Turbine Inlet Cooling for Increasing Capacity and Reducing Emissions During Hot Weather

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Presented at

Turbine Inlet Cooling Association Webinar

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Presentation Outline

- **Background: What is the problem that needs a solution?**
- **What is Turbine Inlet Cooling (TIC)?**
- **TIC Technologies**
- **Economic Benefits of TIC**
- **Environmental Benefits of TIC**
- **Factors Affecting the Performance of TIC Technologies**
- **Factors Affecting the Economics and Selection of TIC Technology**
- **Summary of the Presentation**

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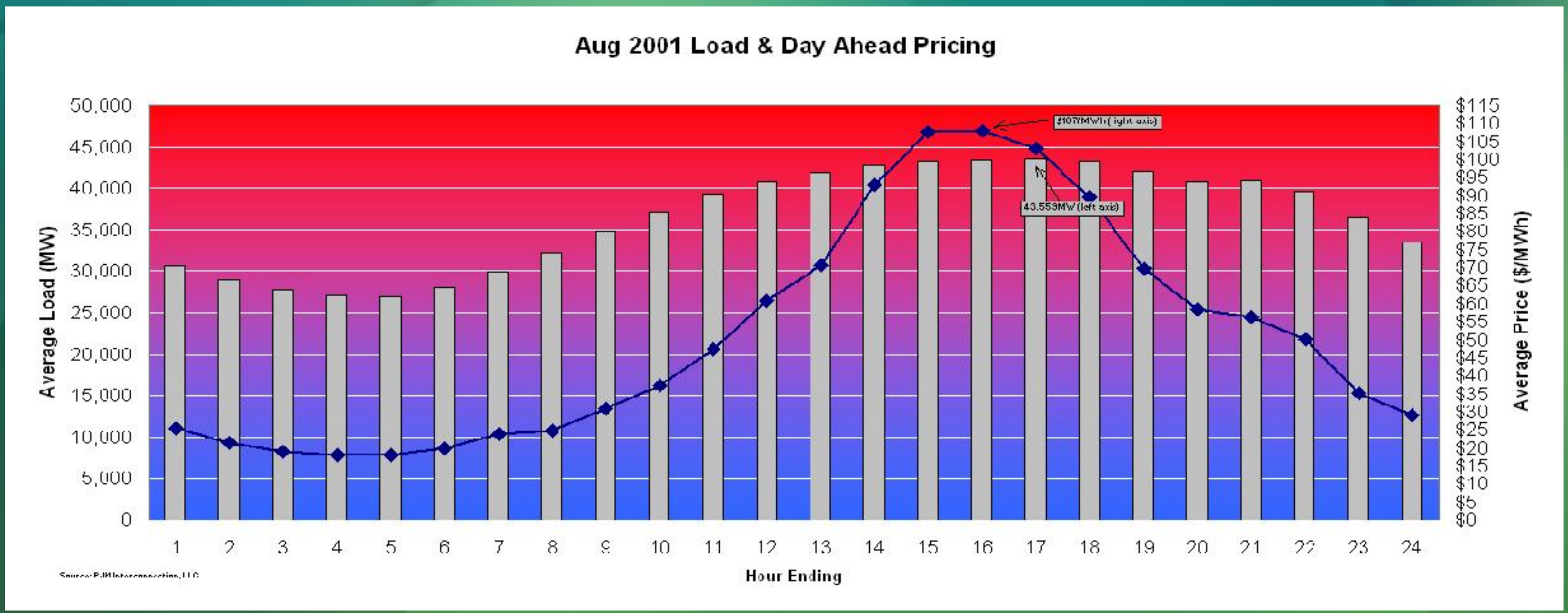
Power Demand and Electric Energy Price Rise with Hot Weather



- Price of electric energy for the ratepayers goes up during the peak demand period: as much as 7 times that during the off-peak period

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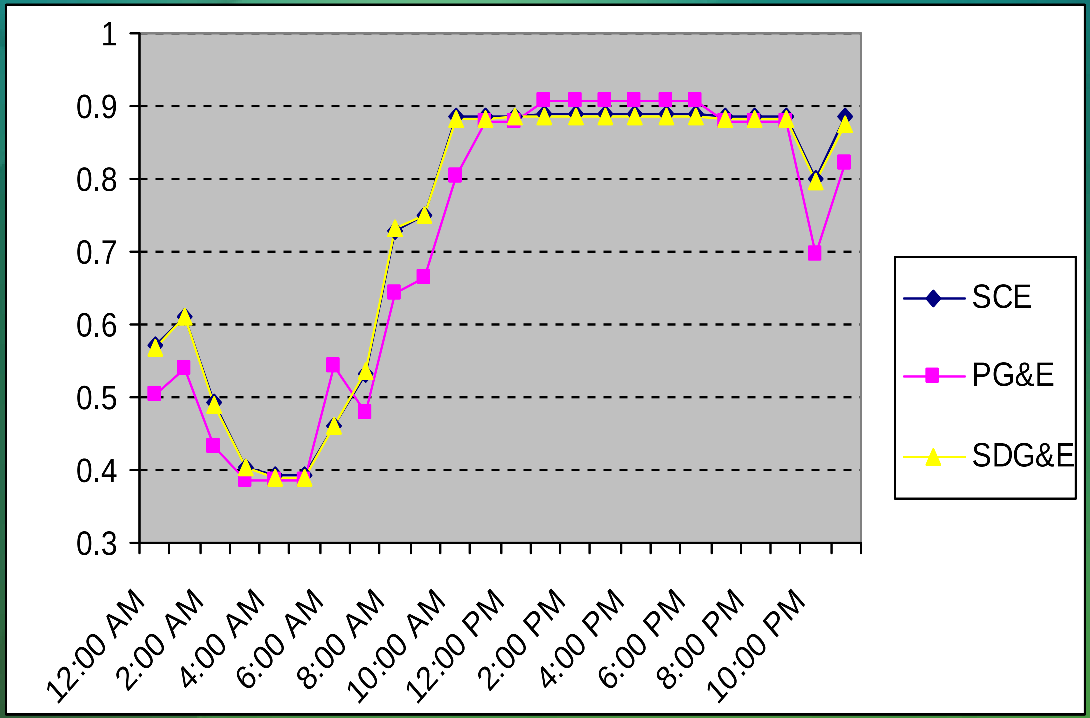
Emissions (lbs/kWh) also Increase During On-Peak Period



Y-Axis Unit: CO_2 Emissions, lbs/kWh (California)

Source: Scot Duncan Presentation at ASHRAE June 2007

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Problem:

Some of the Characteristics of Combustion Turbines

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Some of the Unfortunate Characteristics of All Combustion Turbine Power Plants

- **During hot weather, just when power demand peaks,**

1. Power output decreases
   - Up to 35% below rated capacity
   - Extent of the decrease depends on the CT design
2. Efficiency decreases leading to increased fuel consumption (higher heat rate) and increased emissions per kWh
   - Up to 15% below rated capacity
   - Extent of the decrease depends on the CT design

