Combustion Turbine Inlet Cooling (CTIC) for Power Augmentation: An Overview

Dharam V. Punwani

President, Avalon Consulting, Inc.

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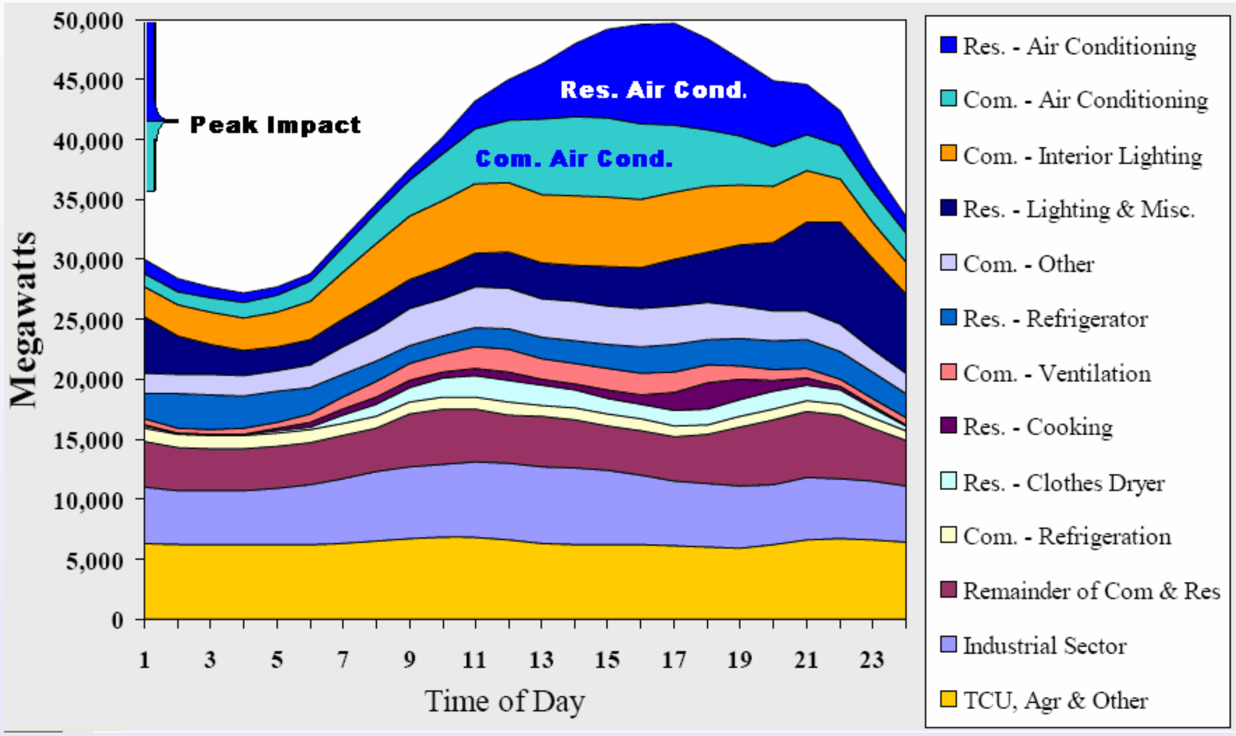
High Summer Temperatures Lead to High Air Conditioning Loads that become Major Contributors to the Peak Power Demand



