Turbine Inlet Cooling: A Pathway for Maximizing the Potential of CHP for Decarbonizing the Electric Grid

Dharam V. Punwani
Executive Director, Turbine Inlet Cooling Association
Presented at
Technology and Market Assessment Forum
Energy Solutions Center, Washington, DC
June 26, 2024

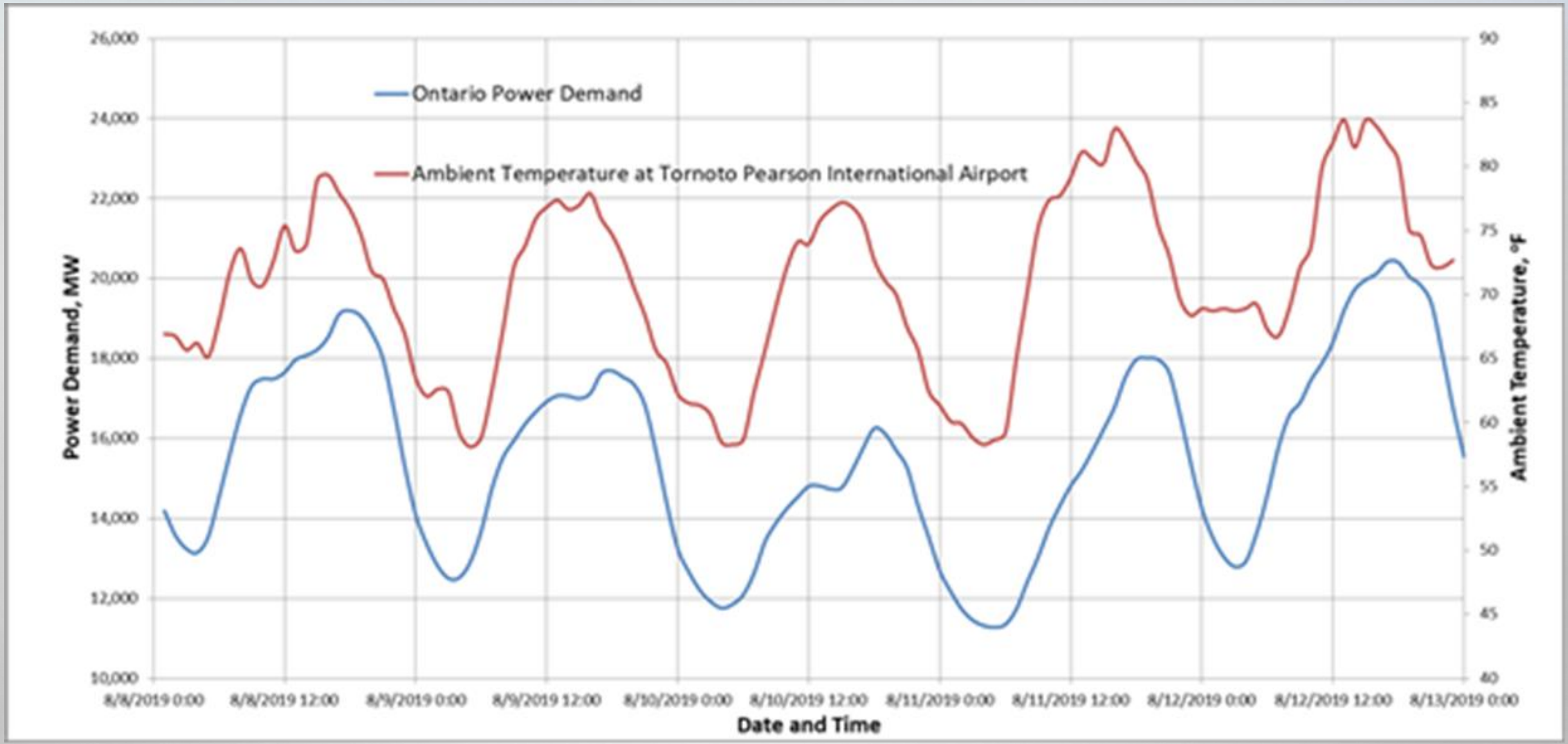
TURBINE INLET COOLING ASSOCIATION turbineinletcooling.org

Presentation Outline

- How hot weather impacts electricity demand, price, and carbon emissions?
- Why CHP systems are pathways for decarbonizing electric grid
- Why use CTs?
- What problems hot weather creates for CTs?
- Four impacts of hot weather on CHP systems that use CTs
- How to overcome the impacts of hot weather on CHP?
- What is turbine inlet cooling (TIC)?
- What are the TIC technology options and the factors affecting technology selection?
- Case study examples of the effects of TIC technology and humidity on net capacity gain and unit capital cost ($/MW of capacity gain)
- Four (4) examples of CHP systems successfully using TIC
- Conclusions & Recommendation

