total life-cycle water use estimates have been generated for coal-fired power plants which use the three most common cooling types: recirculating, once-through, and cooling ponds. In a 2010 study, Fthenakis and Kim show that the total water withdrawn per MWh of energy produced using coal is substantial. Total water withdrawals for coal-fired power plants for each of the three cooling types are shown in the following graph [Fthenakis & Kim, 2010]:

Figure 2. Life-cycle water withdrawal for coal-, natural gas-, and nuclear-based electricity, employing different cooling types, in comparison to renewable technology life-cycle withdrawals [Adapted from Fthenakis & Kim, 2010].



Regional differences

The amount of water used for each stage of the coal-powered electricity process differs from geographic region to region. These differences underscore the need for more location-based and plant-specific research for coal energy's water dependencies as well as impacts. A 2006 report from the DOE states that future water "conflicts will be national in scope, but regionally driven." In the West, the coal industry will be faced with water right issues and sporadic drought. In the East, the CWA's intake structure regulations and local drought will strain the industry [Feeley et al., 2006].

WATER IMPACTS

Generally, water supply and demand imbalances lead to lowered agricultural yields, a reduction of aquatic biodiversity, and politically difficult decisions [Elcock, 2010]. For each stage of the coal energy generation process, surface and groundwater are negatively impacted [DOE & Sandia, 2006]. The primary impacts occur during mining, refining, transportation, electricity generation (cooling), and waste removal:

Figure 3. Table of coal energy process stages and associated water impacts.

Process Stage	Water Impact
Mining	Ground and surface water impacted by tailings and drainage
Refining	Pollution and consumption of water
Transportation	Water extracted from slurry is of poor quality and requires treatment; barge traffic conflicts with recreational uses
Electricity Generation	Thermal and air emissions impact surface waters and ecology; chemicals added to cooling water include de-scaling agents and biocides; thermal pollution and possible downstream evaporation rate increases [Dziegielewski & Bik, 2006]; fish kills at water intakes
Waste Removal	Leaching into groundwater and spills into surface waters take a toll on human and environmental health

Coal waste

Coal ash is an unavoidable waste product of coal combustion, and it often contains toxic levels of heavy metals. Coal ash ponds are not well documented or regulated by the EPA, despite the fact that pond leakage and spills have caused numerous cases of groundwater poisoning across the U.S. The material represents the single greatest threat to drinking water quality at the electricity generation stage for coal energy. Regulations are pending regarding the treatment of coal ash as a hazardous material, which would involve a more intense and expensive removal process. **Coal slurry water** (i.e., water that is removed from coal slurry before the coal can be combusted) is rife with toxins, as is "**blowdown**" water from the cooling towers and boilers. **CO_2** is a greenhouse gas that is unnaturally increasing global temperatures (i.e., exacerbated climate change). The effects of climate change include sea level rise, more common and powerful hurricanes, drought, heat waves, mass migrations due to famine and disease, and generally volatile weather patterns.

Costs to human health

The communities which surround and are downstream of coal energy activities bear the most negative health impacts. A recent study by Synapse Energy Economics, Inc. estimates the health impacts associated with coal energy can be given both a dollar value and a cost in terms of human lives (at the national scale and for individual plants) [Fisher et al., 2011]. The study is part of a growing field of research that is meant to provide a solid foundation for what many environmental non-profits and NGOs already know to be true: **the benefits of coal energy are outweighed by its true costs**.

RECENT DEVELOPMENTS

January 2012 – The EIA now expects coal-fired electricity to drop from roughly 50 percent of the total supply to 39 percent by 2035, which is less than last year's estimate of 43 percent. Appalachian coal production is expected to drop by more than 25 percent by 2035 (Quinones, 2012).

Natural Gas

RESEARCH AREA

Natural gas is viewed by many in the United States as the preferred energy alternative to coal and to nuclear power for base load electricity production. It has the lowest carbon dioxide emissions per unit of energy produced of any of the fossil fuels, its environmental footprint is often regarded as small, and supplies beneath American soil are substantial. However, there is a debate between government agencies, industry representatives, and non-profit and non-governmental environmental groups over the actual impacts of a growing natural gas industry, and specifically with regard to unconventionally acquired natural gas. As with coal, facts are not always forthcoming, and environmental effects are not always clear.

Generally, industry-level research on the technical and engineering challenges of conventional and unconventional natural gas acquisition have outpaced both governmental regulation and the scrutiny of environmental groups. Advocates of state regulated natural gas exploration and production point to job creation and natural gas's role as the "cleanest" fossil fuel, while opponents argue that certain types of production (e.g. unconventional, including shale gas) are inadequately regulated and are untested at a large scale [Harder, 2010].

The U.S. has installed 142 gigawatts (GW) of natural gas combined cycle (NGCC) capacity since 2000, but facilities have been largely underutilized. The staggering increase in shale gas production by 33% over the course of the last 2 years suggests that a higher percentage of the U.S. NGCC capacity will be switched on. The ongoing controversy surrounding federal and state legislation related to the natural gas industry is a key indication that existing laws are not up to the task of dealing with the boom.

Legislation

Several pieces of legislation and regulations are directly relevant to water use by the natural gas industry [Feeley, 2006]:

- The **Clean Water Act (CWA)** and specific sections are described in the *Legislation* section of the Coal Summary.
- The **Safe Drinking Water Act (SDWA)** is also outlined in the *Legislation* section of the Coal Summary.
- The **Energy Policy Act of 2005** expressly exempts certain types of natural gas activity (i.e., hydraulic fracturing) from being regulated under the Safe Drinking Water Act. Some unconventional natural gas advocates view the section as a clarification rather than an exemption, because hydrofracking "was never regulated under the SDWA" [Harder, 2010]. Under the Energy Policy Act, natural gas industry reporting of water use is not required [Groat, 2009]. It also exempts the oil and gas industries from the storm water runoff provisions of the CWA [Harder, 2010].
- The **New Source Performance Standards (NSPS)** as outlined by the DOE emphasize emissions rather than water use. The NSPS apply to all thermoelectric plants that have a nameplate capacity of greater than 73 MW. The **New Source Review (NSR)** permitting process, which is part of the NSPS, requires the installation of Best Available Control Technologies (BACT) in emission attainment areas, and the lowest achievable emissions rates (LAER) in non-attainment areas [Woods et al., 2007].[3] Choice of control technologies focuses on controlling emissions, not on reducing water use.
- Under the **Natural Gas Act (NGA) §3(a)**, the DOE must approve exports and imports of natural gas across borders. Meanwhile, §3(c), added in 1992, provides that some exports can be deemed in the "public interest" and allowed to proceed without modification or delay [DOE, 2010].
- The **Emergency Planning and Community Right-to-Know Act** requires that **Material Safety Data Sheets** (MSDS) be made available to firemen and other emergency personnel in the event of an accident. An **MSDS** is supposed to list all known substances being used at a gas well site, but it is unlikely to list the specific and propriety chemical compounds being used [Soeder & Kappel, 2009].
- **Toxic Substances Control Act of 1976** is a largely ineffectual law meant to regulate harmful substances by giving the EPA the authority to catalog and test them. The

[3] "Attainment areas" are areas in which limits on harmful emissions have been attained. "Non-attainment areas" are those in which air quality is degraded as a result of emission limit violations.

law exempts "trade secret" chemicals from being disclosed to the public [Schifman, 2011].

