Water Requirements for Existing and Emerging Thermoelectric Plant Technologies

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Executive Summary

In light of the critical relationship between power generation and water, the National Energy Technology Laboratory (NETL) has initiated a research program to develop advanced technologies to reduce the consumption of freshwater by thermoelectric power systems. Table ES-0-1 shows water consumption and cooling duty factors for several power generation platforms, with and without carbon dioxide capture and compression. There is almost a fourfold increase in water consumption per net kWh between the lowest water consuming platform and the highest. Also the addition of CO_2 capture and compression increases water consumption by 50% to 90%.

The water consumption factors in Table ES-1 are based on a system in which the effluent process water from heat exchangers is cooled in an evaporative cooling tower and re-circulated. “Consumption” represents water that must be made up to account for evaporation in the cooling tower and a relatively small amount that is consumed in unit operations within the generation process. Table ES-0-1 also presents cooling duty factors, thermal cooling load per kWh of net generation. These factors enable one to estimate the impacts of different cooling water system configurations (e.g., once-through, wet cooling, dry cooling). The percent change with the addition of CO_2 capture is different for cooling duty and water consumption because cooling duty does not include process water requirements.

These factors are developed for the purpose of deriving the water-related impacts from different power plant deployment scenarios, such as those forecasted by the NEMS and MarKal models. The body of this report presents the calculation methodologies and data sources used to estimate the factors set forth in Table ES-1. This information will enable analysts to adjust the factors to represent the impact of advanced technologies in the areas of power generation, CO_2 capture and compression, and systems to provide process cooling.

Table ES-0-1. Water consumption and cooling duty factors for thermoelectric power plants[i]

	Without CO_2 Capture	With CO_2 Capture	% change with CO_2 capture
Water Consumption Factors (gallons per MWh net power)*			
Nuclear[6]	720	--	
Subcritical PC	520	990	+90%
Supercritical PC	450	840	+90%
IGCC, slurry-fed	310	450	+50%
NGCC	190	340	+80%
Cooling duty factors (MMBtu per MWh net power)			
Subcritical PC	4.7	11	+130%
Supercritical PC	4.1	9.3	+130%
IGCC, slurry-fed	3.0	3.7	+20%
NGCC	2.0	4.2	+110%

** Based on a cooling water system utilizing wet recirculating cooling towers*

[i] Factors derived from the NETL Report “Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity” adjustments described in Appendix A.

1 Background

Water, once considered a nearly inexhaustible resource, is increasingly limited, and water requirements for electricity production must compete with other demands, such as agriculture and sanitation. The 2007 drought in the southeastern U.S. underscored this issue with several nuclear power plants in the region reducing their output by up to 50% due to low river levels in August 2007.[1] Future water-related impacts on the industry may also come in the form of regulation. The Environmental Protection Agency is developing regulations under §316(b) of the Clean Water Act that will require that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact.

The water-related impacts of fossil fuel conversion platforms are a function of (1) the cooling and process water needs of the conversion platform, and (2) the system used to provide the cooling water. Thermoelectric power plants use water primarily to condense the process steam used to drive the turbines, with relatively minor amounts of water used for process steam make-up and other water-intensive processes, Figure 1-1.

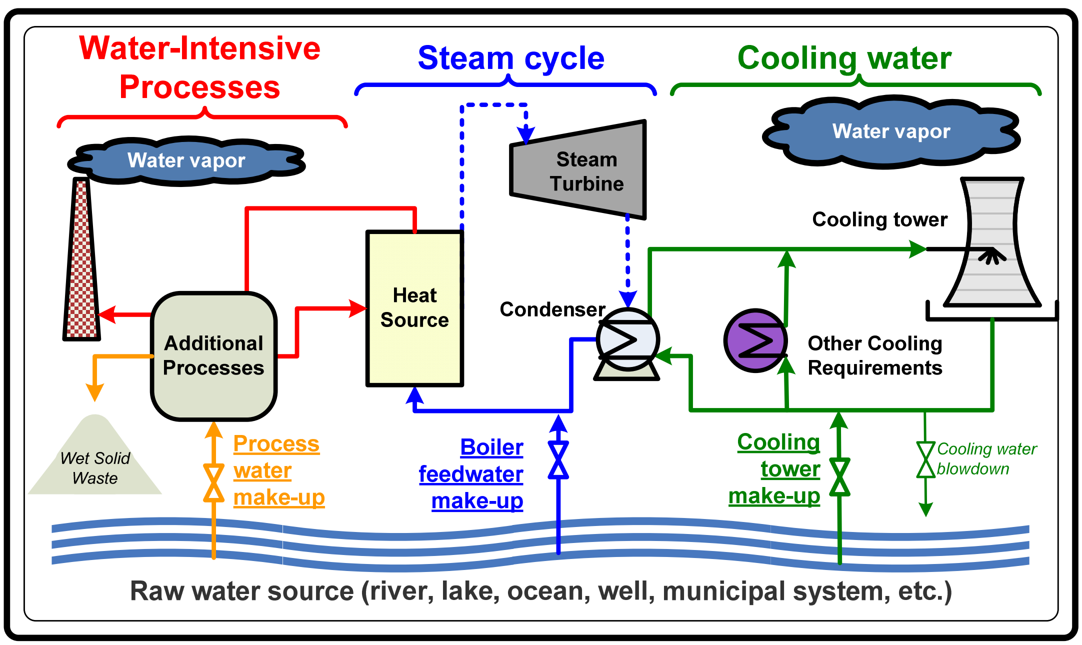


Figure 1-1. Water flow schematic for power plants

Traditionally power plants employed a once-through cooling water system where water is drawn from a water body, used to condense steam, and then returned warmer. More recently water systems include cooling towers that lower the temperature of the discharge water. A further progression is recirculating systems where the bulk of the water is cooled in evaporative cooling towers and reused with a lesser amount discharged and made up. A still further reduction in water use is possible in dry cooling systems – beneficial for arid regions – that use closed loop air cooling thus eliminating losses due to evaporation.

In December 2006, the National Energy Technology Laboratory (NETL) participated in a DOE-wide peer review of the analyses that are conducted to show the benefits of the DOE research and development portfolio. One of the recommendations from the peer review panel was for DOE to consider the water-related impacts associated with advanced thermoelectric plant technologies. This report is responsive to that recommendation.

The NETL research portfolio has the potential to significantly reduce the water-related impacts of thermoelectric plants. In addition to specific efforts on water use in existing plants, many of the advanced power platforms require less cooling load and have less of an increase in water demand associated with incorporation of CO_2 capture and compression equipment than current technologies. In 2002, NETL initiated a research effort specifically focused on water systems for thermoelectric power plants. NETL focuses on four technology pathways: (1) use of nontraditional sources of process and cooling water; (2) innovative water reuse and recovery; (3) advanced cooling technologies; and (4) advanced water treatment and detection technology. Many of the efforts involve integration with existing power plant operations, but are also applicable to advanced thermoelectric technologies. The program goals are set forth in Table 1-1. More information on the NETL efforts can be found at:
http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html

Table 1-1. NETL Water-Energy Technology Goals for Thermoelectric Plants with Wet Recirculating Cooling Systems

	Target Year	Target Reduction in Freshwater Withdrawal and Consumption*	Levelized Cost ($/thousand gallons water conserved)
Short Term Goal	2015	50%+	$3.90
Long Term Goal	2020	70%+	$2.60

* *Targets elative to the estimations of water usage in the NETL Power Plant Water Usage and Loss Study*[2]

2 Cooling Water Systems

Water drawn from a natural body can be either *consumed* – evaporated to the atmosphere – or *withdrawn* with the majority returned to its source as a liquid with some level of contaminants and/or temperature change. There are two basic cooling system configurations – once-through and recirculating, Figure 2-1. In a once-through cooling system, water from an external water source passes through the condenser and is then returned to the source. This system *withdraws* a significant amount of water, but *consumes* little, although some evaporation will likely occur downstream of the facility. To minimize the thermal impact to the water source, a cooling tower may be added to allow air cooling of the water (with associated losses due to evaporation) prior to returning the water to its source.

