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Nuclear power plant freshwater use - a serious economic and reliability vulnerability

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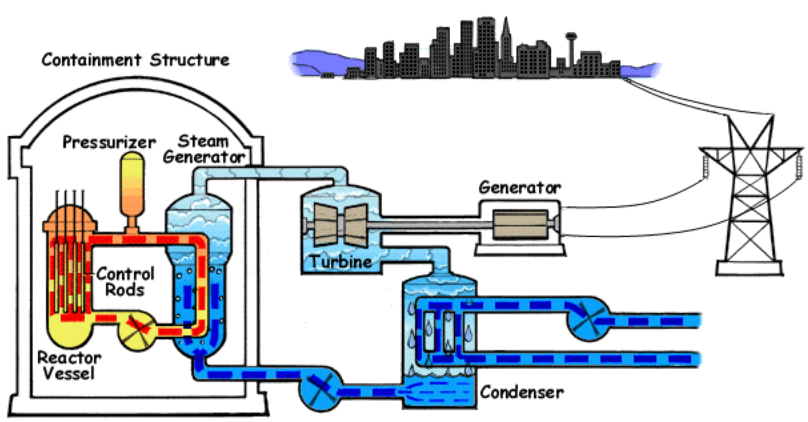
Vast amounts of water are used for thermal electricity generation – a source of increasing concern as summer temperature extremes rise and droughts become more intense and prolonged due to climate change. Freshwater withdrawals for thermal electricity generation are about four times the public water supply to all households in the United States. Freshwater withdrawals for nuclear generation alone – about 20 percent of U.S. generation – are greater than public water supply to U.S. households.

The increase in thermal electricity generation to power data centers for AI is adding to this problem. Freshwater withdrawals for electricity are second only to irrigation, and not by much: 95.1 billion gallons a day compared to 118 billion gallons a day.[i]

How thermal plants use water

Condensing the steam that drives the turbine in thermal plants – coal, nuclear, and gas[ii] – is integral to their operation. A nuclear power plant steam cycle is shown in the schematic of a pressurized water reactor below. Most of the residual heat in the steam is transferred to the condenser cooling water, which is heated up. The basic condenser scheme is the same in other thermal plants.



Schematic of a pressurized water reactor electricity generation system.
Source: Nuclear Regulatory Commission[iii]

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Heating the water evaporates some of it; the fraction depends on the specifics of the management of the condenser water. When cooling towers are used the heated water is trickled onto metal baffles, where it is cooled by evaporation. The unevaporated cooled portion of the water can be reused, with makeup water being supplied from a source like a river or lake.

Condenser water can also be discharged directly to the water bodies like rivers, lakes, and the ocean, from whence it was first withdrawn. This is known as “once-through” cooling. The hotter discharge water results in an increase in evaporation. The temperature increase and discharge temperature are regulated.

In all cases, the water lost through evaporation becomes unavailable to downstream users. It is, in effect, consumed.

Cooling towers require the least amount of water withdrawal while consuming the most water by evaporation. Their benefit is less thermal discharge to adjacent water bodies. The reverse is the case for once-through cooling – much more water withdrawn but considerably less water consumed. In round numbers, water losses by evaporation average between 300 gallons (once-through cooling) and 700 gallons (cooling towers) per megawatt-hour (MWh). Freshwater withdrawals are much more variable – about 1,100 gallons per MWh for cooling towers and over 40,000 gallons per MWh for once-through cooling.

Impacts on aquatic life and ecosystems

There are significant impacts on aquatic life due to the sheer volume of water that must be withdrawn. Screens are needed to keep organisms out of the condenser. The entrainment of organisms and their impingement on the screens installed on intake pipes were described by the EPA when it promulgated its 2014 rule to reduce those impacts:

> “The withdrawal of cooling water by existing facilities removes and kills hundreds of billions of aquatic organisms from waters of the United States each year, including plankton (small aquatic animals, including fish eggs and larvae), fish, crustaceans, shellfish, sea turtles, marine mammals, and many other forms of aquatic life. Most impacts are to early life stages of fish and shellfish.”[iv]

Tens of millions of pounds of fish production are lost each year in the U.S. to water intakes by power plants and large factories.