In the near term, the legislative activity most relevant to the proliferation of unconventional natural gas production will be at the state level. The inertia of existing federal legislation as well as basic geological constraints ensure that this will be the case. The *Regional Differences* section outlines the major unconventional gas resources in the U.S.

Pennsylvania

A suite of natural gas-related bills in Pennsylvania, which sits atop the Marcellus Shale and has been developing it a breakneck speed, has come before the PA House and Senate. Many other states are looking to Pennsylvania as the proving ground for the law of eastern unconventional gas resources. Some of the debated topics include the following bills [Penn State, 2011]:

- **House Bill 623:** 80% of royalties from leasing of state forestry land would go to reduce property taxes, while 20% would go to the PA Oil and Gas Lease fund for conservation purposes.
- **Senate Bill 834:** would require the Department of Conservation and Natural Resources to hold regular auctions of drilling rights in state forests.
- **Senate bill 490:** 94.6% of the $184 million expected to be generated for the Oil and Gas Lease Fund would be put into the General Fund. Only 2.7% would go to the permit process and inspections.
- **House bill 473:** Surface owner's Bill of Rights, meant to protect surface owner's from well-related environmental degradation. Did not pass [Pifer, 2011].
- **House bill 1155:** well operators would be presumed responsible for well water pollution within 2,500 feet of well. (Did not pass) [Pifer, 2011].

Additionally, "forced pooling," which would reduce the number of wells on a given natural gas field, may be considered for the 2011-2012 legislative season [Pifer, 2011].

Government research

The three most prominent federal agencies doing research related to natural gas are the DOE, the USGS, and the EPA. At the state and local level, countless basin councils and commissions, departments of environmental protection, quality, and conservation have also entered the fray.

For instance, in its 2009 Annual Energy Outlook, the EIA—the energy resources accounting office of the DOE—devoted a substantial amount of its analysis to natural gas and predicted declining demand [EIA, 2009]. A similar conclusion was reached by The Brattle Group, Inc., an independent energy research organization, for the following reasons: (1) under a cap and trade scheme, CO_2 prices may not be high enough, (2) renewables reduce natural gas demand as "must take" resources, (3) electricity conservation may become widespread, (4) protections and incentives are offered to coal but not to natural gas under the recently defeated cap and trade bills, and (5) non-electric gas demand is likely to be low due to conservation by retailers and CO_2 price impacts [Levine et al., 2010].

In some cases, government scientists write academic articles that are based largely on government data. For instance, Elcock (2010) projects national water supply and energy demand scenarios to 2030, identifying areas of possible water use conflicts and suggesting that some areas warrant further investigation. The author discusses the water requirements of drilling, processing, and pipeline transport of natural gas conventional and unconventional sources, and supports her conclusions using previous studies done by the NETL (a DOE lab) [Elcock, 2010].

A USGS grant-funded report by Dziegielewski et al. in 2006 concluded that plants burning coal, coal mixtures, or petroleum tended to have higher water usage than plants burning natural gas. The report concluded that water conservation is not a priority at thermal plants with water-cooled steam turbine generators. Once-through cooled facilities concern themselves with fish kills at intakes and thermal discharges, not overall withdrawal or consumption [Dzigielewski & Bik, 2006]. In 2009, a former director of the USGS, Charles Groat, gave a presentation at the University of Texas Austin specifically addressing the effects of unconventional natural gas development on groundwater. Some of his conclusions are described in the Water Impacts section that follows.

The U.S. EPA completed its final public hearing on the environmental impacts of fracking in the summer of 2010 and it expects the report to be out in 2012. The EPA's role in unconventional natural gas research is controversial. Its authority is limited by the "trade secret" provisions of the Toxic Substances Control Act, and many reports by the EPA, including ones in which there are substantial criticisms of unconventional natural gas development, have gone unpublished [Urbina, 26 Feb. 2011]. Some regional scientists allege that the national EPA study is being used to silence or delay much-needed regional studies [Urbina, 3 Mar. 2011].

Specific natural gas industry goals

The industry's view of the challenges that natural gas development faces is familiar: conflicts among multiple users, long term planning, and open communication with government and public groups. Predictably, natural gas advocates also seek to eliminate the perception of excessive water use and to address misconceptions about treatment technology [Satterfield et al., 2008].

Natural gas companies must also contend with other fossil fuel industries. In Colorado, for example, coal plants are challenging Colorado's Clean Air, Clean Jobs Act, which requires Xcel Energy to switch several coal plants to natural gas or alternative energy [Williams, 2011]. The major shale gas companies in the U.S. are Chesapeake Energy, Anadarko, Range, XTO, and Devon [Groat, 2009].

WATER DEPENDENCIES

Process of using natural gas as a fuel source

Water is used during the **extraction** (fuel acquisition), **treatment** (fuel preparation), **transport**, and **combustion** (electricity generation) of natural gas [EPA, 2007], as well as during preparatory activities (e.g. power plant construction) and cleanup activities (e.g. produced water removal).

Potential water resources include surface water, private sources, wells, municipal supplies, waste water, and reuse [Satterfield et al., 2008]. Many wells purchase potable water from municipal utilities to provide the water needed for the gas well requirements [Kitasei & Eilbert, 2011].

Extraction

There are two major methods for acquiring natural gas: **conventional** (shallow), and **unconventional** (deep). Unconventional techniques tap into tight sand, coal bed methane, and gas shale formations, usually through hydraulic fracturing. Hydraulic fracturing (or simply "**fracking**") is used to ensure favorable rates of gas production in otherwise inaccessible natural gas resources [Elcock, 2010].

Conventional gas extraction uses water only as a drilling fluid and has negligible water requirements. Conversely, unconventional gas extraction can have substantial water demands, depending on the type of geological resource being exploited. Coal bed methanes (CBM), which are common in the western US, tend to be net *producers* of water. CBM produced water varies in quality and can range from hyper-saline to potable [Groat, 2009]. Tight sands and gas shales generally do not contain substantial quantities of preexisting (i.e. "formation") water, so water must be acquired from elsewhere.

Fracking a well typically requires 2 to 4 million gallons and occurs over the course of a few days [Kitasei & Eilber, 2011]. A well can be fractured several times during its life and a typical well will produce gas for 20 years [Elcock, 2010]. Other estimates put the water requirements at closer to 5 million gallons: drilling one deep shale well requires between 65,000 and 600,000 gallons, while fracking the same well requires roughly 4.5 million gallons [Chesapeake Energy, 2011].

Byproducts and produced water are generally stored in holding ponds until they can be removed (see *Waste removal*). And while some researchers estimate that shale gas requires only 0.01 gallons per kilowatt-hour more than conventional natural gas [Kitasei & Eilbert, 2011], the freshwater resource-related impacts may be substantially greater.

Overall, fresh water consumption for the production of conventional natural gas-powered electricity is expected to increase from 1.4 billion gallons per day (bgd) to 1.6 bgd over the next two decades and mostly in the Rocky Mountain oil and gas supply region. As recently as 2010, industry analysts also expected consumption of water for unconventional natural gas production to remain surprisingly low (about 0.003 bgd). The same study concludes its section on natural gas production with the following statement [Elcock, 2010]:

> "*…[U]nintended increases in water consumption can occur over a fairly short time period, [and] impacts can be localized, suggesting that future production locations may need to be evaluated for potential impacts on local water resources.*"

Treatment

Extracted gas is sent to gas treatment facilities to remove impurities such as hydrogen sulfide (an acid gas), dissolved carbon dioxide, hydrocarbons, and water vapor [EPA, 2007].