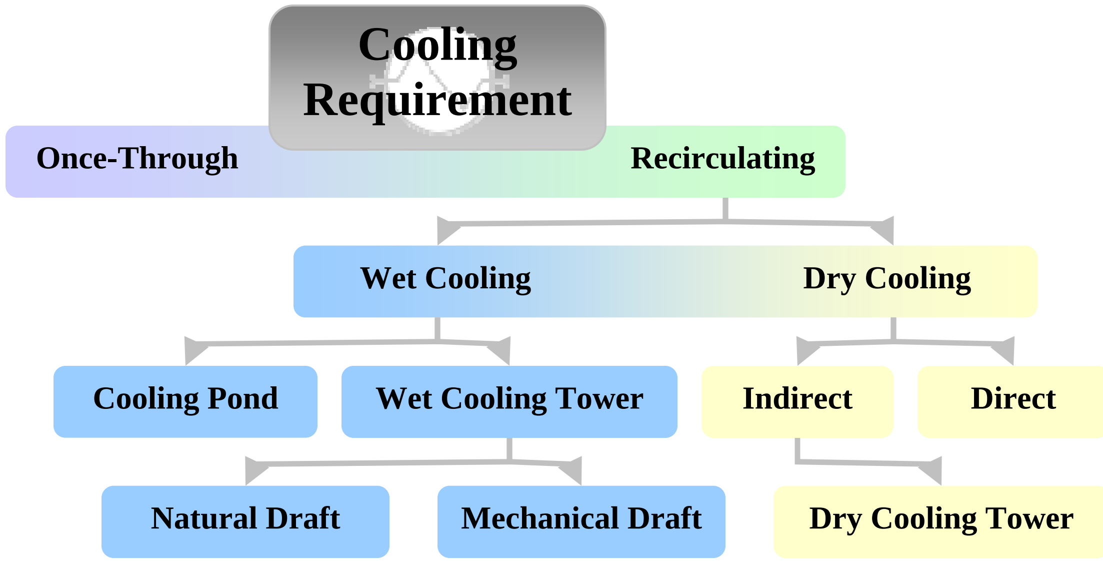


Figure 2-1. Cooling water system configurations

In a recirculating system, cooling water exits the condenser, goes through a fixed heat sink and is then returned to the condenser, so water *withdrawal* is low, but *consumption* is high relative to a once-through configuration. Typical heat sink options for recirculating systems are mechanical or natural draft cooling towers and cooling ponds. In cooling towers, the water is cooled by the air to near the wet-bulb temperature using the principle of evaporation. Water flows over a media called fill which serves to increase contact time with the air and maximize heat transfer. Mechanical draft cooling towers use fans to push or pull air through the towers, while natural draft cooling towers utilize large concrete chimneys facilitating a natural air current up the tower. While they require less power, natural draft towers are extremely large and generally only used at facilities with high cooling water requirements.

Make-up water to the cooling tower is required to replace the water that evaporates to the atmosphere. Evaporation losses are typically the largest contributor to water consumption in a cooling tower system and can be estimated based on the cooling water flow rate and the cooling water temperature rise.

As water evaporates in the cooling tower, any dissolved solids that came in with the raw make-up water will concentrate. To control the water chemistry and thus avoid scale formation and corrosion in the cooling water system, water must be discharged in a "blowdown" process. The required blowdown rate is highly dependent on the make-up water quality and is often determined based on cycles of concentration – the ratio of dissolved solids in the cooling water relative to the make-up water. With poor make-up water quality, the maximum allowable cycles of concentration is low requiring a high blowdown rate. A mid-range blowdown rate (corresponding to a water quality requiring a cycles of concentration of 4) would be one third of the evaporation losses or 25% of the entire make-up cooling water flow.[3] The water discharged as part of the blowdown process may be returned to the original source or sent to a water treatment facility. The quantity discharged is the primary difference between the raw water *withdrawal* and the water *consumption* in a wet recirculating cooling tower system.

When water availability is limiting, a dry cooling system may be utilized. Dry cooling can be either direct or indirect and in each case uses convective heat transfer to provide cooling so no evaporation of water occurs. In a direct dry cooling system, the turbine exhaust steam enters condenser tubes and is cooled by ambient air fans. In an indirect system, cooling water is used to condense the steam as in a wet recirculating system. Then the cooling water flows through tube bundles that are cooled in a mechanical or natural draft cooling tower. Cooling water make-up requirements can be nearly eliminated by use of dry cooling systems, but process and steam make-up water requirements are unaffected.

Wet recirculating systems are roughly 40% more expensive than once-through systems, while dry cooling systems are 3 to 4 times more expensive than a wet recirculating system.[4] Figure 2-2 shows the average total cost and number of cooling systems for fossil/biomass-fueled steam plants in the U.S. for 2005. While once-through has the highest market share, environmental regulations and permitting requirements will likely push developers to choose more expensive options in the future.

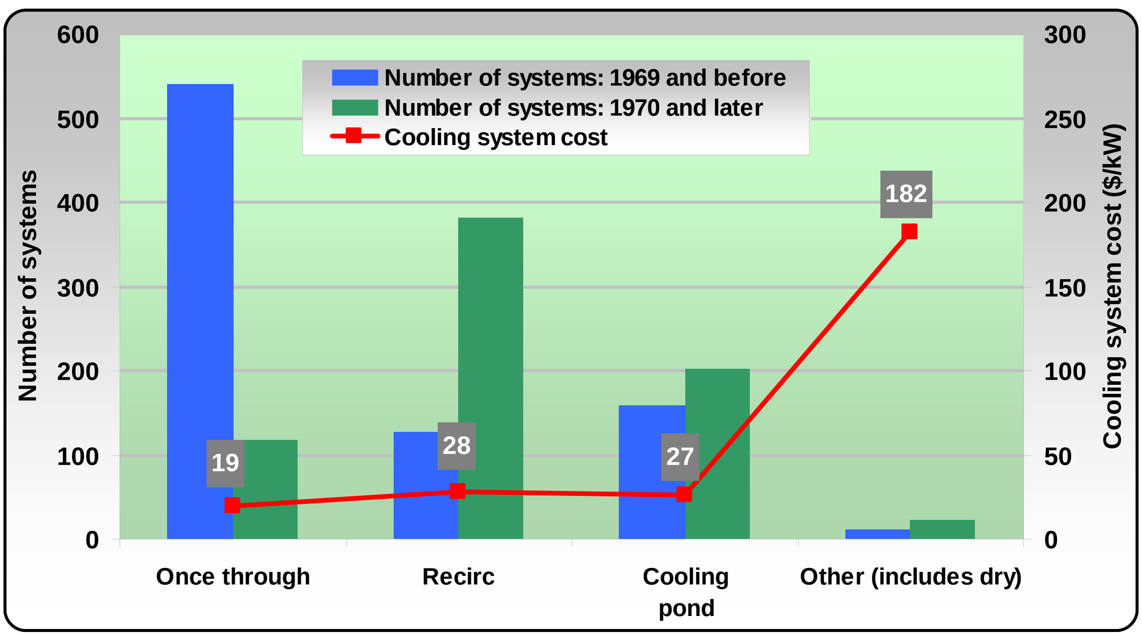


Figure 2-2. Average total cost and number of cooling systems by type[5]

3 Water requirements for power generation platforms

3.1 Data Sources and Comparison

In the 2007 NETL report, "Cost and Performance Baseline for Fossil Energy Plants" (NETL Baseline), various greenfield thermoelectric plant technologies were designed and costed. Water consumption, while not the primary focus of the NETL Baseline report, was quantified for PC, NGCC and IGCC plants. The analysis in Sections 3 and 4 of this report stems from these designs.[ii]

Figure 3-1 compares water consumption for six power generation platforms using the design water consumption values from the NETL Baseline report. The units are gallons of water consumed per net kWh of generation. All else equal, more efficient platforms will consume less water per kWh of net generation.

NGCC and IGCC power plants have lower water consumption due to the fact that around 2/3 of a combined cycle power plant's output comes from the combustion turbines which require minimal water when compared to the steam cycle. Like PC plants, nuclear power generation is all from a steam cycle; however, nuclear plants utilize lower pressure and temperature steam, and as a result require more steam and cooling water relative to the power produced.

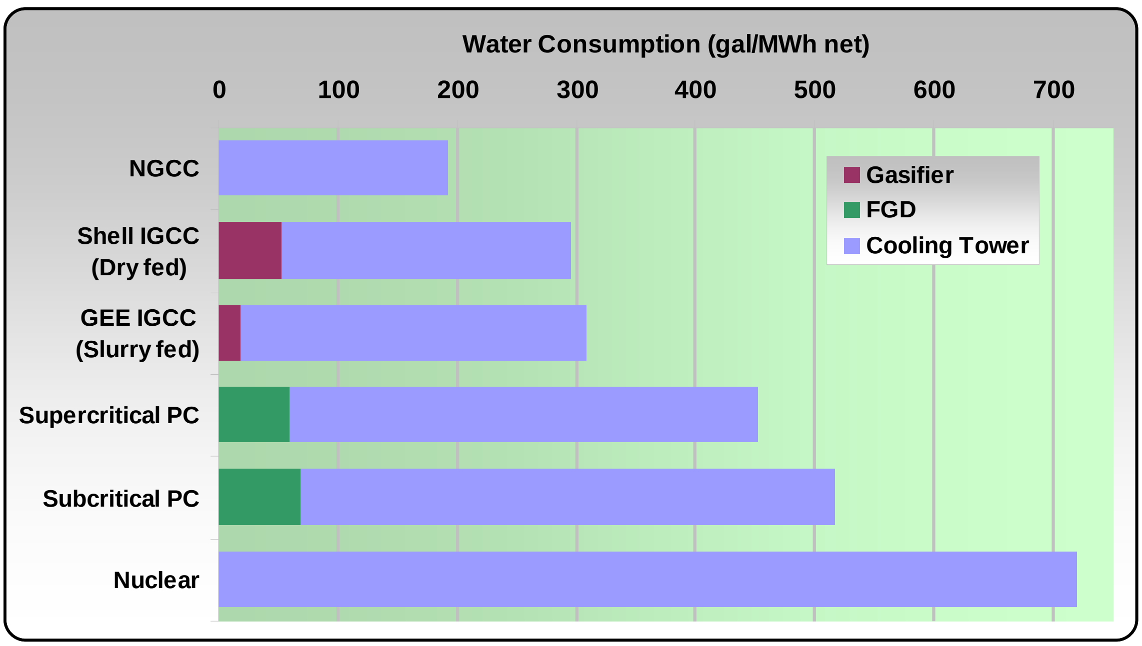


Figure 3-1. Water consumption for nuclear[6] and greenfield coal and natural gas thermoelectric power plants utilizing wet cooling towers[3]