It is more than a matter of the quantity of water. Fungicides are added to cooling water when cooling towers are used to prevent fouling of the baffles. Discharging hot water back into rivers and lakes impacts those ecosystems, and can, for instance, encourage algal blooms. Power plant condenser water discharges have maximum temperature limits. Summer water intake temperatures are higher and thus tend to be the limiting factor in power plant thermal discharge requirements. Thermal discharges impact both freshwater and marine aquatic life, including benthic organisms (bottom dwellers). A recent review article in the Frontiers in Marine Science summarized the latter impacts as follows:

> “Thermal discharges adversely impact marine benthic organisms by decreasing biodiversity and changing community structure, largely due to elevated temperatures and reduced oxygen levels.”[v]

Limiting the temperature of the discharged water is therefore critical to limiting certain ecological impacts. As climate change creates more frequent and intense periods of warmer ambient temperatures of water bodies and the atmosphere, thermal power plants are at risk of exceeding maximum temperature limits or getting variances with attendant increased adverse environmental impacts.

Climate change impact on output and reliability

One way to limit the impact of thermal discharges when full power operation would cause an exceedance of discharge temperature is to derate the power plant and reduce the power output. This has already occurred numerous times, including in France and the United States, since the turn of this century. The extreme heat wave in France in June 2026 resulted in the loss of 4,100 MW of capacity, including the shutdown of one reactor (Golfech in southwestern France, one of the areas most impacted by the heat wave) and the derating of other reactors.[vi]

Derating often decreases electricity output just when loads are likely to be near their maximums. That is not yet the case in France as yet since air-conditioning use is not widespread, the historical, pre-climate-change-impact summers being mild. France is a winter-peaking system that exports electricity in the summer; exports declined significantly in June 2026, resulting in revenue loss. Derating in the United States, where air-conditioning use is high, would impact reliability by reducing available capacity in the time of peak loads. Datacenters supplied by thermal generation, including nuclear power, would be vulnerable to derating. They have back-up power, often in the form of diesel generators. Using these backup generators to compensate for thermal power plant derating would increase greenhouse gas emissions as well as air pollution.

The economics of nuclear power plants would also be impacted by derating should it last for more than a brief period. Nuclear power is often celebrated as “baseload” or “firm” power supply, which operates 24/7, when normal, design conditions are present. Average capacity factor for U.S. nuclear power plants is generally over 90 percent. They are typically shut down for only for a few weeks for refueling and maintenance, on average once every 18 to 24 months. High capacity factors are integral to nuclear plant economics, because most of the cost of the electricity they generate is represented by their very high capital cost, which is spread out over the total annual generation. Derating decreases electricity output and hence increases the average cost of generation, which is already high for new nuclear power plants when operating at design capacity factors.

The impact has already been seen; it is projected to worsen with greater warming, according to this analysis by Coffel and Mankin:

> “Climate change to date has increased average thermal power plant curtailment in nuclear, coal, oil, and natural gas fired plants by 0.75–1 percentage points; with each degree Celsius of additional warming, we project curtailment to increase by 0.8–1.2 percentage points during peak demand, requiring an additional 18–27 GW of capacity, or 40–60 additional average-sized power plants, to offset this global power loss.”[vii]

The Electric Power Research Institute, which is the research arm of electric utilities, estimates that losses due to increasing temperatures will amount to $1.4 billion per year by 2050.

> “[T]he increase in ambient air and water temperatures reduces thermal power generation. Coal, nuclear and natural gas plants experience a 0.25%-0.72% reduction in

> power output for a 1°C increase in the ambient temperature….[A]verage annual generation losses could add up to around 29 TWh for coal, nuclear and natural gas combined in 2050….Concurrently, average losses in generation income could total $1400 million for these thermal plants in 2050.”[viii]

The prospect for more prolonged droughts would make matters worse, constraining where new reactors could be located and involving greater derating for existing ones.