Plant/device construction

In life-cycle analysis of water resources, plant and device construction are considered "upstream" components of the total water requirements. When averaged over the lifespan of a natural gas treatment facility or power plant, the additional water requirements are negligible in comparison to the hydraulic fracturing and ongoing power plant cooling requirements.

Transport and storage

Wherever possible, natural gas is transported via pipelines as a gas or as liquefied natural gas (LNG). Pipes must be tested periodically to ensure that they are leak free, and hydrostatic testing is a preferred technique. During a hydrostatic test, the pipes are filled with water to check for leaks [Elcock, 2010]. Pipeline transport reduces truck traffic, air pollution, and road wear [Satterfield et al., 2008].

Natural gas can be stored in existing NG reservoirs, aquifers, and salt caverns. In the case of salt caverns, water must be injected to dissolve preexisting salt formations. The Worldwatch Institute estimates that 500-600 gallons of water are needed per million BTU of natural gas storage in salt caverns [Grubert & Kitasei, 2010].

Electricity generation

Roughly 80 % of the water consumed when using natural gas as an electrical energy source occurs at the electricity generation stage [Kitasei & Eilbert, 2011]. To generate electricity, natural gas is combusted in either a traditional steam-cycle plant or in a natural gas combined cycle plant. Steam-cycle plants are about 40% efficient and must boil water to produce the mechanical energy required to power their generators. NGCC plants use a combustion turbine—similar to a jet engine—that requires no boiler water, and also use a traditional steam-powered generator. In an NGCC system, waste heat is taken from the combustion turbine and used to power the associated boiler. About 66% of the electricity produced in a combined cycle system comes from the turbine component, while the other 34% comes from the steam component. NGCC systems are much more efficient and typically require much less water than steam-cycle systems of a similar size.

Flue gas desulfurization (FGD), which can require significant quantities of water at coal-fired power plants, is not necessary at natural gas-fired power plants due to NG's low sulfur content [Grubert & Kitasei, 2010].

Both systems, steam-cycle and combined cycle, can use either wet cooling or dry cooling. The differences between wet cooling and dry cooling are discussed in the Coal Summary.

In January 2011, Western Resource Advocates presented a startling economic valuation of water resources for a model 500 megawatt NGCC power plant using either a wet- or a dry-cooled system.[4] Their results are summarized in the following table:

[4] The wet cooled system is closed-loop (i.e., it uses cooling towers).

Figure 4. Table of costs, annual water consumption, and added value of water for a model 500 MW natural gas combined cycle power plant using either wet or dry cooling [Tellinghuisen, 2011].

500 MW Natural Gas Combined Cycle, Wet vs. Dry Cooling		
Cooling Type	Wet	Dry
Capital Cost ($)	7,629,421	30,414,637
Total Annual Cost ($)[5]	1,528,977	5,137,211
Vol. water consumed (million gallons/year)	910.1	(none)
Added value of water ($) per million gallons per year	3,966	(none)

By their reasoning, the use of dry cooling in the arid west only makes sense when the cost of water (i.e., cost of water rights) exceeds $52,179 per million gallons or 5.2¢ per gallon. Still, on a per kilowatt·hour basis, combined cycle plants can consume less than half of the water of coal steam plants [Kitasei & Eilbert, 2011].

A review by Fthenakis and Kim (2010) summarizes the results of various government and academic studies and provides the following figures for water withdrawals and consumption for natural gas-powered electricity [Fthenakis & Kim, 2010]:

The article also provides life-cycle water withdrawals for various fuel types (see the *Life-cycle view of water resource use*).

Waste removal

Substantial quantities of waste are generated during drilling, fracking, and combustion. During drilling and fracking, "flowback" and "produced water" present the greatest waste management challenges to drilling companies and environmental regulators. At the combustion stage, the most significant waste stream is carbon dioxide gas. The environmental effects of these waste streams are discussed in the Water Impacts section, which follows.

Filtration and reuse of contaminated gas well water are methods used to minimize waste [Kitasei & Eilbert, 2011]. In many cases, the water is too salty to be used for irrigation or other purposes, so it is either reinjected into the ground or sent to wastewater treatment plants (WWTP), which are generally ill-equipped to "treat" the contaminated water. At a

[5] Annual cost equals the capital cost plus annual operations and maintenance costs over the 30 year life of the plant.

wastewater treatment plant, settling tanks allow denser material to be separated out, while the remaining water is diluted with fresh water until the WWTP operators are comfortable releasing it.

When CO_2 is treated as waste, the water requirements of handling it can be colossal. By volume, natural gas is 93.9% methane (CH_4), 3.2% ethane (C_2H_6), 1.0% carbon dioxide (CO_2), 0.8% nitrogen (N), 0.7% propane (C_3H_8), and 0.4% n-butane (C_4H_{10}) [Woods et al., 2007], so it is unsurprising that carbon is a byproduct of combustion.

The process of "capturing" the gas from the flue and then compressing it are the most water intensive steps in the entire process [Ciferno et al., 2010]. The final step, sequestration, involves injecting the compressed CO_2 into geoformations. Sequestration generates produced water which must be managed.

CCS added to NGCC increases raw water usage by 81%, due largely to the significant cooling water demands associated with the Econamine process which isolates the CO_2 from the other gasses (see Figure 1 in Coal Summary). The Carbon Dioxide Recovery (CDR) cooling water requirements used for flue gas conditioning are much greater than for the NGCC plant energy generation itself: 681,000 gpm vs. 60,000 gpm [Woods et al., 2007].

Life-cycle view of water resource use

Fthenakis et al. (2010) compare the life-cycle water uses of a variety of fossil fuels, including natural gas, but it does not consider the differences in total water consumption with regard to source type (conventional vs. unconventional). The major differences they outline concern cooling system type [Fthenakis & Kim, 2010]. See Figure 2 in the Coal Summary for life-cycle water withdrawal factors for natural gas-based electricity and other fuel types.

Regional differences

Unconventional gas resources differ between the Eastern and Western U.S. A major difference is that coal bed methane wells, which tend to be net producers of water, are more common in the West [Groat, 2009] and the geology makes reinjection of produced water a viable option.

