TURBINE INLET COOLING ASSOCIATION turbineinletcooling.org

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November 25, 2014

U.S. Environmental Protection Agency
Attention Docket ID No. EPA–HQ–OAR–2013–0602
Mail code 28221T
1200 Pennsylvania Ave. NW.
Washington, DC 20460.

Via email: a-and-r-docket@epa.gov
Attention Docket ID No. EPA–HQ–OAR–2013–0602

Re: Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, EPA–HQ–OAR–2013–0602, 79 Fed. Reg. 34830 (June 18, 2014)

Dear Administrator McCarthy:

The Turbine Inlet Cooling Association (hereinafter, "TICA") commends EPA for taking important steps to reduce greenhouse gas emissions and appreciates the opportunity to comment on the Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (hereinafter "proposed rule" or "Carbon Guidelines"). TICA is a trade association that promotes the development and exchange of knowledge related to turbine inlet cooling (TIC) technologies, for enhancing power generation. We are glad to highlight the role turbine inlet cooling technologies can play in achieving reductions in carbon emissions. Indeed, TIC provides a cost-effective, demonstrated solution to reduce source emissions by maximizing the productivity of more efficient and lower emission natural gas-fired turbines in combined cycle and simple-cycle systems. . Our analysis shows that installing TIC on every large existing natural gas turbine in the country could increase summertime output by 26.5 gigawatts (GW). Such full-scale deployment would offer significant environmental and economic benefits:

- If TIC were used on these turbines for just 25 percent of the year, nationwide CO_2 emissions would be reduced by the equivalent of taking more than two-million cars off the road or more than 900,000 homes off the grid annually;
- Ratepayers would save at least $20-billion;
- And increased summertime capacity would compensate for more than 90 percent of the announced coal-fired unit retirements.

Because TIC technologies increase the capacity and efficiency of relatively clean natural gas units, we believe that these technologies can and should play a key role in helping states achieve their emission targets. Our recent analysis (Attachment) further shows that TIC provides a demonstrated and cost-effective tool to ensure continued electric reliability despite announced coal-fired retirements.[1] Accordingly, <u>we urge EPA to highlight TIC's benefits in the final rule and to clarify that TIC may serve as a compliance option for states looking to increase their reliance on natural gas combined cycle power plants.</u>

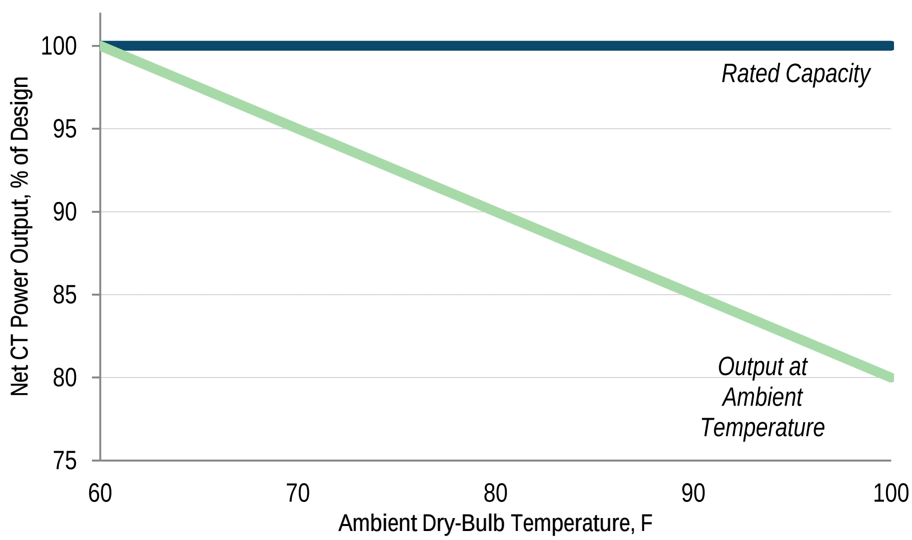
[1] Our comments include lengthy excerpts from this analysis ("Turbine Inlet Cooling: Technology Options to Increase Clean Electricity Production in Hot Weather"), which is attached in its entirety to this letter.

High Temperatures Undermine the Benefits of Natural Gas Units

EPA set state emission targets based on four building blocks representing tools that states can use to reduce greenhouse gas emissions. These include increasing reliance on existing natural gas combined cycle units ("building block two"). The inclusion of this factor demonstrates that EPA believes states should reduce carbon emissions by increasing their reliance on the existing natural gas combined cycle (NGCC) fleet. We agree that increasing reliance on existing natural gas systems should be a key component of a state's compliance strategy. The Proposed Rule overlooks, however, the inherent shortcomings of these units.

Natural gas turbines are rated to perform at 59 degrees Fahrenheit and 60 percent relative humidity at sea level. As outside air temperatures rise, the mass flow of air entering the turbine decreases, causing the capacity of natural gas turbines to plummet. In states like Texas, where average daily temperatures exceed 59 degrees Fahrenheit,[2] gas turbines are therefore underperforming for much of the year. As Figure 1 illustrates, this can lead to a substantial loss in electricity production. When outside temperatures reach 100 degrees Fahrenheit, gas turbines produce only 80 percent of their rated capacity.

FIGURE 1: NATURAL GAS CAPACITY DECREASES IN HIGH TEMPERATURES[3]



This loss is significant when multiplied across the electricity fleet. In fact, nationwide, data from the Energy Information Administration shows that summertime capacity of gas combustion turbines declined by nearly 33 GW in 2012.[4] (see Table 1). This loss is comparable to taking

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[2] Current Results, "Average Annual Temperature for Each State" (reporting average temperatures of 64.8 degrees Fahrenheit) (http://www.currentresults.com/Weather/US/average-annual-state-temperatures.php) (visited Nov. 24, 2014).

[3] Punwani, D.V. and C.M. Hurlbert, 2005, "Unearthing Hidden Treasure." Power Engineering.

[4] Energy Information Administration (EIA), 2013, "Electric Power Annual" (Table 4.3) (http://www.eia.gov/electricity/annual/pdf/epa.pdf).

more than 60 power plants offline[5] – precisely at the time when electricity demand is at its highest due to summer air conditioning use.

TABLE 1. SEASONAL LOSS IN NATURAL GAS POWER-GENERATION CAPACITY[6]

Fuel	Winter Capacity, MW	Summer Capacity, MW	Capacity Loss in Summer Relative to Winter, MW
Natural Gas	455,214	422,364	32,850

When ambient temperature is high, combustion turbines are also becoming less efficient – i.e., using more fuel (and producing more emissions) per MWh of useful electricity. In fact, combustion turbines can become as much as 15 percent less efficient in hot weather. This drop in capacity and efficiency occurs at precisely the time when electricity demand is at its highest, as a result of high air conditioning use. Many utilities simply accept this loss as a cost of doing business. And utility commissions allow them to fill this gap with higher emitting – and less efficient – peaking plants ("peakers").

The proposed rule does not consider these inherent limitations of natural gas units. Fortunately, as elaborated below, TIC provides a cost-effective, demonstrated solution to enhance electric reliability and would allow states to maximize the productivity of their more efficient and lower emission NGCC turbines.

Turbine Inlet Cooling Expands Natural Gas Capacity and Reduces Associated Emission from these Units

TIC refers to a suite of technologies that cool the incoming air in a natural gas combustion turbine to allow it to run more efficiently and function closer to its rated capacity. In this way, TIC technologies restore higher capacity to natural gas turbines, even during the hottest days of summer, eliminating the need to deploy less efficient, dirtier/higher emission systems when consumer demand peaks.

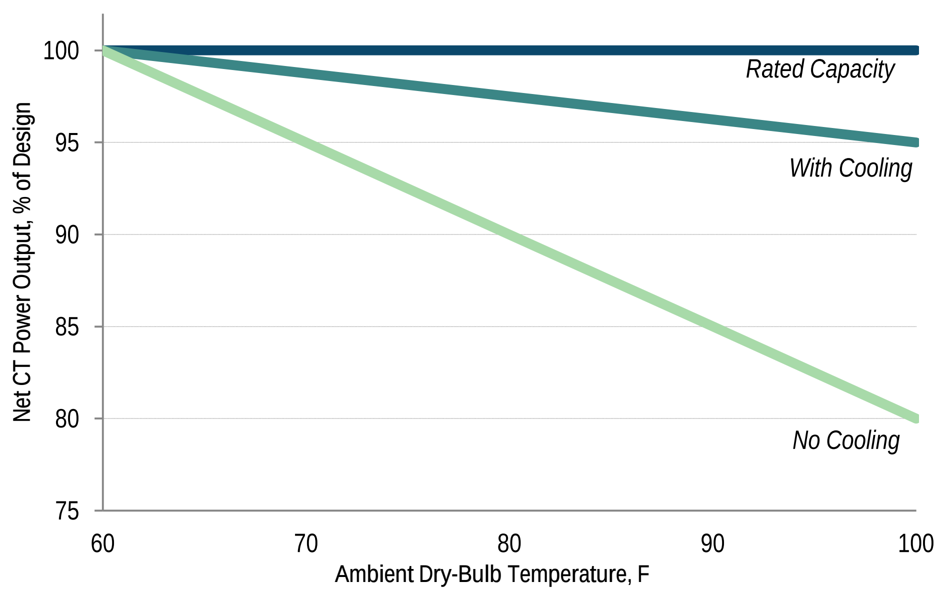
TIC encompasses several different technologies. In its most basic form, evaporative systems, such as "wetted media," "fogging," and "wet compression" simply add moisture to cool the air before it enters the compressor section of a combustion-turbine system. Evaporative systems provide less cooling when ambient air is more humid. Another technology, known as chillers, cools the inlet air to a predetermined set point without adding moisture. These systems provide greater increased output than evaporative cooling and can fully restore rated capacity, or even exceed the rated capacity by reducing inlet temperatures *below* 59 degrees Fahrenheit.

[5] Assuming a typical 500 MW power plant.
[6] EIA 2013, *supra* note 4 (Table 4.3).

However, chillers require more electricity to operate than evaporative systems.[7] Thermal Energy Storage can be added to chillers to provide higher peak period output (by shifting parasitic load from on-peak to off-peak periods) and flexible capacity. Hybrid TIC systems use a combination of these approaches.

