Regional Analysis of Dry Cooling Retrofits on NGCC Using IECM

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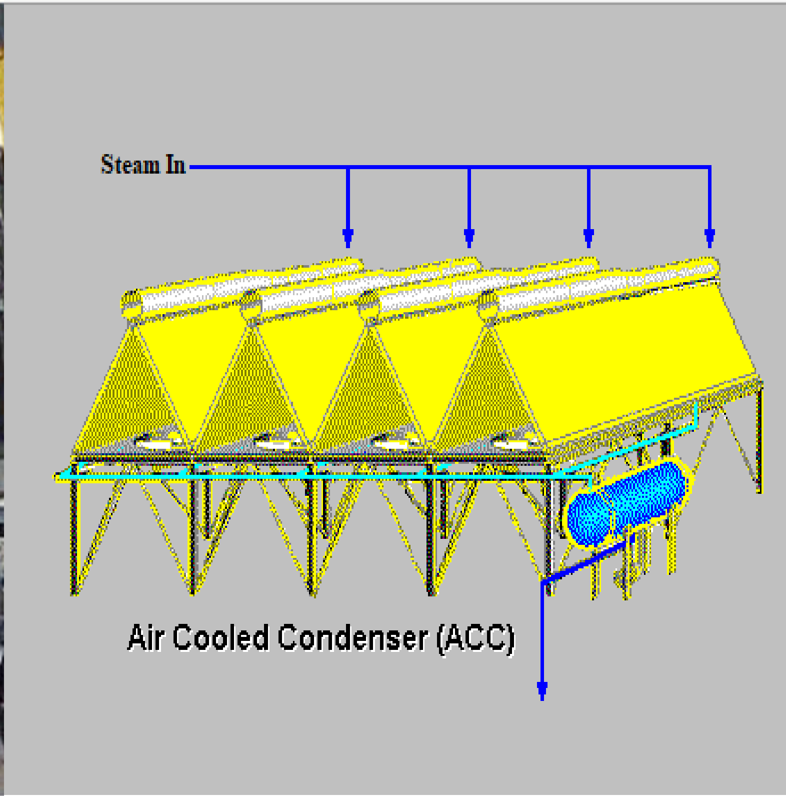

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Project Objectives

- Estimate the potential water savings benefit of retrofitting dry cooling systems at existing natural gas combined cycle (NGCC) power plants currently using wet cooling towers in a water-stressed (dry/arid) region
- Estimate the cost and cost-effectiveness of such retrofits
- Identify potential shortfalls in regional net generating capacity due to the derating impact of dry cooling retrofits

Project Scope

- Expand a prior study of dry cooling retrofits at coal-fired (PC) power plants to now analyze existing NGCC power plants using wet cooling towers in the study region
- Define the case study region to include three western U.S. states: Arizona, Colorado, and New Mexico
- Evaluate potential reductions in net generating capacity on both an annual and monthly average basis under current conditions

NGCC Power Plants Modeled

Plants in Arizona	• West Phoenix (2 units) • Kyrene (1 unit) • Santan (2 units) • Desert Basin (1 unit) • Harquahala Generating Project (1 unit)	• Red Hawk (1 unit) • Griffith Energy LLC (1 unit) • Gila River Power Block 3 (1 unit) • Mesquite Generating Station Block 1 (1 unit)
Plants in Colorado	• Cherokee (1 unit) • Rocky Mountain Energy Center (1 unit)	
Plants in New Mexico	• Luna Energy Facility (1 unit)	