Hot Weather Increases Electric Power Demand

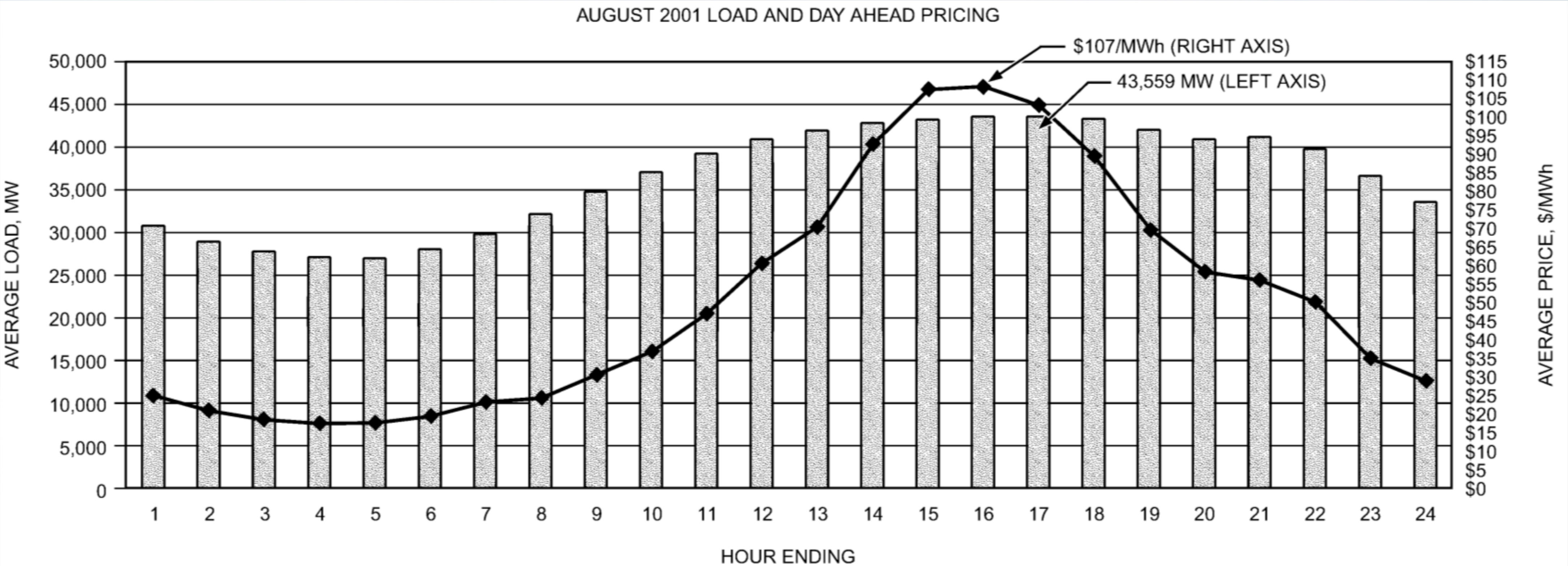
An Example



Example of Hourly Ambient Temperature and System Load Profiles in Ontario, Canada
(Punwani, D., et al, “ASHRAE Design Guide for Combustion Turbine Inlet Cooling, 2022”)

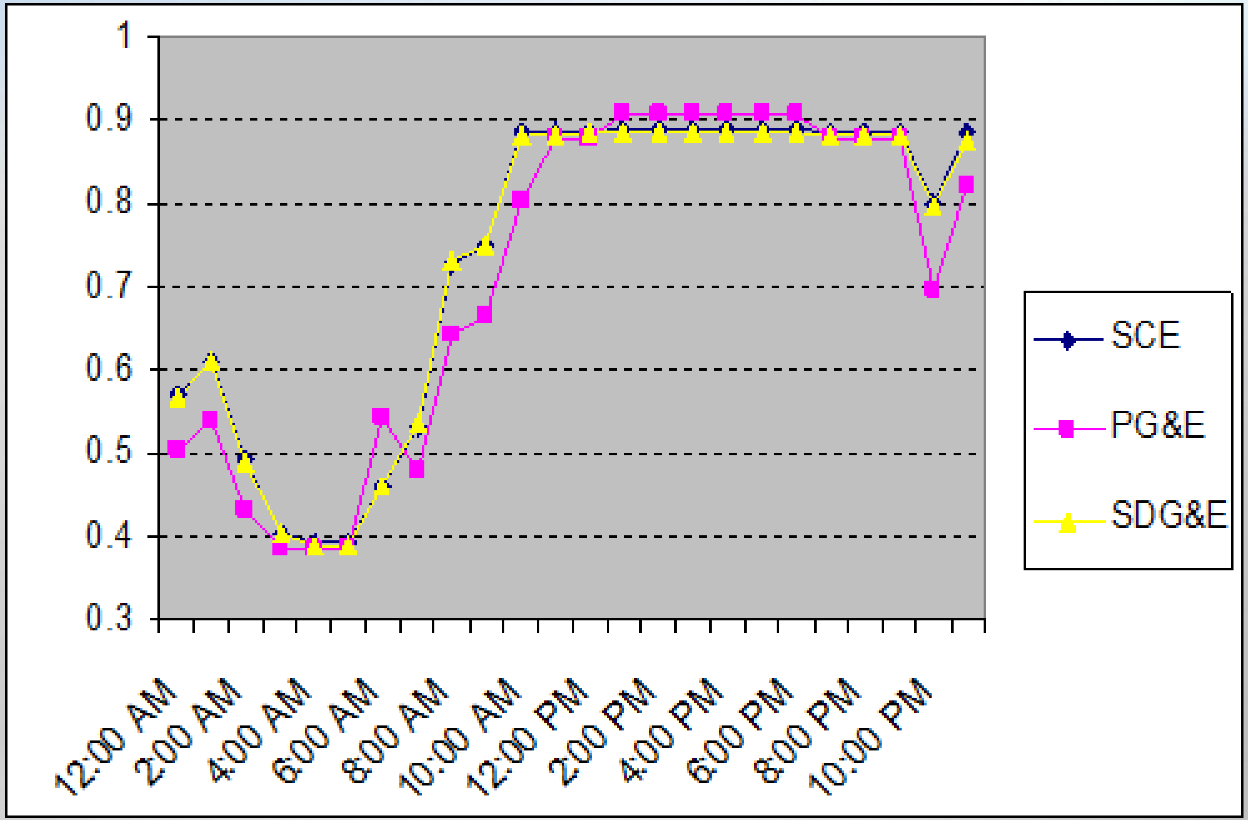
Hot Weather Increases the Price of Electric Energy

An Example



- Actual price of electric energy depends on the mix of power generation systems connected to the grid

Increase in Power Demand Increases CO_2 Emissions



Notes:

- *Y-Axis Scale Shows lb. of CO_2/kWh*
- *PG&E (Pacific Gas & Electric); SCE (Southern California Edison); SDG&E (Diego Gas & Electric)*

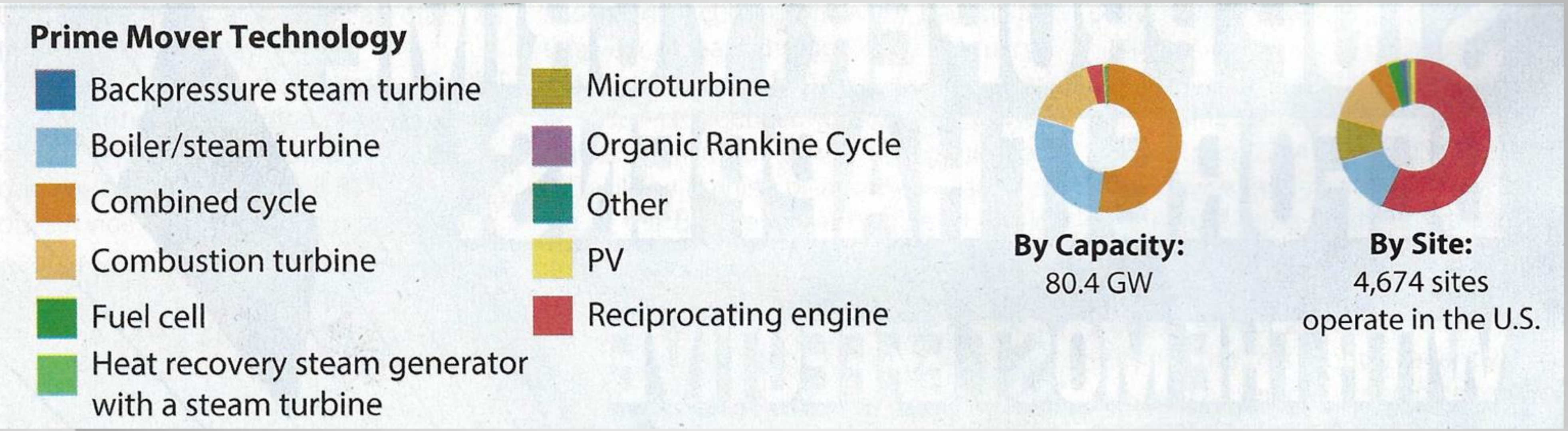
.