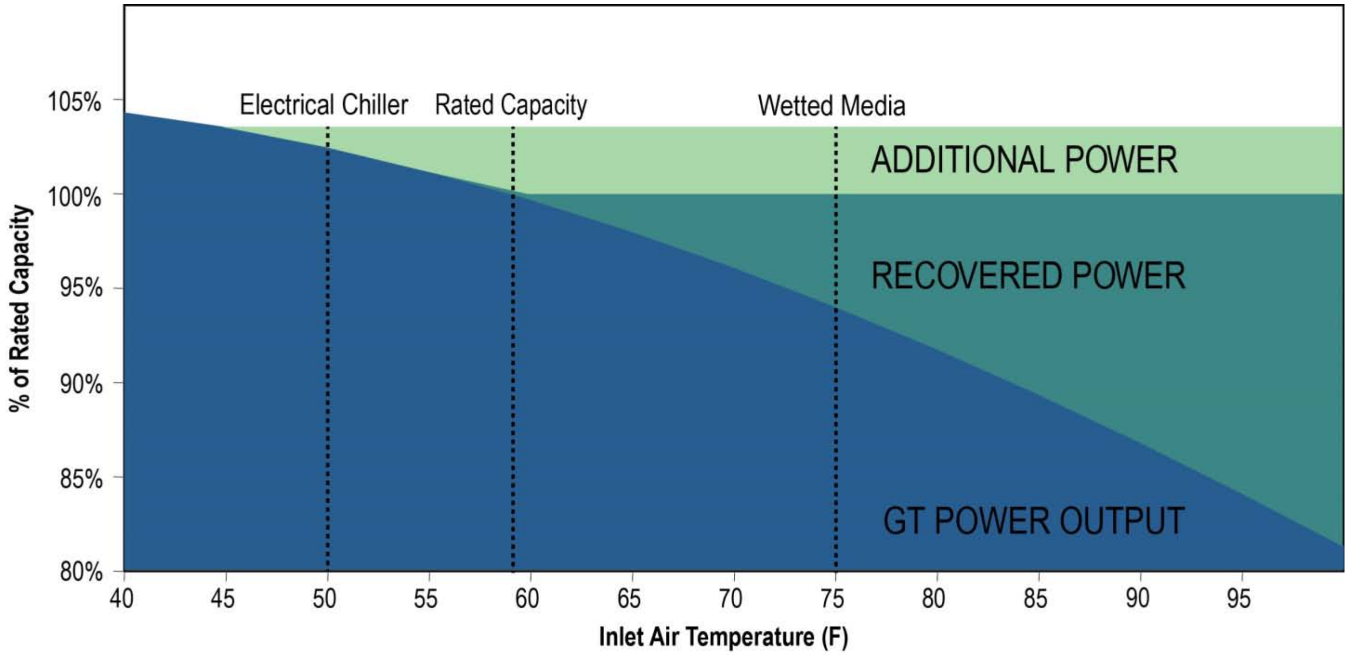
Figure 2 illustrates the increase in capacity from TIC. Figure 3 depicts an example of the benefits of two TIC technologies. It shows that wetted media can restore a significant portion of lost capacity by cooling the inlet air to 75 degrees Fahrenheit and that chillers can cool the air to as low as 45 degrees, allowing the turbine capacity to even *exceed* the rated capacity. The triangle labeled “recovered power” in Figure 3 depicts the gains associated with a chiller set to 59 degrees Fahrenheit (i.e., a complete restoration to rated capacity). The “additional power” represents marginal gains from cooling the inlet air below 59 degrees, the temperature at which the combustion turbines are rated.

FIGURE 2: TIC CAPACITY INCREASES BY TEMPERATURE[8]



[7] *See* Attachment (Figure 4) for additional data on parasitic load, which is relatively modest for all TIC technologies.
[8] Punwani, D.V. and C.M. Hurlbert, 2005, “Unearthing Hidden Treasure.” Power Engineering.

FIGURE 3: CAPACITY BENEFITS OF TIC TECHNOLOGIES[9]



By installing chillers on combustion turbines nationwide, utilities can ensure that their systems are operating near winter capacity year-round. The potential gains from the universal adoption of this approach are sizable. Nationwide, our analysis shows that TIC could increase summertime output by 26.5 GW (see Attachment).

EPA Should Expressly State that Turbine Inlet Cooling is a Valuable Compliance Option for Affected Units

Section 111(d) requires EPA to set the standard to reflect the emissions limits achievable through the "best system of emission reduction taking into account the cost … and any nonair quality health and environmental impact … the Administrator determines has been adequately demonstrated." While EPA did not consider the potential role of Turbine Inlet Cooling when setting the state emission targets, TIC satisfies these requirements. Indeed, as elaborated below and more thoroughly in our recent analysis (Attachment), TIC (1) reduces CO_2 emissions, (2) is cost effective, (3) enhances electric reliability, and (4) is adequately demonstrated. EPA should highlight these benefits in the final rule and expressly state that TIC is a valuable compliance tool for affected units, notwithstanding its omission from the building blocks. Building block two contemplates increasing the average utilization rate of NGCC units to 70 percent. TIC would allow for even greater utilization of these units, thus reducing the need for states to rely as heavily on the other building blocks to achieve their targets.

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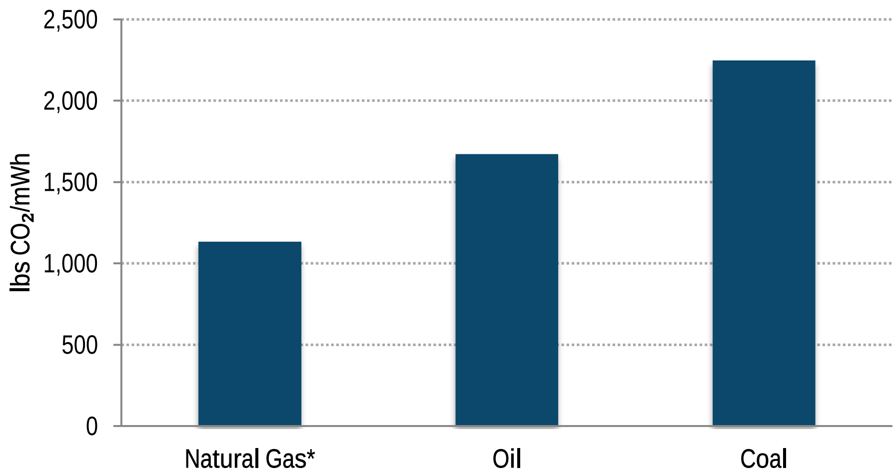
[9] Actual increased capacity will be slightly lower due to the electricity required to operate TIC equipment (i.e., parasitic load). See Attachment for additional data on parasitic load, which is relatively modest for all TIC technologies.

TIC Reduces CO_2 Emissions

TIC represents a valuable set of tools to help reduce an array of air pollutants, including carbon dioxide (CO_2). TIC is suitable for use on all natural gas combustion turbines. As EPA recognizes, these systems are significantly cleaner than oil or coal. In fact, a natural gas plant produces roughly 1,135 pounds of CO_2 per MWh – just half the emissions (2,249 lbs CO_2/MWh) of a coal-fired plant.[10] (Figure 4)

FIGURE 4. COMPARISON OF CARBON DIOXIDE EMISSIONS FROM GAS-, OIL-, AND COAL-FIRED POWER PLANTS[11]



Increasing the use of TIC on all natural gas combustion-turbine systems reduces or eliminates the need to rely on dirtier peaker units to increase summertime capacity. As a result, TIC not only reduces CO_2 emissions, but also helps prevent the emission of a host of air pollutants that would have been produced by these displaced units. Nationally, this amounts to nearly 10.25 million pounds of avoided CO_2 and 77,489 pounds of avoided NOx per hour of operation. Put another way, if TIC technologies were used at every natural gas turbine in the country for just 25 percent of the year, nationwide CO_2 emissions would be reduced by the equivalent of taking more than two-million cars off the road or more than 900,000 homes off the grid annually.[12]

By installing chillers on combustion turbines nationwide, utilities can ensure that their systems are operating near winter capacity year-round. The potential gains from the universal adoption of this approach are sizable. In fact, our analysis shows that nationwide, summertime output

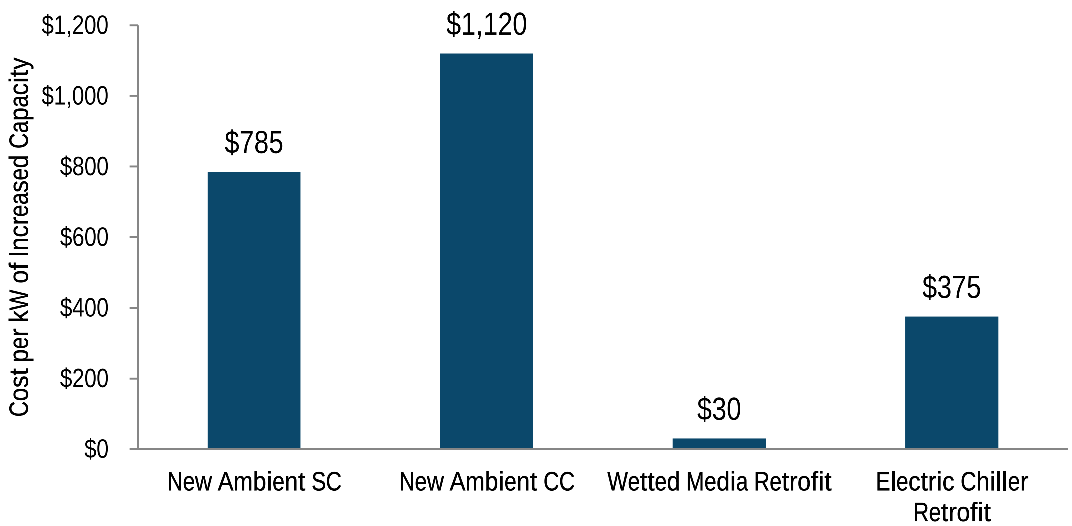
[10] U.S. EPA, 2013, "Air Emissions" (http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html).
[11] *Id*. *CO_2 emissions from chilled gas units are comparable to unchilled units. As elaborated below, TIC offers CO_2 benefits by displacing less efficient oil- and coal-fired systems.
[12] Car and home equivalencies calculated using U.S. EPA's Greenhouse Gas Equivalencies Calculator (http://www.epa.gov/cleanenergy/energy-resources/calculator.html), which assumes 4.75 metric tons of CO_2E per vehicle per year and 7.72 metric tons of CO_2E per home per year. Estimate assumes systems are operating on average 25% of the year (i.e., 2,190 hours). Actual usage will vary dependent upon local temperatures.

could increase by 26.5 GW, with corresponding reductions in CO_2 and NOx emissions.[13] (see Attachment, Table 2). By allowing natural gas combined-cycle turbines to perform more efficiently, TIC reduces the need to supplement power production with less-efficient, dirtier, simple-cycle peakers.

1. **TIC Is Cost-Effective and Saves Consumers Money**

Though TIC requires an up-front investment, it is considerably cheaper than the cost of building new capacity. (see Figure 5). While cost varies by technology, all TIC technologies are very cost-effective, ranging from only $30/kW (wetted media) to $375/ kW (chilling) for plant retrofits. By comparison, constructing a new natural gas combustion-turbine system without TIC is estimated to cost $1,120/kW for a combined-cycle unit and $785/kW for a simple-cycle unit.[14] At these rates, it would cost about $28.1-million to retrofit a 500-MW combined-cycle system with an electric chiller to achieve a 75 MW increase in capacity.[15] In contrast, it would cost roughly $84-million to construct a new combined-cycle system to produce the same capacity.[16] What's more, because TIC is simply installed at existing infrastructure, there are no additional siting or interconnection fees. TIC can be installed in less than one year, further adding to its economic benefits. These savings transfer to ratepayers in the form of lower utility bills.

FIGURE 5: TIC IS COST-EFFECTIVE[17]



Nationally, achieving up to a 26.6-gigawatt increase in summertime capacity by installing chillers at existing combustion-turbine plants cost up to $10-billion dollars,[18] while building new

[13] CO_2 and NOx reductions are sizable, but will vary by location, dependent upon what is being displaced.
[14] TAS Energy, Internal Estimates.
[15] 75,000 kW x $375/kW = $28.1-million.
[16] 75,000 kW x $1,120/kW = $84-million.
[17] Cost estimates for new construction in Figure 5 and accompanying text are based on installation costs for a system in Aniston, AL (95 degrees Fahrenheit and 42.5% Relative Humidity).
[18] 26.6 GW x $375 per kW of increased capacity from an electric chiller retrofit = $9.97 billion. This is a conservative estimate, as other TIC technologies can be installed at lower cost.

combined-cycle gas plants to increase capacity by that same amount would cost nearly $30-billion.[19] Thus, full-scale deployment of chiller systems could save ratepayers at least $20-billion.[20]

2. TIC Improves the Reliability of the U.S. Electricity System

TIC technologies can enhance electric reliability. More than 75 percent of U.S. coal-plant capacity is already more than 30-years old – the operating lifetime for which coal plants were typically designed[21] – and more than one-third went online before 1970.[22] An aging fleet, declining natural gas prices, and a suite of EPA Clean Air Act rules are forcing these facilities to reconsider how they do business. As a consequence, many utilities are beginning to announce planned retirements of their coal-fired power plants. As of October 2013, 150 coal-fired units – representing 28.2 gigawatts (GW) – had already announced future retirements.[23] Utilities in these states will need to explore other options to ensure that they can continue to provide reliable electricity.