Total = 12 plants and 14 units modeled

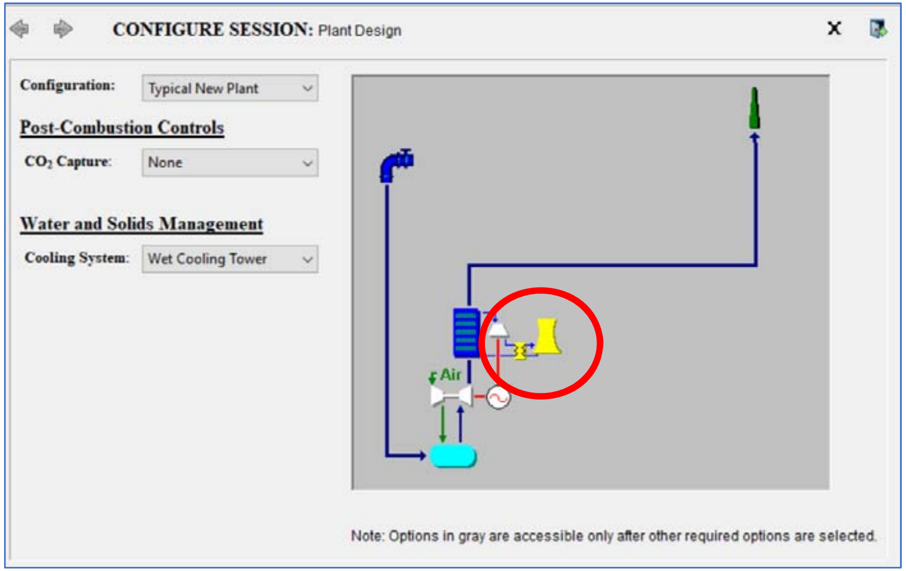
Data Attributes and Sources

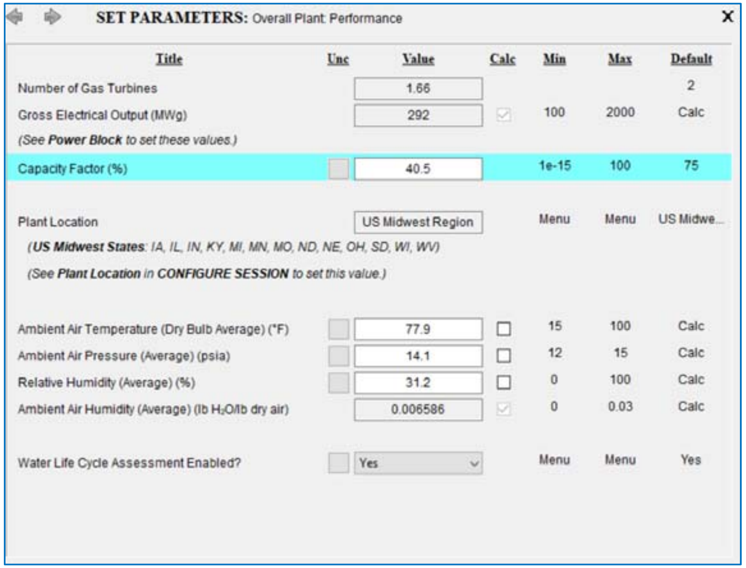
Category	Parameters	Database(s)
Unit attributes	Nameplate capacity (gas turbine, steam turbine and the total), online year	National Electric Energy Data System; Energy Information Administration (EIA) Form 860
	Cooling system type	EIA Form 923
	Gross and net generation, gross and net heat rates (annual averages)	Velocity Suite
	Natural gas prices	Velocity Suite
Monthly unit operating information	Gross and net generation, gross and net heat rates	Velocity Suite
Ambient conditions	Air dry-bulb temperature, relative humidity, air pressure	National Climatic Data Center

All data are for calendar year 2017.

Configure and Model Existing Units in Integrated Environmental Control Model (IECM)

- In the Integrated Environmental Control Model (IECM), an existing unit is specified by attributes including unit type, age, nameplate capacity (gas and steam turbines), steam cycle heat rate, net plant heat rate, annual electricity generation, and ambient air conditions.