Why CHP Systems are Pathways for Decarbonizing Electric Grids?

- All electric grids have and will continue to have carbon emissions, until they are supported 100% by renewable and nuclear sources
- Any system that reduces load on the electric grid is a pathway for decarbonizing the grid
- Since a CHP system generates most of the electric power need of a facility at the facility's site, instead of increasing load on the grid, it is a pathway for decarbonizing the grid
- CHP also helps reduce a grid's 4-6% transmission and distribution (T&D) losses

Role of Combustion Turbine for Power Generation

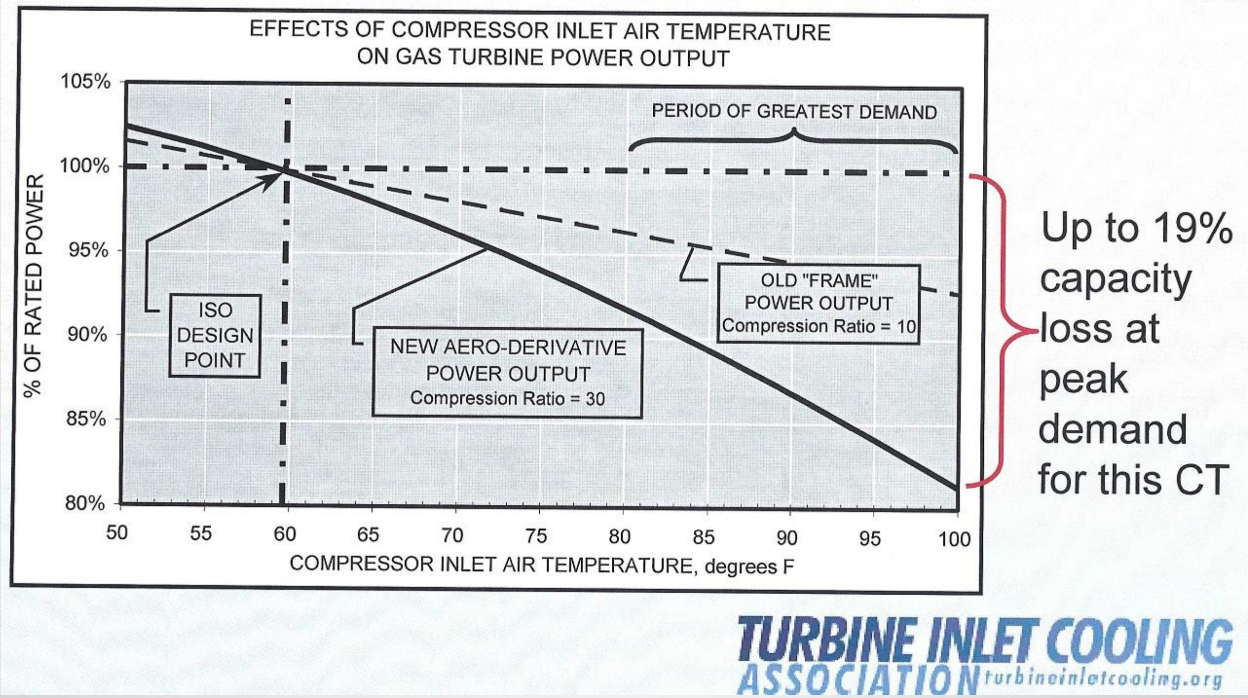
- Produce 38-40% of US electric energy and offer fuel flexibility
- Prime movers of choice for large capacity CHP systems
- Prime movers of choice for a facility's thermal energy needs for high-temperature and/or high-pressure steam
- CHP systems that operate CHP mode are the most efficient for simultaneous production of heat and electric power
- According to the U.S. DOE database, CTs account for the maximum installed CHP capacity as shown:



Hot Weather Decreases CT Output Capacity

- High ambient temperatures decrease output capacity below its rated capacity
- Quantitative impact of ambient temperature varies with CT design rxa:

An Example

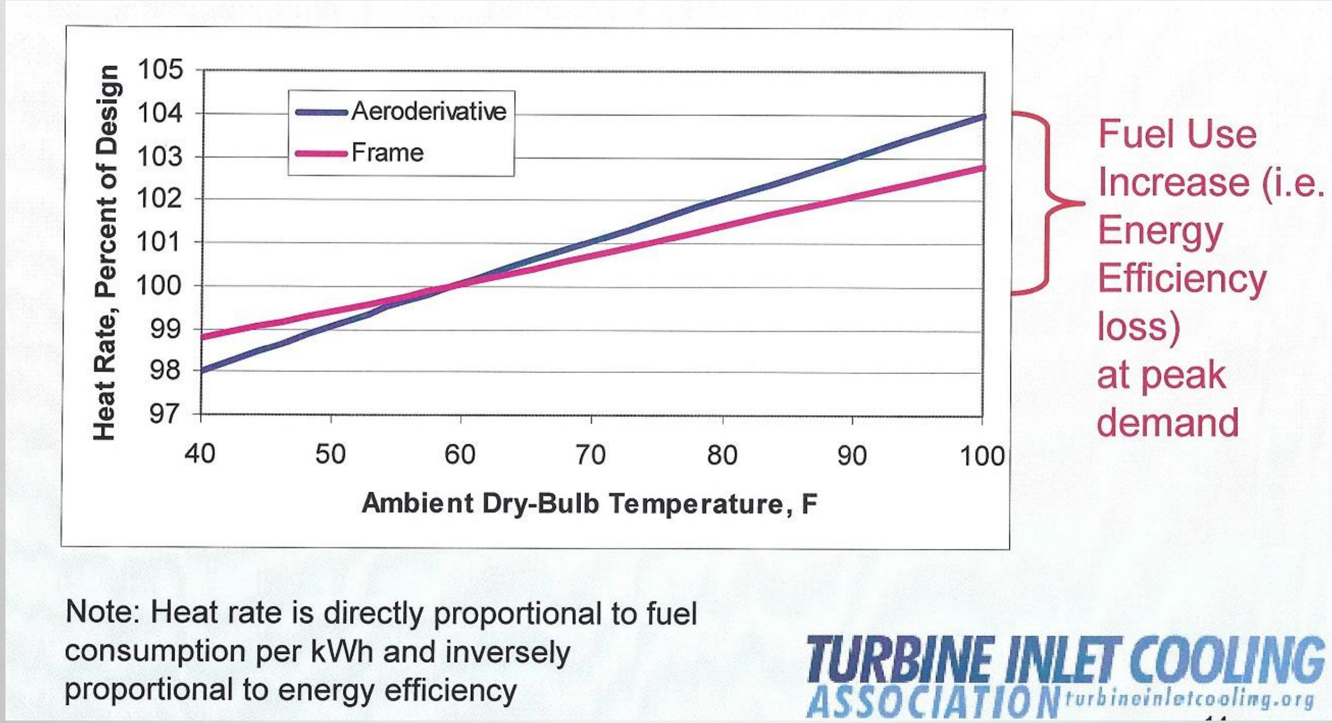


- Aeroderivative CTs are more sensitive to ambient temperatures.