[ii] The water requirements associated with each technology that were determined by the NETL Baseline report were adjusted. The key assumptions related to water consumption and withdrawal used in the original study and a description of the subsequent adjustments are described in Appendix A. These adjusted factors are utilized throughout this report.

3.2 Subcritical and Supercritical PC plants

As the least efficient type of fossil fuel power plant examined here, a subcritical PC plant also consumes the most water. Due to the lower steam pressure as compared to a supercritical plant, less energy can be transferred from the boiler to the turbine, so more steam flow, and thus more cooling water flow is required to generate the same electricity. A subcritical plant's lower efficiency also drives it to consume more water in the steam cycle and FGD process. Schematics highlighting the water flows in a subcritical and a supercritical PC plant with a wet FGD unit can be seen in Figure 3-2 and Figure 3-3.

A PC plant may have a wet FGD unit requiring make-up water. In an FGD, the flue gas enters a large vessel where it is sprayed with a slurry of about 10% limestone and 90% water. The sulfur in the flue gas and calcium in the limestone create gypsum, still in a slurry form. Although much of the water is removed from the gypsum by a dewatering process and then recycled to the system, a significant amount must be made-up when the wet gypsum leaves the plant. Water is also lost from the plant in the form of water vapor in the flue gas. Although some of this water is from the FGD system, most of this water is generated from combustion or was contained in the coal when it arrived at the plant.

In the steam cycle, the boiler feedwater (BFW) system requires blowdowns and subsequent make-up water. Because BFW make-up water is treated to remove impurities, the blowdown and make-up rates are not significant compared to the cooling water system requirements.

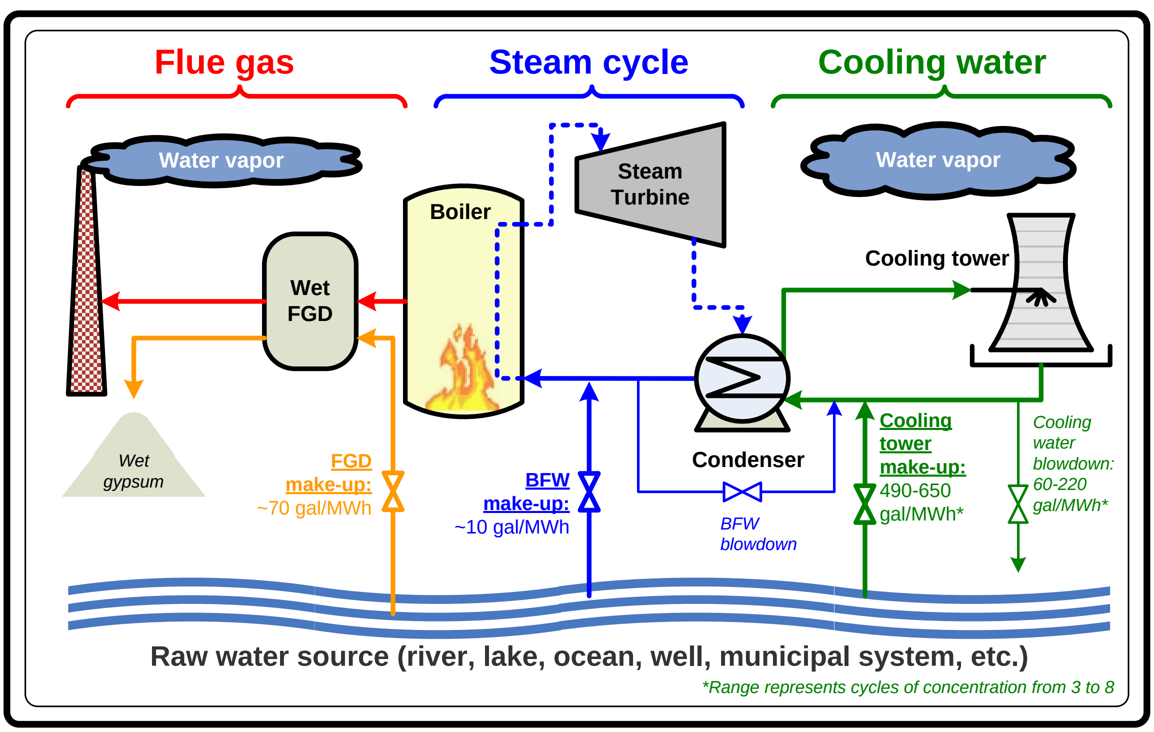


Figure 3-2. Water flow schematic for a greenfield subcritical pulverized coal power plant utilizing a wet cooling tower and a wet FGD[3]

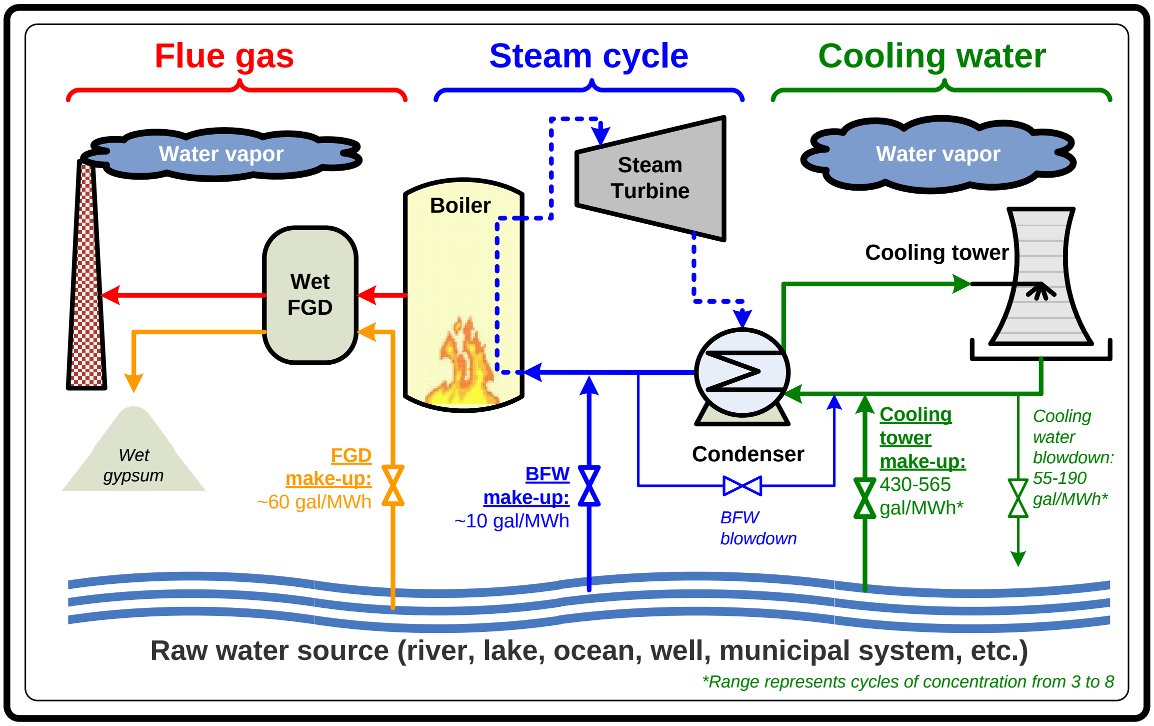


Figure 3-3. Water flow schematic for a greenfield supercritical pulverized coal power plant utilizing a wet cooling tower and a wet FGD[3]

3.3 IGCC plants

An IGCC power plant's water profile is significantly lower than either sub- or supercritical PC plants as shown in Figure 3-4. This is mainly due to the fact that the gas turbine, which requires minimal cooling water, produces around 60% of the plant's entire electrical output. Hot exhaust gas from the gas turbine passes through a heat recovery steam generator (HRSG) to drive a steam cycle. It is worth noting that an IGCC's steam cycle operates at significantly lower pressure than a PC plant's does (1800 psig, as compared to 2400 psig for subcritical and 3500 psig for supercritical plants)[7], so an IGCC plant consumes more water per MWh produced from the *steam turbine* than does a PC plant.[iii]

In addition to the use of cooling water for the steam condenser, an IGCC plant has cooling requirements in several other gas process steps. In the air separation unit (ASU), cooling water is required to cool compressed air prior to the air entering the cold box where cryogenic air separation occurs. In an IGCC's acid gas recovery (AGR) unit, hydrogen sulfide removal occurs through absorption by a chemical or physical solvent that then must be regenerated using heat. Cooling water is primarily utilized in the condenser of the regenerator tower and to cool the regenerated solvent. Finally, a

[iii] For the GEE IGCC configuration modeled in NETL's baseline report, the steam turbine has a capacity of 299 MW and requires 3,485 gpm of make-up water associated with the condenser, yielding 699 gal/MWh gross for just the steam turbine condenser. For the PC plant, the cooling water make-up requirement is lower at 555 gal/MWh gross power. However, if the power output of the entire IGCC plant including the steam and gas turbines is accounted for, then the GE plant's cooling water make-up requirement is 271 gal/MWh gross power.

relatively small amount of cooling water is required for compressor intercoolers in the tail gas treating unit (TGTU).