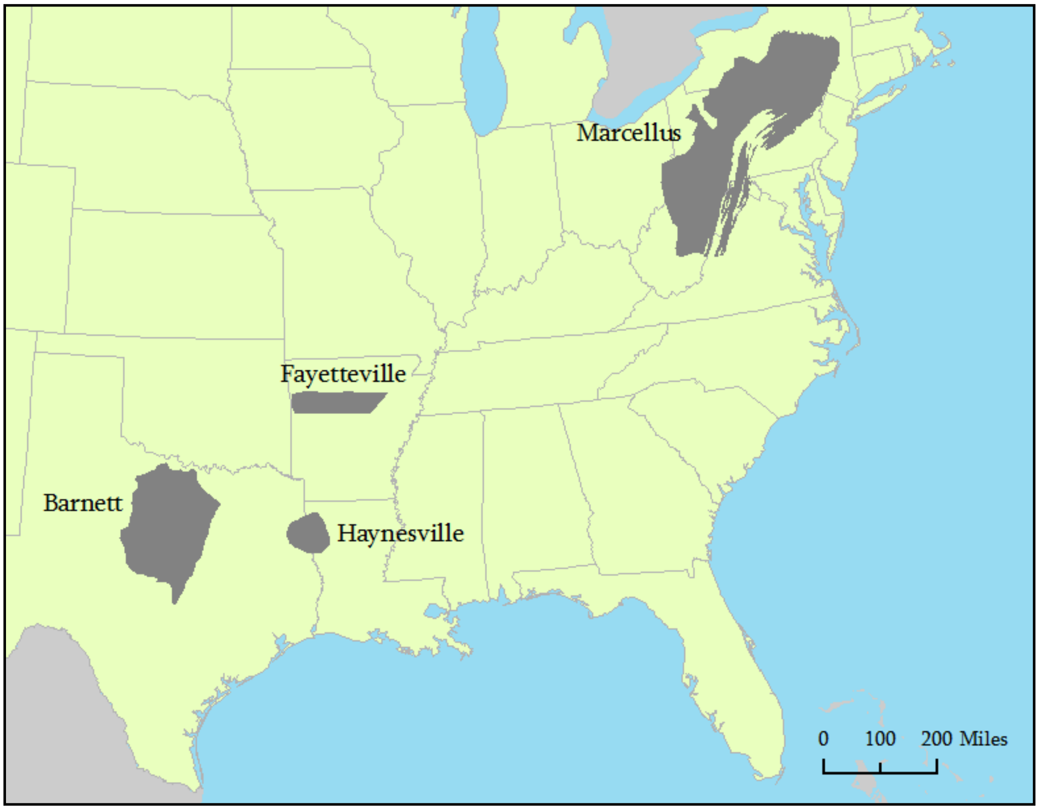


Figure 5 (above)**.** The four major gas shale areas in the central and eastern US are the Barnett, the Haynesville, the Fayetteville, and the Marcellus formations. The following map shows where the resources are located [Data from FracTracker, 2010].

Figure 6 (below)**.** Industry projected water demands for wells in the four major gas shale plays in the U.S. [Adapted from Satterfield et al., 2008].

Name	Water used per well (thousand gallons)	Wells per year	Total water per year
Barnett	420 (drilling) 2,940 (fracking) **3,360 (total)**	600	2.016 billion gallons
Haynesville	1,050 (drilling) 2,730 (fracking) **3,780 (total)**	200	756 million gallons
Fayetteville	63 (drilling) 2,940 (fracking) **3,003 (total)**	250	756 million gallons
Marcellus	84 (drilling) 3,780 (fracking) **3,864 (total)**	60	2.310 billion gallons

In the Marcellus region, WWTPs are proving inadequate for dealing with the high volumes of highly saline flowback and produced water. For the Marcellus areas, reinjection of produced water is a poor option due to geology. Furthermore, land constraints and humid climate prevent evaporation ponds from being a suitable option, so wastewater treatment plants will face significant challenges [Grubert & Kitasei, 2010]. After "treating" the water, WWTPs discharge it into local surface waters [Urbina, 26 Feb. 2011].

WATER IMPACTS

There are hundreds of thousands of gas wells in the United States. A snapshot reveals that Pennsylvania has 17,000 active gas wells [Urbina, 1 Mar. 2011], Wyoming has 27,000, and Texas has 93,000 [Urbina, 26 Feb. 2011]. At present, there is no comprehensive database of all gas wells in the United States, but it is clear that accidents and negligence—even rare occurrences of either—can have terrible impacts on communities and ecosystems.

Contaminated fluids

The three greatest environmental challenges related to gas production are: (1) supplying water to wells without impacting local water resources, (2) avoiding degradation of small watersheds due to heavy equipment movement, and (3) disposing of large quantities of contaminated fluid [Soeder & Kappel, 2009]. The environmental challenges faced by natural gas-powered thermoelectric facilities include the following: (1) supplying water to cooling systems and boilers without impacting local water resources, (2) avoiding degradation of upstream habitats due to fish kills at cooling water intakes, and (3) avoiding degradation of downstream habitats due to chemical and thermal loading.

The major direct water impacts occur during drilling, fracking, and power plant cooling, but the other energy production stages may have negative impacts. Drilling and fracking fluids, which are touted by unconventional natural gas advocates as being "99.5% fresh water and sand" [Harder, 2010], contain friction reducers, biocides, scaling inhibitors, coagulants, and surfactants that are added to increase fluid mobility [Elcock, 2010].

Produced water (formation water) is water that existed within the rock formation itself. It often contains high salt concentrations and can contain naturally occurring radioactive material, arsenic, benzene, and mercury. Flowback is the fracking fluid that seeps back out of the ground. Both are waste streams [Grubert & Kitasei, 2010].

Despite claims that 99.5% of the drilling fluid is water and sand, the volumes of water involved are so large that the remaining 0.5% at one well might represent 15,000 gallons of pure chemicals. One well can produce 27 tons of salt per year. Reinjection and wastewater treatment is not possible in all locations. Evaporation ponds are used in some areas to dry the fluid until it can be moved to landfills, or "recycled" as contaminated road de-icer [Urbina, 1 Mar. 2011].

The solution to aboveground contamination is a policy of stricter handling standards, use of less harmful chemicals, and use of adequately lined storage pits. Below ground contamination may be curbed with better well casing techniques and more accurate identification of zones that should be isolated due to their proximity to fresh groundwater resources [Grubert & Kitasei, 2010].

Figure 7. Photograph of a poorly lined produced water pit at a natural gas drilling site near Nitro, West Virginia. The plastic tarp used to line the pit had leaked, causing a fish kill event within a nearby stream [Photo: S. Sheldon, 2009].

Erosion, landslides, and soil loss can occur as a consequence of drilling pad construction and associated traffic, including transport of water to the site [EPA, 2007].

Figure 8. Table of natural gas energy process stages and associated water impacts.

Process Stage	Water Impact
Extraction	Ground and surface water impacted by produced water and flowback; watersheds degraded by heavy equipment traffic
Treatment	Consumption of some water for process cooling
Transport/Storage	Water used in pipe testing; use of conduits reduces truck traffic; water used to dissolve salt caverns
Electricity Generation	Thermal and air emissions impact surface waters and ecology; chemicals added to cooling water include de-scaling agents and biocides; thermal pollution and possible downstream evaporation rate increases [Dziegielewski & Bik, 2006]; fish kills at water intakes
Waste Removal	Mismanaged produced water negatively impacts human health through drinking water contamination and degrades aquatic habitats

Costs to human health

It is unclear at this time what quantifiable costs to human health are associated with using natural gas as an energy source. Much of the focus of governmental research (e.g. studies done by the EPA) has been on the costs associated with coal as a fuel source—much to the chagrin of the coal industry. A big obstacle to doing a national scale study on the health costs of natural gas is that the industry is managed on a state by state basis, so aggregated records are scarce. Perhaps the greatest obstacle to doing such a study, however, is that many of the chemicals associated with natural gas drilling and fracking are protected by federal legislation as "trade secrets" and their human health effects are unknown.