Hot Weather Reduces the Energy Efficiency of CTs

- Energy efficiency decreases (heat rate increases) below its rated efficiency

- Quantitative impact varies with the CT Design

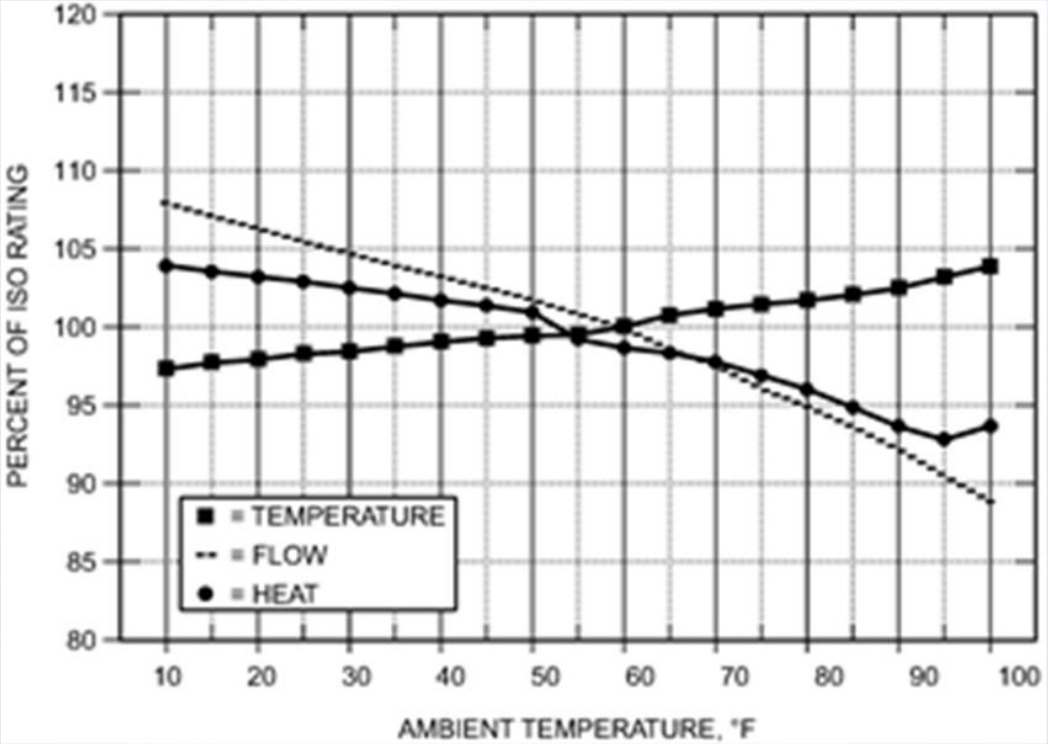


In power generation business, even 1% change in efficiency is a big deal

- Aeroderivative CTs are more sensitive to ambient temperatures.

Hot Weather Decreases Availability of Useful Thermal Energy from CTs for CHP

Example



Effects of hot weather on CT exhaust gases:
Temperature increases, but mass flow rate decreases more significantly. Overall availability of thermal energy decreases.

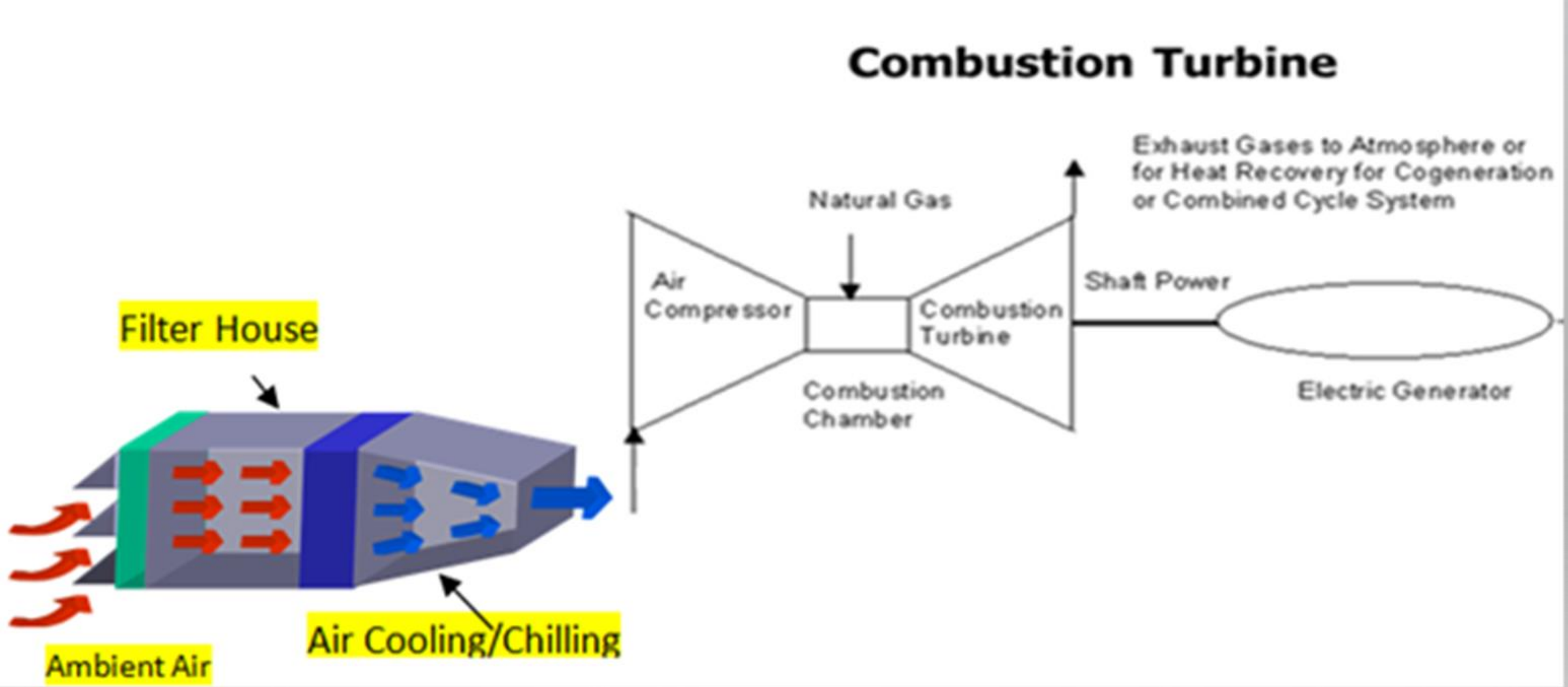
Source: ASHRAE Combined Heat and Power Design Guide (1996)