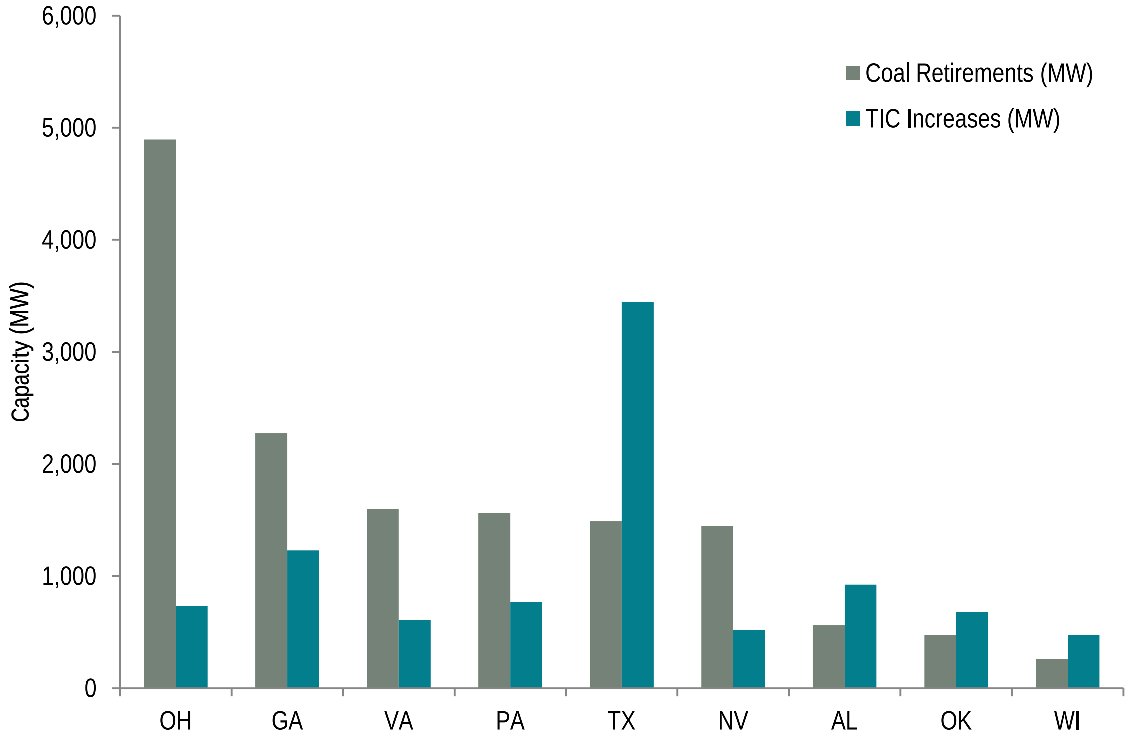
Notably, nearly half of the states facing the largest number of planned coal retirements are also among the top 20 states with the greatest potential to improve their capacity through TIC. (Figures 6 & 7) Widespread use of these simple technologies could thus compensate for more than 90 percent of the announced coal-fired unit retirements. This will ensure continued electric reliability despite a changing electricity fleet. If TIC were implemented to increase capacity at existing combustion turbines, some of the economic and reliability impacts of these retirements could be mitigated. This suggests TIC should be a key component of the long-term reliability planning in these states.

Texas leads the nation in potential to replace coal retirements with TIC-driven capacity increases. While the state has 1.5 GW of retiring coal capacity, it can increase summertime capacity at its existing gas plants by nearly 3.5 GW with the use of TIC, amounting to a 2 GW seasonal surplus. Among the top 20 states for coal retirements, Alabama, Oklahoma, and Wisconsin could likewise replace their retirements entirely with TIC-driven capacity increases. Even where TIC cannot singlehandedly substitute for retirements, it can still play a significant role in ensuring continued reliability. For instance, Georgia, which has the second highest level

[19] 26.6 GW x $1,120 per kW of a new ambient combined cycle plant = $29.77 billion.
[20] Wetted media could be installed at all combustion turbines for an even lower cost, though capacity gains might be limited due to ambient humidity.
[21] NREL, NREL/TP-570-25119, June 1999, "Life Cycle Assessment of Coal-Fired Power Production" (http://www.nrel.gov/docs/fy99osti/25119.pdf).
[22] Union of Concerned Scientists, Nov. 2012, *Ripe for Retirement: The Case for Closing America's Costliest Coal Plants*, at 18 (Fig. 1) (http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-Full-Report.pdf).
[23] Union of Concerned Scientists, December 2013, *Ripe for Retirement: An Economic Analysis of the U.S. Coal Fleet*, at Appendix 1 (http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-An-Economic-Analysis-of-the-US-Coal-Fleet.pdf) (note that these anticipated retirements are in addition to facilities that have already closed; UCS reports that 18.2 GW of capacity had closed between 2011-2013).

of announced retirements in the country, could replace 54 percent of its retirements through TIC.

FIGURE 6: RETIRING COAL CAPACITY VS. POTENTIAL TIC CAPACITY INCREASE



3. <u>TIC Is Adequately Demonstrated</u>

While underutilized, TIC is a proven technology, which can be used on natural gas turbines of any size. In fact, TIC technologies have already been installed at hundreds of facilities in the United States,[24] with thousands of additional units worldwide. The potential is even greater. Our analysis shows (Attachment) that full-scale deployment of these technologies could increase generation capacity during hot summer weather by 26.6 GW.

[24] Turbine Inlet Cooling Association, 2012, "Partial Database of Turbine Inlet Cooling (TIC) Installations" (http://turbineinletcooling.org/data/ticadatap.pdf).

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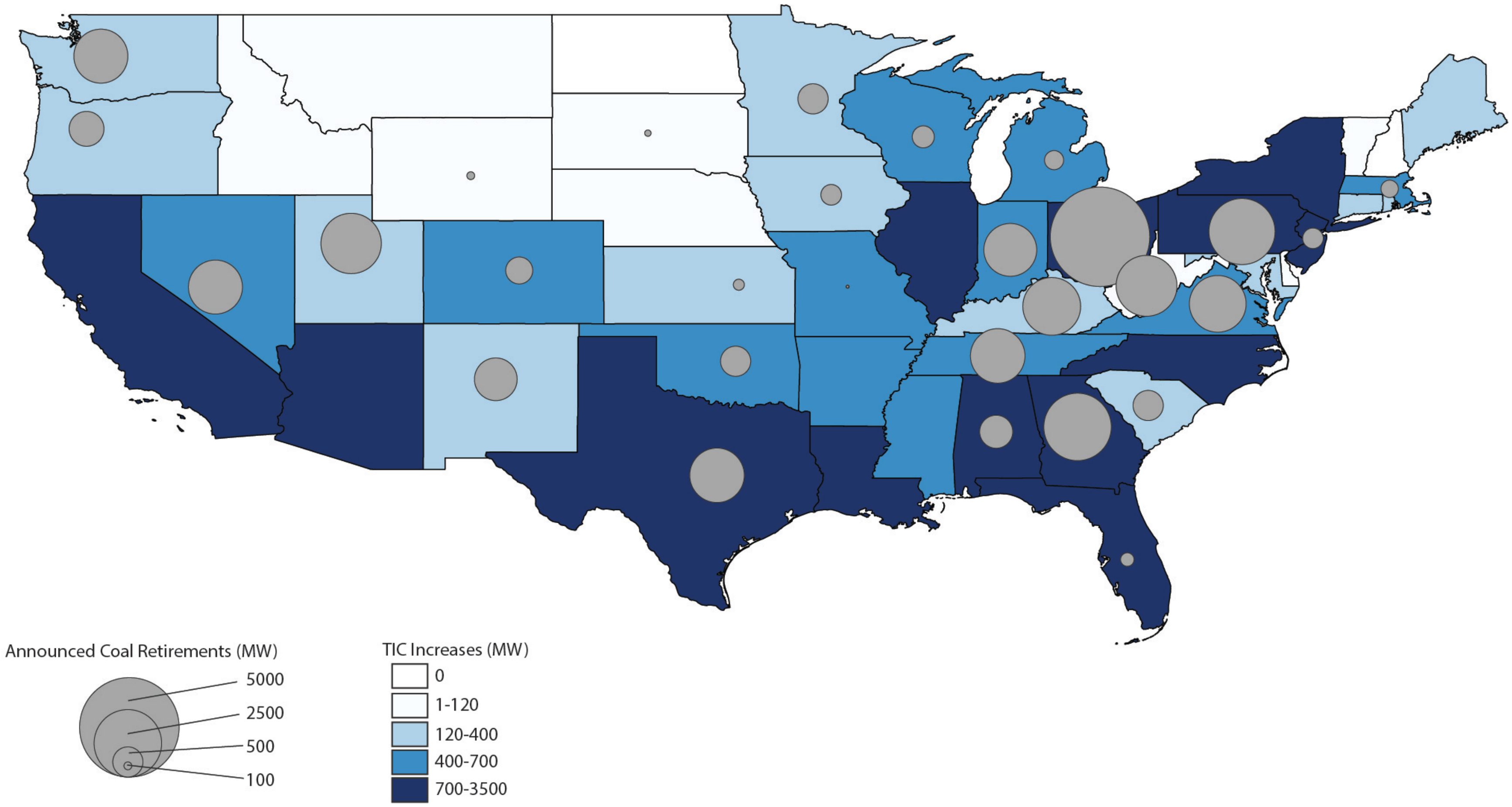
FIGURE 7: SIGNIFICANT OVERLAP OF STATES WITH HIGH LEVELS OF COAL RETIREMENT AND TIC OPPORTUNITY



CONCLUSION

We commend EPA for emphasizing the benefits of natural gas combustion in the proposed rule. As EPA notes, NGCC units are significantly less polluting than their coal or oil counterparts. EPA appropriately set state emission targets assuming an increased reliance on these units. Unfortunately, combustion turbines using natural gas units cannot perform at their rated capacity during hot weather. As elaborated above, TIC technologies increase the capacity and reduce CO_2 emissions, are cost effective, enhance electric reliability, and are adequately demonstrated. EPA should elaborate these benefits in the final rule and explain that TIC is a valuable compliance tool for affected units. EPA should further urge states to require installation of turbine inlet cooling technologies in their natural gas combustion turbine units to ensure that they are maximizing their use of these relatively clean units.

Thank you for the opportunity to comment. We look forward to working with EPA throughout the rulemaking process.

Sincerely,

DPunwani

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Turbine Inlet Cooling Association (TICA)
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ATTACHMENT

Turbine Inlet Cooling

Technology Options to Increase Clean Electricity Production in Hot Weather

September 2014

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The Turbine Inlet Cooling Association (TICA) is a non-profit organization that promotes the development and exchange of knowledge related to gas turbine inlet cooling (TIC) for enhancing power generation worldwide.

Summary

Electric power generation accounts for 40 percent of U.S. greenhouse gas emissions,[1] making it the largest source of emissions in the country. For decades, America's electric infrastructure has been fueled largely by coal. In fact, coal currently provides 37 percent of the electricity used in the United States.[2] This fleet is aging. More than 75 percent of U.S. coal-plant capacity is already more than 30-years old – the operating lifetime for which coal plants were typically designed[3] – and more than one-third went online before 1970.[4] An aging fleet, declining natural gas prices, and a suite of EPA Clean Air Act rules are forcing these facilities to reconsider how they do business. As a consequence, many utilities are beginning to announce planned retirements of their coal-fired power plants. As of October 2013, 150 coal-fired units – representing 28.2 gigawatts (GW) – had already announced future retirements.[5] The Union of Concerned Scientists (UCS) projects that an even greater number of facilities (comprising 59 GW of generation capacity) may be "ripe for retirement."[6] As UCS recognizes, such retirements create an "historic opportunity to accelerate the transition to a cleaner energy future."[7]

Turbine Inlet Cooling (TIC) technologies are readily available, reliable and proven options to cost-effectively accelerate this transition. While natural gas-fired combustion-turbine systems are significantly cleaner than coal or oil, they are not able to perform at their full potential during the hot, summer months. In fact, the power output of all combustion-turbine systems decreases when the ambient temperature warms above 59 degrees Fahrenheit, due to the fact that warmer air is less dense. TIC cools the air entering the combustion turbine so that it produces more electricity and can operate more efficiently in hot weather. In this way, TIC increases summertime capacity at natural gas units precisely when demand is at its highest.