Source: CMU/UW

Configure and Model Existing NGCC Units with Wet Cooling Tower Systems

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Steam Generator Parameters

SET PARAMETERS: Power Block: Steam Cycle Performance

Title	Unc	Value	Calc	Min	Max	Default
Heat Recovery Steam Generator						
HRSG Outlet Temperature (°F)		193		150	500	250
Steam Cycle Heat Rate, HHV (Btu/kWh)		9900		6000	1.1e+04	9000
Adjusted Steam Cycle Heat Rate, HHV (Btu/kWh)		9900	☑	6000	1.5e+04	Calc
Cooling Water Temperature Rise (°F)		20	☑	10	50	Calc
Auxiliary Heat Exchanger Load (*1) (%)		1.41	☑	0	20	Calc
Steam Turbine						
Total Steam Turbine Output (MWg)		121.9	☑	0	2000	Calc
Power Block Totals						
Power Requirement (% MWg)		2	☑	0	15	Calc

*(*1) % Primary Steam Cycle*

Ambient Conditions

SET PARAMETERS: Water Systems: Performance

Title	Unc	Value	Calc	Min	Max	Default
Wet Cooling Tower						
Ambient Air Temperature (Dry Bulb Average) (°F)		77.9	☐	15	100	Calc
Air Wet Bulb Temperature (Average) (°F)		59.22	☑	15	100	Calc
Cooling Water Inlet Temperature (°F)		90		50	120	90
Cooling Water Temperature Drop (°F)		20	☑	10	50	Calc
Cycles of Concentration		4		2	20	4
Tower Drift Loss (*1) (%)		0.001		0	0.1	0.001
Auxiliary Cooling Load (*2) (%)		1.41	☑	0	20	Calc
Tower Overdesign Factor (% total load)		0		0	20	0
Power Requirement (% MWg)		0.7093	☑	0	15	Calc

*(*1) % Recirculating Water*

*(*2) % Primary Steam Cycle*

Source: CMU/UW

Key Results for Existing NGCC Units with Wet Cooling Towers (CY 2017)

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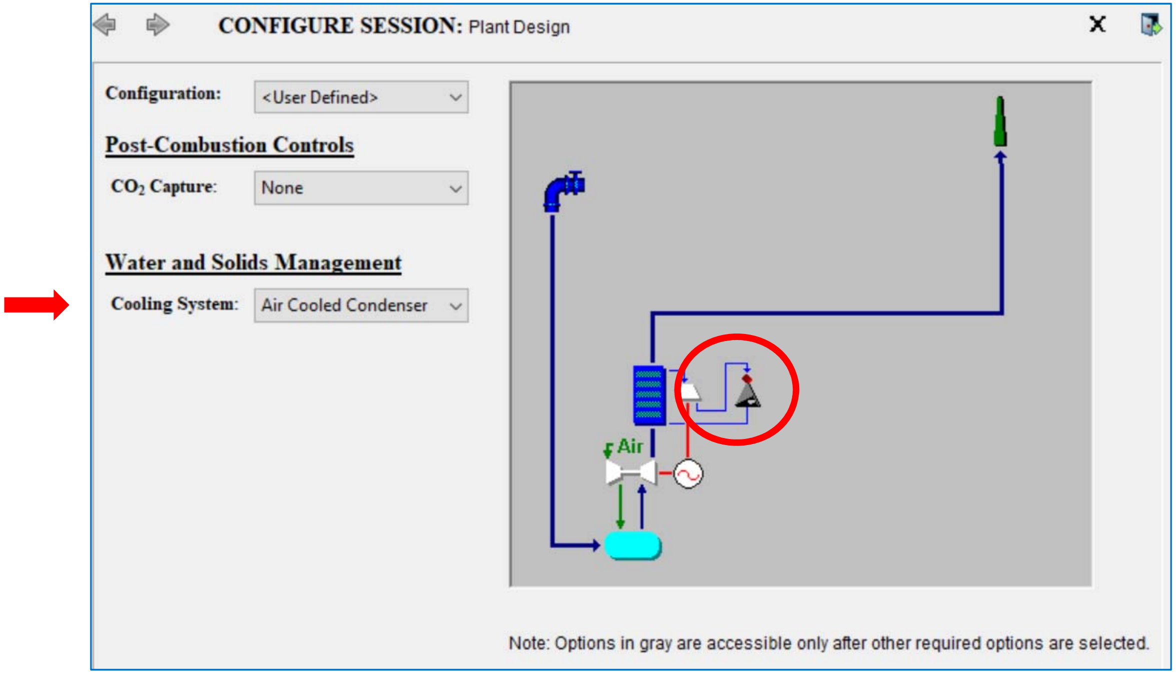
Study Unit ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Air dry bulb temp. (°F)	77.9	77.9	77.9	77.9	77.9	64.5	77.9	77.9	77.9	77.9	77.9	63.5	51.4	51.4
Air relative humidity (%)	31.2	31.2	31.2	31.2	31.2	33.2	31.2	31.2	31.2	31.2	31.2	41.3	52.6	52.6
Unit age in 2020 (years)	19	17	18	15	14	18	19	16	18	17	17	14	5	16
Nameplate capacity (MW)	135.6	570	292	622.1	290.2	654.2	646.3	441.6	573.1	691.5	619	650.3	624.8	684.7
Net capacity (MW)	120.6	519.3	284.1	610.5	285	637.9	610.6	432.7	551.6	679.1	608.2	638.7	614.2	637.9
Net plant efficiency (HHV,%)	40.1	42.3	46.0	46.4	45.7	46.7	42.5	47.0	45.8	46.6	48.1	44.6	48.6	40.9
Capacity factor (%)*	21.0	44.5	40.5	43.1	42.0	35.0	19.4	13.7	43.0	33.9	44.8	45.3	57.2	35.7
Net generation (BkWh/yr)	0.222	2.026	1.009	2.307	1.049	1.957	1.037	0.520	2.079	2.015	2.388	2.536	3.080	1.996
Water consumption (gallons/MWh)	**320**	**306**	**300**	**357**	**336**	**286**	**350**	**248**	**260**	**322**	**289**	**302**	**215**	**272**