Four Adverse Impacts of Hot Weather on CHP Systems Using CTs

1. **Decreases power output capacity**
   - Increases the need of buying electric power from the grid
   - Decreases CHP's potential for decarbonizing electric grid
2. **Decreases electricity generation efficiency**
   - **In**creases the need to burn more fuel per unit of electric energy
   - Increases on-site carbon emissions
3. **Decreases availability of useful thermal energy**
   - Increases the need to burn more fuel for meeting thermal needs
   - Increases on-site carbon emissions
4. **Increases the annual cost of electric and thermal energy needs**

Turbine Inlet Cooling (TIC)

Cools the inlet air to the compressor of the CT system



Turbine Inlet Cooling Technology Experience: ~50 Years

- TIC is not new.
- It has been successfully used since as early as 1975.
- TICA's* limited database has over 400 installations
- TICA database shows that TIC has been installed on at least 1,165 CTs of 125 models, from 21 OEMs
- Capacities of the CT systems with TIC range from 1 MW to 3,162 MW*

Note:

*Turbine Inlet Cooling Association (TICA). Actual number of TIC installations is in thousands

Turbine Inlet Cooling Technologies

- 1. Adiabatic Wetted-Media Evaporative Cooling
- 2. Non-Adiabatic Wetted-Media Evaporative Cooling
- 3. Fogging for Evaporative Cooling
- 4. Indirect Evaporative Cooling
- 5. Wet Compression (Fog Overspray)
- 6. Indirect-Heat Exchange with Chilled Water
- 7. Thermal Energy Storage for Chilled Water Indirect-Heat Exchange
- 8. Indirect Heat Exchange with Refrigerant Evaporation
- 9. Indirect-Heat Exchange with Liquefied Natural Gas
- 10. Hybrid Cooling Systems

TIC Information Resources: www.turbineineltcooling.org and ASHRAE Design Guide for Combustion Turbine Inlet Cooling (2022)

Factors Affecting Turbine Inlet Cooling Selection

- Each TIC technology has its pros and cons.
- No one technology is best for all power plants
- Factors affecting technology selection include:
  * Value of the additional electricity and thermal energy produced by TIC
  * 8,760 hours/year of weather data for the plant location
  * Plant's annual operating schedule
  * CT design
  * Fuel cost
  * Capital cost limitation
  * Physical space limitation

Turbine Inlet Cooling Benefits

Overall: Overcomes all the negative impacts of hot weather

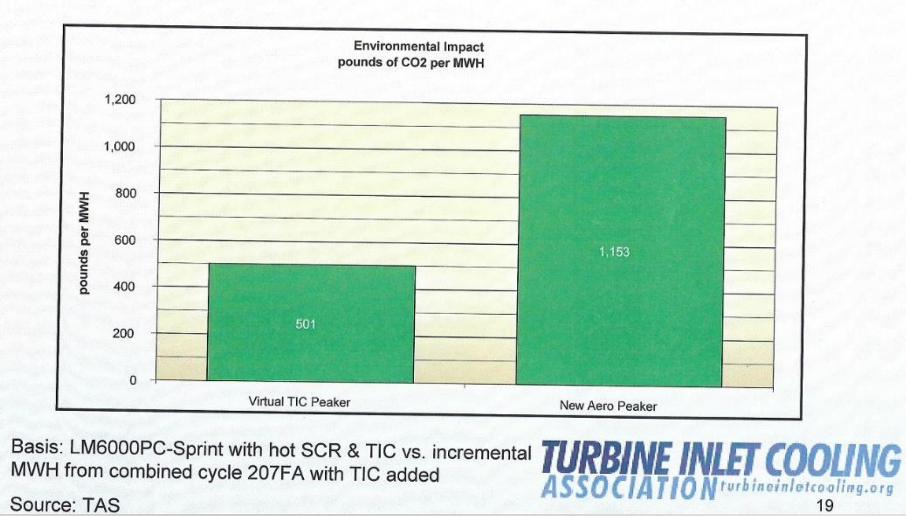
- Increased power output capacity
- Increased energy efficiency
- Increased available thermal energy
- Reduced on-site carbon emissions per Unit of Electric Energy (lb/kWh)[1]
- Reduced grid-wide carbon emissions[2]
- Reduced unit capital cost ($/kW) for Increased capacity compared to a new uncooled CT
- Reduced unit fuel cost ($/kWh) compared to an uncooled CT

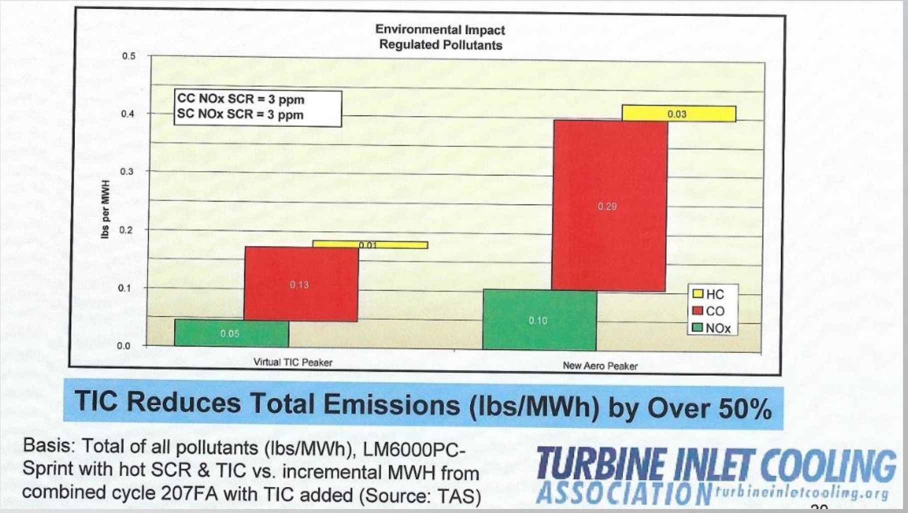
Notes:

1. Due to increased efficiency
2. Due to reduced need to operate less efficient
3. for meeting grid demand

Emissions Reduction Benefit of TIC

Example

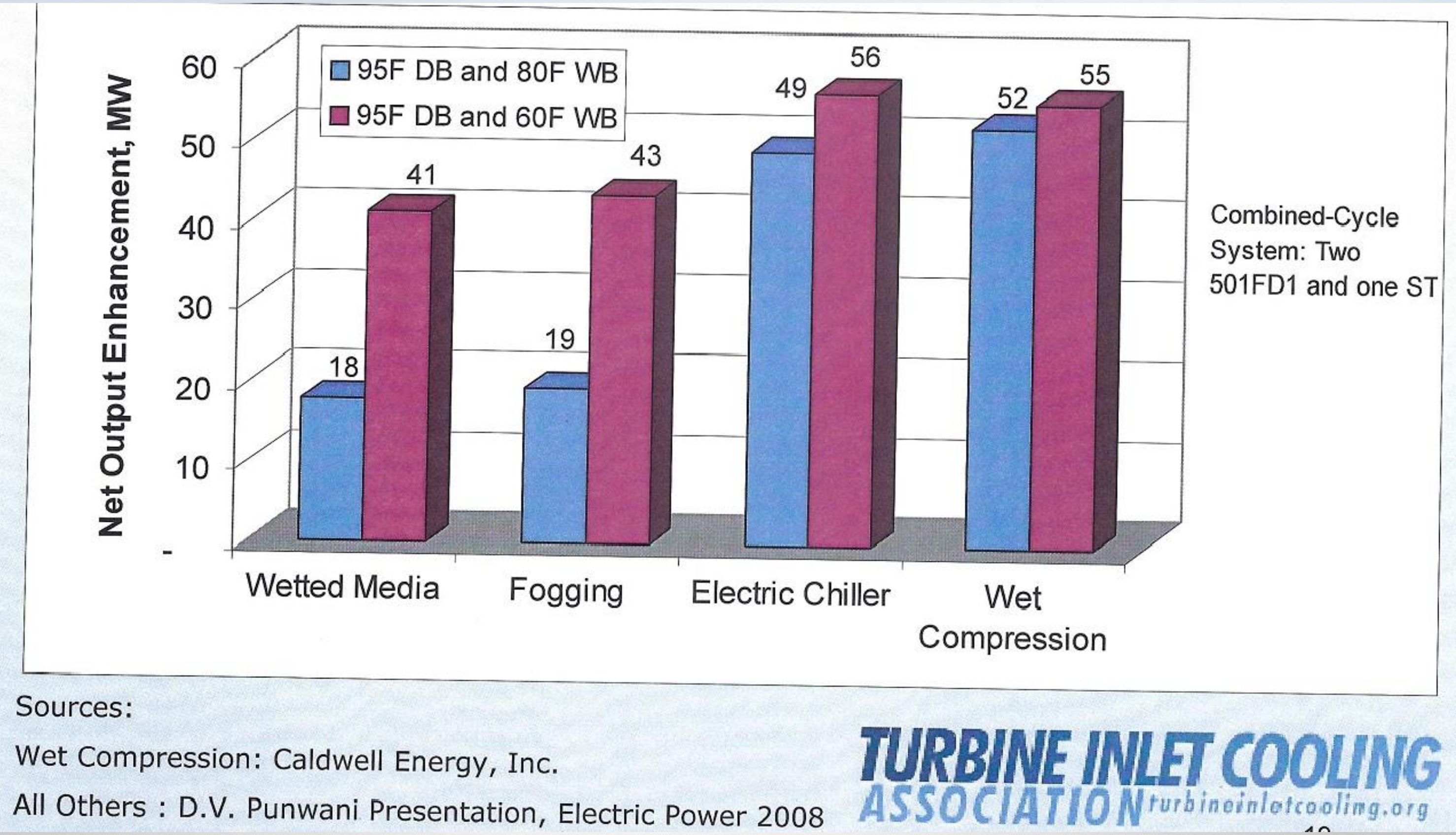




- TIC on a nominal 500 MW CC eliminates the need to operate a nominal 40-50 MW SC peaker and also eliminates its associated higher emissions of CO_2 and regulated pollutants

Effect of Technology and Humidity on Net Output Power Capacity Gain

Note: Each case study's results are only applicable to the SPECIFIC site evaluated and should not be generalized