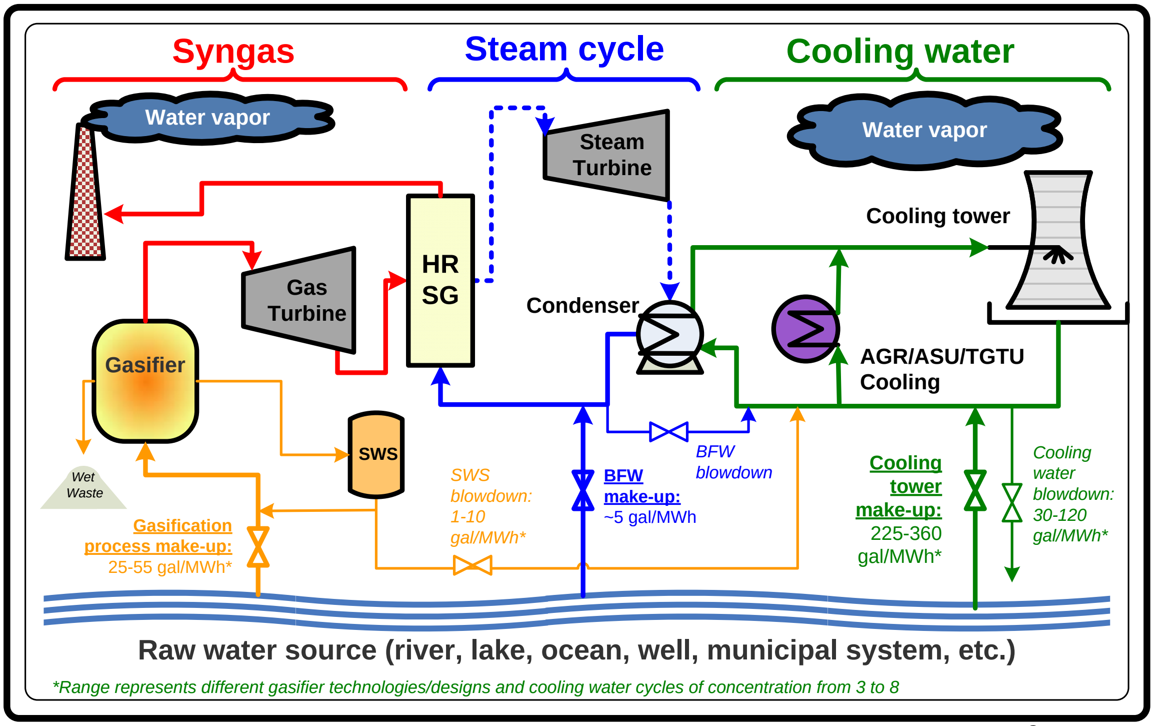


Figure 3-4. Water flow schematic for a greenfield IGCC plant utilizing a wet cooling tower[3]

IGCC plants also have water make-up requirements related to the gasification process itself. In the gasifier, coal, oxygen and steam are reacted to produce a combustion-able gas called syngas. Each of the different IGCC gasifier designs modeled in the NETL Baseline report utilizes water for different sub-processes as shown in Table 3-1. In gasifiers marketed by Shell and ConocoPhillips (E-GAS), humidification of the syngas stream makes up a large portion of the gasifier's water demand. Syngas humidification along with steam and nitrogen dilution of the syngas aids in minimizing formation of NO_x during combustion in the gas turbine burner section. The E-GAS and General Electric Energy (GEE) gasifiers are slurry fed meaning that water is added to the coal prior to gasification. A portion of the water is consumed in the gasification process as it is converted to syngas. For these slurry fed designs, molten slag leaving the gasifier is quenched in water, then the slurry of water and slag drops out of the stream and is disposed of. Although some of the slurry water can be recovered, significant make-up is still required. In each of the designs, the syngas leaving the gasifier is quenched and subsequent scrubbing of the gas with water occurs. When possible, the water is recovered and utilized in another process and or otherwise recycled within the system. For example, the quench and scrubber water are sent to a sour water stripper (SWS) where the impurities are removed from the water. A portion of the blowdown from the SWS effluent may be recycled to the cooling water system.

Table 3-1. Water intensive processes utilized by different IGCC gasifier designs[3]

	GEE	CoP E-GAS	Shell
Ash Handling	×	×	×
Slurry/Slag Handling	×	×	
Quench/Scrubber	×	×	×
Humidifier		×	×
Gasifier Steam			×
Gas Turbine Dilution			×

3.4 NGCC plants

NGCC plants have no process water usage such as that required in an FGD or for the gasifier processes. It also operates similarly to an IGCC plant in that the gas turbine generates 65%-70% of the total plant output. The result is a configuration with an even lower water profile than for the IGCC plant. The NGCC design does, however, consume roughly 25% more water relative to power generation from the *steam turbine* than does a subcritical PC plant despite operating under similar steam conditions. This difference stems from the use of the HRSG to heat the BFW in the NGCC design as opposed to using extraction steam in the PC design (thus reducing the condenser duty relative to the power from steam generation). A schematic of a greenfield NGCC plant's water requirement is shown in Figure 3-5.

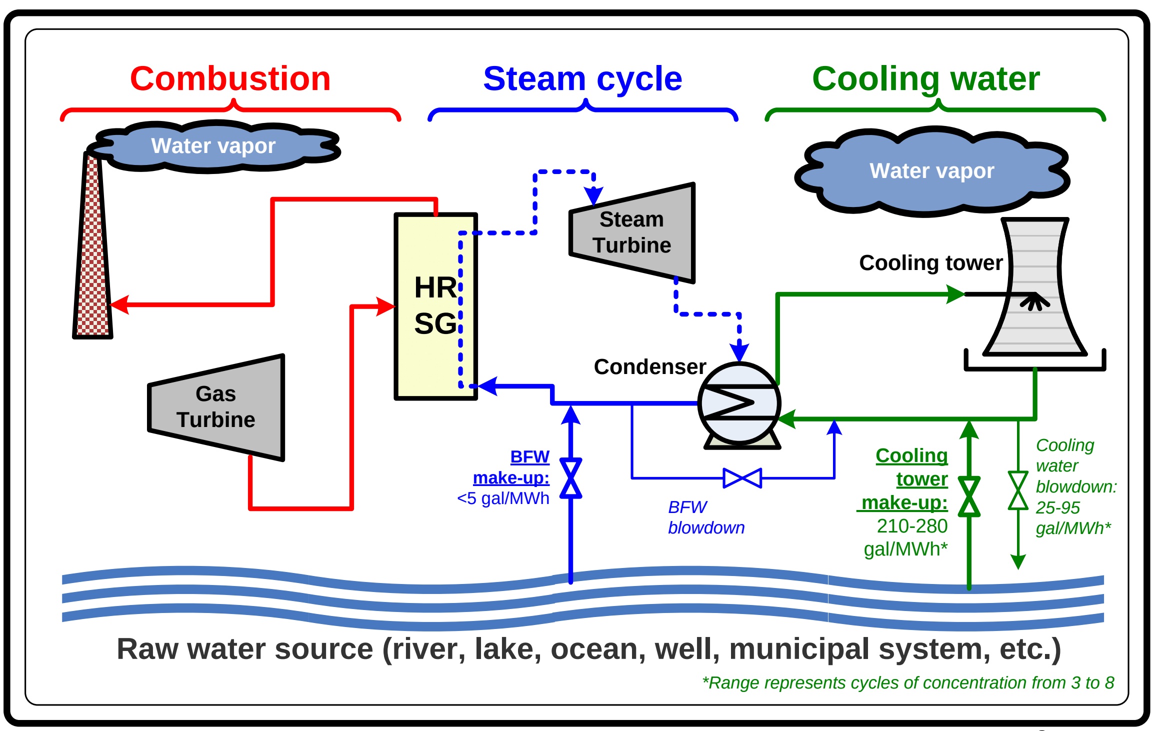


Figure 3-5. Water flow schematic for a greenfield NGCC plant utilizing a wet cooling tower[3]