Source: Scot Duncan Presentation at ASHRAE June 2007

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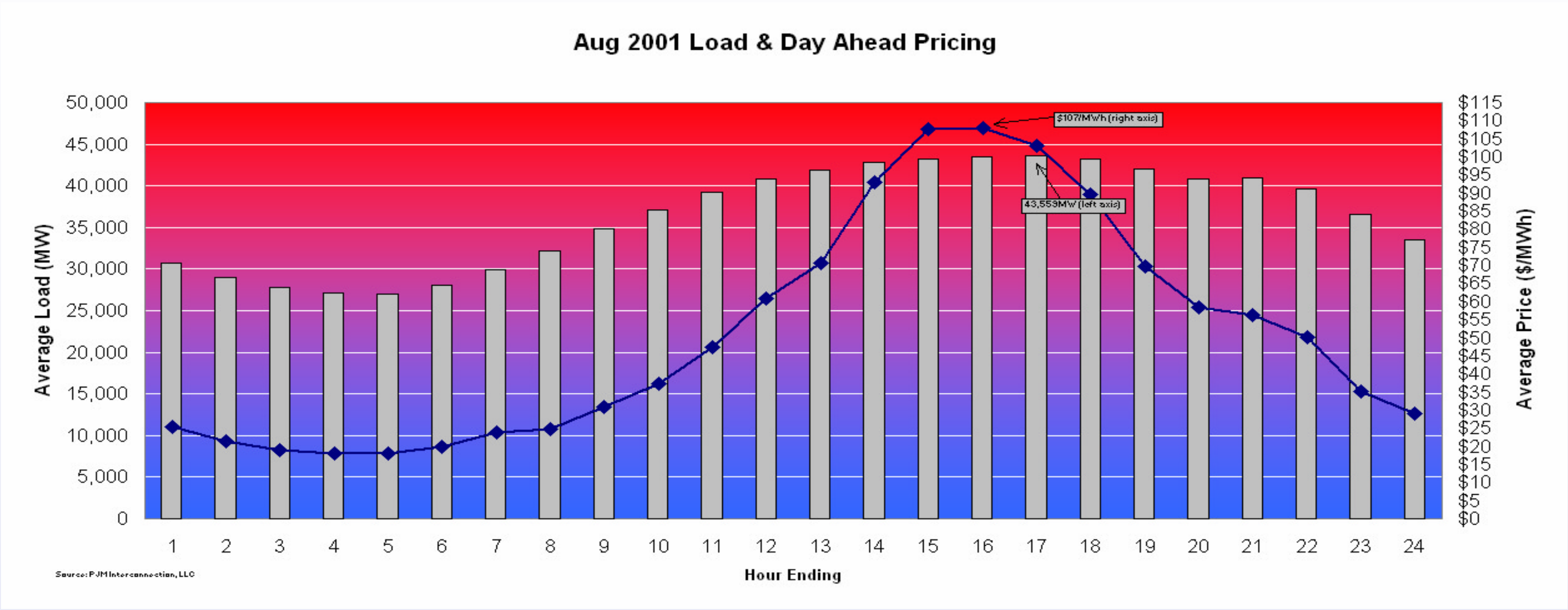
Power Demand and Electric Energy Price Rise with Hot Weather



- ➔ **Price of electric energy for the ratepayers goes up during the peak demand periods: as much as 4 times the value during the off-peak periods**

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Power Plant Operation Priority for Reducing Emissions

- The preferred order of operating fossil power plants using natural gas should be:

  1. CT in combined-cycle system (Lowest Heat Rate i.e. Highest Energy Efficiency)
  2. CT in simple-cycle system
  3. Steam turbine system (Highest Heat Rate i.e. Lowest Energy Efficiency)

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Combustion Turbine Power Plants Fundamental Flaws

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

1. Power output decreases significantly
   - *Up to 35% below rated capacity*
   - *Depends on the CT characteristics*
2. Fuel consumption (heat rate) and emissions increase per kWh