Alternate cooling technologies are less efficient and more expensive

Air cooling has been explored as an alternative, given the prospects of more constrained and uncertain water supplies. It is used in a small fraction of coal and natural gas plants as well as in some condensers in industry. Water is preferred for condensers because, being 800 times denser than air, it takes far less energy to remove the same amount of heat and condense the steam. The vast amount of air required demands more energy, resulting in a loss of efficiency relative to water cooling. At high ambient temperatures, turbine and condenser operating parameters (notably backpressure) may be exceeded.

Southern Company, which built the only two new reactors to come online in this century in the United States (Vogtle 3 and 4 in Georgia), prepared an analysis of air-cooled condensers for the AP1000 reactors in 2007 when it was “questioned” about the possibility. It came to the following conclusions in a filing with the Nuclear Regulatory Commission:[ix]

- “[U]nlike a wet system, an air-cooled system does not include an additional buffer between the nuclear supplied steam and the environment. If tube leaks develop within the ACC [Air-Cooled Condenser], the nuclear supplied steam is released directly into the ambient air.”
- The air-cooled-condenser system is less efficient.
- Major operational issues would be created at ambient air temperatures above 95^{o}F:
    - Backpressure at the turbine may exceed the “allowable operating pressure. This would cause the unit to be taken offline at the time when system demand was at its peak.” This would make it “unacceptable” from a reliability standpoint.
    - The air-cooled condenser system “would not function with the currently designed AP1000 turbine”; as a result, using air-cooled condensers would require steam turbine redesign.
    - Increasing operational backpressures would reduce output.
- Southern Company concluded that at the time of preparation of the assessment “an air-cooled system is not technically feasible (or even possible) for an AP1000 unit constructed at the Vogtle site.”

That conclusion does not mean that an air-cooled system would not be feasible for Small Modular Nuclear Reactors (SMRs) whose designs are not yet completed or approved. But it strongly indicates that major changes would be needed for air-cooling and that they would need to be integral to the power plant’s design. Loss of efficiency – and thus increase in cost of electricity (already high) – is also likely. Moreover, the high design temperature discussed in the Southern Company paper is 95°F. This temperature is currently exceeded frequently in the summer in much of the United States. The National Climate Assessment estimates that that number of days exceeding that temperature would increase significantly in most of the United States if global average temperatures increase by 2°C (3.6°F).[x] The world is currently on track to exceed this limit in the coming decades.

Consider the massive Fermi America datacenter being built near Amarillo in the panhandle of Texas (Potter County). It is projected to reach 11,000 MW of capacity when fully operational, with about 6,000 MW of combined cycle natural gas plants and four AP1000 nuclear reactors (the design used for Vogtle 3 and 4). Potter County currently has about 48 days of temperature above 95°F; this is expected to increase by about 30 days to 78 days for a global temperature rise of 3.6°F (2°C). Temperatures also exceed 100°F on many days currently; that number is also expected to rise. As a result, much more extensive design changes than discussed by Southern Company in its 2007 paper would be required. Even so, reliable operation would be far from assured given that climate projections are uncertain and extremes may well exceed current estimates.

The specifics for SMRs would be different, depending on the configuration, operating temperatures and other parameters. But loss of efficiency, higher electricity cost, and uncertainty as to reliability in the face of temperature extremes would apply to them as well. The Electric Power Research Institute evaluated alternative cooling systems and concluded that there would be significantly increased capital and operating costs if air-cooled systems are used. For instance, a mechanical draft air-cooled heat exchanger for a 600 MW nuclear plant would cost between 5% and 25% more and its operating cost would be 1.8 times to 3 times higher, leading to an overall increase in annual condenser costs of 60% to 70%.[xi]

Wind and solar electricity require little to no water

Finally, it should be noted that wind-generated electricity requires no water for its operation. Utility-scale solar only needs a small amount of water for cleaning the panels; on the order of 20 gallons per MWh are consumed, compared to 300 to 700 gallons for nuclear power.