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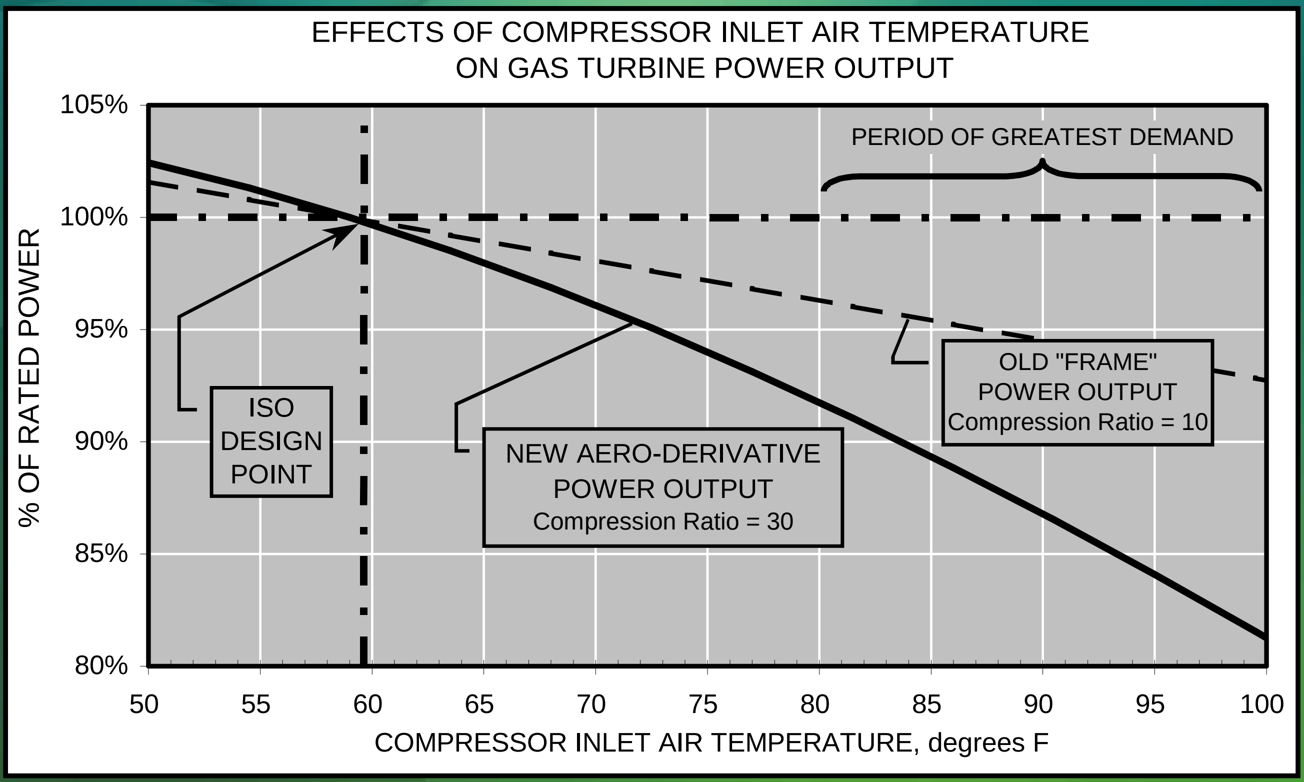
Effect of Hot Weather on CT Generation Capacity Depends on CT Design



Up to 19% capacity loss at peak demand for this CT

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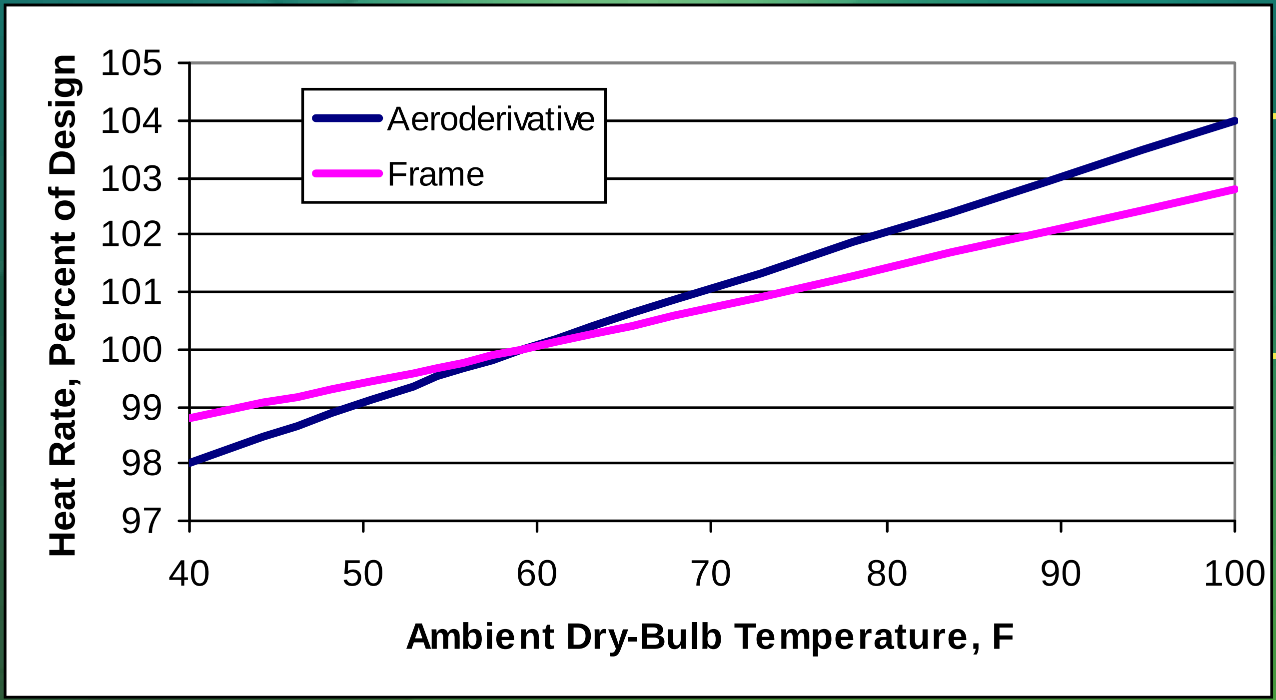
CT Power Plants Energy Efficiency Decreases (i.e. Heat Rate Increases) with Increase in Ambient Temperature



Fuel Use Increase (i.e. Energy Efficiency loss) at peak demand

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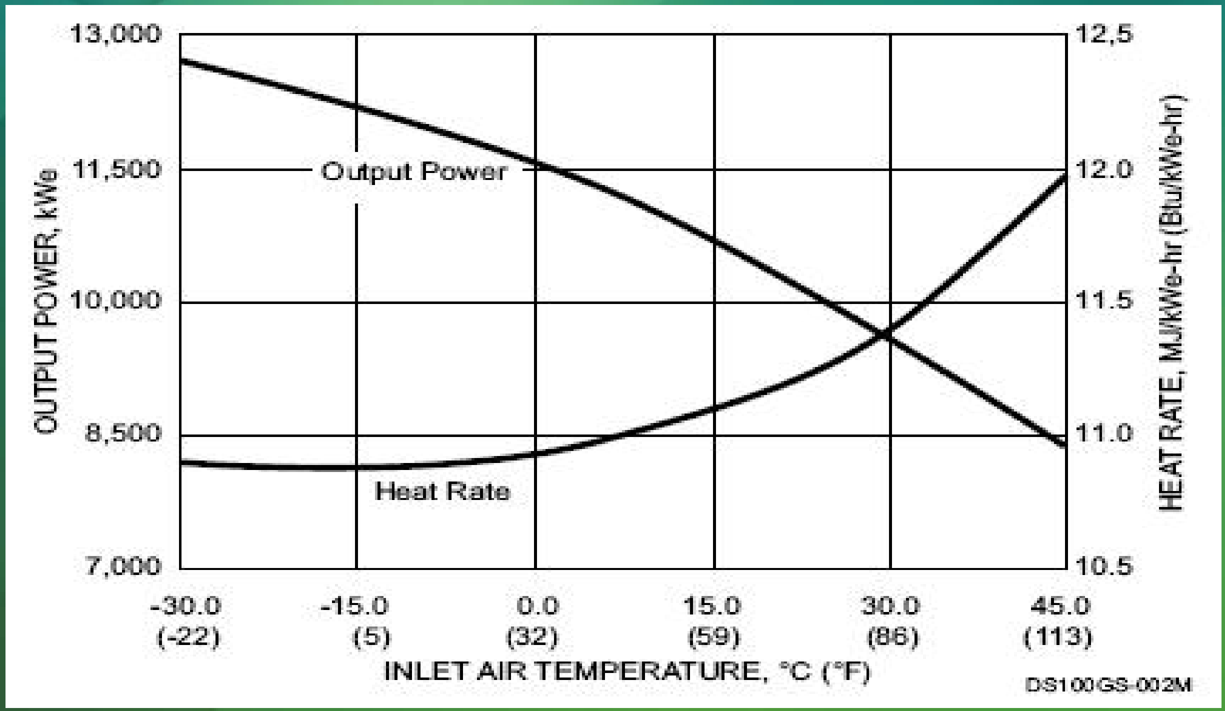
Smaller Capacity Systems More Sensitive to Ambient Temperature

Capacity Loss of over 21% from ~10,750 kW to ~8,500 kW



Source: Solar Turbines

Efficiency loss of over 8 % from HR of ~ 11,100 to ~12,000 Btu/kWh

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Effect of Hot Weather on the U.S. Generation Capacity Reduction*

Fuel	Winter Capacity, MW	Summer Capacity, MW	Summer Capacity Loss, MW
Petroleum	60,878	56,781	4,097
Natural Gas	432,309	401,272	31,037