3.5 Nuclear Plants

In a nuclear plant, energy from the decay of uranium heats pressurized water which is then used to produce steam in the steam generator (SG). All power produced comes from the steam cycle as it does for PC plants. However, nuclear plants have a higher cooling tower load relative to net power generation because the steam conditions and efficiency are limited by metal brittleness effects from the nuclear reactor. Figure 3-6 shows the water requirements for a nuclear power plant.[6]

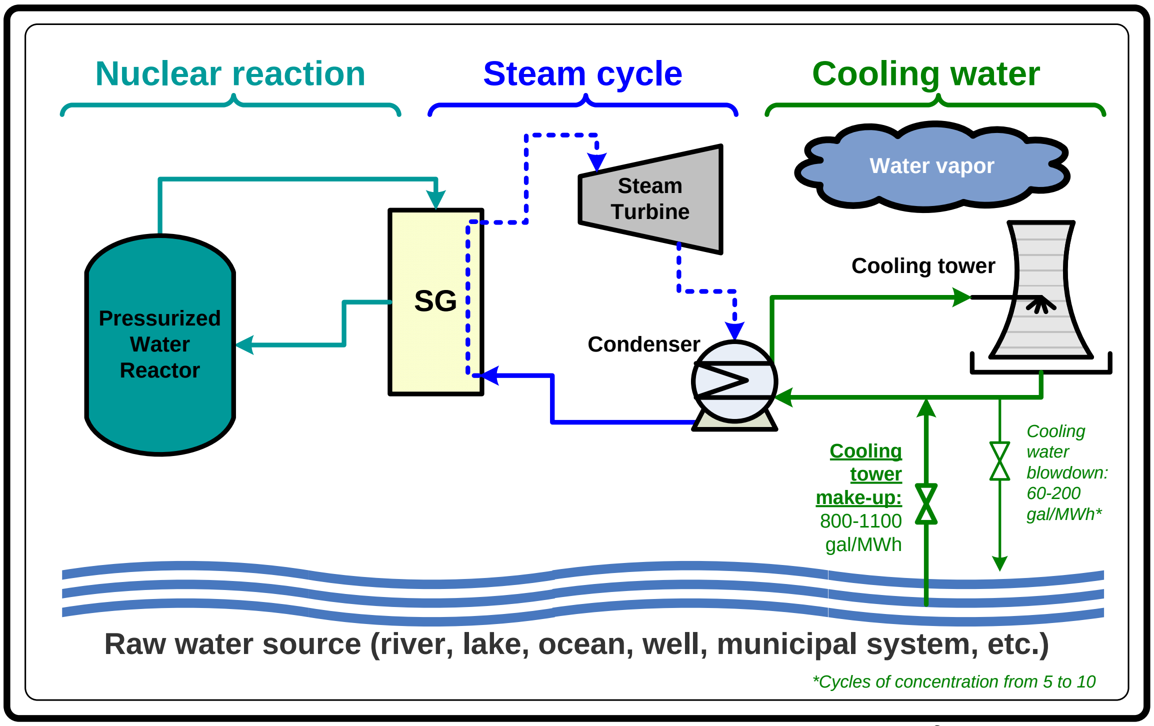


Figure 3-6. Water flow schematic for a nuclear plant utilizing a wet cooling tower[6]

4 Carbon capture and water usage

The NETL Baseline report designed and costed thermoelectric plants with the capability to capture carbon dioxide for each of the fossil energy plant technologies. Based on the technologies used in these designs, installing carbon dioxide recovery (CDR) equipment increases the water requirement per net power generation of a plant, due both to a reduction in the plant efficiency (Figure 4-1) and to the cooling water and process water requirements associated with carbon dioxide capture and compression.

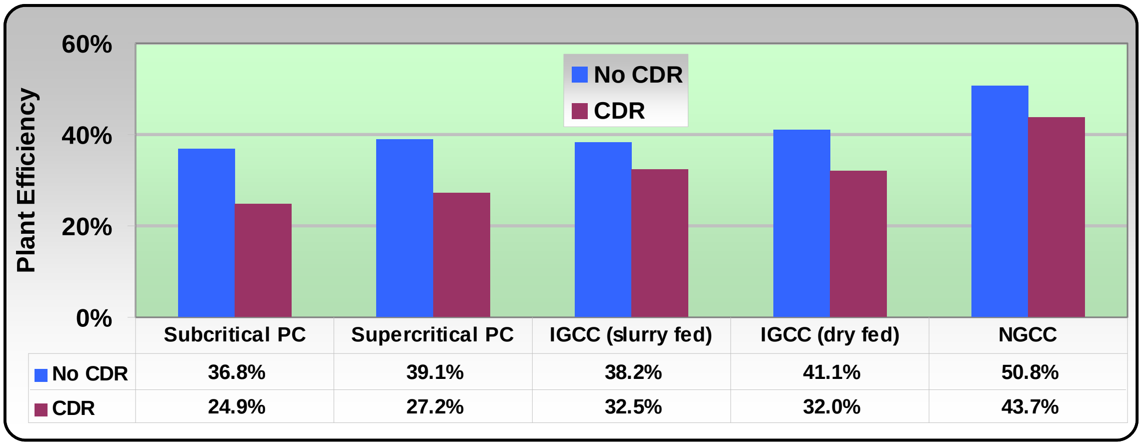


Figure 4-1. Comparison of net plant efficiencies (HHV basis) with and without CDR[3]

The CO_2 recovery method for PC and NGCC plants assumed in the NETL Baseline study is a monoethanolamine (MEA) recovery unit based on the Fluor Econamine FG Plus technology. The data presented here are specific to that technology, however, research in this area is ongoing and systems with improved efficiency, costs, and/or water balances are being pursued.

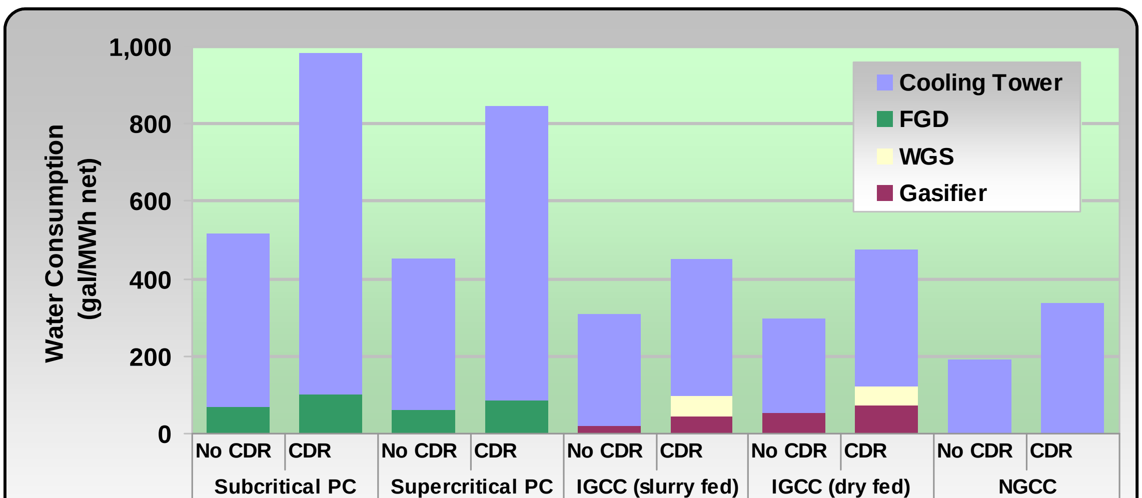
In an MEA process, the flue gas is cooled and SO_2 in the stream is further reduced after it leaves the FGD. The gas then contacts the MEA, which absorbs the CO_2. The CO_2-laden MEA is then steam-heated to release the CO_2. The carbon dioxide is compressed for shipment, and the MEA is recovered and reused. Overall, the CDR facility involves a number of subprocesses which collectively require a significant amount of cooling water. This includes flue gas cooling, water wash cooling, absorber intercooling, reflux condenser duty, reclaimer cooling, the lean solvent cooler, and CO_2 compression interstage cooling. At the same time, however, the cooling water requirements associated with the steam turbine condenser are reduced as a portion of the steam is routed to the MEA regenerator where it is condensed. In addition, a portion of the cooling water that is evaporated is offset by collecting water that condenses as the CO_2 is cooled and compressed. In a plant without CDR equipment, this water would have left the stack as water vapor.