RECENT DEVELOPMENTS

December 2011 – The EPA issued its initial findings regarding Wyoming fracking pollution. The report documents the contamination of an aquifer beneath Pavillion, WY, but not of drinking water wells. The report also highlights a variety of other environmental offenses—many of which were legal at the time—of the drilling companies, including contamination of some near-surface wells with benzene and xylene by conventional drilling, failure to adequately record fracking chemical information on Material Safety Data Sheets, and failure to adequately seal most wells with concrete (Soraghan, 2012b).

February 1, 2012 – Following the passage of stricter laws governing fracking fluid chemical disclosure in Louisiana, Montana, and Wyoming, new requirements took effect in Texas, applying to newly permitted wells. Colorado has similar requirements taking effect on April 1, 2012. Oklahoma and West Virginia are currently considering similar rules (Gronewold, 2012).

February 1, 2012 – The Vermont House of Representatives is expected to push through a three-year ban on hydraulic fracturing in the state. The mere threat of groundwater contamination in the state was enough to halt development (Sullivan, 2012).

February, 2012 – The 2013 budget approved by President Obama requests $45 million for a study of the effects of hydraulic fracturing to be undertaken by the USGS and the DOE. It will build upon an ongoing study by the EPA and broaden the scope of the investigation to include air and other environmental impacts in addition to water quality impacts (Soraghan, 2012)

February, 2012 – New York environmental regulators are still processing public comments and have not yet made a decision about whether or not to end the current moratorium on unconventional natural gas development in the state (Sullivan, 2012b).

Nuclear

RESEARCH AREA

The U.S. generates roughly 19% of its electricity from 104 nuclear reactors at 54 nuclear power plants. The preferred fuel source for nuclear fission (i.e., atom splitting) is **uranium 235** (U-235). The fission process creates heat, which boils water and creates steam for spinning a generator turbine [Dennen et al., 2007]. In this way, nuclear power plants are similar to all other thermoelectric facilities. Much of the research done by the nuclear energy industry focuses on maximizing both technological and economic efficiency during electricity production and fuel preparation. Meanwhile, security and safety are at the heart of most laws regulating nuclear energy.

Many aspects of the nuclear industry are not open to public scrutiny to the degree that the coal and natural gas industries are. In fact, the federal government sees the Nuclear Reactors, Materials, and Waste Sector as a separate entity from the Energy Sector and subject to different regulatory and protective authority.[6] The DOE is responsible for the regulation and protection of Energy Sector facilities, while the U.S. Nuclear Regulatory Commission (NRC) and the Department of Homeland Security (DHS) Office of Infrastructure Protection are responsible for the regulation and protection of nuclear industry, respectively [Chertoff, 2009].

Legislation

Several key pieces of legislation are meant to provide for the safe and secure use of nuclear energy by civilians:

- The **Atomic Energy Act of 1954** (AEA) was the original piece of legislation that allowed for the development and regulation of non-military uses of nuclear materials (e.g. U-235). It gives the NRC oversight over the use of nuclear materials [Chertoff, 2009] and directs the NRC to issue 40-year permits for commercial nuclear power plants, with the option of a 20 year extension at the expiration of the original permit. In 2009, roughly half of the nuclear reactors had been approved to operate for an additional 20 years [Conti et al., 2010]. An amendment to the original AEA gives the EPA authority to set standards and to offer guidance

[6] From the U.S. Department of Homeland Security's *National Infrastructure Protection Plan* (2009), p. 3, footnote: "The Energy Sector includes the production, refining, storage, and distribution of oil, gas, and electric power, except for commercial nuclear power facilities."

to protect the environment from the radioactive materials that result from nuclear energy production [EPA et al., 2011].

- The **Resource Conservation and Recovery Act** (RCRA) is the law which empowers the EPA to regulate hazardous materials over the entire life-cycle of the materials use (i.e., cradle-to-grave). This law, as with many laws directing the EPA to protect the public and the environment from nuclear energy activity, is not specific to nuclear waste. Areas of regulation under the RCRA include waste generation, transportation, treatment, storage, and disposal [EPA et al., 2011].
- The **Uranium Mill Tailings Remediation Control Act** (UMTRCA) requires the EPA to set environmental and public health standards for air emissions, soil, and groundwater at operating and closed radioactive fuel production sites [EPA et al., 2011]. It also gives the DOE authority to direct remediation activity at 26 former uranium production sites in the U.S. [National Research Council, 2010]. Uranium- and thorium-rich tailings (i.e., overburden) are not classified as radioactive waste under U.S. laws, so storage in radioactive waste disposal facilities is not required [National Research Council, 2010].
- In 2005, the Navajo Nation Council passed a law to ban uranium mining and processing at locations within Navajo Indian Country [National Research Council, 2010].
- The **Low-Level Radioactive Waste Policy Act** (LLRWPA) require each state to construct facilities for disposal of commercial low-level waste (i.e., the least radioactive class of radioactive waste) produced within its borders. It also encourages states to work together to develop regional disposal facilities [EPA et al., 2011].
- The disposal of high-level radioactive waste (i.e., HLRW, the most radioactive class of nuclear waste) generated by commercial and defense activities is regulated under the **Nuclear Waste Policy Act** (NWPA). The NWPA directs the DOE to develop a deep geologic repository for the waste and gives the NRC the authority to license the site. The EPA retains its authority to set radioactive exposure limitations for humans and the environment [National Research Council, 2010; EPA et al., 2011]. Yucca Mountain in Nevada was chosen as the best geologic repository.
- The **Energy Policy Act of 2005** (EnPA) specifically directs the EPA to protect the public from releases of radioactive materials from the Yucca Mountain HLRW repository by setting exposure standards. The EnPA also required the EPA to sponsor research by the National Academy of Sciences to provide recommendations for exposure limitations. The EPA standards must be consistent with NAS's recommendations [EPA et al., 2011]. To date, the use of Yucca

Mountain as a repository of spent fuel and other highly radioactive materials is uncertain. The Fiscal Year 2010 Budget of the White House significantly reduced the amount of funding available to the project, and the Obama Administration has indicated skepticism about its political and economic feasibility [National Research Council, 2010].

- The **Clean Water Act (CWA)** and specific sections are described in the *Legislation* section of the Coal Summary.
- The **Safe Drinking Water Act (SDWA)** is also outlined in the *Legislation* section of the Coal Summary.
- The **Marine Protection, Research, and Sanctuaries Act** (MPRSA) authorizes the EPA to issue permits and set regulations for the disposal of wastes in the ocean when the disposal won't endanger human health, marine ecology, or the economy. MPRSA specifically prohibits ocean disposal of high-level waste [EPA et al., 2011].
- After the terrorist attacks on September 11, 2001, Congress swiftly passed the **Homeland Security Act** (HSA) establishing the Department of Homeland Security (DHS) and defining its mission to reduce the vulnerability of critical infrastructure facilities to attack, disasters, and other emergencies, and to coordinate their activities with the DOE and the NRC. Title II § 201 of the HSA assigns principal authority to DHS to create comprehensive protection plans [Chertoff, 2009].

Government research

The NRC, DHS, and DOE work together to ensure the protection of nuclear reactors and fuel [Chertoff, 2009]. Energy-related governmental research tends to favor high technology solutions and the protection of that technology. Nuclear energy research is especially opaque—more so than even the coal and natural gas industries.