Source: U.S. Department of Energy's Energy Information Agency 2012 Database

* Most of it is due to the reduced capacity of combustion turbine

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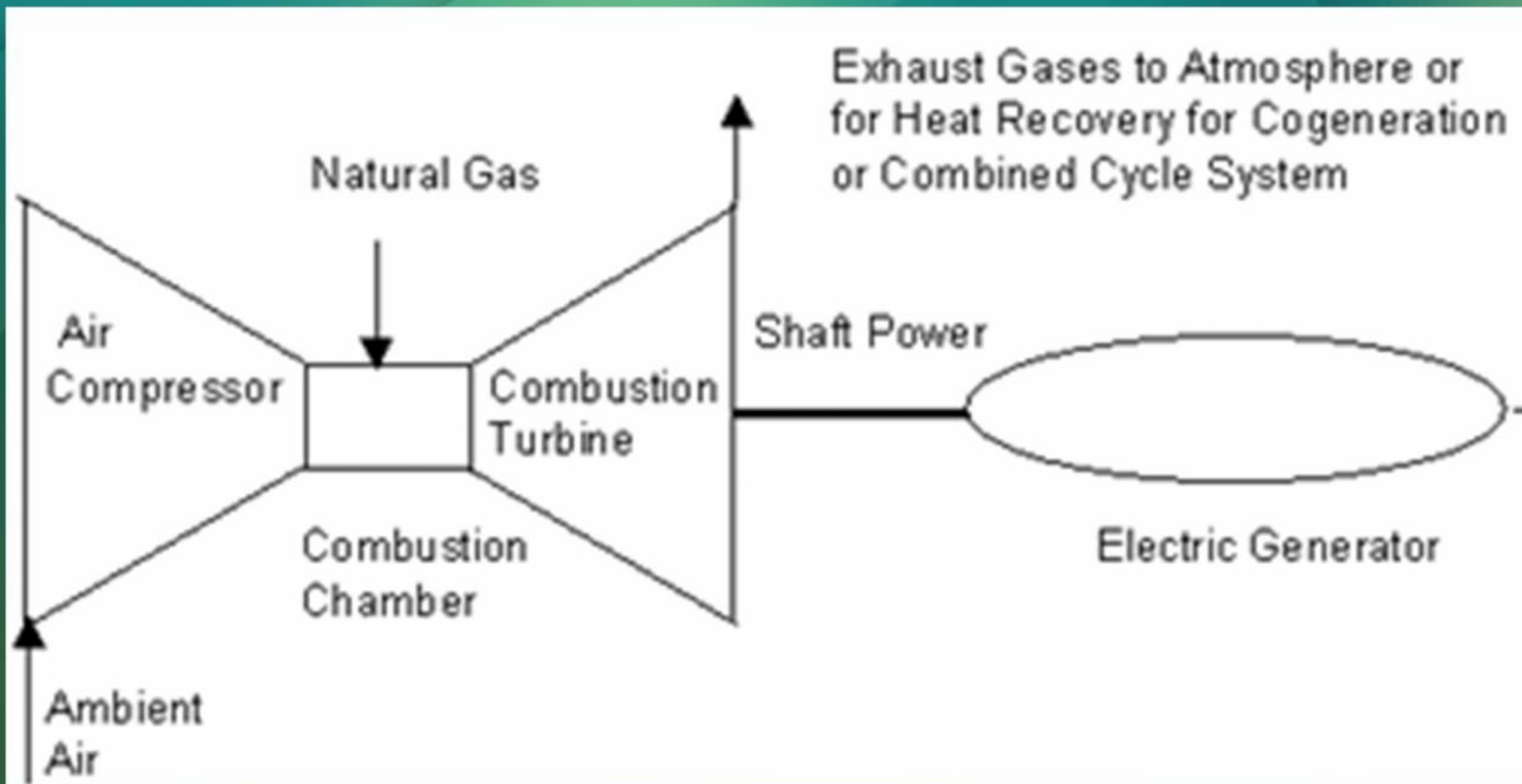
Major Components of a Combustion Turbine System



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Why CT Power Output Capacity Decreases with Increase in Ambient Temperature?

- Power output of a turbine is proportional to the mass flow rate of hot gases it receives from the combustion section
- Mass flow rate in the combustion section is proportional to the mass flow rate of the compressed air it receives from the compressor
- Mass flow rate capacity of a compressor is limited by its volumetric capacity for sucking in the inlet air
- Increase in ambient temperature reduces the air density that decreases the mass for the same volumetric flow rate through the compressor
- Reduced mass flow rate of compressed air reduces the mass flow rate of the hot combustor gases that leads to reduced power out put of the combustion turbine

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Why CT Efficiency Decreases with Increase in Ambient Temperature?

- Compressor power requirement increases with increase in air temperature
- Compressor of a CT system consumes almost two-third of the turbine's gross output
- Increased power required of the compressor reduces the net electric power available from the CT system

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Solution:

Turbine Inlet Cooling

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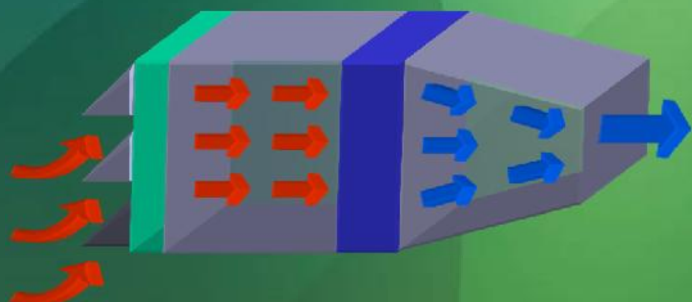
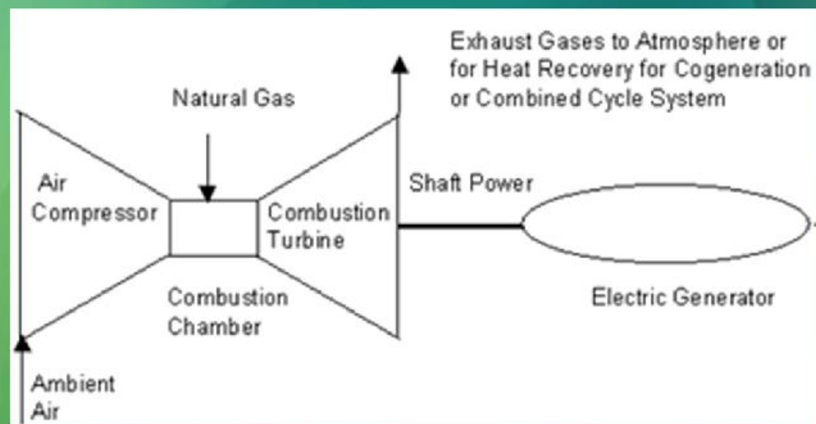
What is Turbine Inlet Cooling?



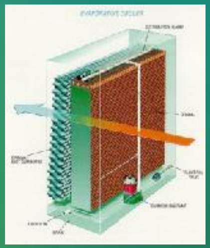


- **Cooling the inlet air before it enters the compressor or during its compression**

Turbine Inlet Cooling Technologies

- **Direct Evaporation**

  - Wetted Media, Fogging



- **Indirect Evaporation**
- **Chilled Fluid using mechanical or absorption chillers:**

  - Indirect or Direct Heat Exchange

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Turbine Inlet Cooling Technologies

- **Thermal Energy Storage (TES)**

  - Chilled Fluid or Ice

- **Wet Compression**
- **LNG Vaporization**
- **Hybrid**

  - Some combination of two or more cooling technologies

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Last year TICA completed a series of webinars on each technology.