For IGCC plants, CO_2 recovery will likely involve a water shift reactor and a physical-absorption based scrubber. The water shift reactor increases the CO_2 concentration in the syngas stream by converting carbon monoxide to carbon dioxide and hydrogen by the addition of steam over a catalyst bed. CO_2 is then removed from the gas stream in a similar manner to that described for PC and NGCC plants, but the greater concentration of CO_2 greatly increases the efficiency of the process. As a result there is less of an increase in cooling water requirements. The increase in cooling duty that does occur is primarily due to an increase in the AGR and ASU cooling requirements and the addition of CO_2 compressor intercoolers.

4.1 Water consumption factors[iv]

Utilizing the design conditions and assumptions of the NETL Baseline report, water consumption factors (net of the blowdown from the cooling water system) for each of the plant technologies with and without CDR equipment were developed and are presented here. Raw water *withdrawal* factors which show the entire volume of water withdrawn for cooling water and process use is provided in Appendix B.

Figure 4-2 compares the water consumption relative to net power generation. In the PC and NGCC cases presented by the NETL Baseline study, water consumption per net generation increases by 90% and 76%, respectively. The bulk of the increase is from higher cooling tower load related to the utilization of the cooling water-intensive chemical-absorption CO_2 recovery method at the back end of the power plant. In the IGCC slurry fed case, CO_2 recovery occurs during the gasification process so the water consumption factor increases by only 46%. More than half of this increase is due to water-intensive processes in the gasifier and in the water gas shift (WGS) process.



	Subcritical PC No CDR	Subcritical PC CDR	Supercritical PC No CDR	Supercritical PC CDR	IGCC (slurry fed) No CDR	IGCC (slurry fed) CDR	IGCC (dry fed) No CDR	IGCC (dry fed) CDR	NGCC No CDR	NGCC CDR
Total	517	985	452	844	309	452	295	475	192	338
Cooling Tower	449	884	392	759	290	355	243	355	192	338
FGD	68	101	59	86						
WGS						52		49		
Gasifier					19	45	53	71		

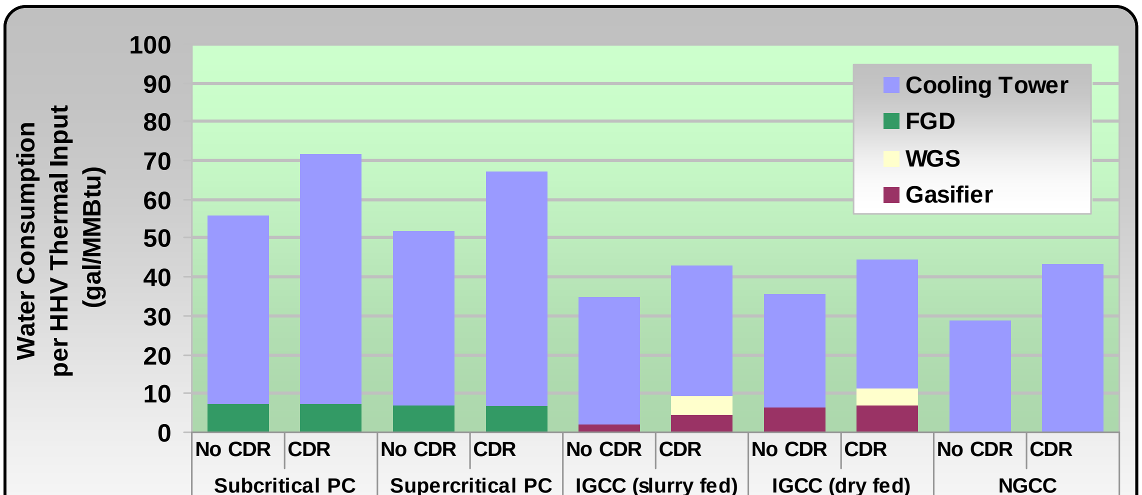
Figure 4-2. Comparison of water consumption factors with and without carbon capture for greenfield plants using wet recirculating cooling towers – net power basis[3]

As previously discussed, the reason for increases in cooling water consumption per net power generation is a combination of the reduction in efficiency and the additional cooling water and process water for CDR equipment. Figure 4-3 shows the water consumption factors on a HHV thermal input basis which essentially removes the impact of the efficiency reductions. This shows that on a constant feed basis, the FGD make-up requirement does not change. The change in water consumption in the cooling water

[iv] See Appendix A for key information on the basis for these factors.

system for the IGCC cases is minimal with most of the increase coming from the addition of the WGS process and additional water demand needed for quench water and in the syngas scrubber.

This information is also useful if policy and economic considerations begin to point to the implementation of carbon capture for existing PC or NGCC plants. Should a plant be retrofitted with CDR equipment, the net power output of that plant would be reduced and thus the increase in water consumption for that specific plant would not increase by the 90% or 76% quoted above. For example, for an existing subcritical PC plant based on the design used in this evaluation, the water consumption assuming a constant coal feed rate would increase by 30% or require roughly 16 gallons of additional make-up water per MMBtu of thermal input (HHV). This additional requirement is almost entirely for the cooling tower load. As a result, if a particular plant has maximized its water draw, the additional water requirements are only associated with the cooling tower load and could thus be achieved with conversion to recirculating or the addition of a dry cooling system.



	Subcritical PC No CDR	Subcritical PC CDR	Supercritical PC No CDR	Supercritical PC CDR	IGCC (slurry fed) No CDR	IGCC (slurry fed) CDR	IGCC (dry fed) No CDR	IGCC (dry fed) CDR	NGCC No CDR	NGCC CDR
Total	55.7	71.8	51.8	67.4	34.6	43.1	35.5	44.5	28.6	43.2
Cooling Tower	48.4	64.4	45.0	60.5	32.5	33.8	29.2	33.2	28.6	43.2
FGD	7.3	7.4	6.8	6.8						
WGS						4.9		4.6		
Gasifier					2.1	4.3	6.3	6.7		

Figure 4-3. Comparison of water consumption factors with and without carbon capture for greenfield plants using wet recirculating cooling towers – constant feed basis[3]

4.2 Cooling water duty factors[v]

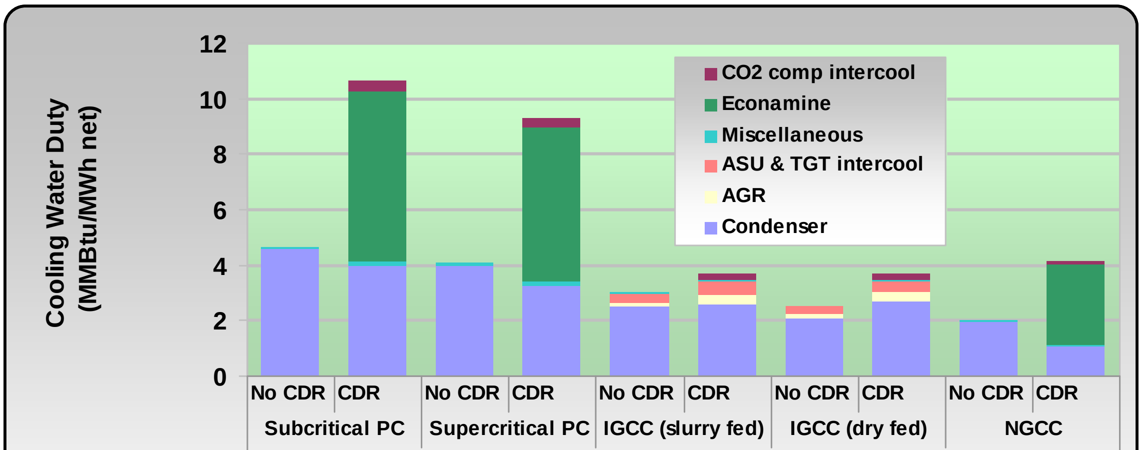
The water consumption factors for the cooling requirements described above can only be applied to wet recirculating cooling towers. Knowing the cooling duty associated with the cooling water systems for plants with and without CO_2 capture allows application of this data to once-through or dry cooling systems. Utilizing the design cooling duty from the NETL Baseline report for various processes within the plants, factors for cooling

[v] See Appendix A for key information on the basis for these factors.

water duty per net power generation and on a constant feed basis were developed as shown in Figure 4-4 and Figure 4-5.