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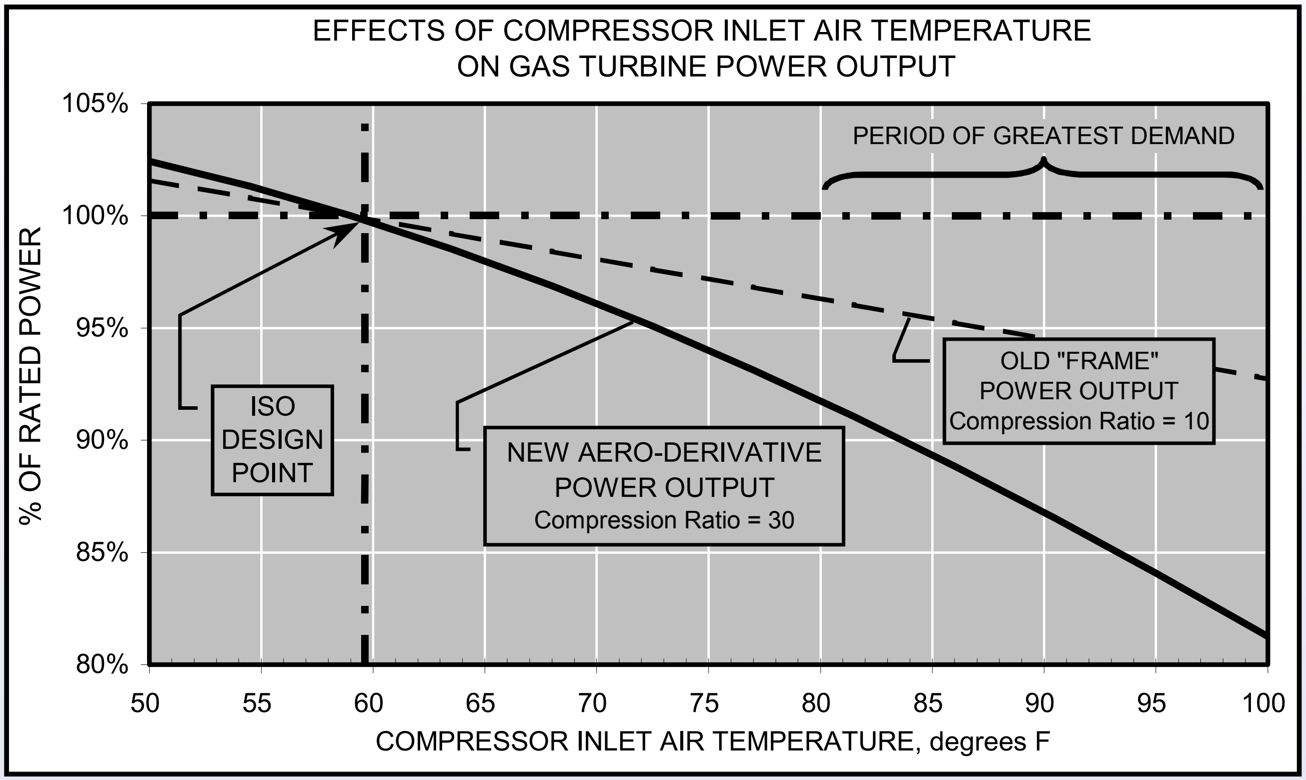
CT Power Plants' Generation Capacity Decreases with Increase in Ambient Temperature



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

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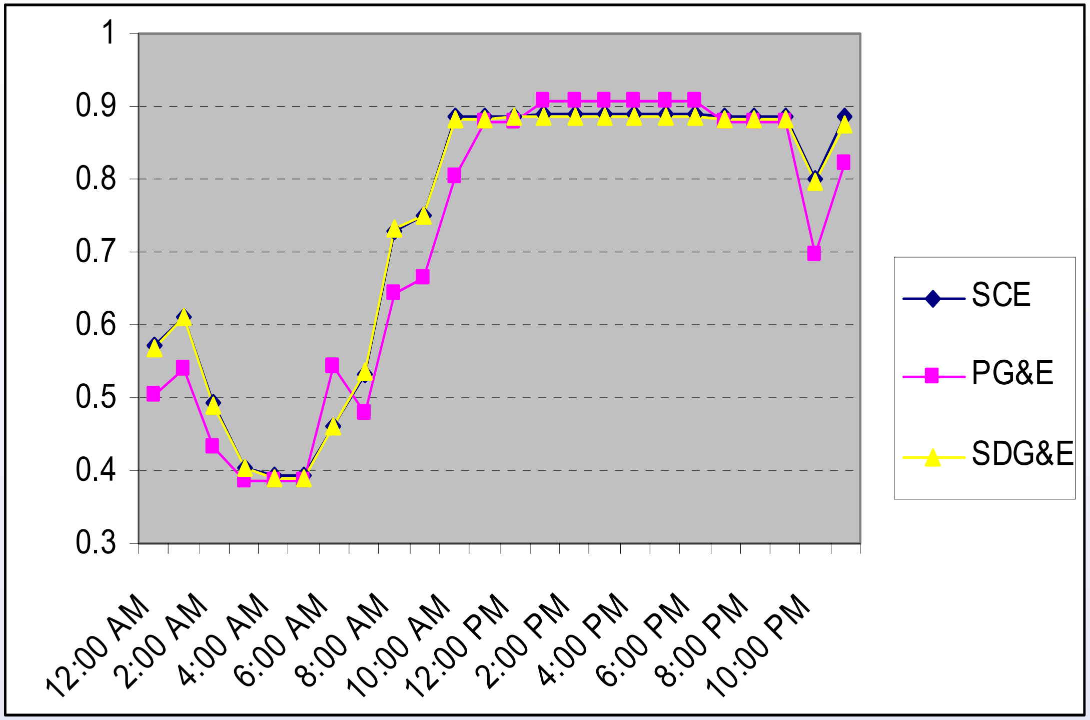
Emissions (lbs/kWh) of CO_2 During Summer (California)