Turbine Inlet Cooling Technologies

- Each TIC technology has its pros and cons
- No one technology is best for all applications
- Evaporative cooling systems can not cool the inlet air to lower than the wet-bulb temperature but require least capital cost and have least parasitic power need
- Chiller systems can be designed to cool the air to any desired temperature but require more capital cost and have high parasitic power need

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Turbine Inlet Cooling Technologies

- TES systems shift chiller parasitic load to off-peak period
- Wet compression improves compression efficiency and low parasitic load
- Hybrid systems minimize the parasitic load to achieve a desired inlet air temperature
- LNG vaporization only applicable where the power plant is located at/or need an LNG vaporization facility

Turbine Inlet Cooling Technologies are Simple and Proven

- **Thousands of plants already benefiting from TIC**
- **TICA web site database of 100+ plants worldwide that are using TIC**

  www.turbineinletcooling.org/database.html

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Turbine Inlet Cooling Technology Performance Calculator

- **Available on the TICA Website**

  http://www.turbineinletcooling.org/calculation_nonmem.php5

- **Member Version (Full Version)**

- **Public Version (Partial Features)**

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Factors Affecting the Capacity Enhancement Potential of TIC

- **TIC Technology**
- **CT Design Characteristics**
- **Weather Data (dry-bulb and coincident wet-bulb temperatures/humidity) for the Geographic Location of the CT**
- **Design Ambient Conditions**
- **Design Cooled Air Temperature (if allowed by the TIC technology)***

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* **Cooling achieved by evap technologies is limited by the humidity**

Benefits of TIC

- Increased Capacity
- Increased Efficiency
- Reduced Emissions
- Reduced Unit Capital Cost ($/kW of capacity increase)

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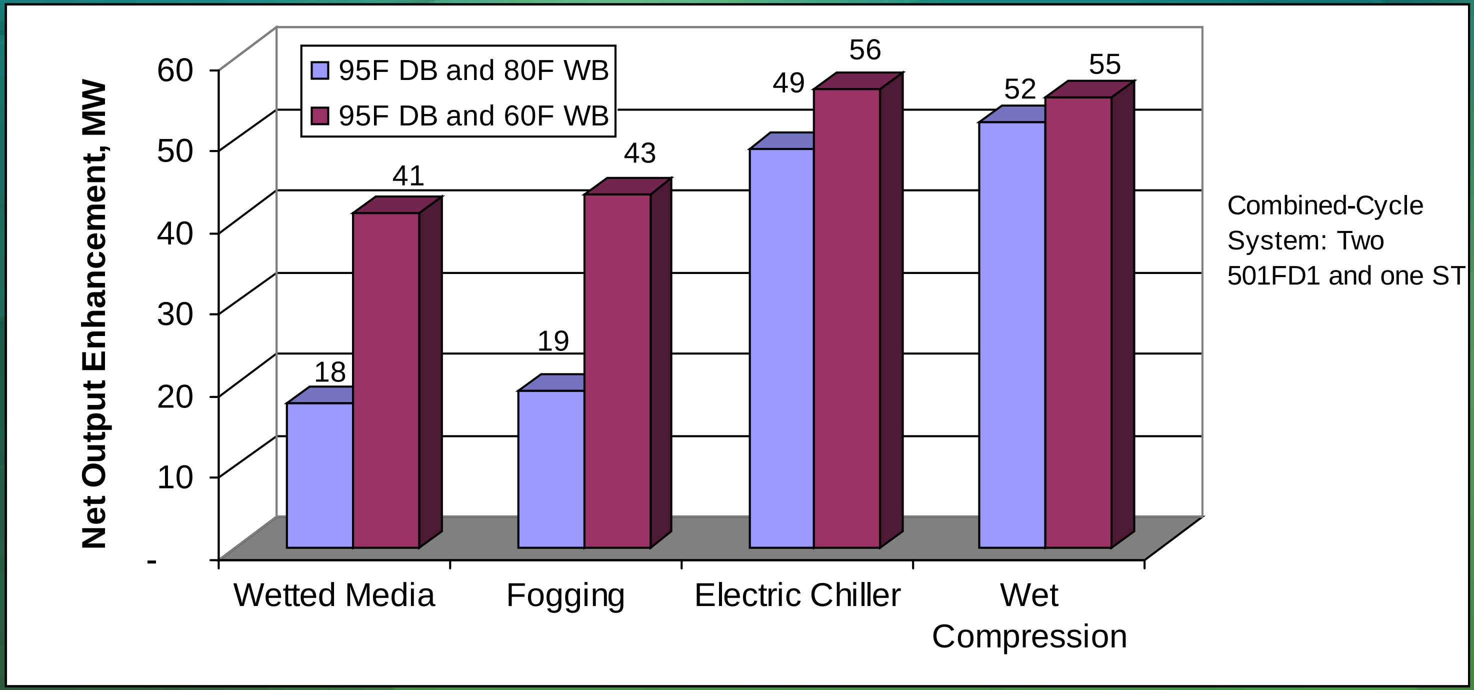
Examples of the Effect of TIC Technology and Humidity on Capacity Enhancement



Sources:

Wet Compression: Caldwell Energy, Inc.

All Others : D.V. Punwani Presentation, Electric Power 2008

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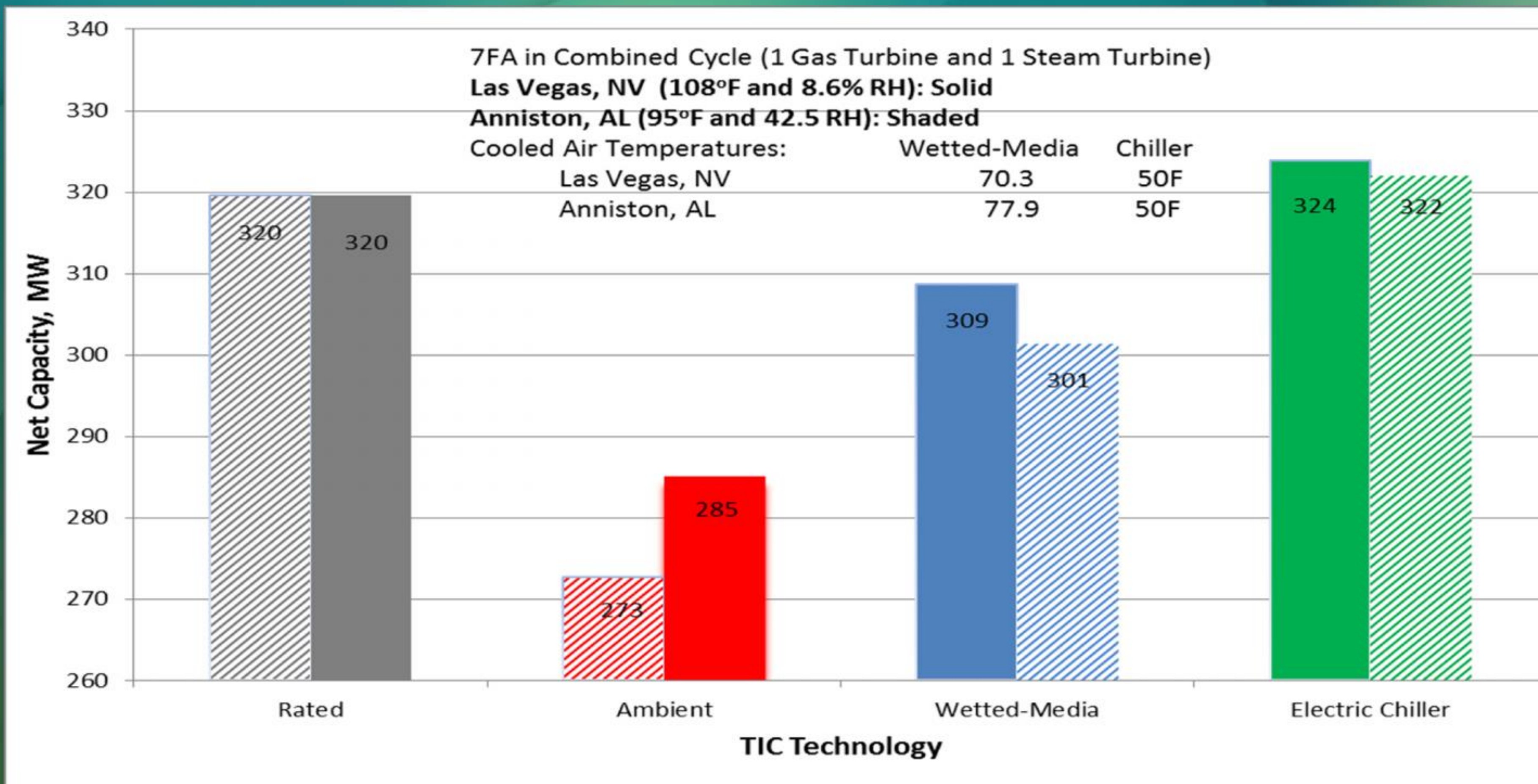
TIC Overcomes the Effects of the CT Performance During Hot Weather