Overheating is arguably the greatest safety risk to nuclear facilities. Cooling technology is a key area of research for nuclear engineers and scientists, and improving the technical efficiency of cooling water withdrawals for electricity production is an especially difficult task. Many industry scientists believe that there is only a small potential for improving the efficiency of once-through and close-loop cooling systems at nuclear power plants [Dziegielewski & Bik, 2006].

Comparatively less research is being done on the adequacy of existing regulatory schema for ensuring the safety of nuclear power plants and the availability of their cooling water sources. One possible explanation is that industry experts tend to view at-plant water use as being strictly dictated by predictable physical laws [Yang & Dziegielewski, 2007]. A 2007 paper by Yang and Dziegielewski demonstrated that federal and state water management strategies may play an equally important role in determining thermoelectric power plant water use rates. For example, all other things being equal, water withdrawal and consumption tend to be lower when power plants must pay for water from municipal supplies, and higher when the plant uses free, permitted water from a local water body [Yang & Dziegielewski, 2007].

In one study, NREL estimated that an additional 3.8 billion gallons per day of fresh water would be needed for the retrofit of all existing natural gas and coal-fired power plants with carbon capture technology. 1.7 bgd would be needed for the CO_2 capture and sequestration systems, while 2.1 bgd would be needed for the additional nuclear power plants *built to compensate for the parasitic load loss resulting from the CO_2 system retrofits of the fossil fuel plants* [Shuster, 2009].

As a purveyor of publically accessible U.S. energy industry statistics and plant-specific information, the EIA provides water use statistics for the fleet of thermonuclear plants through 2000 [Dziegielewski & Bik, 2006].[7] Non-classified NRC records are available through the Agencywide Documents Access and Management System (ADAMS) [Lochbaum, 2011]. Power plant managers have historically been reluctant to participant in voluntary surveys, especially those conducted by academic researchers [Dzigielewski & Bik, 2006], and full disclosure of power plant operations by plant managers to environmental agencies is not incentivized.

There is still a real need for federal guidance and a decision methodology for regulators and managers on energy and water challenges [Vine, 2010] especially within the nuclear energy industry.

Specific nuclear industry goals

Although uranium 235 is a non-renewable resource, nuclear is seen by many as the ultimate answer to U.S. and world energy woes. It is viewed as a reliable source of baseload energy and as a "clean" energy type because it generates no greenhouse gas (GHG) emissions at the power plants [Dennen et al., 2007]. It is also seen as an answer to U.S. dependence on foreign sources of fuel (e.g. oil from antagonistic Middle Eastern nations).

The Nuclear Energy Institute (NEI) describes itself as "the policy organization of the nuclear energy and technologies industry," and having the objective of "ensur[ing] the formation of policies that promote the beneficial uses of nuclear energy and technology in the United States and around the world" [NEI, 2011]. It is generally regarded as the public mouthpiece of nuclear power in the U.S. The following statements are excerpted from "Fact Sheets"

[7] The EIA stopped reporting water use information for nuclear thermoelectric facilities after 2000.

available on the NEI website and underscore an industry-wide and inaccurate view that nuclear power is environmentally benign:

> "…*People and all wildlife are prohibited from the* [uranium ore] *tailings and impoundment area*[s]. *When milling operations cease, the impoundment area is reclaimed and permanently isolated from the environment*" [NEI, 2009a].
>
> "*Nuclear power plants have a small environmental impact and produce reliable electricity in a wide range of weather conditions*" [NEI, 2009b].

The preceding quotations are befuddling for several reasons: (1) it is impossible to prohibit "all wildlife" from tailings and impoundment areas, (2) nothing can be "permanently isolated from the environment" so a statement to the contrary is nonsensical, (3) nuclear power plants degrade aquatic ecosystems as a consequence of their reliance on nearby water resources for cooling systems, and (4) nuclear power plants must shut down during extreme climate events such as droughts and heat waves.

At best, the two most visible NEI "Fact Sheets" on water and environmental impacts of the nuclear energy industry play down the significance of industrial-scale mining, processing, energy generation, and disposal activity. At worst, they wholly misrepresent the substantial human health and environmental risks associated with the industry.

Another priority of the nuclear energy industry is to present nuclear power as a cost effective alternative to natural gas-fired power plants, coal-fired power plants, and renewables. While "cheap" nuclear facilities run on the order of $4,000/kilowatt to construct and maintain—comparable to natural gas and coal facilities that do not have CCS—cutting edge nuclear technology costs closer to $7,000/kilowatt, which exceeds most other types of traditional thermoelectric technology [Levine et al., 2010]. Indeed, capital costs for a nuclear power plant can range between $2-6 billion, and while fuel accounts for a relatively small percentage of the total cost, facility maintenance and security costs are often high [Dennen et al., 2007].

Finally, nuclear power generation has been compared to concentrating solar power (CSP) technology, because some studies have shown that CSP consumes more water per kilowatt·hour of generation than nuclear. In fact, only a subset of CSP technologies has greater water demands than nuclear power facilities. Other CSP power plants and many other renewable energy types such as solar photovoltaics and wind turbines have much lower water demands than nuclear facilities [Dennen et al., 2007].

WATER DEPENDENCIES

Process of using uranium as a fuel source

Large quantities of water are used during the mining, milling, refining, conversion, enrichment, and power generation stages of uranium 235 use as a fuel source [NEI, 2009a, Fthenakis & Kim, 2010]. Water availability is critical to the successful completion of each stage as uranium ore moves through the process until its eventual storage as a spent and highly radioactive fuel.

Mining

There are three types of uranium mines worldwide: **open-pit**, **underground**, and **in-situ leaching** (ISL) mines. 3 active underground and 6 active ISL mines exist in the U.S. [Dennen et al., 2007], and they account for about 5% of global production [Elcock, 2010]. The EPA estimates that there are at least 15,000 abandoned mines in the U.S. that are potential human health hazards because of the presence of technologically enhanced naturally occurring radioactive material (TENORM), like uranium. Only a fraction of the mines (27%) are well-documented [EPA, 2006]. Water use varies by mine type. Generally, ISL mining uses less water than either open-pit or underground mining. During ISL mining, solvents are pumped into the source rock, mobilizing the uranium into solution. The solution is pumped back out of the ground, along with the degraded groundwater. During open-pit and underground mining operations, ores containing extremely low quantities of uranium 238 and the rarer uranium 235 isotopes are milled (i.e., crushed and refined) and leached in a later step.

Water is also used at mine sites for dust control due to mine traffic and revegetation of mined surfaces during site remediation [Dennen et al., 2007].

Milling, Refining, and Conversion

The primary water requirements of the milling and refining stages are for evaporation from tailings ponds and evaporative cooling [Dennen et al., 2007] as the fuel is prepared for conversion from uranium oxide powder (i.e. "yellowcake") into uranium hexafluoride gas (UF_6) [National Research Council, 2010]. The yellowcake powder is converted to uranium hexafluoride by either a dry or wet process. In the U.S., a "dry fluoride volatility" process is used [Lochbaum, 2007].

Enrichment

Uranium hexafluoride gas is "enriched" by increasing the percentage of uranium 235 contained in the material from less than 1% to between 3-5% by mass.