Y-Axis Unit: CO_2 Emissions, Lbs/kWh

Source: Scot Duncan Presentation at ASHRAE June 2007

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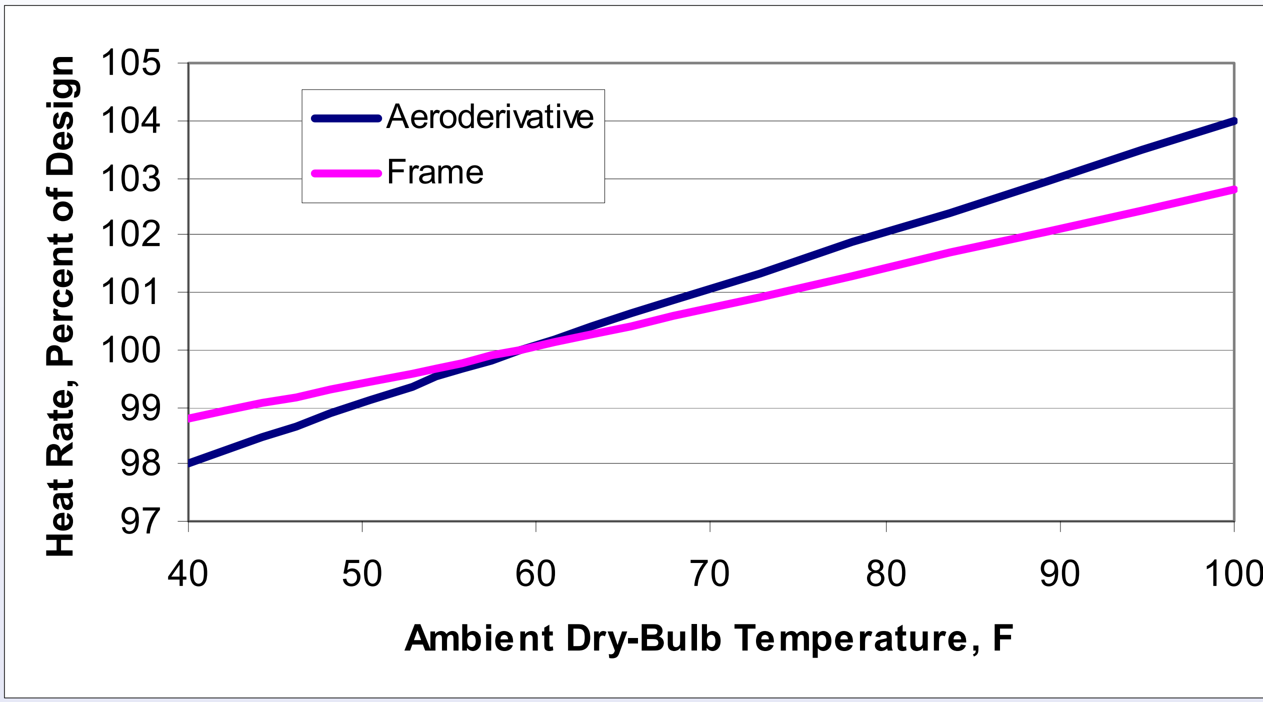
CT Power Plants Energy Efficiency Decreases (i.e. Heat Rate Increases) with Increase in Ambient Temperature