* Based on nameplate capacity

Model Existing NGCC Units Retrofitted with Dry Cooling Systems

- Replace wet cooling tower with a dry air-cooled condenser (ACC) system
  - Same nameplate capacity and capacity factor as before



Source: CMU/UW

Model Existing NGCC Units Retrofitted with Dry Cooling Systems (continued)

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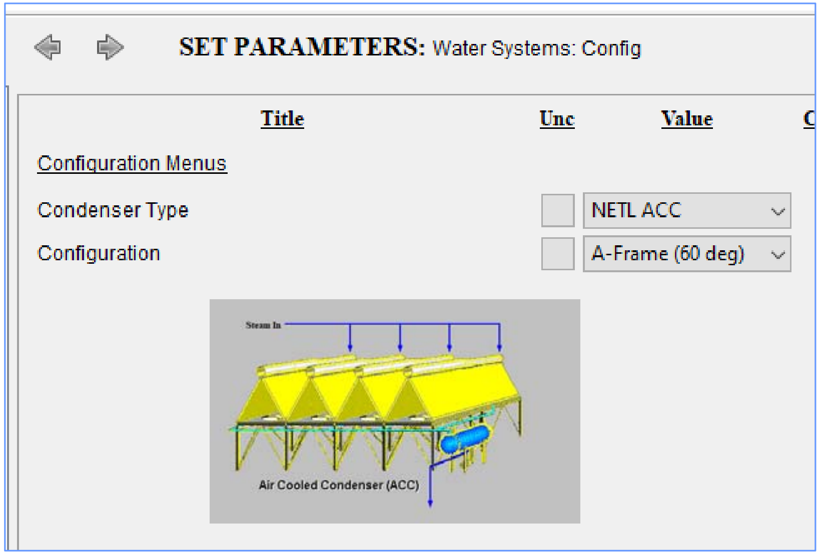
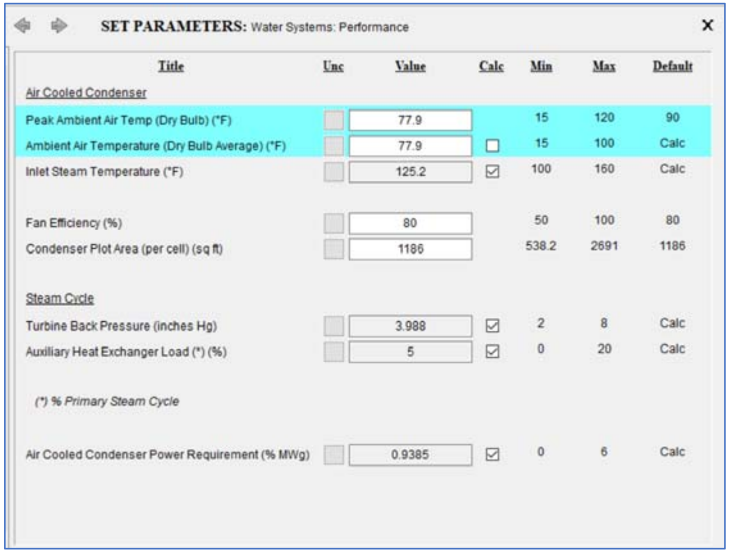
- ACC design based on annual average ambient conditions
- ACC capital cost amortized over remaining life of the unit as of 2020 (based on a 30-year NGCC unit life)