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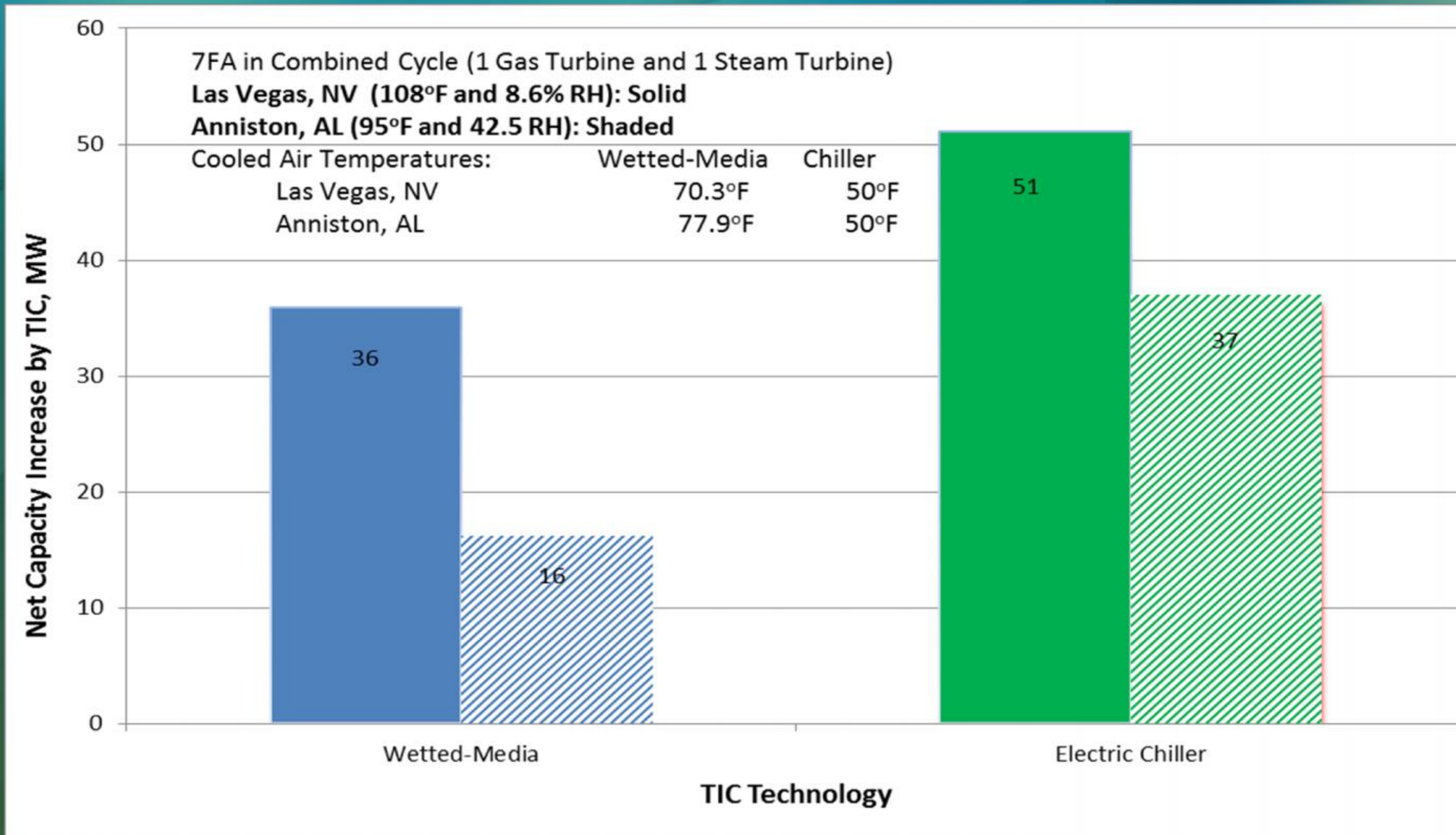
Net Capacity Increase by TIC



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TIC Reduces On-Site and Grid-Wide Emissions

- Reduces on-site emissions* by increasing the efficiency of the turbine being cooled
- Reduces grid-wide emissions* by reducing the need for operating less-efficient and higher-emission power plants

* lb/kWh of all emissions including, CO_2, NOx, Sox

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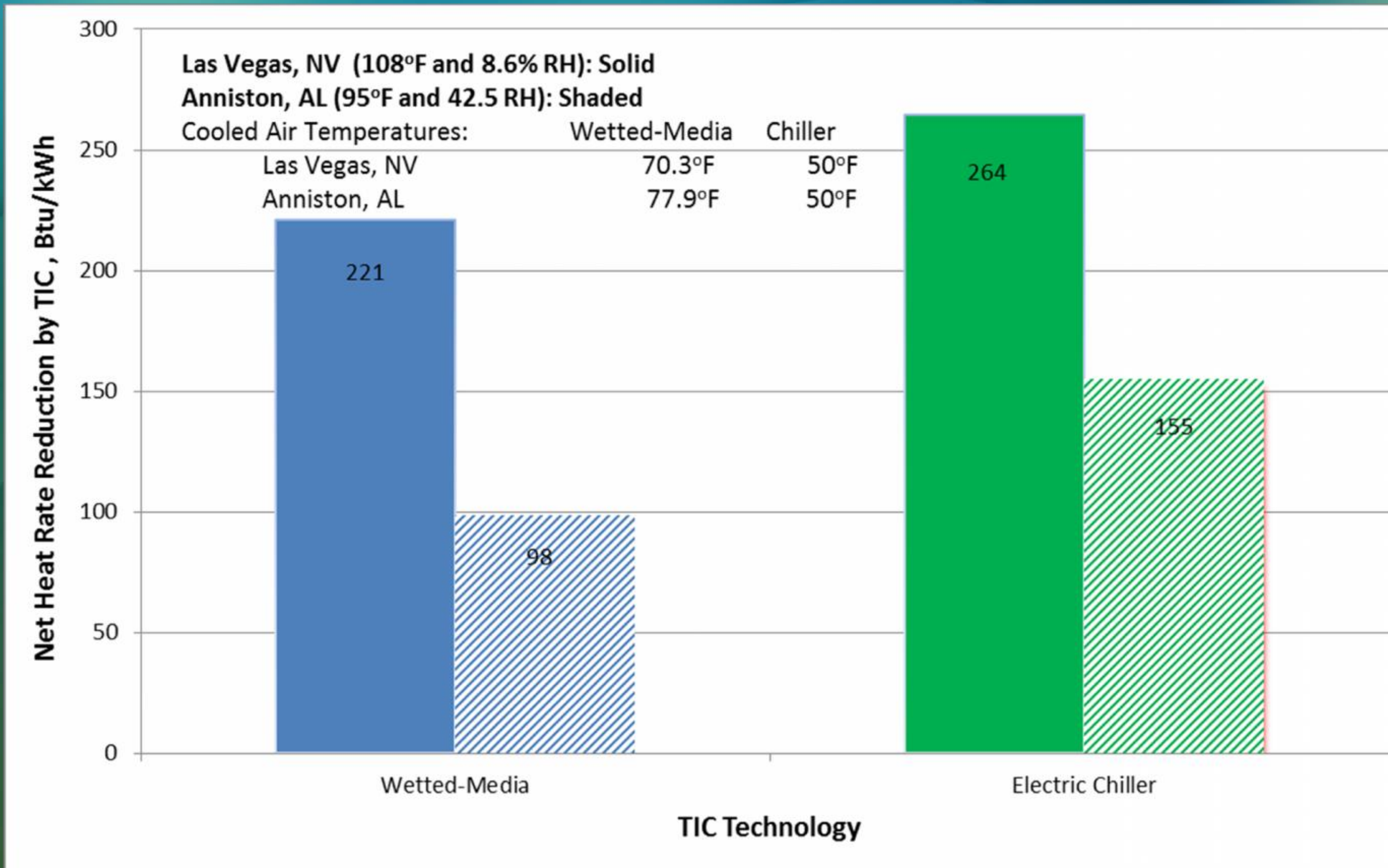
On-Site Net Heat Rate Reduction by TIC