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

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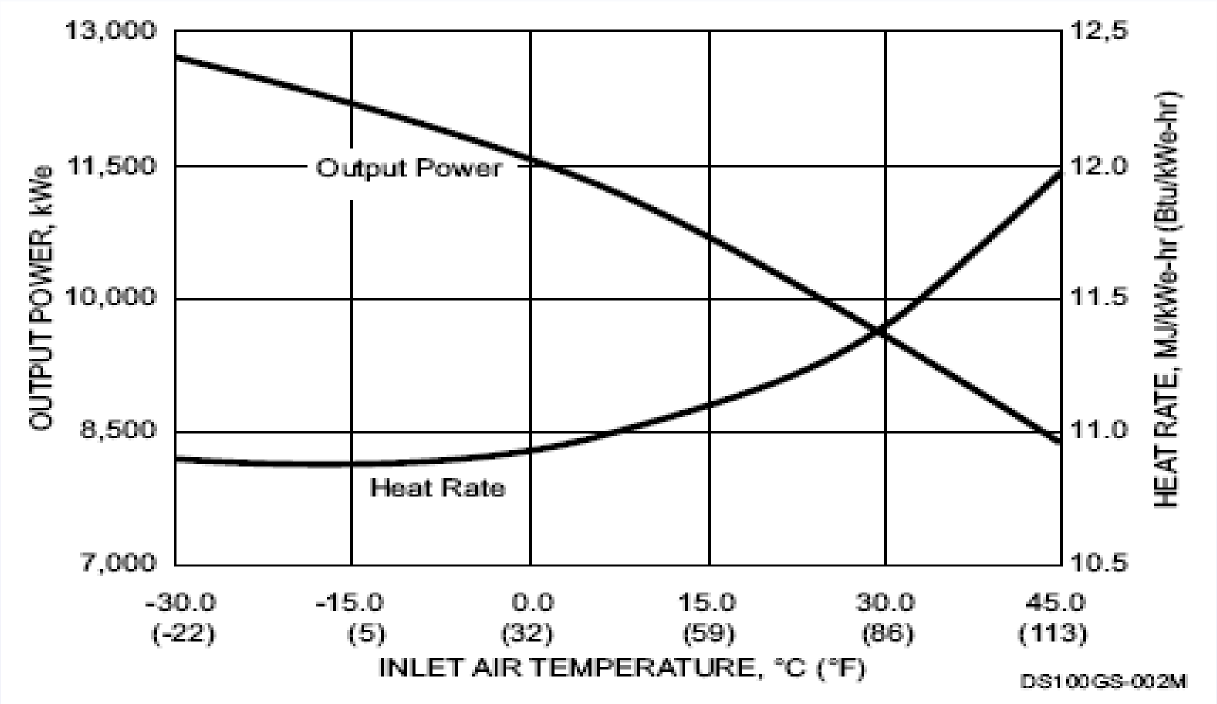
Smaller Capacity Systems More Sensitive to Ambient Temperature

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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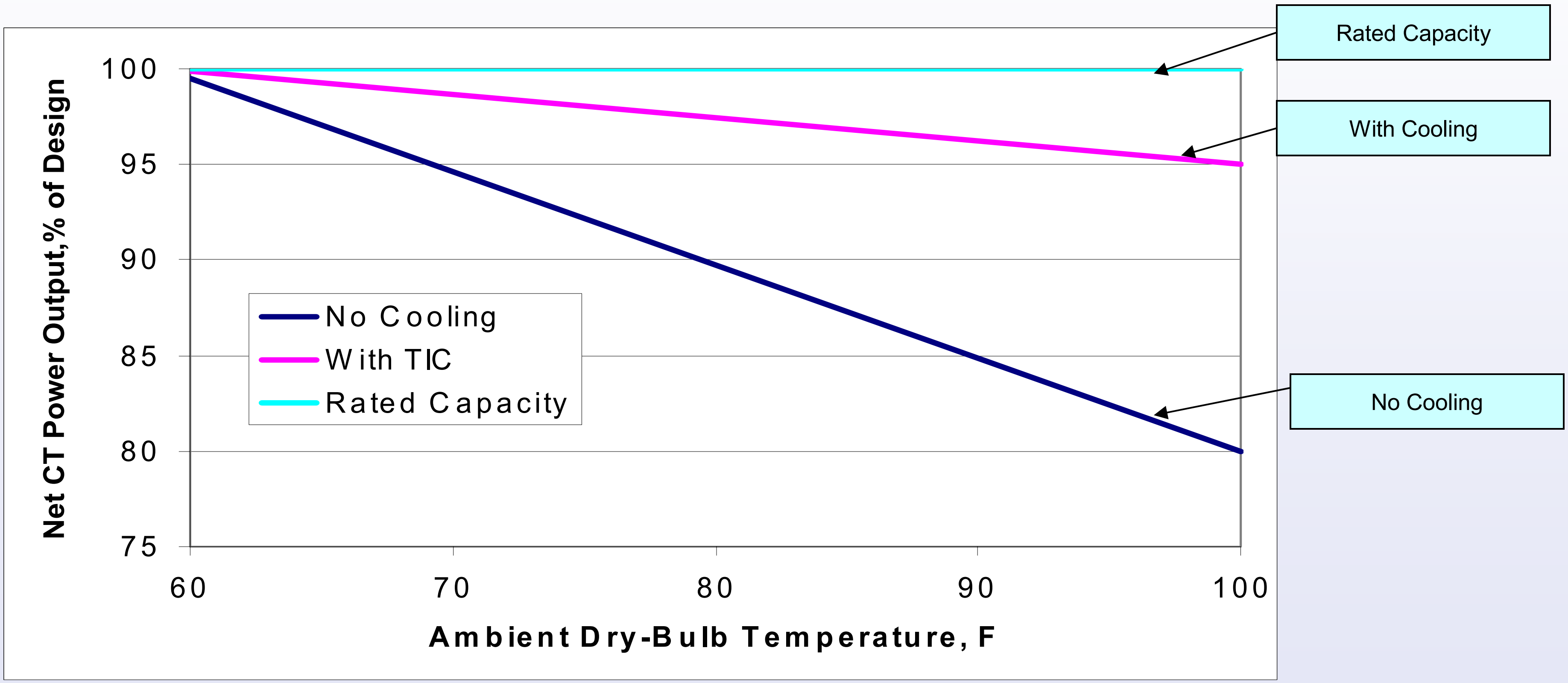
Turbine Inlet Cooling (TIC) Overcomes the Effects of the CT Flaws During Hot Weather