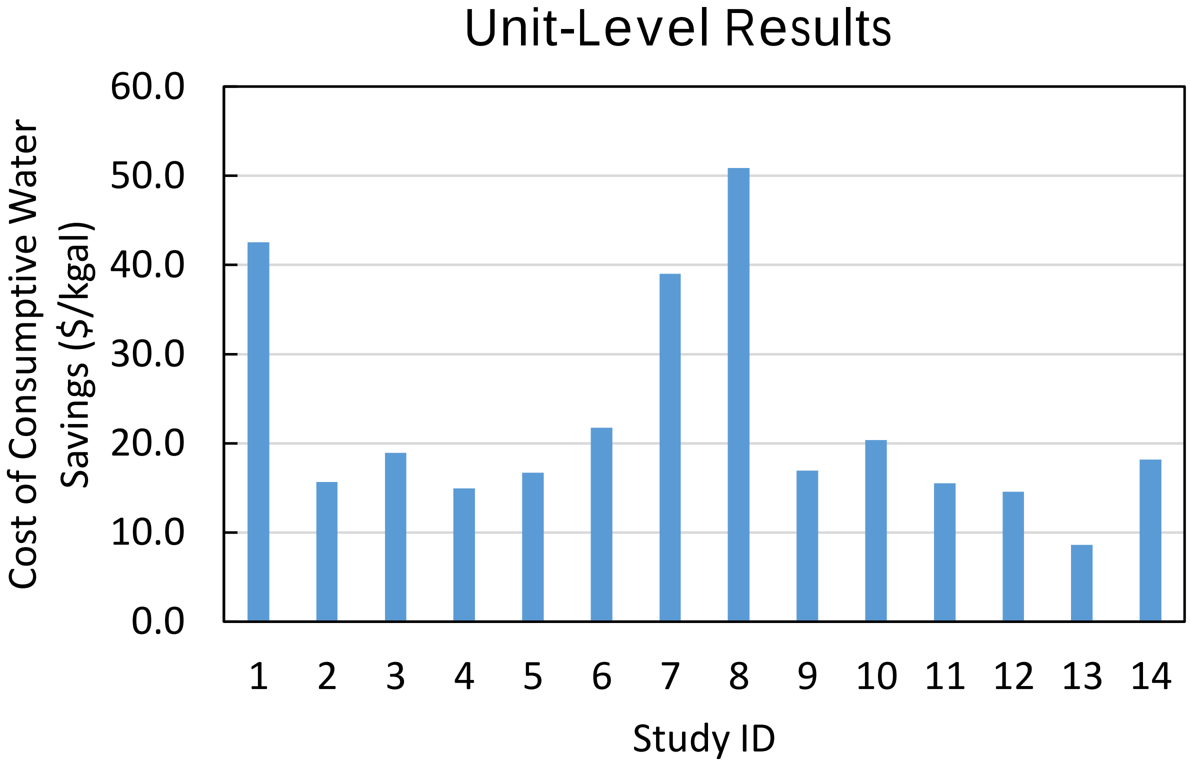
Source: CMU/UW

Key Results for Existing NGCC Units Retrofitted with ACCs (CY 2017)

Study Unit ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nameplate capacity (MW)	135.6	570	292	622.1	290.2	654.2	646.3	441.6	573.1	691.5	619	650.3	624.8	684.7
Net capacity (MW)	119	512.3	280	599.9	280.3	632.4	600.9	427.4	544.8	668.4	599.4	633	612.5	635.9
Net plant efficiency (HHV, %)	39.6	41.7	45.4	45.5	45.0	46.3	41.9	46.4	45.3	45.9	47.4	44.2	48.4	40.7
Capacity factor (%)*	21.0	44.5	40.5	43.1	42.0	35.0	19.4	**13.7**	43.0	33.9	44.8	45.3	**57.2**	35.7
Net electricity generation (BkWh/yr)	0.219	1.998	0.9941	2.266	1.032	1.94	1.021	0.5133	2.053	1.983	2.354	2.514	3.071	1.99