Nearly half of the states facing the largest number of planned coal retirements are also among the top 20 states with the greatest potential to improve their capacity through TIC. Increasing capacity of clean, combined-cycle and simple-cycle natural gas units through the use of TIC is significantly cheaper than constructing new units to provide this same capacity. It can be added as a simple retrofit to an existing unit, rather than investing in expensive permitting and siting determinations for new facilities. Widespread use of this simple technology could compensate for more than 90 percent of the announced coal-fired unit retirements.

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[1] U.S. Environmental Protection Agency, June 18, 2014, 79 Fed. Reg. 34830, at 34843, 40 CFR pt 60, "Proposed Rule: Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units" (http://www.gpo.gov/fdsys/pkg/FR-2014-06-18/pdf/2014-13726.pdf).

[2] U.S. Energy Information Administration, May 21, 2013 "Table 1.1: Net Generation by Energy Source: Total (All Sectors)," (http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01).

[3] NREL, NREL/TP-570-25119, June 1999, "Life Cycle Assessment of Coal-Fired Power Production" (http://www.nrel.gov/docs/fy99osti/25119.pdf).

[4] Union of Concerned Scientists, Nov. 2012, *Ripe for Retirement: The Case for Closing America's Costliest Coal Plants*, at 18 (Fig. 1) (http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-Full-Report.pdf).

[5] Union of Concerned Scientists, December 2013, *Ripe for Retirement: An Economic Analysis of the U.S. Coal Fleet*, at Appendix 1 (http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-An-Economic-Analysis-of-the-US-Coal-Fleet.pdf) (note that these anticipated retirements are in addition to facilities that have already closed; UCS reports that 18.2 GW of capacity had closed between 2011-2013).

[6] *Id.* at 3.

[7] Union of Concerned Scientists 2012, *supra* note 5, at 1.

Moreover, TIC helps reduce emissions throughout the air shed. Combined-cycle systems are the cleanest natural gas systems for power generation. These are followed by natural gas simple-cycle and steam-turbine systems and oil-based steam-turbine systems. Installing TIC on combined-cycle systems reduces air shed emissions by displacing the operation of simple-cycle and gas- and oil-based steam-turbine peakers. Installing TIC on gas-fired simple-cycle units reduces air shed emissions by displacing gas-and oil-based steam-turbine peakers. **Installing TIC technologies at every natural gas turbine in the country would:**

- **Save ratepayers** up to $20 billion,[8] as increasing capacity through TIC costs less than one-third the cost of constructing new natural gas units to provide the same capacity; and
- **Reduce pollution** by avoiding 10.25 million pounds of carbon dioxide (CO_2) and 77,489 pounds of nitrogen oxides (NOx) nationwide per hour of operation of these combustion-turbine systems. Assuming TIC systems are in operation 25 percent of the year, this is equivalent to taking more than two-million cars off the road or more than 900,000 homes off the grid annually.

Before states consider building new, expensive power plants, they should maximize the potential of their existing infrastructure. Through the use of TIC on existing combustion-turbine systems, states can increase the summertime capacity of their fleet by 26.6 gigawatts – seamlessly compensating for more than 90 percent of announced retirements.

In summary, TIC allows states to cost-effectively increase summertime capacity, improve air quality, and ensure continued reliability by strengthening their existing electricity infrastructure. EPA's proposed greenhouse gas rule for existing sources paves the way for this transition by urging states to shift dispatch to clean natural gas generation as one of the four primary building blocks to compliance.

Natural Gas Combustion Turbine Capacity Declines in Summer

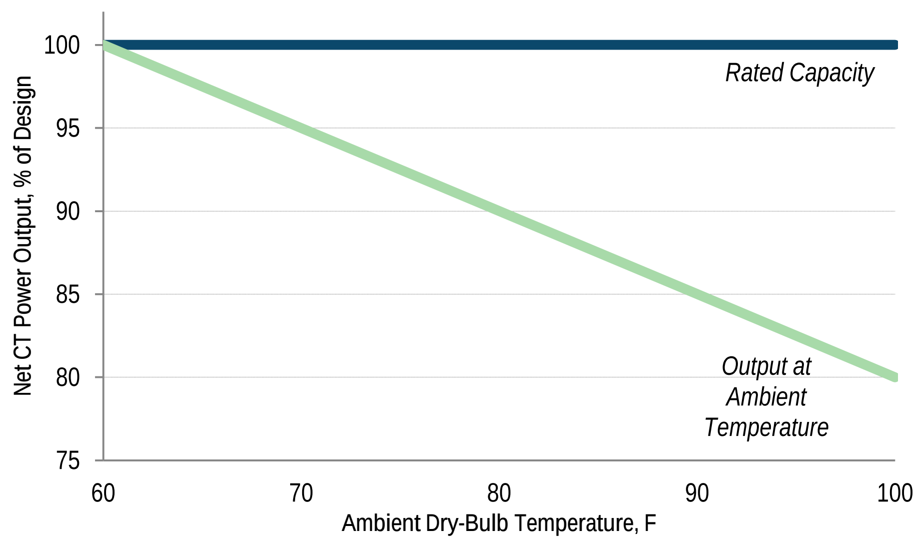
An aging coal fleet, unprecedented low natural gas prices, increases in domestic supply, growing interest in cleaner sources of electricity, and anticipated federal regulations have raised interest in natural gas combustion turbines (CT) in the United States. Natural gas produces significantly lower emissions than oil or coal and – given changing market conditions – gas is increasingly competitive. One little-recognized downside of combustion turbines, however, is that capacity declines with rising outdoor ambient temperatures.

Natural gas turbines are rated to perform at 59 degrees Fahrenheit and 60 percent relative humidity at sea level. As outside air temperature rises, however, the mass flow of air entering the turbine decreases, causing the capacity of natural gas turbines to plummet. In states like Texas, where average daily temperatures exceed 59 degrees Fahrenheit,[9] gas turbines are

[8] Estimate assumes that electric chillers are installed at all natural gas facilities. Alternative TIC technologies (e.g., wetted media) are cheaper, but increase system capacity by a smaller amount.
[9] Current Results, "Average Annual Temperature for Each State" (reporting average temperatures of 64 degrees Fahrenheit) (http://www.currentresults.com/Weather/US/average-annual-state-temperatures.php) (visited May 7, 2014).

therefore underperforming for much of the year. As Figure 1 illustrates, this can lead to a substantial loss in electricity production. When outside temperatures reach 100 degrees Fahrenheit, gas turbines produce only 80 percent of their rated capacity.

FIGURE 1: NATURAL GAS CAPACITY DECREASES IN HIGH TEMPERATURES[10]



This loss is significant when multiplied across the electricity fleet. In fact, nationwide, data from the Energy Information Administration shows that summertime capacity of gas combustion turbines declines by nearly 33 GW.[11] (see Table 1). This loss is comparable to taking more than 60 power plants offline[12] – precisely at the time when electricity demand is at its highest due to summer air conditioning use.

TABLE 1. SEASONAL LOSS IN NATURAL GAS POWER-GENERATION CAPACITY[13]

Fuel	Winter Capacity, MW	Summer Capacity, MW	Capacity Loss in Summer Relative to Winter, MW
Natural Gas	455,214	422,364	32,850

At the same time, the combustion turbines are also becoming less efficient – i.e., using more fuel (and producing more emissions) per MWh of useful electricity. In fact, combustion turbines can become as much as 15 percent less efficient in hot weather. Many utilities simply accept this loss as a cost of doing business. And utility commissions allow them to fill this gap with higher emitting – and less efficient – peaking plants ("peakers"). TIC provides a reliable, cost-

[10] Punwani, D.V. and C.M. Hurlbert, 2005, "Unearthing Hidden Treasure." Power Engineering.
[11] Energy Information Administration (EIA), 2013, "Electric Power Annual" (Table 4.3) (http://www.eia.gov/electricity/annual/pdf/epa.pdf).
[12] Assuming a typical 500 MW power plant.
[13] EIA 2013, *supra* note 11 (Table 4.3).

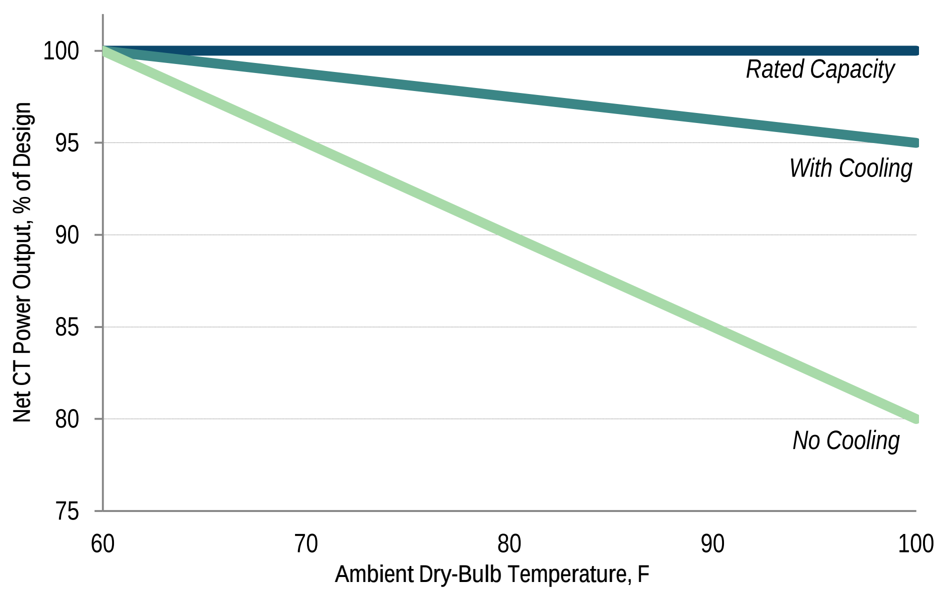
effective solution to ensure that we are maximizing the productivity of the more efficient and lower emission natural gas units.

TIC Provides a Cost-Effective Solution to Summer Capacity Loss

Turbine Inlet Cooling (TIC) refers to a suite of technologies that cool the incoming air in a natural gas combustion turbine to allow it to run more efficiently and function closer to its rated capacity. This is analogous to cooling the air before it enters a building. In its most basic form, evaporative systems, such as “wetted media,” “fogging,” and “wet compression” simply add moisture to cool the air before it enters the compressor section of a combustion-turbine system. Evaporative systems provide less cooling when ambient air is more humid. Another technology, known as chillers, cools the inlet air to a predetermined set point without adding moisture. These systems provide greater increased output than evaporative cooling and can fully restore rated capacity, or even exceed the rated capacity by reducing inlet temperatures *below* 59 degrees Fahrenheit. However, chillers require more electricity to operate than evaporative systems. Thermal Energy Storage can be added to chillers to provide higher peak period output (by shifting parasitic load from on-peak to off-peak periods) and flexible capacity. Hybrid TIC systems use a combination of these approaches.