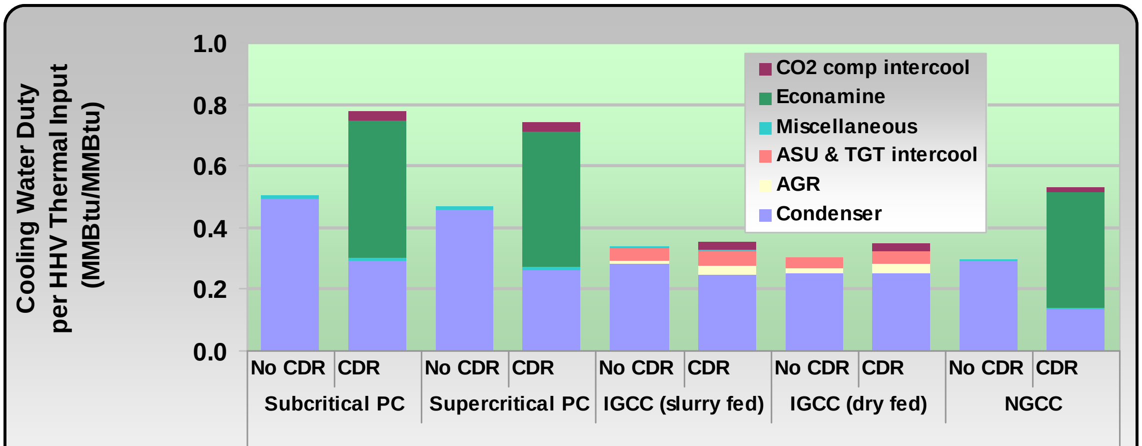
The cooling water duty follows a similar pattern to the water consumption factors with the increase related to CO_2 capture for NGCC and PC plants being far greater than for the various IGCC cases. For PC and NGCC plants, the increase in the cooling tower load is primarily due to the cooling needed for the amine process with some increased load due to CO_2 compressor intercoolers. The condenser duty actually decreases with the addition of CDR equipment both per net power and on a constant feed basis. The reason for this decrease is that a portion of the steam from the steam turbine is routed to the Econamine system and condensed in the solvent regenerator reboiler.

For the IGCC cases, a significant portion of the additional water consumption associated with CDR capability is due to the gasifier and WGS process, so the cooling tower load increase is less significant than the overall water consumption increase. The minor increase in additional cooling system load is due to the reduced efficiency of the CDR configuration, additional cooling load on the AGR unit and the addition of CO_2 compressor interstage coolers. Again this information can be used to evaluate the cooling water needs for retrofitting an existing PC or NGCC plant with CDR equipment with the added flexibility to evaluate dry and once-through cooling systems.



	Subcritical PC No CDR	Subcritical PC CDR	Supercritical PC No CDR	Supercritical PC CDR	IGCC (slurry fed) No CDR	IGCC (slurry fed) CDR	IGCC (dry fed) No CDR	IGCC (dry fed) CDR	NGCC No CDR	NGCC CDR
Total	4.7	10.7	4.1	9.3	3.0	3.7	2.5	3.7	2.0	4.2
CO2 comp intercool		0.39		0.36		0.25		0.22		0.13
Econamine		6.13		5.54						2.91
Miscellaneous	0.10	0.15	0.09	0.14	0.03	0.04	0.03	0.04	0.04	0.04
ASU & TGT intercool					0.36	0.49	0.27	0.43		
AGR					0.10	0.32	0.14	0.32		
Condenser	4.58	4.00	3.99	3.27	2.53	2.61	2.09	2.69	1.97	1.08

Figure 4-4. Comparison of cooling water duty factors for greenfield plants – net power basis[3]



	Subcritical PC No CDR	Subcritical PC CDR	Supercritical PC No CDR	Supercritical PC CDR	IGCC (slurry fed) No CDR	IGCC (slurry fed) CDR	IGCC (dry fed) No CDR	IGCC (dry fed) CDR	NGCC No CDR	NGCC CDR
Total	0.50	0.78	0.47	0.74	0.34	0.35	0.30	0.35	0.30	0.53
CO2 comp intercool		0.03		0.03		0.02		0.02		0.02
Econamine		0.45		0.44						0.37
Miscellaneous	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
ASU & TGT intercool					0.04	0.05	0.03	0.04		
AGR					0.01	0.03	0.02	0.03		
Condenser	0.49	0.29	0.46	0.26	0.28	0.25	0.25	0.25	0.29	0.14

Figure 4-5. Comparison of cooling water duty factors for greenfield plants – constant feed basis[3]

5 Thermal impact of discharges

Another important water-related impact of power generation is the thermal impact to the plant's surrounding environment. This occurs as the condenser coolant rejects its heat to the plant's ultimate heat sink, usually a lake, river or ocean. The thermal impact is measured in degrees F times gallons of water, and therefore depends both on the temperature of discharges and volume.

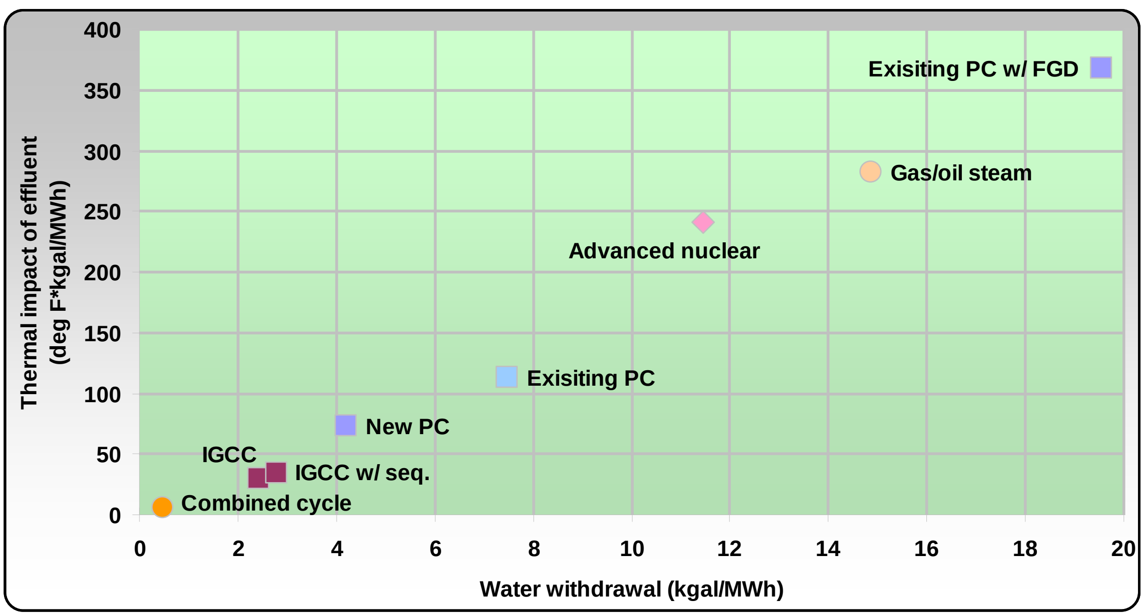


Figure 5-1. Water withdrawal and thermal impact of common thermoelectric power plants[8]

In Figure 5-1, the thermal impact of most thermoelectric electricity sources can be seen on the y-axis. This figure uses the weighted averages of the water withdrawal factor across all plants and their current cooling system configurations in a technology type. Thus plant technologies with a higher proportion of once-through cooling systems would have both higher water withdrawal and a higher thermal impact. Nuclear and new PC plants both have higher thermal impacts than would be predicted by a simple linear analysis of water withdrawal due to differing steam cycle temperatures and efficiencies.

6 Pollutants discharged in effluent

The composition of cooling water discharge is another environmental factor of importance. As water is drawn from its source and through the plant, many processes such as chemical treatment for corrosion prevention will change the original content of the water. Power plants discharging water back to public water bodies must measure and report the amount of pollutants in their effluent streams. As seen in Figure 6-1, for most generating technologies, the effluent discharge factors closely follows the trend established by the water withdrawal factor with the exception of nuclear plants. Nuclear plants are likely to have a lower than expected discharge factor due to the tighter effluent restrictions typically placed on nuclear plants.