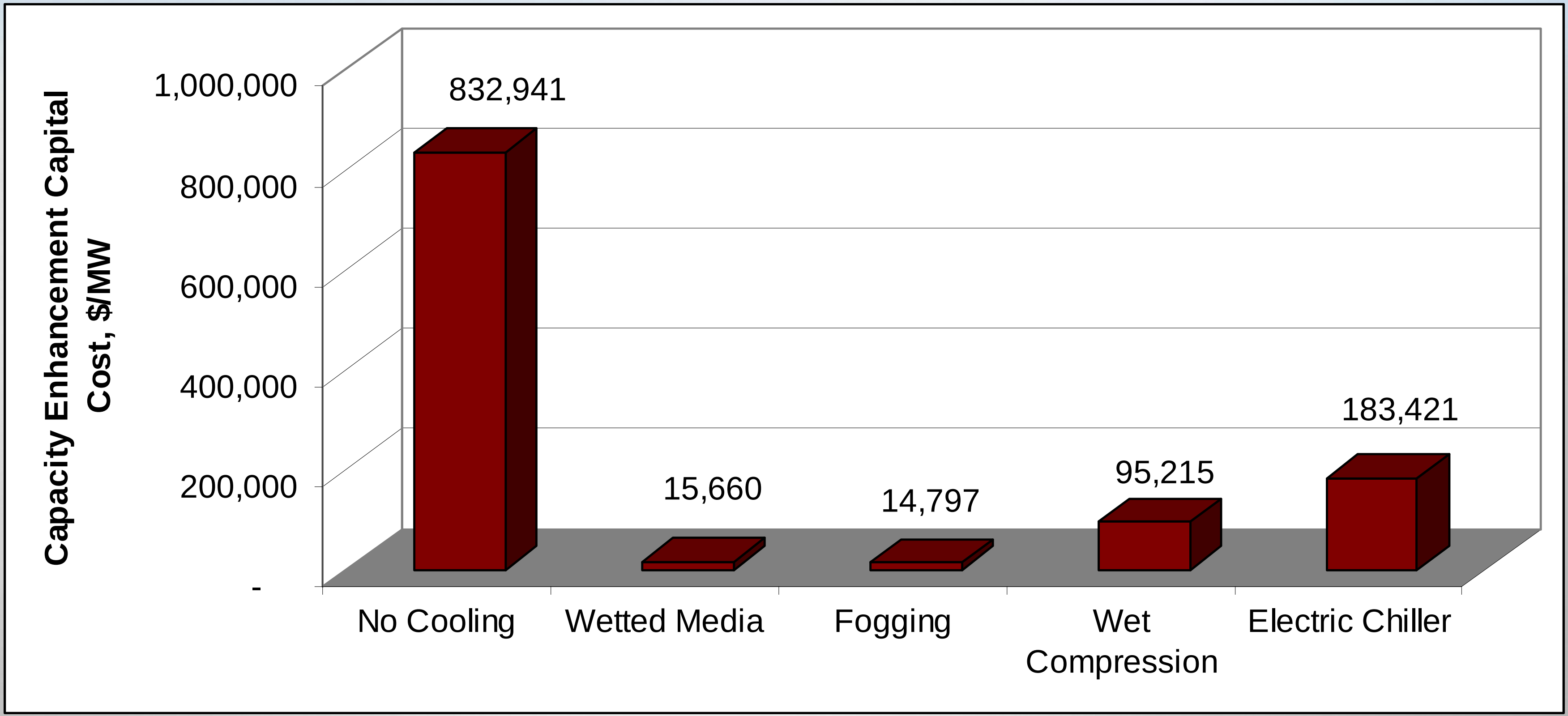


A Case Study Example

- Wetted media and fogging are more sensitive to humidity and produce less capacity gain at higher humidity

Effect of Technology on Unit Capital Cost ($/MW) for Net Output Power Capacity Gain

Note: Each case study's results are only applicable to the SPECIFIC site evaluated and should not be generalized

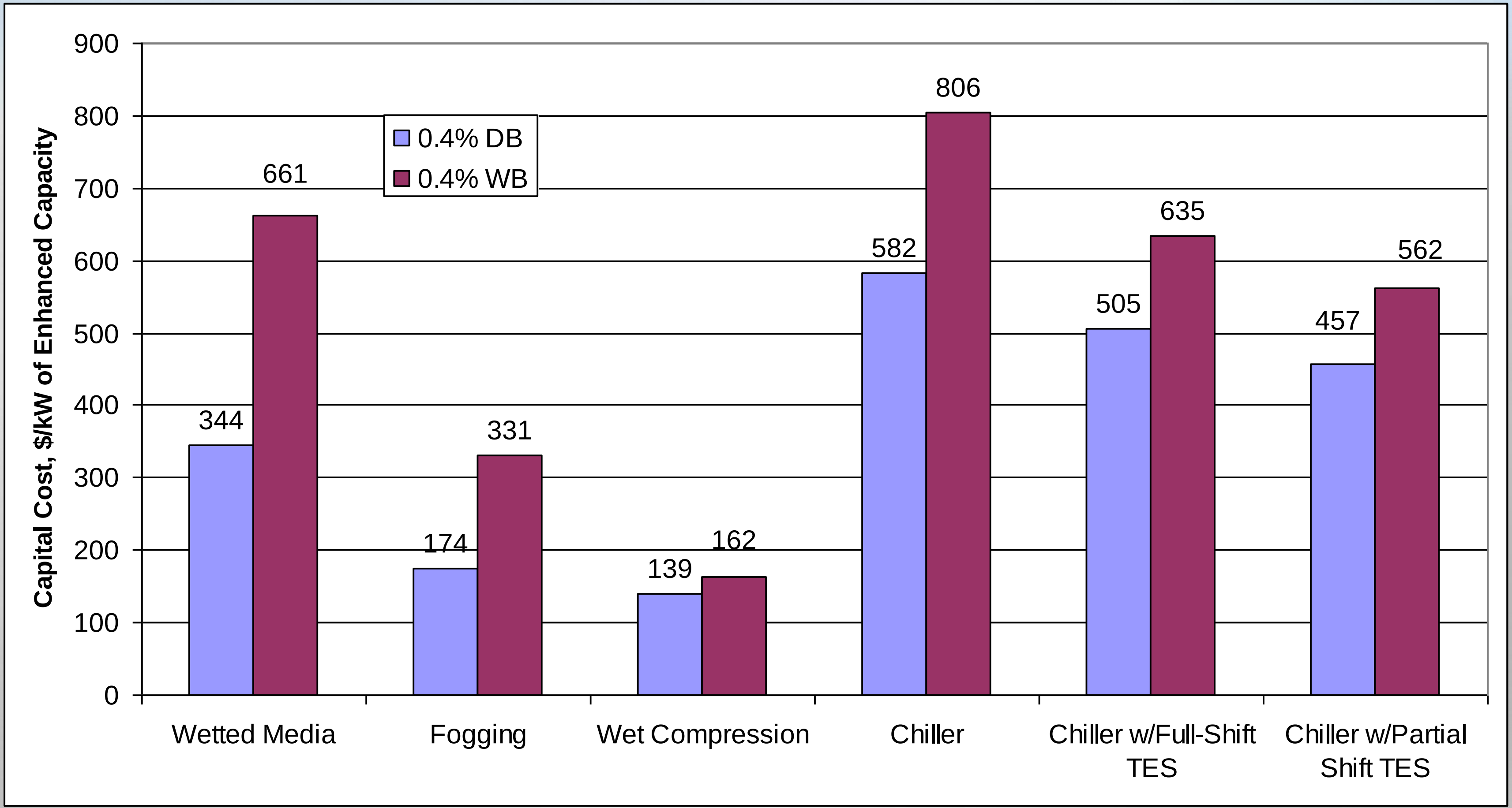


A Case Study Example

- Capacity gain by **all** TIC technologies costs significantly less than that for another uncooled CT.
- The unit capital cost is the lowest for the wetted-media and fogging

Effect of Technology on Unit Capital Cost for Capacity Gain ($/MW)

Note: Each case study's results are only applicable to the SPECIFIC site evaluated and should not be generalized