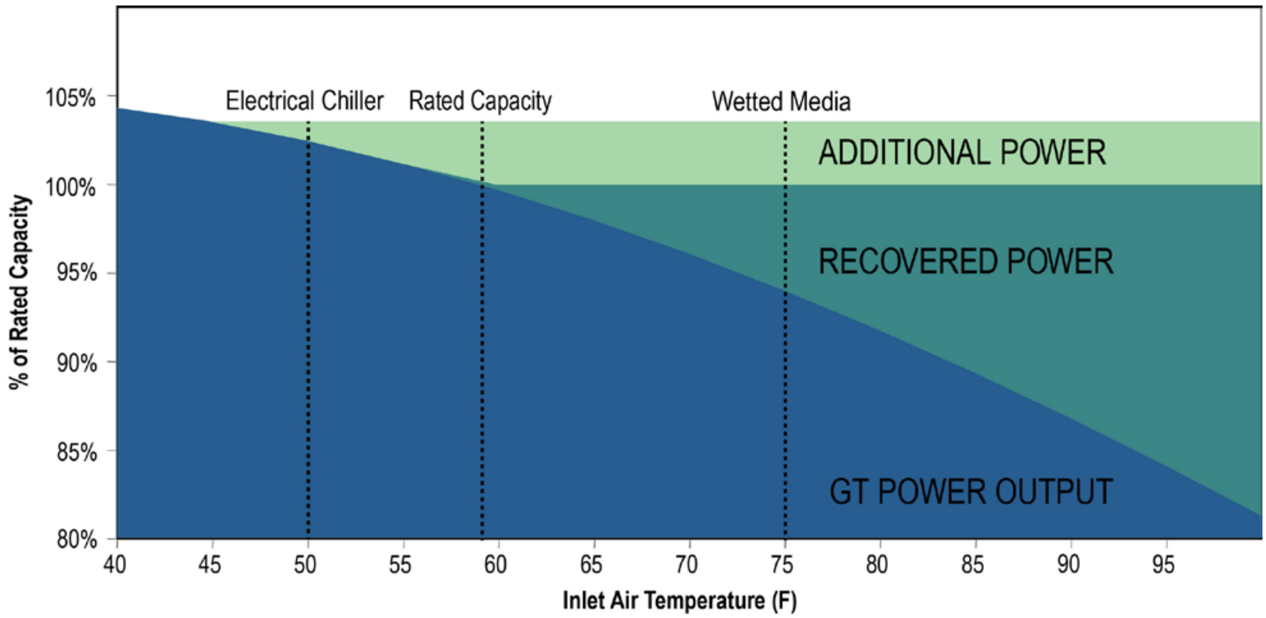
Figure 2 illustrates the increase in capacity from TIC. Figure 3 depicts an example of the benefits of two TIC technologies. It shows that wetted media can restore a significant portion of lost capacity by cooling the inlet air to 75 degrees Fahrenheit and that chillers can cool the air to as low as 45 degrees, allowing the turbine capacity to even *exceed* the rated capacity. The triangle labeled “recovered power” in Figure 3 depicts the gains associated with a chiller set to 59 degrees Fahrenheit (i.e., a complete restoration to rated capacity). The “additional power” represents marginal gains from cooling the inlet air below 59 degrees, the temperature at which the combustion turbines are rated.

FIGURE 2: TIC CAPACITY INCREASES BY TEMPERATURE[14]



[14] Punwani, D.V. and C.M. Hurlbert, *supra* note 10.

FIGURE 3: CAPACITY BENEFITS OF TIC TECHNOLOGIES[15]



Actual benefits will vary dependent upon the selected technology and ambient conditions. Figure 4, for instance, provides a more precise illustration of TIC's benefits. This graphic considers the performance of a turbine in Anniston, AL under relatively hot (95 degrees Fahrenheit) and humid conditions (42.5 percent relative humidity). The turbine is rated to produce 320 MW of electricity at the ISO (International Standards Organization) conditions (i.e., 59 degrees Fahrenheit and 60 percent relative humidity). Under actual ambient conditions, performance falls to only 285 MW. Using wetted media, TIC can increase capacity by 16.2 MW (from 285 MW to 301.2 MW). Using electric chillers, TIC can increase capacity by 43.2 MW (from 285 MW to 328.2 MW). The operating burden ("parasitic load") for TIC is substantially lower than the capacity gains from using either approach, representing only 1 percent (.2 MW) of the increase in capacity using wetted media and less than 15 percent (6.2 MW) of the increase using electric chillers. In either case, TIC provides significant benefits. Moreover, when combining thermal energy storage with the chillers, this 6.2 MW parasitic load can be served using energy that is generated during off-peak hours, when it is less expensive to procure.

By installing chillers on combustion turbines nationwide, utilities can ensure that their systems are operating near winter capacity year-round. The potential gains from the universal adoption of this approach are sizable. Nationwide, summertime output could increase by 26.5 GW, with corresponding reductions in CO_2 and NOx emissions.[16] (see Table 2). By allowing natural gas combined-cycle turbines to perform more efficiently, TIC reduces the need to supplement power production with less-efficient, dirtier, simple-cycle peakers. In fact, using TIC on a 500 MW combined-cycle plant *eliminates* the need to operate a 75 to 95 MW simple-cycle peaker.

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[15] Actual increased capacity will be slightly lower due to the electricity required to operate TIC equipment (i.e., parasitic load). Parasitic load will vary, dependent upon ambient temperatures, as depicted in Figure 4, which considers parasitic load at a facility in Aniston, AL.

[16] CO_2 and NOx reductions are sizable, but will vary by location, dependent upon what is being displaced.

FIGURE 4: EFFECT OF TIC TECHNOLOGIES ON NET CAPACITY[17]

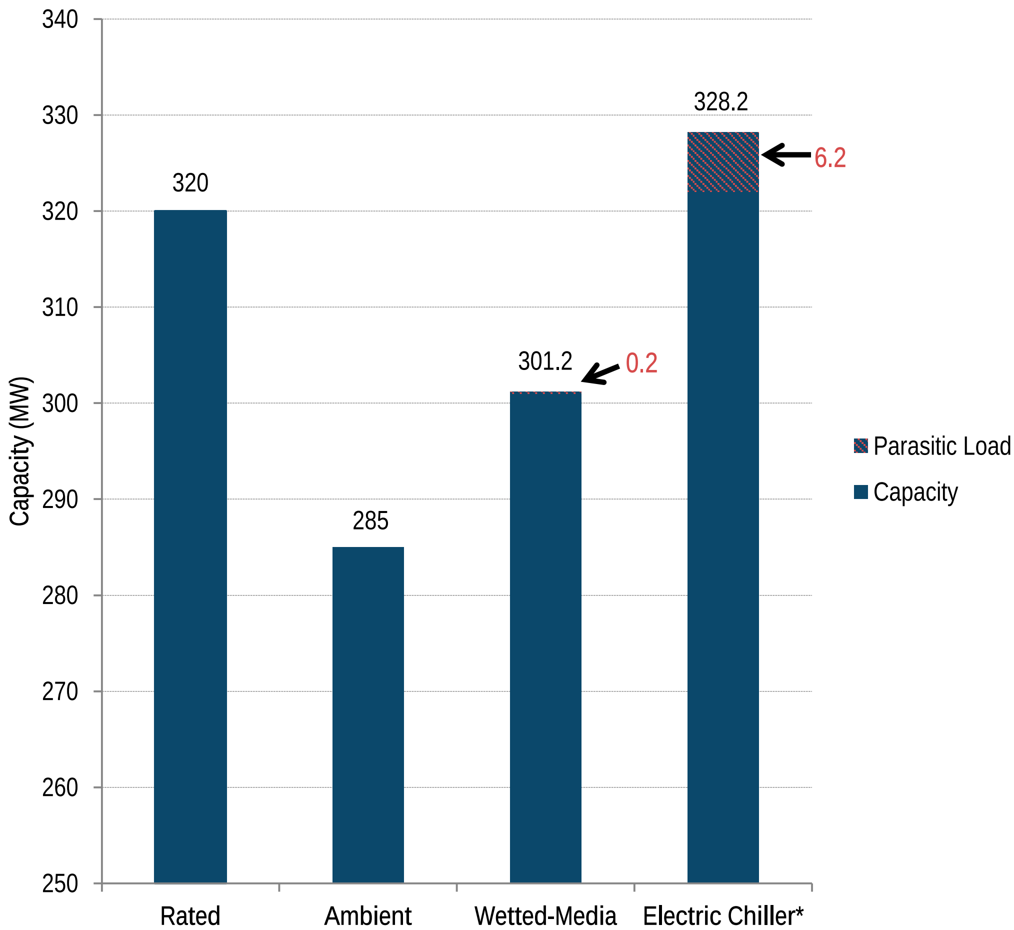


TABLE 2: SUMMER CAPACITY INCREASES BY TIC FOR TOP 20 STATES AND U.S. TOTAL

State	2012 Summer Capacity (MW)[18]	Potential Summer Capacity Gain (MW)
Texas	44,308	3,447
Florida	31,902	2,482
California	26,530	2,064
Georgia	15,793	1,229
Illinois	13,291	1,034
Arizona	12,236	952
Alabama	11,876	924
New York	11,350	883

[17] Based on GE's 7FA Combined Cycle Plant (1 Gas and 1 Steam Turbine), Anniston, AL (95 degrees Fahrenheit and 42.5% Relative Humidity). *If combined with thermal energy storage, the total (322 MW) capacity can be made available during on-peak periods by shifting the parasitic load to operate the chiller to off-peak hours.

[18] EIA 2013, *supra* note 11. (Table 4.7.C)

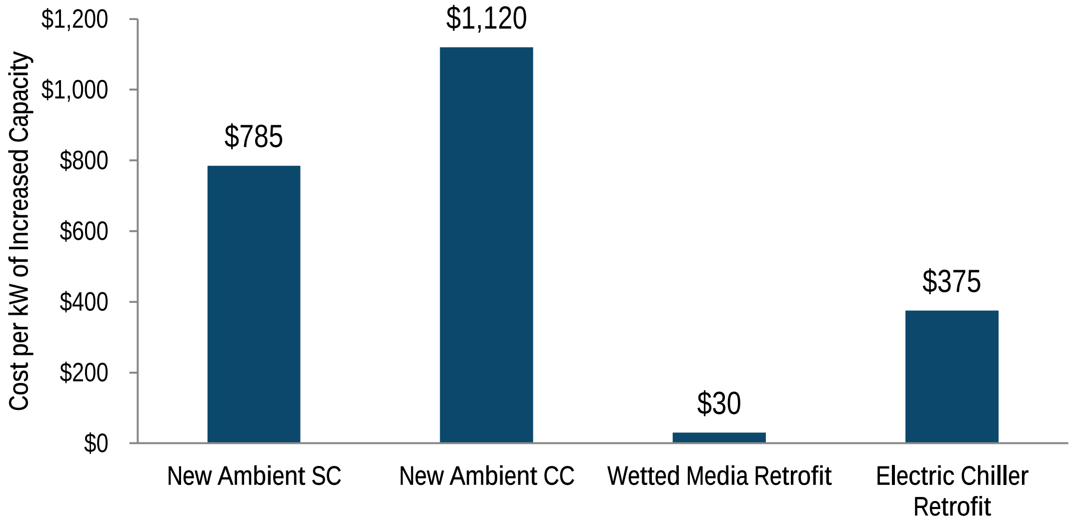
North Carolina	10,086	785
New Jersey	9,971	776
Pennsylvania	9,859	767
Louisiana	9,730	757
Ohio	9,403	732
Mississippi	8,714	678
Oklahoma	8,704	677
Michigan	8,096	630
Virginia	7,847	610
Nevada	6,668	519
Wisconsin	6,072	472
Massachusetts	5,821	453
Top 20 States	**269,257**	**20,871**
U.S. Total	**341,738**	**26,587**

Though TIC requires an up-front investment, it is considerably cheaper than the cost of building new capacity. (see Figure 5). While cost varies by technology, all TIC technologies are very cost-effective, ranging from $30/kW (wetted media) to $375/ kW (chilling) for plant retrofits. By comparison, constructing a new natural gas combustion-turbine system without TIC is estimated to cost $1,120/kW for a combined-cycle unit and $785/kW for a simple-cycle unit.[19] At these rates, it would cost about $28.1-million to retrofit a 500-MW combined-cycle system with an electric chiller to achieve a 75 MW increase in capacity.[20] In contrast, it would cost roughly $84-million to construct a new combined-cycle system to produce the same capacity.[21] What's more, because TIC is simply installed at existing infrastructure, there are no additional siting or interconnection fees. TIC can be installed in less than one year, further adding to its economic benefits. These savings transfer to ratepayers in the form of lower utility bills.