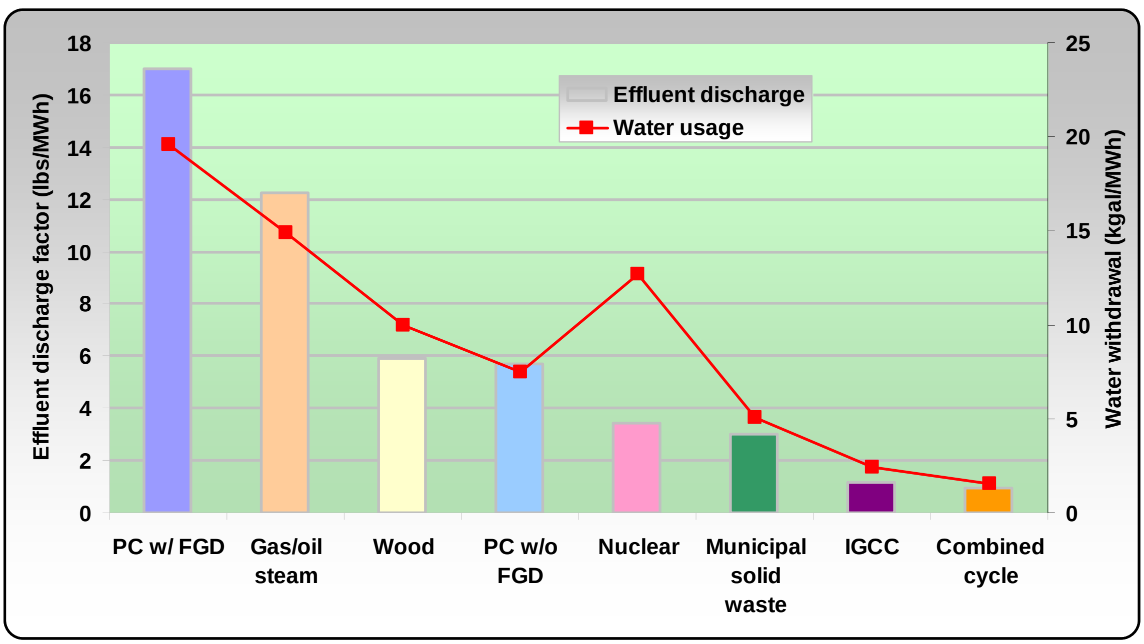


Figure 6-1. Effluent discharge factors for thermoelectric power plants[9]

7 Next Steps

To extend and improve the factors presented here, the following next steps are recommended:

- Refine the water consumption and withdrawal factors presented here by expanding beyond the design basis of the NETL Baseline report with a specific focus on water requirements. Process simulations will be used as necessary.
- Develop water consumption and withdrawal factors for an integrated gasification fuel cell (IGFC) platform.
- Develop water consumption and withdrawal factors for plant designs with oxy-fuel combustion.

Appendix A

Key assumptions in the 2007 NETL baseline report:

- Raw water makeup is assumed to be provided 50% by a publicly owned treatment works and 50% from groundwater
- Cooling water circulation and losses were determined using the following:
  - Design ambient wet bulb temperature of 51.5 ºF to achieve a cooling water temperature of 60 ºF (8.5 ºF approach)
  - Cooling water temperature range of 20 ºF
  - Evaporative losses of 0.8% of the circulating water flow rate per 10 ºF of range
  - Drift losses of 0.001% of the circulating water flow rate
  - Blowdown rates = evaporated losses / (cycles of concentration – 1)
    - Mid-range cycles of concentration of 4 was used (measure of water quality)
- Blowdown from other processes in the plant were assumed to be routed to the cooling water system, backing out makeup water, as follows:
  - PC and NGCC cases with CO_2 capture: condensed water resulting from the cooling and compression of CO_2 (for non CO_2 capture cases, this water leaves with the flue gas)[vi]
  - IGCC cases: a portion of the SWS blowdown is routed to the cooling water system
  - All cases: the boiler feedwater blowdown is routed to the cooling water system
- Note that cooling water and process water requirements will vary significantly with process conditions such as temperature

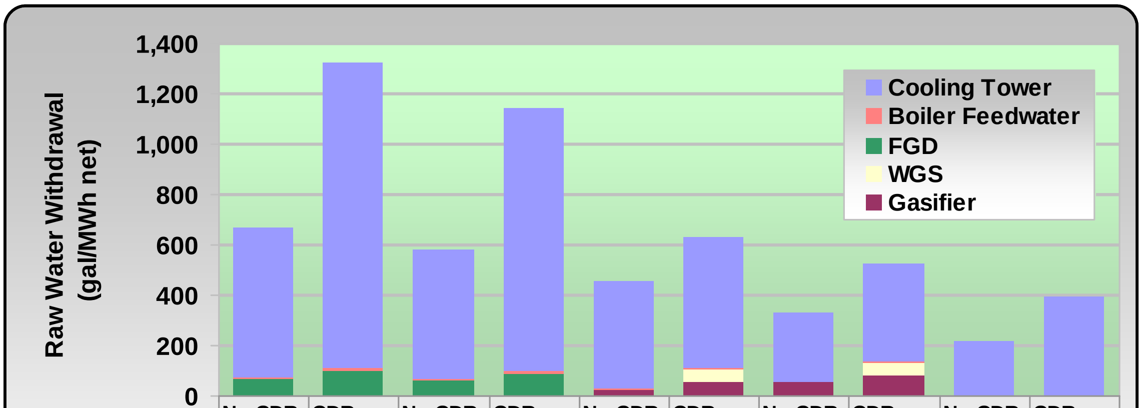
Adjustments to water requirements detailed in the 2007 NETL baseline report:

- In the baseline report, for the PC and IGCC cases, an engineering estimate for miscellaneous cooling duty requirements of 100 MMBtu/hr was added (75 MMBtu/hr for the NGCC cases). This number was adjusted in this analysis as follows:
  - PC cases: assumed to be 55 MMBtu/hr for the subcritical no CO_2 capture cases and was scaled based on coal feed rate for all other PC cases
  - IGCC cases: assumed to be 20 MMBtu/hr for the GEE IGCC no capture case and was scaled based on coal feed rate for all other IGCC cases
  - NGCC cases: assumed to be 20 MMBtu/hr for both cases
- In the baseline report, cooling duty associated with the ASU and the TGTU intercoolers was documented, but not utilized in determining the cooling water circulation rate. The cooling duty and associated cooling water requirements were added for these processes in this analysis.

[vi] Note that this was a significant change between the May 2007 report and the Revised August 2007 report

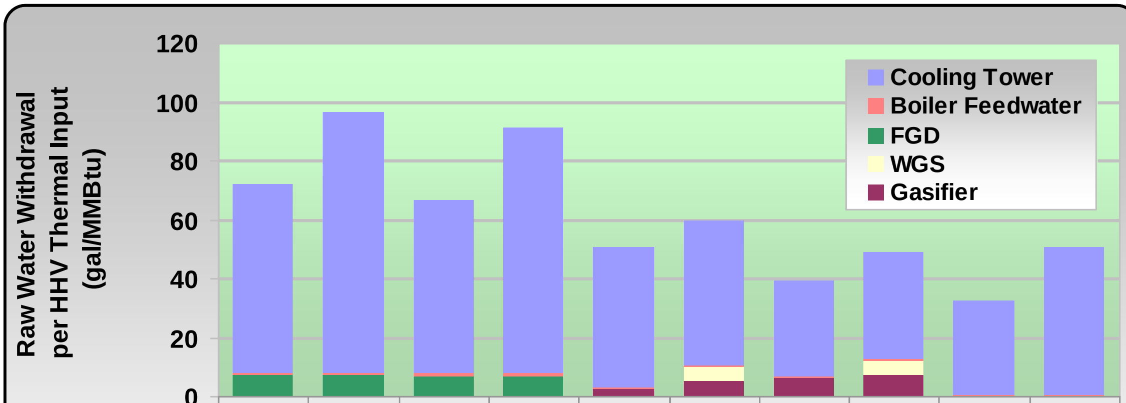
Appendix B

Below are the raw water *withdrawal* factors corresponding to the discussion in Section 4. This analysis incorporates all water withdrawn for various uses in the plant. See Appendix A for key assumptions.



	Subcritical PC		Supercritical PC		IGCC (slurry fed)		IGCC (dry fed)		NGCC	
	No CDR	CDR	No CDR	CDR	No CDR	CDR	No CDR	CDR	No CDR	CDR
Total	667	1,326	582	1,142	454	630	330	526	220	395
Cooling Tower	590	1,213	515	1,044	424	520	272	390	217	392
Boiler Feedwater	8	12	8	12	5	5	4	5	2	3
FGD	68	101	59	86						
WGS						52		49		
Gasifier					26	53	54	82		

Figure B-1. Comparison of raw water withdrawal factors with and without carbon capture for greenfield plants using wet recirculating cooling towers – net power basis[3]



	Subcritical PC		Supercritical PC		IGCC (slurry fed)		IGCC (dry fed)		NGCC	
	No CDR	CDR	No CDR	CDR	No CDR	CDR	No CDR	CDR	No CDR	CDR
Total	71.9	96.6	66.7	91.1	50.9	59.9	39.7	49.3	32.6	50.5
Cooling Tower	63.7	88.4	59.0	83.3	47.5	49.5	32.8	36.5	32.3	50.1
Boiler Feedwater	0.9	0.9	0.9	0.9	0.5	0.5	0.4	0.5	0.4	0.4
FGD	7.3	7.4	6.8	6.8						
WGS						4.9		4.6		
Gasifier					2.9	5.1	6.5	7.6		

Figure B-2. Comparison of raw water withdrawal factors with and without carbon capture for greenfield plants using wet recirculating cooling towers – constant feed basis[3]

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[6] Electric Power Research Institute (EPRI), "Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production – The Next Half Century", Palo Alto, CA: 2002. 1006786.

[7] NETL, 2007

[8] EIA, Form EIA-767.

[9] U.S. Environmental Protection Agency (EPA), *PCSLoads2002 database*, accumulation of data from EPA's Permit Compliance System mainframe database developed to support the 2005 annual screen level analysis of existing effluent standards.