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Turbine Inlet Cooling Environmental Benefits

- **Reduces the need for operating inefficient and higher-emission power plants and thus,**
  - Reduces emissions of pollutants (SOx, NOx, particulates)
  - Reduces emissions of green house gas (CO_2)
- **Minimizes, delays, or even eliminates the need for new plants**

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Turbine Inlet Cooling (TIC) Reduces Need for New Power Plants

- Implementing TIC on combustion turbines in combined-cycle (CC) systems effectively displaces/reduces operations of combustion turbines in simple-cycle (SC) systems
- TIC for each nominal 500 MW CC plant eliminates the need for a nominal 40-50 MW SC peaker and its associated siting, emissions, interconnection and other issues

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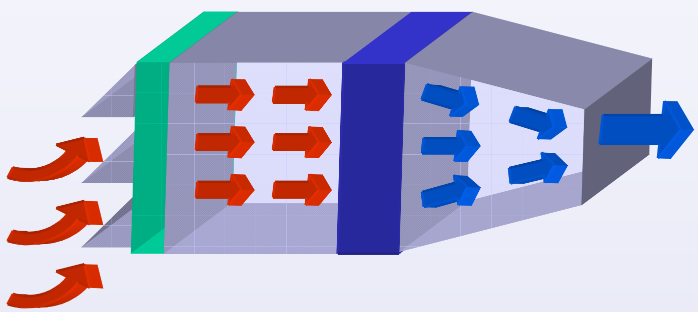
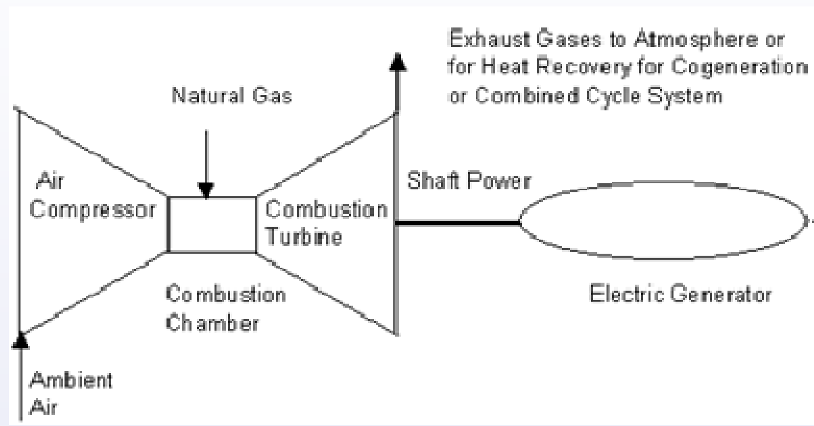
Turbine Inlet Cooling