TIC should also be incorporated into new combustion turbines, where new construction is deemed necessary. This will ensure that these units can perform near their rated capacity year-round. Incorporating TIC in new construction is even more cost-effective than including it in a retrofit, with costs ranging from only $20/kW (wetted media) to $250/kW (chilling). As such, TIC represents a modest component of the total investment.

[19] TAS Energy, Internal Estimates.
[20] 75,000 kW x $375/kW = $28.1-million.
[21] 75,000 kW x $1,120/kW = $84-million.

FIGURE 5: TIC IS COST-EFFECTIVE[22]



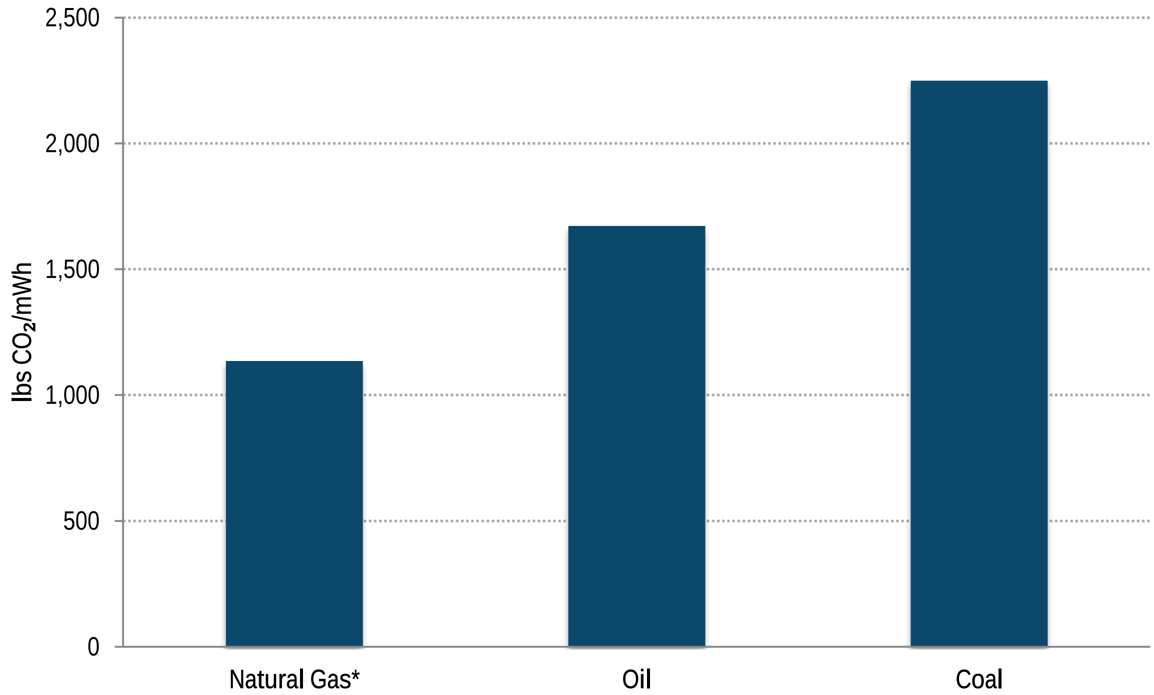
Nationally, achieving up to a 26.6-gigawatt increase in summertime capacity by installing chillers at existing combustion-turbine plants cost up to $10-billion dollars,[23] while building new combined-cycle gas plants to increase capacity by that same amount would cost nearly $30-billion.[24] Thus, full-scale deployment of chiller systems could save ratepayers at least $20-billion.[25]

TIC Offers Significant Air-Quality Benefits

TIC represents a valuable set of tools to help reduce an array of air pollutants, including nitrogen oxides (NOx) and carbon dioxide (CO_2). TIC is suitable for use on all natural gas combustion turbines. As illustrated in Figure 6, these systems are significantly cleaner than oil or coal. In fact, a natural gas plant produces roughly 1,135 pounds of CO_2 per MWh – just half the emissions (2,249 lbs CO_2/MWh) of a coal-fired plant.[26] Natural gas-fired plants also offer significant reductions in NOx and other criteria pollutants relative to coal- and oil-fired systems.[27] By increasing the productivity of these relatively clean systems, TIC reduces the need to use dirtier, less-efficient peakers. Notably, TIC reduces NOx emissions during the summer, when reductions are most needed to prevent ozone violations.

[22] Cost estimates for new construction in Figure 5 and accompanying text are based on installation costs for a system in Aniston, AL (95 degrees Fahrenheit and 42.5% Relative Humidity).
[23] 26.6 GW x $375 per kW of increased capacity from an electric chiller retrofit = $9.97 billion. This is a conservative estimate, as other TIC technologies can be installed at lower cost.
[24] 26.6 GW x $1,120 per kW of a new ambient combined cycle plant = $29.77 billion.
[25] Wetted media could be installed at all combustion turbines for an even lower cost, though capacity gains might be limited due to ambient humidity.
[26] U.S. EPA, 2013, "Air Emissions" (http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html).
[27] *Id.* (natural gas plants produce 1.7 lbs NOx/MWh compared to 6 lbs NOx/MWh for coal-fired units and 4 lbs NOx/MWh for oil).

FIGURE 6. COMPARISON OF CARBON DIOXIDE EMISSIONS FROM GAS-, OIL-, AND COAL-FIRED POWER PLANTS[28]



Increasing the use of TIC on all natural gas combustion-turbine systems reduces or eliminates the need to construct new units to increase summertime capacity. As a result, TIC helps prevent the emission of a host of air pollutants that would have been produced by these displaced units. Nationally, this amounts to nearly 10.25 million pounds of avoided CO_2 and 77,489 pounds of avoided NOx per hour of operation, as shown in Figure 7. Put another way, if TIC technologies were used at every natural gas turbine in the country for just 25 percent of the year, nationwide CO_2 emissions would be reduced by the equivalent of taking more than two-million cars off the road or more than 900,000 homes off the grid annually.[29]

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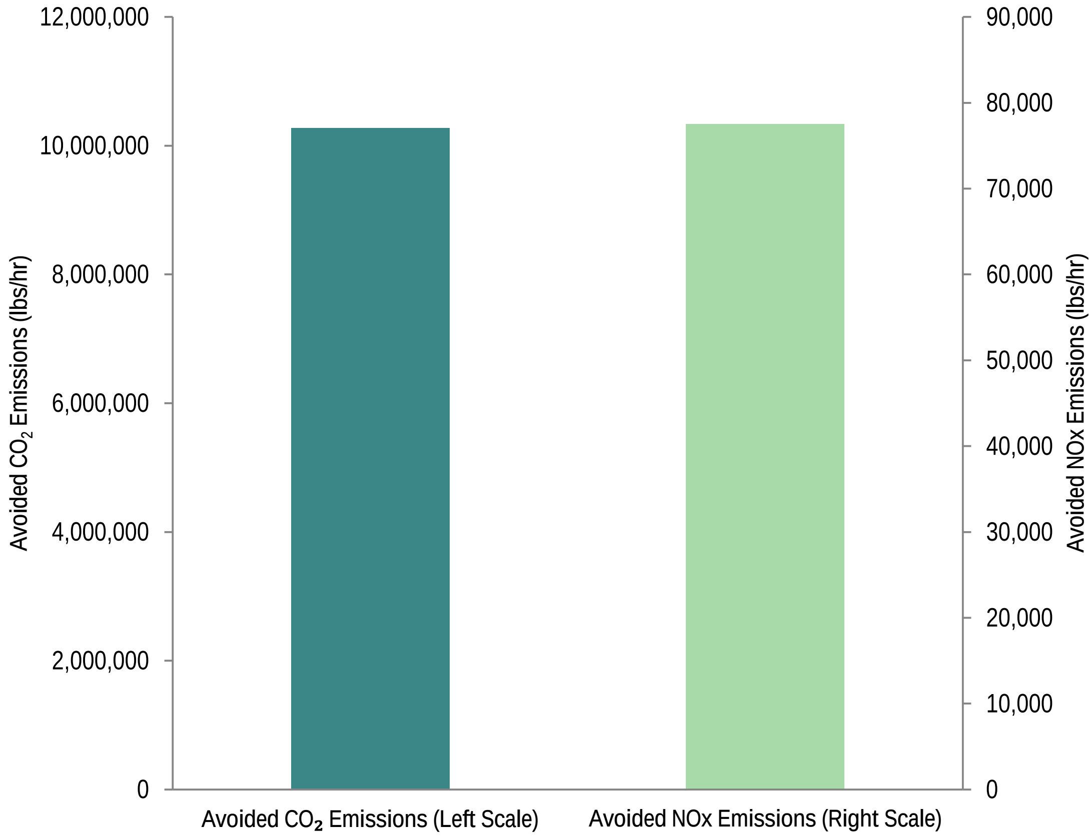
[28] *Id*. *CO_2 emissions from chilled gas units are comparable to unchilled units. As elaborated below, TIC offers CO_2 benefits by displacing less efficient oil- and coal-fired systems.

[29] Car and home equivalencies calculated using U.S. EPA's Greenhouse Gas Equivalencies Calculator (http://www.epa.gov/cleanenergy/energy-resources/calculator.html), which assumes 4.75 metric tons of CO_2E per vehicle per year and 7.72 metric tons of CO_2E per home per year. Estimate assumes systems are operating on average 25% of the year (i.e., 2,190 hours). Actual usage will vary dependent upon local temperatures.

FIGURE 7: REDUCED CO_2 AND NO_x EMISSIONS BY AVOIDED OPERATION OF SIMPLE-CYCLE AND STEAM-TURBINE PEAKERS THROUGH USE OF TIC TECHNOLOGIES



TIC Can Increase Capacity in States that Need It Most

Driven by an aging coal fleet, low natural gas prices, and a suite of Clean Air Act rules, the U.S. power mix is in transition. In fact, as of October 2013, announced coal retirements totaled 28.2 gigawatts of generation capacity.[30] (see Table 3). Utilities in these states will need to explore other options to ensure that they can continue to provide reliable electricity. In some instances, this may mean constructing new natural gas-fired units at great expense to ratepayers. If TIC were implemented to increase capacity at existing combustion turbines, some of the economic and reliability impacts of these retirements could be mitigated. Furthermore, regulators should ensure that any new gas turbines approved for construction include TIC.

[30] Note that this figure is limited to announced retirements, which are in addition to 18.2 GW of coal-fired generation that retired from 2011-2013. *See* UCS 2013, *supra* note 5.