Detailed, hour-by-hour modeling by the Institute for Energy and Environmental Research has shown that thermal generation is not needed for a reliable decarbonized electricity system.[xii] A major benefit of transitioning to such a system is to yield back the vast amounts of water now used for thermal generation, including nuclear generation, for other purposes. The value of water is set to rise; its availability less certain. These factors will make water a source of increasing conflict in water-stressed areas. The vast amounts of water now used for thermal generation can and should be seen as a great new resource for resilience, sustainability, and economic opportunity. Continuing with thermal generation, including nuclear, would forgo those possibilities.

[i] United States Geological Survey (2015). Freshwater withdrawals in the United States, https://www.usgs.gov/water-science-school/science/freshwater-withdrawals-united-states, viewed on 2026-02-09. Data are for 2015.

[ii] Peaking gas turbines, which account from a very small fraction of natural gas generation, do not have a steam system and need no condenser. Other natural gas generation involves steam – produced either in natural gas-fired boilers or from the exhaust of a gas turbine – which is used to drive a steam turbine.

[iii] PWR schematic, USNRC at https://www.nrc.gov/images/reading-rm/basic-ref/students/student-pwr.gif

[iv] EPA (2014). National Pollutant Discharge Elimination System-Final Regulations To Establish Requirements for Cooling Water Intake Structures at Existing Facilities and Amend Requirements at Phase I Facilities, Federal Register 79 FR 48300, August 15. https://www.federalregister.gov/documents/2014/08/15/2014-12164/national-pollutant-discharge-elimination-system-final-regulations-to-establish-requirements-for The EPA rule includes all power plants and factories that withdraw more than two million gallons per day. At 95.1 billion gallons per day, power plant freshwater withdrawals are far larger than industrial withdrawals (14 billion gallons per day): USGS (2014).

[v] Qingxue Leng et al. (2024). Impacts of thermal and cold discharge from power plants on marine benthos and its mitigation measures: a systematic review. Frontiers in Marine Science. 20 December. https://doi.org/10.3389/fmars.2024.1465289

[vi] Forrest Crellin and Hugo Lhomedet, “Europe's heatwave curbs French nuclear plants,”, 24 June 2026

[vii] Ethan D. Coffel and Justin N. Mankin (2021). “Thermal Power Generation is Disadvantaged in a Warming World.” *Environmental Research Letters*, Vol. 16. https://iopscience.iop.org/article/10.1088/1748-9326/abd4a8/pdf

[viii] EPRI (2020) Abstract. Climate Change Effects on Thermal Power Generation and Projected Losses in Generation and Income in the U.S. for the Period 2020–2050. https://ieeexplore.ieee.org/document/9449688

[ix] Southern Company (2007). Feasibility of Air-Cooled Condenser Cooling System for the Standardized AP1000 Nuclear Plant. March 17. The paper was an “Attorney Work Product prepared in anticipation of litigation” filed with the Nuclear Regulatory Commission (Exhibit # - JTI000034-00-BD01, Docket # - 05200011. Admitted 2009-03-17). https://www.nrc.gov/docs/ML0907/ML090780687.pdf

[x] National Climate Assessment Interactive Atlas Explorer, viewed on 2026-02-10. https://www.arcgis.com/apps/instant/atlas/index.html?appid=abf66b78b1dc47b192b15f07fb84de34&webmap=b7318ec0f2eb46a3ac1c068c8a34aecc.

[xi] Electric Power Research Institute (2013). Advanced Cooling Options for Nuclear Power Plants. https://restservice.epri.com/publicdownload/000000000001025068/0/Product

[xii] Arjun Makhijani (2016). Prosperous, Renewable Maryland, Institute for Energy and Environmental Research. November. https://ieer.org/wp/wp-content/uploads/2016/11/RenewableMD-Roadmap-2016.pdf