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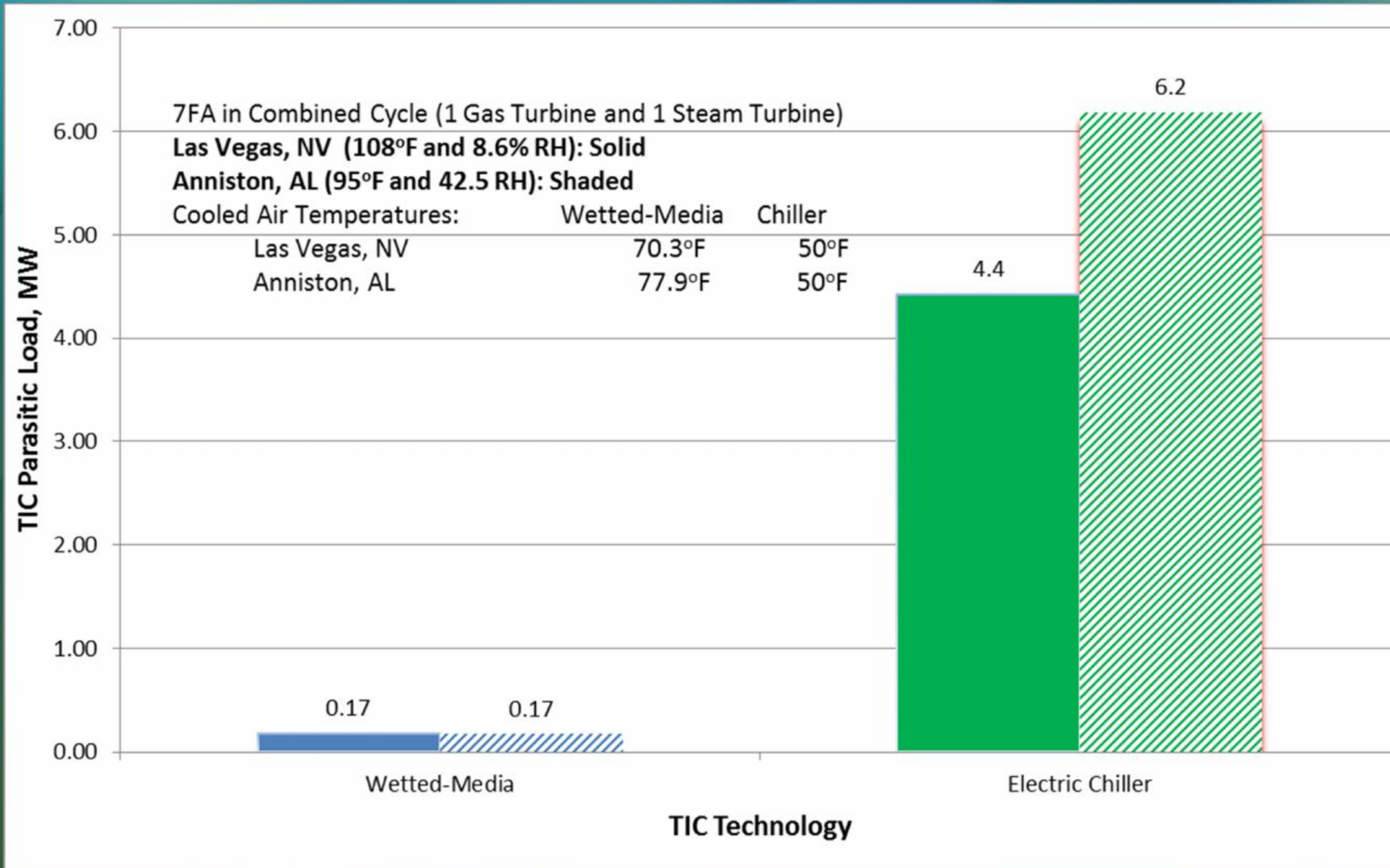
Parasitic Power Load of TIC



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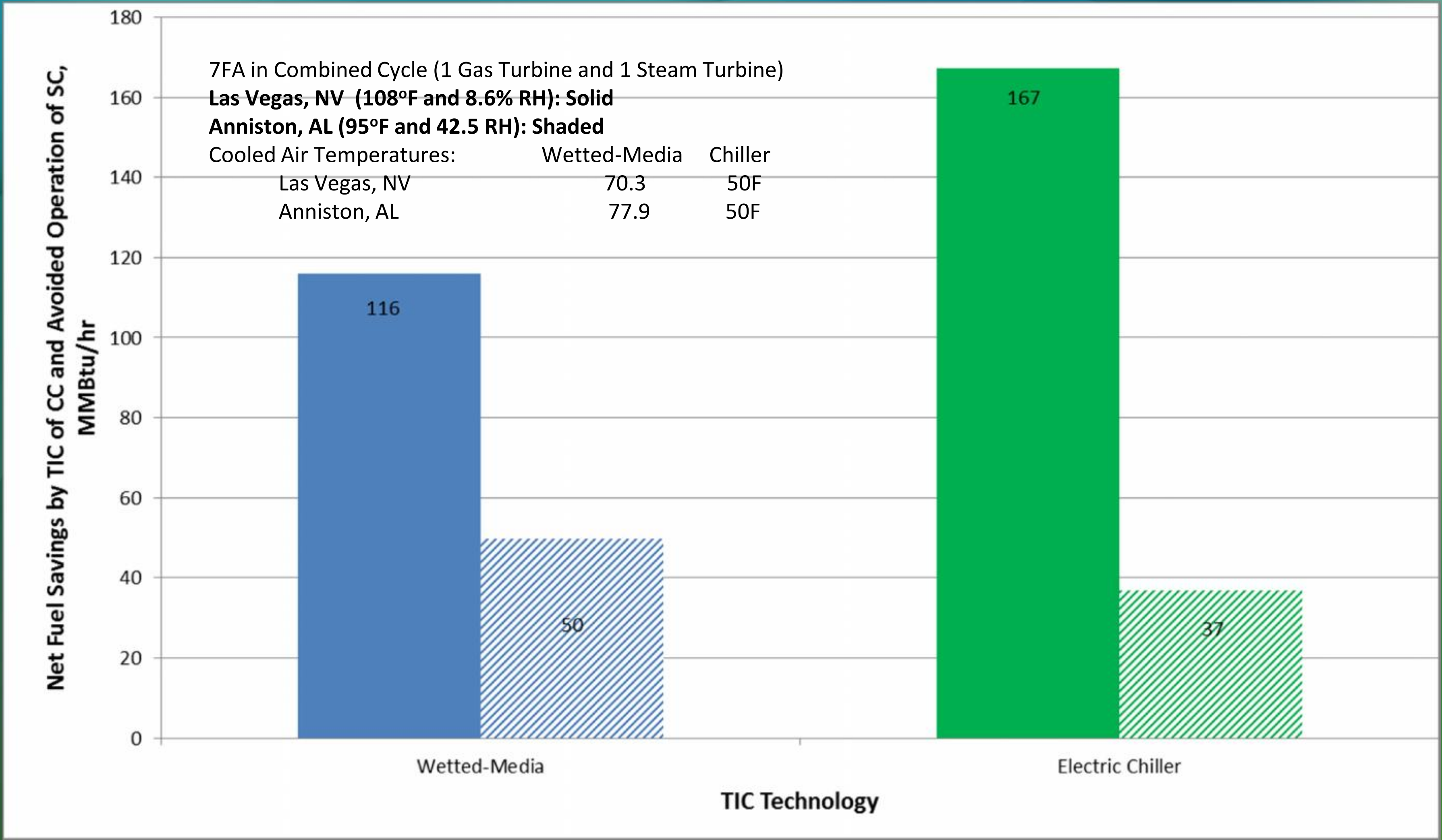
Fuel Saving by TIC of a Combined-Cycle Plant