Water consumption (gallon/MWh)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Increase in Levelized Cost of Energy (LCOE) (2017 $/MWh)	**13.6**	**4.8**	**5.7**	**5.3**	**5.6**	**6.2**	**13.7**	**12.6**	**4.4**	**6.6**	**4.5**	**4.4**	**1.9**	**5.0**
Percent increase in LCOE **	24.2	13.3	15.9	17.1	17.2	18.3	31.8	29.7	13.5	20.3	14.6	14.4	5.9	13.8

* Based on nameplate capacity **Relative to pre-retrofit, assuming capital cost of all existing plant equipment is fully amortized before and after retrofit

Cost of Water Savings by Dry Cooling Retrofit*



Regional Averages:

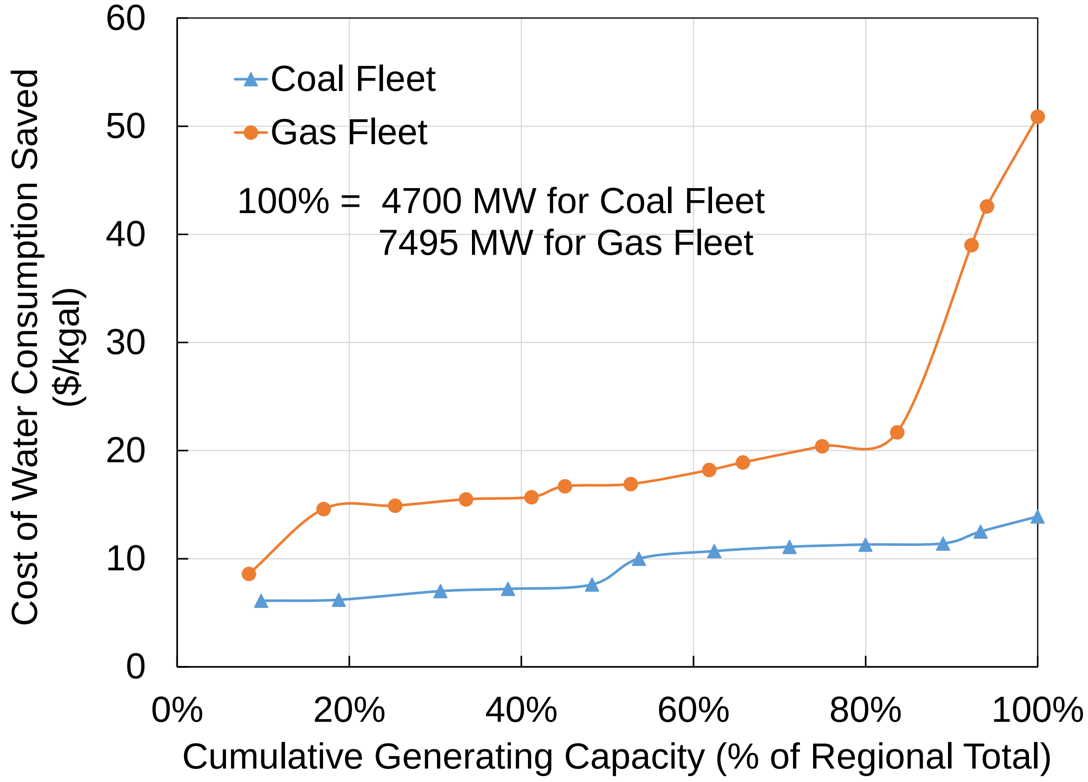
- 100% drop-in unit-level water consumption
- $6.7/MWh (18%**) increase in LCOE
- $22.5 per thousand gallons of water saved
- Costs increase for difficult retrofits and decrease for higher water prices