Enriching can be done by centrifuge or gaseous diffusion. The former uses less water per unit mass of uranium produced than the latter. Both processes are energy intensive [Dennen et al., 2007].

Electricity generation

Power generation is the most water intensive stage of the nuclear fuel cycle, both in terms of water withdrawn and water consumed. As with other thermoelectric technologies, water is needed to cool the plant to produce electricity in either a once-through or a closed-loop system.

For both boiling water reactors (BWR) and pressurized water reactors (PWR) [Lochbaum, 2007], water from a nearby surface water source or from municipal supplies is used to carry heat away from the plant. A variety of water-related events have been at the heart of past near-meltdowns in the United States: flooding and leaking roofs that damaged cooling equipment, ice blockage of cooling water intakes, and blockage of cooling water intakes by aquatic organisms [Lochbaum, 2007; Lochbaum, 2011].

Generally, nuclear power plants use fresh, once-through systems for their cooling needs [Sovacool, 2009], but some use recirculating (i.e. closed-loop) systems with cooling towers. In the case of closed-loop plants, water is withdrawn to replace the water vapor that is carried away by the heated air exiting the cooling tower [Madsen et al., 2009]. Water is also used for essential service systems [Lochbaum, 2011], such as air conditioners, main turbine oil coolers and heat exchangers, and back-up generators [Madsen et al., 2007]. The recent meltdown at the Fukushima nuclear power plant in Japan occurred when auxiliary diesel generators that provided backup power for the plant's cooling system were destroyed by a tsunami [DOE & Sandia, 2006].
Advanced cooling options for thermoelectric facilities that reduce at-plant water dependencies do exist, but they are costly, complex, and perform poorly in warm weather [DOE & Sandia, 2006]. For instance, saline water sources may be used for cooling water (a common argument among proponents of nuclear power), but cooling tower performance is reduced with increasing cooling water salinity [DiFilippo et al., 2005]. Only in one of the driest cities in America was an advanced cooling system made economically and politically feasible; the Palo Verde Nuclear Facility in Phoenix, Arizona, is unique for its use of treated effluent for its cooling system [Dennen et al., 2007].

Nuclear fuel generates heat even when electricity is not being produced. The power plants must continuously remove the "decay heat" produced by the reactor core and to cool essential equipment and buildings [Sovacool & Sovacool, 2009]. In addition to carrying away excess decay heat, many older nuclear facilities must remain at full flow to reduce bio-fouling in the cooling water systems [Dziegielewski & Bik, 2006].

Life-cycle view of water resource use

As with coal- and natural gas-based electricity, the life-cycle water needs of nuclear energy can be substantial. Nuclear energy is particularly water intensive. Refer to Figure 2 in the Coal Summary for a comparison to other electricity generation technologies.

Regional differences

If the NEI Fact Sheet is to be taken at face value, domestic uranium production accounted for less than 10% of the fuel requirements in the United States. Imports accounted for the rest. Most uranium reserves in the U.S. are found in the western states: Arizona, Colorado, New Mexico, Utah, and Wyoming. Some are in Texas [NEI, 2009a]. Uranium mining may be viewed as a substantial economic boon by the counties in which it is mined.

The only uranium conversion (i.e., uranium oxide to uranium hexafluoride) facility in the U.S. is in Metropolis, Illinois. The only uranium enrichment facility in the U.S. is in Paducah, Kentucky. The Paducah facility uses gaseous diffusion technology [National Research Council, 2010].

As of April 2008, the NRC was considering 23 applications for a total of 34 new nuclear reactors. 21 of the 23 proposed facilities would be in the Southern States Energy Board (SSEB) region. The SSEB is an interstate compact between 16 southeastern states and two territories. The tendency is to request permits to build on existing nuclear sites in order to use familiar water supplies and to work within existing water withdrawal permit limitations and other environmental regulations [Feldman & Garrett, 2008].

In the future, there may be a tendency for new thermoelectric plants of all kinds to concentrate within the most economically desirable transmission corridors, due to the recent restructuring of the electric utility industry. Power plant developers are no longer required to abide by certain state-specific site selection regulations [Parfomak, 2008].

WATER IMPACTS

Aquatic habitats and public drinking water supplies may be impacted at any stage of the nuclear fuel cycle.

Spills and leaks

In July 2008, the NRC released the draft *Generic Environmental Impact Statement for In-Situ Leach* (ISL) *Uranium Milling Facilities* (GDEIS), to evaluate the impacts of ISL. In the report, the NRC recognizes the possibility of large impacts on cultural, ecological, and groundwater resources, depending on the site-specific mine conditions. The groundwater impacts would be the result of spills, leaks, and solvent injection [National Research Council, 2010]. Spills and leaks are also risks during the milling, refining, conversion, enrichment, electricity generation, waste removal, and waste storage stages. Ultimately, though, the greatest measurable impacts on water resources occur at the electricity generation stage.

No nuclear power plants in the U.S. use dry cooling technology [Dennen et al., 2007]. 43.6% of U.S. nuclear facilities use wet recirculating systems, 38.1% use once-through systems, and 18.3% use cooling ponds [Shuster, 2009]. In short, all nuclear facilities are critically dependent on nearby water resources. An inevitability of that connection is leakage due to aging systems and spills due to human activity. For instance, in December 2005, Exelon Corporation reported to environmental regulators that its Braidwood reactor in Illinois had released millions of gallons of radioactively contaminated water into the environment [Sovacool & Sovacool, 2009].

Cooling water

Nuclear facility impacts on water resources are not limited to leaks and spills. Upstream and downstream ecosystem impacts are often substantial and are related to physical, thermal, and chemical stresses. Fish larvae can be impinged on intake structures or destroyed (entrained) within the cooling systems [Barnthouse, 2000]. Unlike coal-fired power plants, nuclear facilities do not release combusted gases and must release a greater percentage of their waste heat through their cooling system [Stillwell et al., 2009]. Thermal shock can kill aquatic species and can permanently alter ecosystem dynamics. Chronic high temperature discharges can be as detrimental to ecosystem health as instantaneous thermal discharges. Thermal loading also increases downstream evaporative losses [Shuster, 2009], thereby removing the water from use as drinking water or by ecosystems within the supporting watershed. Encouragingly, thermal effects may be short lived [Poornima et al., 2006], but habitat degradation and diminished fish stocks persist with continuing thermonuclear electricity generation. An extreme example of fish losses due to thermonuclear activity occurs at the Crystal River Power Plant in Florida. Scientists estimate that approximately 23 tons of fish of recreational and commercial value are lost each year as a consequence of larvae mortality at the plants cooling water intake structures alone [Sovacool & Sovacool, 2009]. Cooling effluents and cooling tower blowdown[8] also contain chemical stress factors like biocides (e.g. chlorine to prevent biofouling) [Poornima et al., 2006], salts, heavy metals—and if leakage is occurring at the power plant—radioactive material.

Water impacts are not limited to the watersheds in which electricity is being consumed. For instance, electricity from the Palo Verde Nuclear power plant is sold to residents in Southern California [Dennen et al., 2007]. Similarly, Intel microchips are produced and sold to other parts of the world using a tremendous amount of water-intensive energy [Power, 2008]. In both cases, water is evaporated at the Palo Verde plant, eventually falling as rainfall in another watershed.

Figure 9. Table of nuclear energy process stages and associated water impacts.