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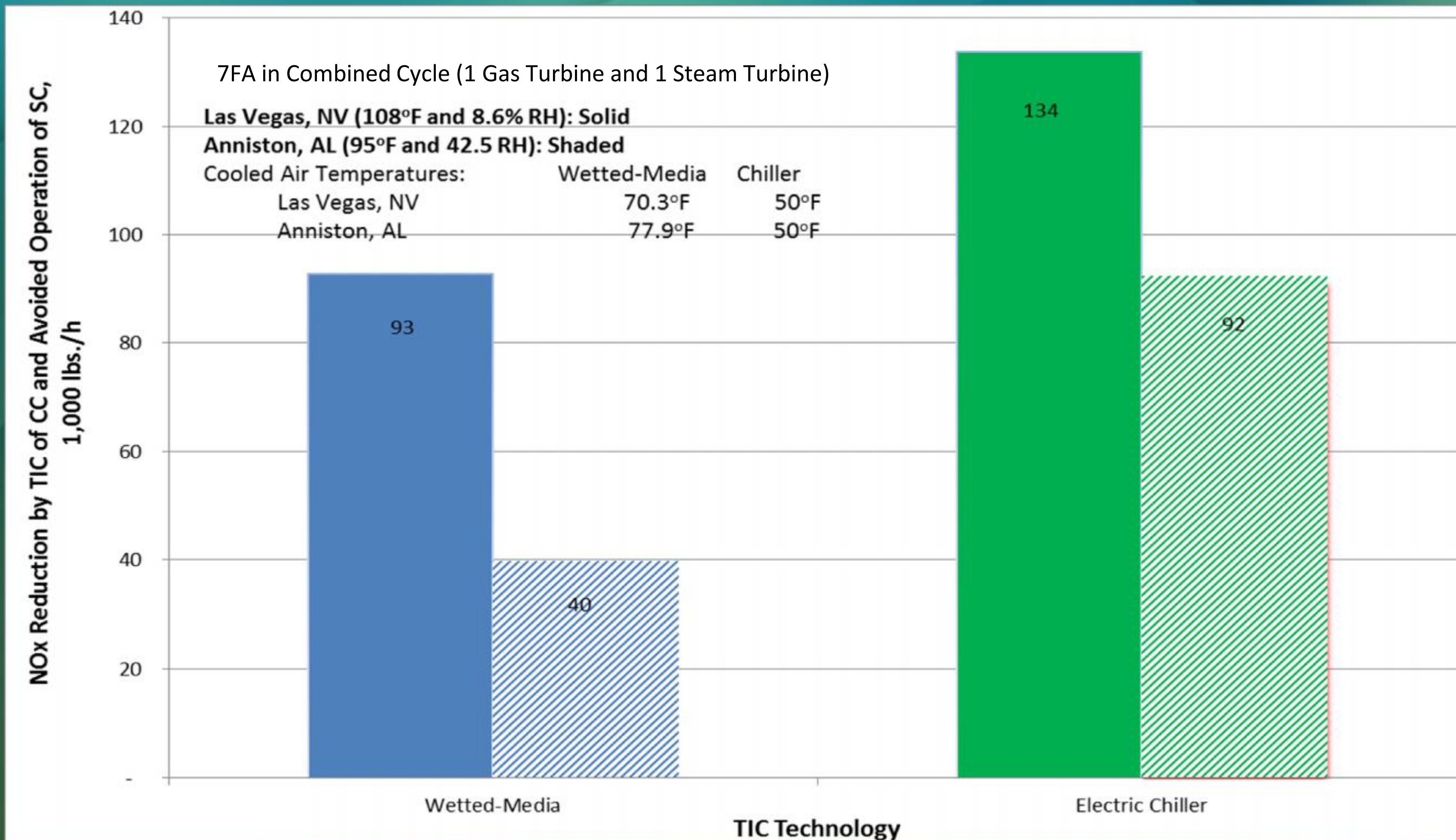
Grid-Wide NOx Reduction by TIC of a Combined-Cycle System



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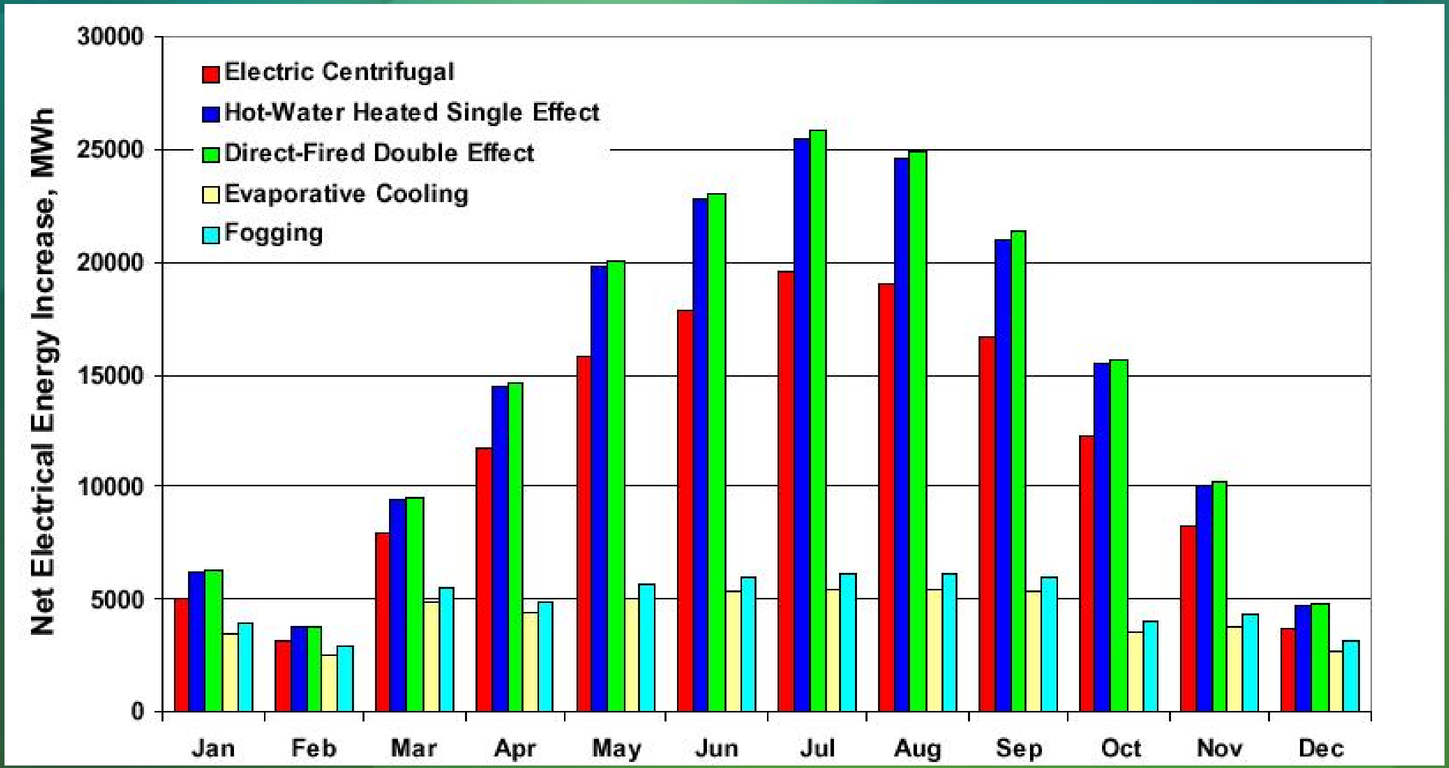
TIC Reduces the Need for Siting New Power Plants or Operating Less Efficient Power Plants During Hot Weather

Example

- TIC on a nominal 500 MW CC plant eliminates the need for siting a new or operating an existing 75-95 MW SC peaker
  - Eliminates costs associated with siting, construction and interconnections of a new plant
  - Reduce long lead time for a new plant (TIC requires <1yr)

Example of Monthly Incremental Net Electric Energy Provided by Some of the TIC Technologies

(316 MW Cogeneration Plant Near Houston, TX)



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

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Factors Affecting the Economics of TIC

- TIC Technology
- Annual Operating Hours
- CT Characteristics
- 8,760 Hours Annual Weather Data for the Geographic Location of the CT
- Market Value of the Additional Electric Energy Produced
- Fuel Cost