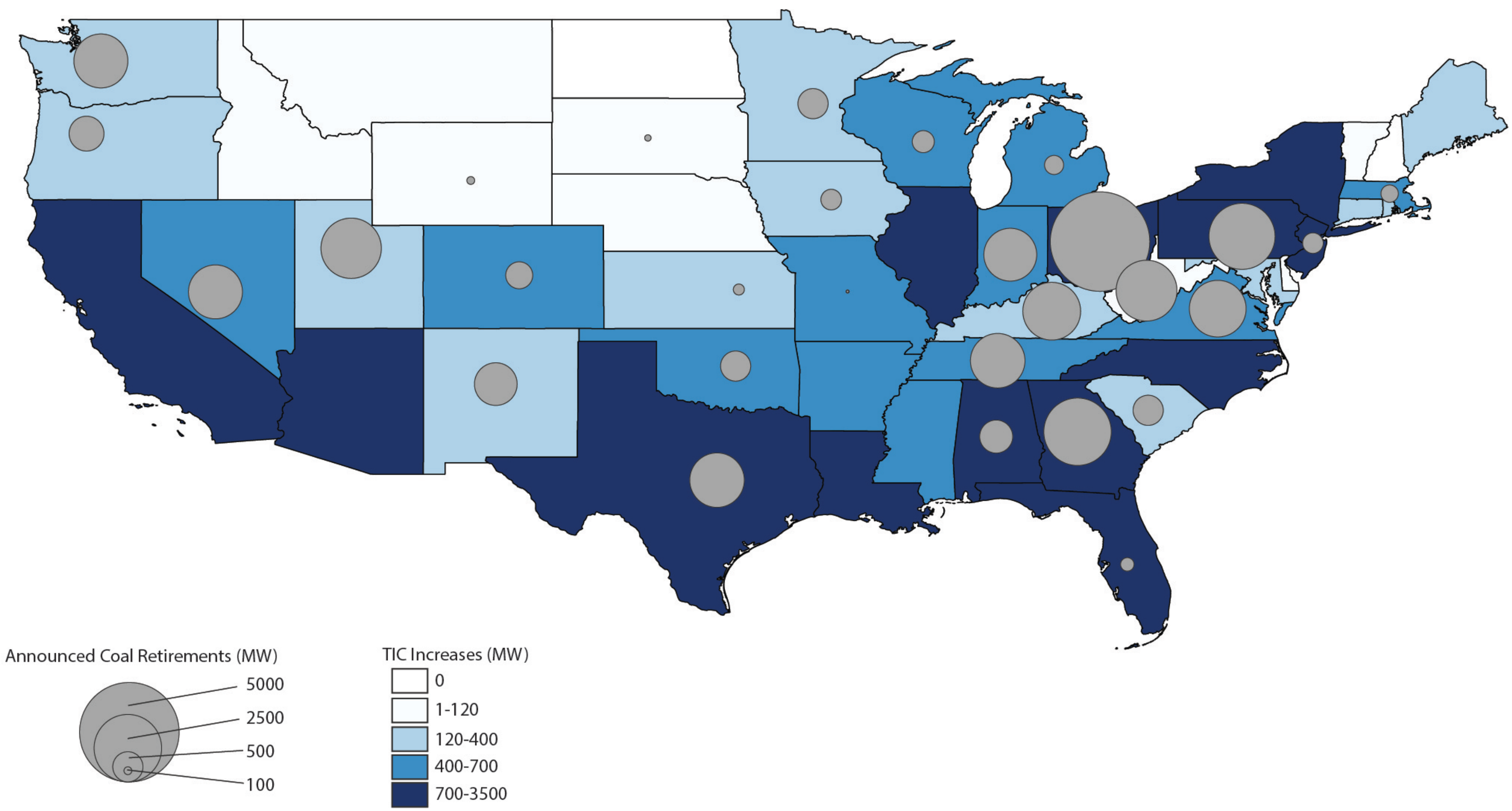
TABLE 3: ANNOUNCED COAL RETIREMENTS FOR TOP 20 STATES AND U.S. TOTAL RETIREMENTS[31]

State	MW
Ohio	4,896
Georgia	2,275
West Virginia	1,842
Utah	1,829
Kentucky	1,650
Virginia	1,601
Pennsylvania	1,563
Texas	1,490
Tennessee	1,485
Washington	1,460
Nevada	1,446
Indiana	1,402
New Mexico	924
Oregon	601
Alabama	562
Minnesota	476
South Carolina	474
Oklahoma	473
Colorado	363
Wisconsin	260
Top 20 States	**27,072**
U.S. Total	**28,169**

Strikingly, full-scale deployment of TIC could increase summertime natural gas capacity by 26.6 GW. This suggests over 94 percent of retiring coal capacity could be replaced by increased generation from gas plants with TIC technologies. In addition, many of the states with the greatest potential for increased capacity through TIC are those facing the largest number of planned retirements. (see Figure 8 and Appendix for 50-state data on both announced retirements and TIC potential).

[31] Union of Concerned Scientists 2013, "Coal Generators Announced for Retirement or Conversion" (unpublished supplemental table to "Ripe for Retirement: An Economic Analysis of the U.S. Coal Fleet," *supra* note 5).

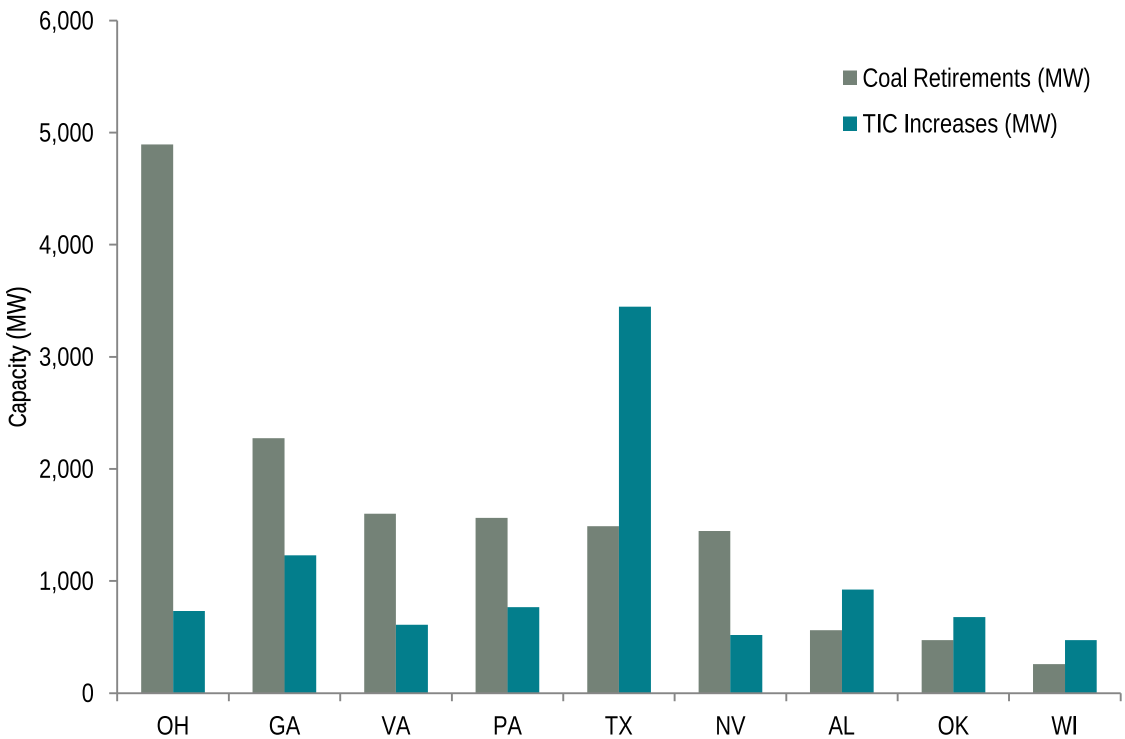
FIGURE 8: SIGNIFICANT OVERLAP OF STATES WITH HIGH LEVELS OF COAL RETIREMENT AND TIC OPPORTUNITY



In fact, nine of the states with the greatest potential to increase their capacity through TIC are among the top 20 states with the largest number of announced retirements. (see Figure 9). This suggests that TIC should be a key component of the long-term reliability planning in these states.

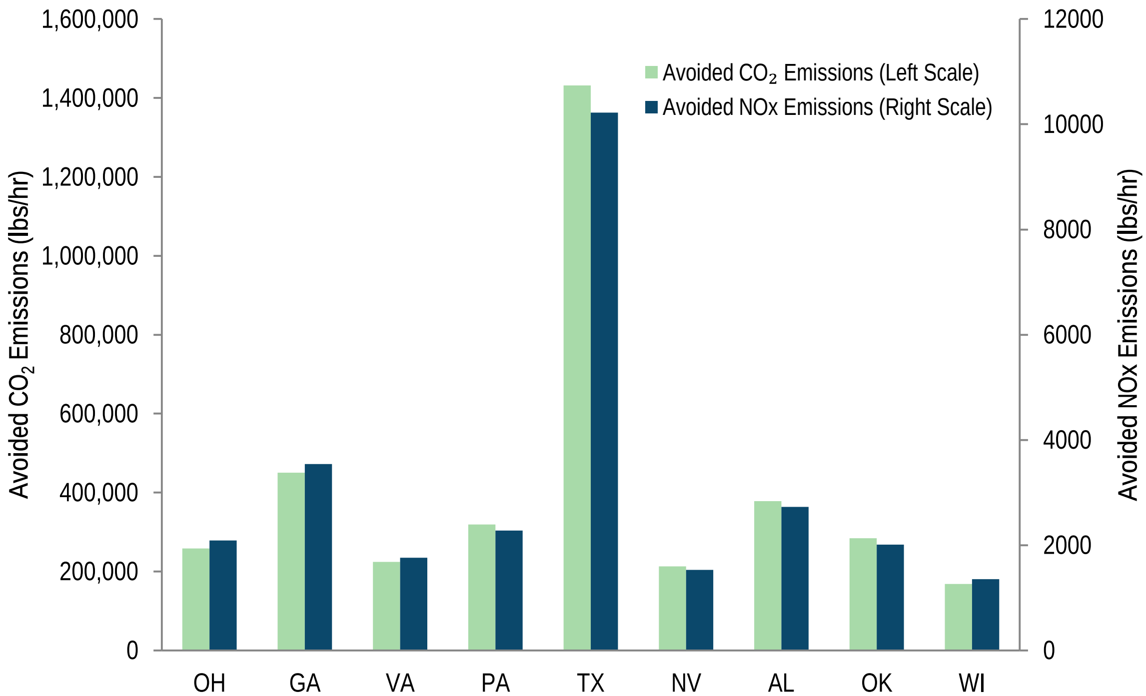
Texas leads the nation in potential to replace coal retirements with TIC-driven capacity increases. While the state has 1.5 GW of retiring coal capacity, it can increase summertime capacity at its existing gas plants by nearly 3.5 GW with the use of TIC, amounting to a 2 GW seasonal surplus. Among the top 20 states for coal retirements, Alabama, Oklahoma, and Wisconsin could likewise replace their retirements entirely with TIC-driven capacity increases. Even where TIC cannot singlehandedly substitute for retirements, it can still play a significant role in ensuring continued reliability. For instance, Georgia, which has the second highest level of announced retirements in the country, could replace 54 percent of its retirements through TIC.

FIGURE 9: RETIRING COAL CAPACITY VS. POTENTIAL TIC CAPACITY INCREASE



Installing TIC on gas turbines not only enhances electric reliability in states facing significant coal-fired retirements, but will also have substantial air-quality benefits. As noted above, by increasing reliance on natural gas-fired combined-cycle systems, TIC improves capacity and efficiency and displaces dirtier simple-cycle or oil-fired peakers. As Figure 10 illustrates, increasing reliance on TIC will lower both CO_2 and NOx in the states that are facing the largest numbers of coal-fired retirements.

FIGURE 10: REDUCED EMISSIONS FROM TIC USE IN STATES WITH GREATEST RETIREMENT/TIC OVERLAPS



The potential for TIC to enhance summertime capacity exists nationwide – including in states that do not anticipate significant retirements. In fact, in many of these states, TIC potential *exceeds* announced retirements. For instance, Florida could replace 2,500 percent of its announced retirements by simply deploying TIC at existing natural gas-fired combustion turbine units. TIC potential likewise exceeds retirements in Missouri (2,100%), Michigan (342%), and New Jersey (327%). By failing to install TIC, utilities in these jurisdictions are overlooking a low-cost option to increase summertime output and ensure continued reliability, while reducing emissions.