***Based on fully amortized plants*

** Based on nominal water price of $1.13/kgal*

Source: CMU/UW

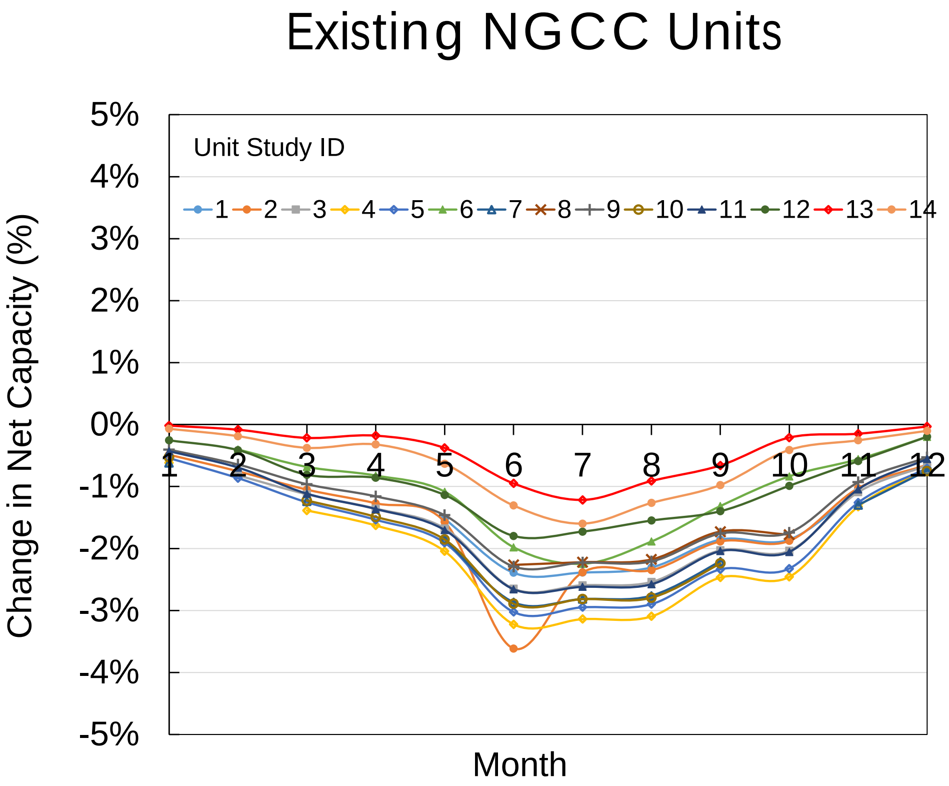
Water Savings Supply Curves for NGCC and Pulverized Coal (PC) Plants