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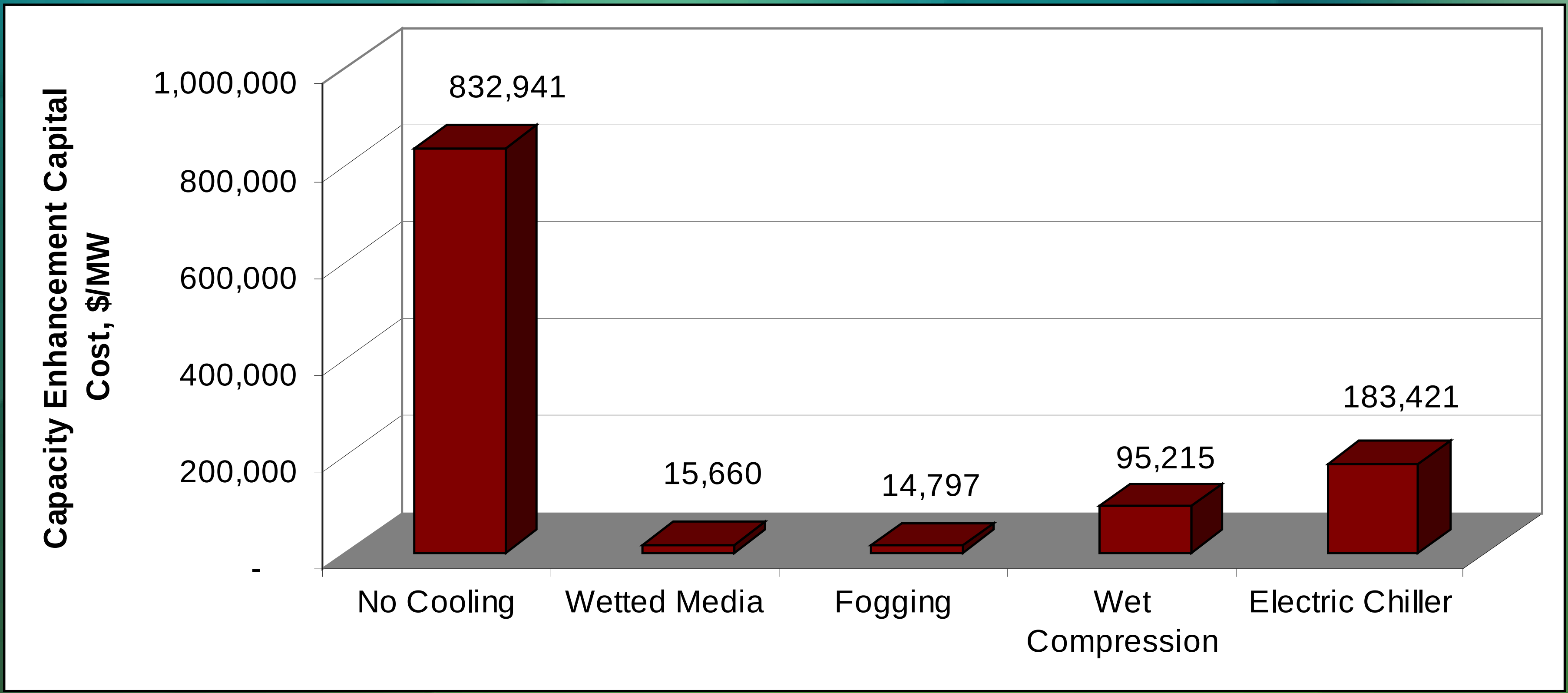
Examples of the Effect of TIC Technology on Capital Cost for Incremental Capacity



317 MW Cogeneration System Snapshot at 95°F DB and 80°F WB

Source: Punwani et al ASHRAE Winter Meeting, January 2001

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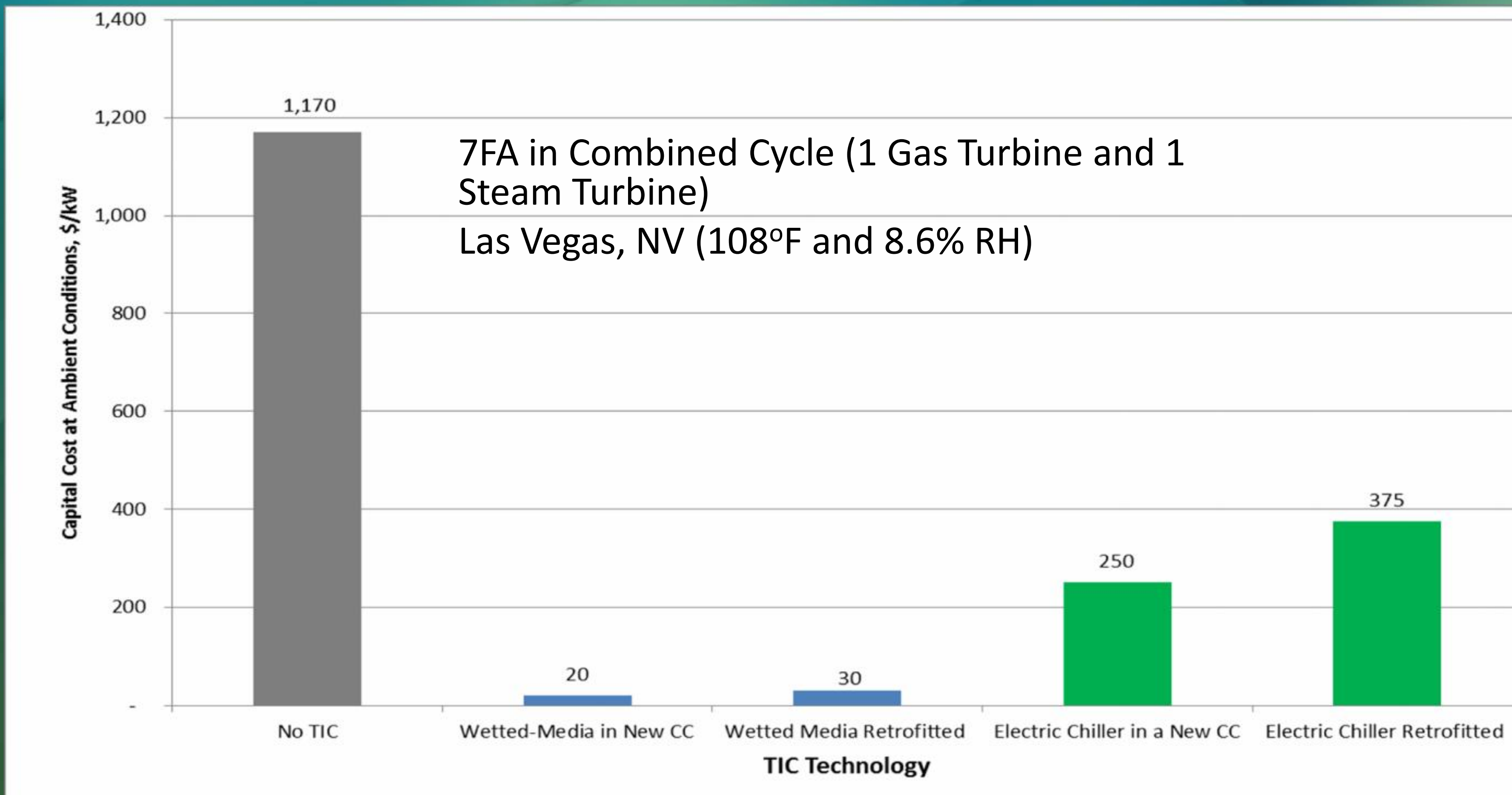
Examples of the Effect of TIC Technology on Capital Cost for Incremental Capacity



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Economic Benefits

- Generates more MWh during peak demand periods when electric energy value is high
- Reduces capital cost per unit of the increased generation capacity compared to new power plants
- Reduces fuel cost of electric energy generation compared to the low energy efficiency “peakers”
- Reduces cost for ratepayers by potentially lower capacity payments to be provided by the independent system operators (ISOs) to power producers

Suggested Regulatory and Policy Positions

- Regulators should recognize TIC is a valuable solution to their supply problem during hot weather and
  - **Use** the full potential of existing combustion turbine plants
  - **Require** TIC use before allowing construction of new capacity
  - Ensure capacity payments provide appropriate returns for systems using TIC

- Policymakers should recognize the value of TIC for reducing emission and
  - **Exempt** the TIC from environmental re-permitting
  - Create incentives for plant owners to use TIC technology

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Summary

Turbine Inlet Cooling

- Significantly increases CT power output during hot weather
- Multiple options of commercially-proven technologies are available
- Generally economically attractive for the plant owners and rate payers
- Helps reduce emissions and thus, good for the environment

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Upcoming TICA Webinars on Best Practices

- June 11, 2014: Wetted-Media Evaporative Cooling
- August 13, 2014: Fogging
- October 8, 2014: Chiller Systems
- December 12, 2014: Thermal Energy Storage
- February 11, 2015: Wet Compression
- April 8, 2015: Hybrid Systems

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Q & A

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