Process Stage	Water Impact
Mining	Introduction of liberated impurities from source rock including heavy metals, salts, and radioactive isotopes during ISL and as runoff from open-pit and underground mine tailings to ground and surface water
Milling, Refining, and Conversion	Water used in evaporation ponds and for cooling is removed from natural habitats and can be a stress on aquatic species; spills and leaks can introduce low-level radioactive materials (e.g. uranium, thorium, tritium) into the environment
Electricity Generation	Fish larvae are killed at the intake and within the cooling systems whether electricity is being generated or not; thermal plumes degrade downstream habitats; consumed water is no longer immediately available for ecosystem use or as drinking water; cooling tower blowdown and reactor leaks introduce pollutants into freshwater resources
Waste Removal and Storage	Spills and leaks introduce radioactive pollutants into the environment

Costs to human health

Direct costs to human health as a consequence of nuclear energy generation are difficult to quantify. In fact, a 2010 study by the National Academy of Sciences—meant to identify the "unpriced" consequences of energy generation—was unable to estimate costs associated with

[8] Over time, impurities build up in the cooling towers and boilers at closed-loop facilities. In order to maintain efficiency, the impurities are purged into nearby waters as "blowdown" [Sovacool & Sovacool, 2009].

nuclear power plants and radioactive fuel transportation due to financial resource constraints and limited time [National Research Council, 2010].

The most visible examples of financial and human health costs are related to remediation after disasters. The 1979 meltdown of the Three-Mile Island power plant in the U.S., the 1986 Chernobyl nuclear plant meltdown in the Ukraine, and March 2011 meltdown at the Fukushima nuclear plant in Japan all give a low-range approximation of the true costs of using nuclear power and the near certainty of both unexpected events and human error.

While the possibility of nuclear disaster always looms, a less visible impact on public health is radionuclide ingestion due to contamination of surface waters by active mines. Abandoned and rehabilitated mines can contaminate ground and surface water supplies over long time periods. Bioaccumulation of contaminants in fish can be a source of risk to people who catch and ingest them [National Research Council, 2010].

Ultimately, the greatest risk to human health stems from the dependence of nuclear reactors on the availability of abundant water supplies and their poor record of performance during heat waves. During the 2003 heat wave in France that killed 14,802 people, nuclear power plants were forced to dial back their energy generation in order to stay within their nationally mandated thermal discharge limits [Stillwell et al., 2009]. The U.S. has similar environmental standards, and our nuclear power plants face similar risks.

RECENT DEVELOPMENTS

February 9, 2012 – The Nuclear Regulatory Commission voted to approve the construction of the first new nuclear reactors built in the U.S. since 1978 for an existing nuclear facility in Georgia. The new reactors are expected to cost $14 billion to build and to be online by 2017. The construction is backed by an $8.3 billion federal loan guarantee (Northey, 2012). The nearest water source is the Savanah River, which will like be used for the new reactors' cooling needs.

ONLINE RESOURCES

Many publically accessible online tools exist that provide information about the U.S. coal industry, as well as individual plants. Governmental databases provide information for interested individuals out of legislative obligations, while independent public interest firms provide resources out of a desire to slow—and perhaps reverse—the rate of fossil fuel and uranium-based energy production in the U.S. None of the databases and informational tools is well advertised, and only a few offer user-friendly and engaging interfaces. Below is a listing of national energy-related databases. Some specifically provide data on power plants while others provide environmental data that is influenced by the presence of energy facilities or operations. Level of user-friendliness, accessibility, scope (i.e., geographic region, focus), spatial resolution, intended audience, and mapping capabilities are included in the table on the next page.

A note on power plant tracking

The NETL, which is one of the most advanced labs in the field of energy industry analysis, recognizes that *proposed* power plants and plants that will *eventually become operational* are different things. When tracking new coal-fired power plants, for instance, the NETL divides facilities into five separate categories: announced, permitted, near construction, under construction, and actual (i.e., operating) [NETL, 2010]. Ultimately, only some of the plants that get announced get permitted, and only some of those which get permitted are actually built. These distinctions are among the countless vagaries that can make map-based learning and outreach a complicated, confusing, and intimidating prospect for a novice environmental advocate.

The single greatest problem with all of the following power plant and environmental databases is that **they are not in the mainstream and are being used by only a fraction of the population**. Opportunities abound for improving and aggregating existing data sets into cohesive informational units and digital outreach tools.

Figure 10.

Name	User-Friendliness	Access-ibility	Scope	Spatial Resolution	Mapping tools?	Audience
ALL Consulting	Moderate	Available upon request	National, power plants	High	**Yes**	Facility managers interested in finding alternative water resources
Carbon Monitoring for Action (CARMA)	High	Public	National, power plants	High	**Yes**	Coal activists and community groups
Clean Water Act Listing of Impaired Streams	Low	Public	National, listing of impaired rivers	High	No	Environmental practitioners and activists
EPA eGrid Power Profile	High	Public	National, zip code level listing of electricity subregions and emissions	Low	No	The general public, business owners
EIA Survey 767 (1996-2005)	Low	Public	National, power plant database with water source information, withdrawals, and consumption	High	No	Energy industry analysts, environmental practitioners
EIA Survey 860 (1990 – 2008)	Low	Public	National, power plants, technology type, emissions, generation, coal ash	High	No	Energy industry analysts, environmental practitioners
EIA Survey 923 (2009-present)	Low	Public	National, power plants, replacing old forms 767 and 923	High	No	Energy industry analysts, environmental practitioners
Energy Justice Network	High	Public	National, power plants	High	**Yes**	Environmental activists and community groups
Environmental Working Group	High	Public	National, utility-specific water quality	High	No	Individuals interested in their water quality
EPA's Greenbook of non-attainment areas [Woods et al., 2007]	Low	Public	National, regionally focused air-quality guide	Moderate	No	Environmental practitioners and energy developers
EPA PCS & ICIS-NPDES	Low	Public	National, water discharge permits	High	No	Environmental practitioners
EPA Toxic Release Inventory Explorer [Armstrong et al., 2009]	Low	Public	National, document toxic releases	High	**Yes**	Practitioners and community groups
FracTracker	Moderate	Public	National, pilot focus on Marcellus shale region, document impacts of NG industry	High	**Yes**	Practitioners, environmental activists, community groups
IEEE Spectrum	High	Public	Worldwide, water/energy conflicts	Low	Some	The general public

Name	User-Friendliness	Access-ibility	Scope	Spatial Resolution	Mapping tools?	Audience
National Water Use Information Program (NWUIP) [Dziegielewski & Bik, 2006]	Moderate	Public	National, aggregated water use stats	Low	No	Water management and environmental practitioners
NETL Coal Power Plant Database	Low	Public	National, coal power plants	High	No	Environmental, energy, and water management practitioners
Sierra Club: Stopping the Coal Rush	High	Public	National, coal power plants	High	**Yes**	Coal activists and community groups
SourceWatch	High	Public	Worldwide, Wikipedia-style coal industry database	Moderate	No	Coal activists and community groups
Synapse Energy Economics	Low	Private	National, coal power plants	High	No	Internal document used by Synapse and shared with Civil Society Institute
USGS StreamStats	Low	Public	National, stream flow data	High	**Yes**	Stream hydrologists, environmental practitioners, and community groups

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