Conclusions/ Recommendations

The nation is in the midst of an energy revolution. Coal is providing a diminishing portion of America's electric capacity and additional plants are poised to retire. As of October 2013, 150 coal units – representing 28.2 GW of electricity – had announced their retirement. At the same time, the Environmental Protection Agency is beginning to regulate greenhouse gas emissions from the power sector. These circumstances are leading to increased pressure on natural gas combustion turbines. Rather than building new units, utilities should first ensure that they are maximizing the productivity of the existing system.

Turbine Inlet Cooling (TIC) provides a proven, reliable, cost-effective and clean approach to increase summertime capacity. These technologies have already been installed at hundreds of facilities in the United States,[32] with thousands of additional units worldwide. In fact, full-scale deployment of these technologies could increase generation capacity during hot summer weather by 26.6 GW – replacing upwards of 90 percent of announced coal retirements. What's more, much of this potential exists in precisely the places that anticipate the largest number of retirements. Thus, TIC can help ensure continued reliability while reducing emissions, including NOx emissions on days with the greatest ozone potential. Increasing capacity of combined-cycle gas units will reduce reliance on less efficient and dirtier peakers, helping ease the transition to a clean-energy future.

EPA is moving forward with greenhouse gas regulations for existing power plants and states will soon need to develop compliance plans to reduce CO_2 emissions in the electricity sector. TIC provides a low-cost way to increase the capacity of clean and efficient natural gas combustion-turbine units, leading to lower emissions throughout the air shed. In this way, TIC can help states increase reliance on less carbon-intensive affected fossil fuel-fired Electric Generating Units, as recommended in one of the four building blocks identified in the proposed greenhouse gas rule.[33] The inclusion of building block 2 in the proposed rule reflects EPA's judgment that reducing emissions by shifting dispatch to natural gas units is desirable. TIC increases the capacity of these units so that an even greater proportion of summer peak power could be met with low-emission clean natural gas combined-cycle units. EPA should clarify that states have the flexibility to recognize the air-quality benefits from actions such as TIC, which reduce reliance on less-efficient, dirtier units.

In the face of coal-fired unit retirements, utilities may seek to construct new gas-fired combustion-turbine units at significant cost to ratepayers. Before authorizing such projects, utility commissions should ensure that utilities have maximized the benefits of their existing investments by retrofitting these combustion turbines with TIC. Summertime capacity can be increased by retrofitting existing units with TIC at a significantly lower cost than constructing new facilities. To ensure that these modest investments are not discouraged, regulators should further ensure that capacity payments provide appropriate returns for systems using TIC. Where new power generation with natural gas is deemed necessary, it should likewise be required to incorporate TIC to ensure that the full potential of capital investments is realized. Because TIC provides a cost-effective and clean solution to capacity constraints during hot weather, regulators should support policies that encourage its use.

[32] Turbine Inlet Cooling Association, 2012, "Partial Database of Turbine Inlet Cooling (TIC) Installations" (http://turbineinletcooling.org/data/ticadatap.pdf).

[33] U.S. EPA, *supra* note **Error! Bookmark not defined.**, 79 Fed. Reg. at 34862-34866 (http://www.gpo.gov/fdsys/pkg/FR-2014-06-18/pdf/2014-13726.pdf).

Appendix

Methodology

To determine the potential capacity increase from the deployment of TIC technologies, we began with each state's total summer natural gas capacity, as reported in the 2013 EIA Electric Power Annual (which includes data for 2012).[34] Potential capacity increase from use of TIC technologies will vary depending on ambient temperature and humidity. For the purposes of this analysis, we assumed that each state's decrease in summer capacity compared to winter capacity is equal to the national average (i.e., 7.78%). Capacity increase will also vary with TIC technology used; however, because this analysis assumes winter, rather than nameplate capacity as the baseline, this is a conservative assumption that at least one of the TIC technologies can achieve. We estimated potential capacity increases from the use of TIC technologies by applying this capacity factor (7.78%) to each state's current summer gas capacity.

To compare the opportunity for increased generation with anticipated coal retirements, we collected data from the Union of Concerned Scientists' 2013 update to its Ripe for Retirement report.[35] This report provides announced coal retirements by state along with potential coal retirements based on UCS' ripeness methodology. The body of this White Paper is limited to announced coal retirements. Actual retirements may be greater, dependent upon long-term natural gas prices and other factors. The Appendix to this White Paper includes data for UCS' more aggressive "ripe for retirement" scenario.

Air-quality benefits are based on NOx and CO_2 emissions from displaced natural gas simple-cycle turbines, and boiler and steam turbine systems using natural gas and oil, which would be displaced by an increase in capacity at natural gas combined-cycle and simple-cycle turbines. Estimates are based on anticipated fuel savings from the avoided operation of simple-cycle gas and boilers using natural gas and oil. We translated these fuel-savings estimates into air-quality benefits by applying a standard emission rate for carbon dioxide (116.25 lbs per MMBtu saved) and NOx (0.8 lbs per MMBtu saved).

[34] EIA, *supra* note 11 (Table 4.7.C).
[35] UCS 2013, *supra* note 5.

State	Total Gas Turbine Capacity, MW		Announced Coal Retirements (MW)[36]	Ripe for Retirement Coal Generation (MW)[37]	2012 Fuel Savings by TIC on Combined-Cycle by Avoided Operation of Simple Cycle MMBtu/hr[38]	2012 Fuel Savings by TIC on Simple Cycle by Avoided Operation of Steam Turbines (Gas and Fuel Oil Boilers), MMBtu/hr[39]	Reduction in CO_2 Emissions by TIC on Combined-Cycle by Avoided Operation of Simple Cycle, lbs/hr[40]	Reduction in CO_2 Emissions by TIC on Simple Cycle by Avoided Operation of Steam Turbines (Gas & Fuel Oil Boilers), lbs/hr[40]	Reduction in NOx Emissions by TIC on Combined-Cycle by Avoided Operation of Simple Cycle, lbs/hr[41]	Reduction in NOx Emissions by TIC on Simple Cycle by Avoided Operation of Oil-Fired Simple Cycle, lbs/hr[42]
	2012 Summer Capacity w/o TIC[43]	2012 Summer Increase by TIC[44]								
Alabama	11,876	924	562	5,854	2,931	321	340,678	37,271	2,344	385
Alaska	839	65	-	48	121	75	14,009	8,676	96	90
Arizona	12,236	952	-	173	3,081	293	358,133	34,117	2,465	352
Arkansas	5,414	421	-	-	1,426	92	165,751	10,714	1,141	111
California	26,530	2,064	-	184	5,960	1,068	692,883	124,142	4,768	1,281
Colorado	5,279	411	363	317	950	354	110,453	41,147	760	425
Connecticut	2,972	231	-	400	773	56	89,862	6,551	618	68
Delaware	1,485	116	-	-	358	45	41,643	5,233	287	54
District of Columbia	10	1	-	-	-	2	-	203	-	2
Florida	31,902	2,482	98	6,243	7,619	1,013	885,691	117,767	6,095	1,216
Georgia	15,793	1,229	2,275	5,600	2,781	1,096	323,315	127,390	2,225	1,315
Hawaii	-	-	-	-	-	-	-	-	-	-
Idaho	1,111	86	-	-	198	76	22,995	8,801	158	91
Illinois	13,291	1,034	-	593	1,171	1,624	136,182	188,761	937	1,948
Indiana	5,642	439	1,402	4,079	881	459	102,470	53,320	705	550
Iowa	2,275	177	223	1,370	405	155	47,075	18,058	324	186
Kansas	2,378	185	88	781	-	416	-	48,387	-	499
Kentucky	4,829	376	1,650	999	-	845	-	98,266	-	1,014

[36] UCS 2013, *supra* note 5.
[37] *Id.*
[38] Assumed average heat rate of 7,000 Btu/kWh for the combined cycle and 10,750 Btu/kWh for the simple cycle.
[39] Assumed average heat rate of 10,750 Btu/kWh for simple cycle and 13,000 Btu/kWh for boiler/steam turbine systems.
[40] Assumed natural gas is only methane with-heating value of 1,000 Btu/Standard Cubic Feet.
[41] Assumed average NOx emissions from gas turbines using natural gas is 0.8lb/MMBtu (range is 0.397 to 1.72).
[42] Assumed average NOx emissions from gas turbines using fuel oil No. 2 is 1.2lb/MMBtu (range is 0.55 to 2.5).
[43] EIA 2013, *supra* note 11.
[44] Potential capacity increase from use of TIC technologies will vary based on ambient temperature. For the purposes of this analysis, we assumed that each state's decrease in summer capacity is equal to the national average (i.e., 7.78%). Capacity increase will also vary by TIC technology used; however, because this analysis assumes winter capacity and not nameplate, these are conservative assumptions that many of the TIC technologies can achieve. Assumed capacity increase in combined cycle is 1.5 times that of simple cycle.

Louisiana	9,730	757	-	1,173	2,329	306	270,722	35,576	1,863	367
Maine	1,556	121	-	-	390	38	45,369	4,443	312	46
Maryland	1,718	134	-	1,712	94	244	10,967	28,386	75	293
Massachusetts	5,821	453	166	136	1,634	38	190,005	4,452	1,308	46
Michigan	8,096	630	184	6,719	1,614	449	187,662	52,159	1,291	538
Minnesota	4,666	363	476	465	752	365	87,453	42,471	602	438
Mississippi	8,714	678	-	2,920	2,185	214	253,998	24,929	1,748	257
Missouri	5,232	407	19	2,094	683	506	79,419	58,824	547	607
Montana	362	28	-	219	-	63	-	7,369	-	76
Nebraska	1,432	111	-	1,190	126	175	14,668	20,344	101	210
Nevada	6,668	519	1,446	-	1,657	173	192,614	20,118	1,326	208
New Hampshire	1,207	94	-	264	351	<1	40,844	52	281	1
New Jersey	9,971	776	237	1,180	1,985	554	230,754	64,443	1,588	665
New Mexico	2,413	188	924	-	492	127	57,184	14,785	394	153
New York	11,350	883	-	192	2,669	386	310,250	44,817	2,135	463
North Carolina	10,086	785	-	691	1,483	876	172,457	101,778	1,187	1,051
North Dakota	-	-	-	115	-	-	-	-	-	-
Ohio	9,403	732	4,896	198	1,432	787	166,430	91,497	1,145	944
Oklahoma	8,704	677	473	1,590	2,297	146	266,979	16,943	1,837	175
Oregon	3,010	234	601		852	16	99,023	1,842	681	19
Pennsylvania	9,859	767	1,563	1,811	2,548	197	296,171	22,916	2,038	237
Rhode Island	1,725	134	-	-	503	-	58,512	-	403	-
South Carolina	5,134	399	474	1,577	817	409	94,974	47,488	654	490
South Dakota	933	73	25	-	110	97	12,768	11,317	88	117
Tennessee	5,172	402	1,485	2,740	541	581	62,852	67,545	433	697
Texas	44,308	3,447	1,490	175	11,408	911	1,326,216	105,919	9,127	1,093
Utah	1,731	135	1,829	58	390	69	45,363	8,007	312	83
Vermont	-	-	-	-	-	-	-	-	-	-
Virginia	7,847	610	1,601	1,887	1,386	542	161,170	62,979	1,109	650
Washington	3,767	293	1,460	-	954	87	110,855	10,142	763	105
West Virginia	1,074	84	1,842	860	-	188	-	21,853	-	226
Wisconsin	6,072	472	260	1,839	958	488	111,319	56,761	766	586
Wyoming	117	9	57	227	-	20	-	2,373	-	24
Total	**341,738**	**26,587**	**28,169**	**58,673**	**71,296**	**17,044**	**8,288,140**	**1,981,333**	**57,037**	**20,452**