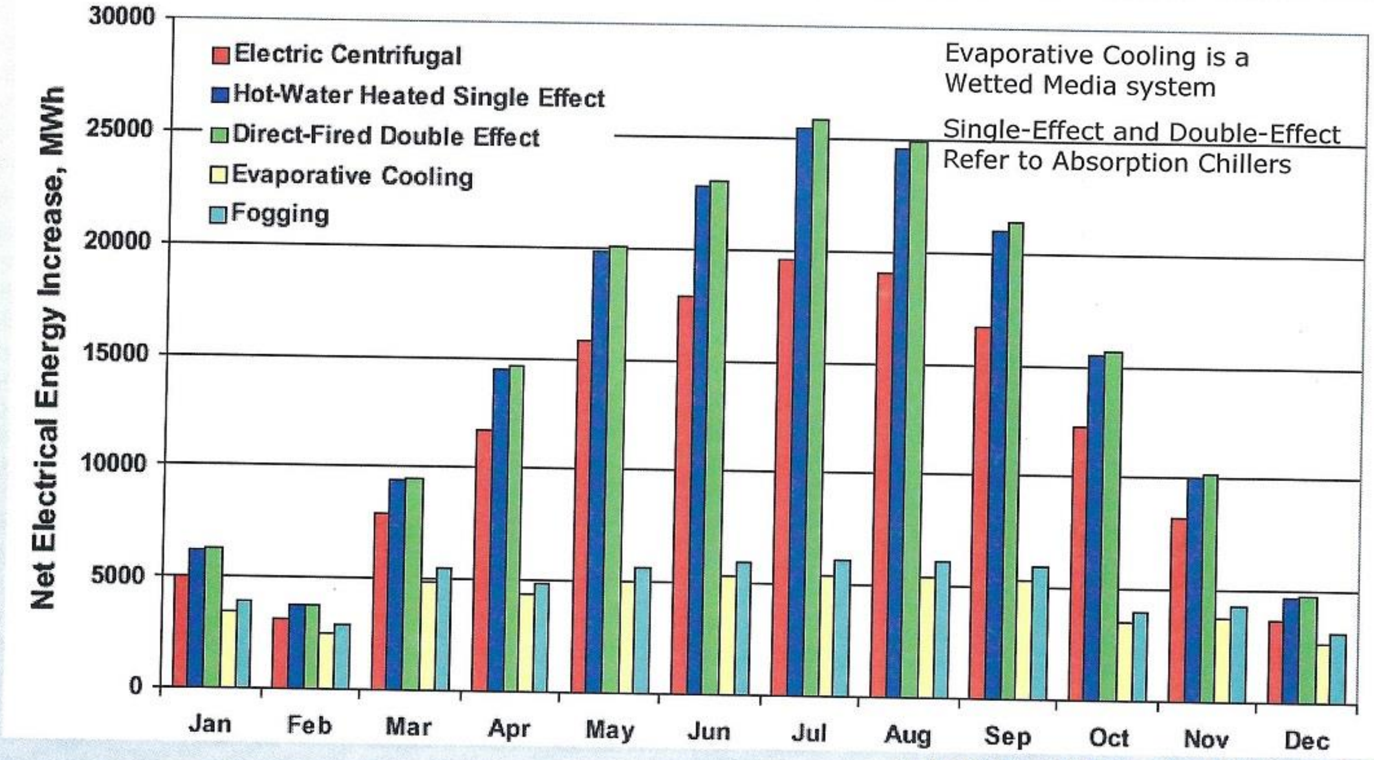


A Case Study Example

- The unit capital cost for all technologies is higher at higher humidity
- Thermal energy storage (TES) helps reduce unit capital cost for chilled water systems

Effect of Technology on Monthly Net Incremental Electric Energy Generated

Note: Each case study's results are only applicable to the SPECIFIC site evaluated and should not be generalized



Source: D.V. Punwani et. al. Presented at ASHARE 2001

TURBINE INLET COOLING ASSOCIATION turbineinletcooling.org

A Case Study Example

- TIC can produce gains through out the year
- The highest gains occur during the summer months

TICA Award Winning Success Story Example 1 of 4: Princeton University - Princeton, NJ

- One 14.6 MW LM1600
- Using TIC since 1996
- TIC uses Low Temp Fluid cooling
- Chilled water system used for TIC
- Cooling turbine inlet air from 98 °F to 42 °F increases power output 20% or 2.5 MW (from 12.5 to 15.0 MW)

Benefitting from TIC for 28 years

Midwest Cogen Assoc (MCA) Award Winning Success Story
Example 2 of 4:
University of Cincinnati - Cincinnati, OH

- Two 12.5 MW Titan 130 with HRSG
- Using TIC since 2003
- TIC uses chilled water
- CHW system for TIC and campus DC incorporates two CHW TES tanks
- Cooling from 80 °F to 55 °F increases output 19% or 4 MW (21 to 25 MW)

Benefitting from TIC for 21 years

TICA Award Winning Success Story Example 3 of 4: University of Texas at Austin - Austin, TX

- One 32 MW LM2500
- Using TIC since 2011
- TIC uses chilled water
- Chilled water system for TIC and campus District Cooling incorporates two CHW TES tanks
- Cooling turbine inlet air from 100 °F to 50 °F increases power output 24.5% or 6 MW (from 24.5 to 30.5 MW)

Benefitting from TIC for 13 years

TICA Award Winning Success Story Example 4 of 4: Thermal Energy Corporation, Houston Medical Center, TX

- 46 MW LM6000 CT w/ HRSG
- Using TIC since 2010
- TIC uses chilled water
- CHW system for TIC and DC incorporates a CHW TES tank
- Cooling inlet air from 92 °F increases output 24.5% or 10.44 MW (32.32 to 42.76 MW)
- Added another 48 MW LM6000 CT with TIC in 2024

Benefitting from TIC for 14 years and installing one more CT with TIC

TIC Benefits for TECO and the Electric Grid

* Predictable output, regardless of ambient conditions
* Increased annual[1] average net electric power output capacity: 5.7 MW
* Increased annual[1] electric energy output: 17,700 MWh
* Increased steam production gain estimate: 2%
* Decreased electric heat rate: 200 BTU/kWh
* Annual[1] fuel saving for electric production: 26,000 MMBTU
* On-site carbon dioxide emissions reduction: 0.013 tons/MWh
* Annual[1] on-site carbon dioxide emissions reduction: 1,700 tons
* ERCOT electric grid's average carbon dioxide emissions: 0.384/MWh
* Annual[1] reduction in electric grid carbon dioxide emissions: 7,140 tons[2]

Notes:
1. 3,100 annual operating hours
2. 6,800 tons due to the gird load prevented by the additional on-site electric energy produced by TIC and 340 tons due saved T&D loss (5%)

Source: Mike Manoucheri, CEO, TECO (June 2024)

Conclusions & Recommendation

- Turbine Inlet Cooling (TIC) is a cost-effective pathway for maximizing the potential of CHP systems for electric grid decarbonization by maximizing their power output during hot weather.
- TIC also decreases carbon emissions at the CHP site by increasing its efficiency during hot weather.
- TIC reduces a facility's annual costs of meeting electric and thermal energy needs
- TIC has an extensive experience base, including many CHP systems.
- Some CHP systems have been benefiting from TIC for over 20 years.

More CHP system owners/operators should consider evaluation and implementation of TIC.

Contact Information

- **Dharam (Don) Punwani**
  Email: exedir@turbineinletcooling.org
- Phone: 630-357-3960
- Website: https://www.turbineinletcooling.org
- LinkedIn: https://www.linkedin.com/company/turbine-inlet-cooling-association