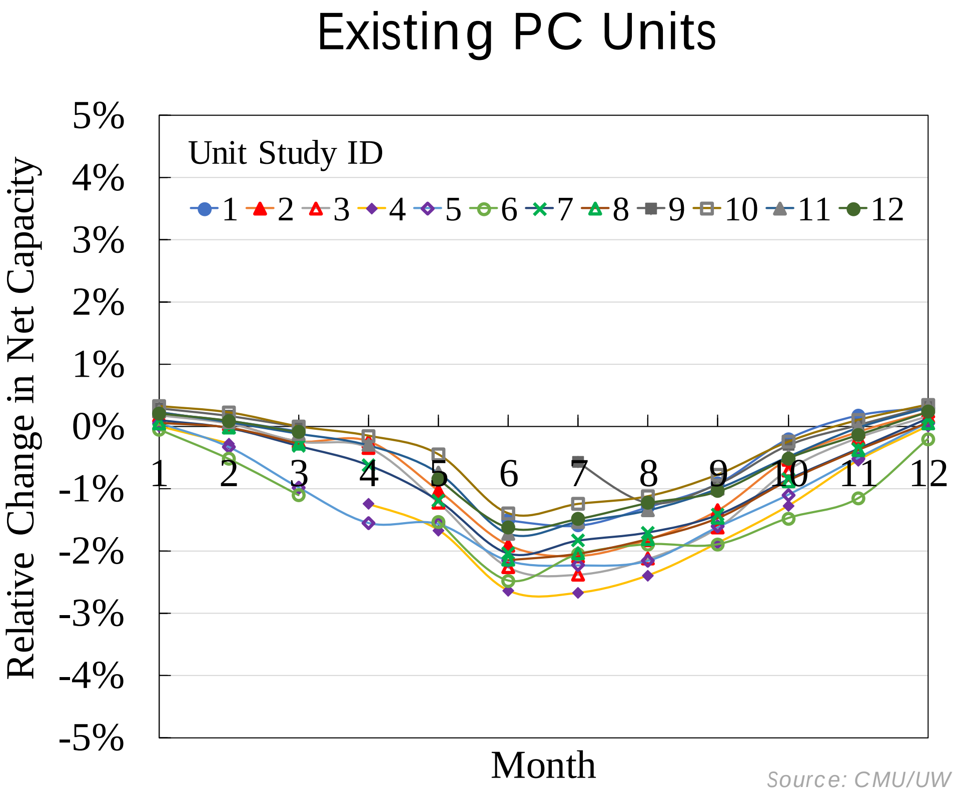


- The unit cost of water saved at NGCC plants is higher than for PC plants, mainly because of lower NGCC capacity factors.
- Differences in cooling duty, amortization period and other site-specific factors also contribute to higher costs at NGCC units.

Source: CMU/UW

Monthly Change in Net Unit Capacity for NGCC and PC Retrofit Cases





Source: CMU/UW

Summary of Changes in Net Regional NGCC Capacity with Dry Cooling Retrofits

Average monthly decrease in net regional NGCC capacity:

- 23 MW to 167 MW on an absolute basis, or
- 0.3% to 2.2% on a relative basis
- Largest decreases in capacity occur in June and July

Annual average decrease in net regional NGCC capacity:

- 86 MW, or 1.2% of total regional NGCC capacity with wet cooling
- This is higher than the average decrease of 0.8% for PC units, due mainly to higher steam cycle heat rates at NGCC units

In Summary

- This work has quantified the potential water savings benefit of dry cooling system retrofits at NGCC plants now using wet cooling towers in a water-stressed region.
- Also quantified tradeoffs in terms of higher cost and shortfalls in net generating capacity.
- Together with prior analysis of coal-fired plants, these results can be used to better inform water use strategies and policies for power plants in a water-stressed region.
- Further analysis and additional data are needed to assess impacts for shorter time periods (e.g., daily, hourly).

Acknowledgements

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