- **Cooling the inlet air before or during compression in the compressor that supplies high-pressure compressed air to the combustor of the CT**

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TIC Technologies

Two Categories

- ➔ Reduce Temperature of the Inlet Air Entering the Compressor
- ➔ Reduce Temperature of the Inlet Air During Compression

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TIC Technologies

Reducing Inlet Air Temperature

- **Direct Evaporation**: Wetted Media, Fogging
- **Indirect Evaporation**
- **Chilled Fluid:** Indirect Heat Exchange, Direct Heat exchange
- **Chilled Fluid in TES:** Full-Shift and Partial-Shift
- **LNG Vaporization**
- **Hybrid:** Some combination of two or more cooling technologies

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TIC Technologies

<u>Reducing Inlet-Air Temperature During Compression</u>

- **Wet Compression (or Fog Overspray)**

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Turbine Inlet Cooling (TIC) Technologies are Simple and Proven

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

Factors Affecting the Capacity Enhancement Potential of TIC

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

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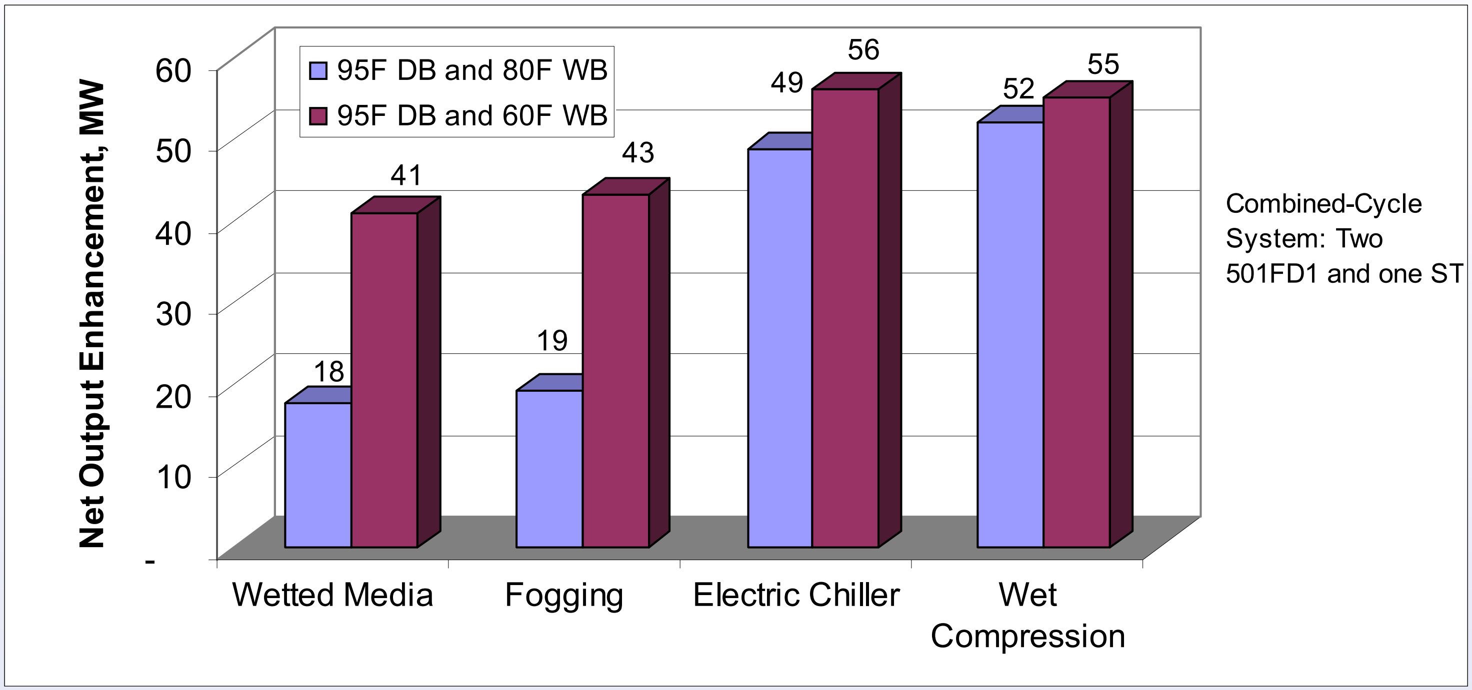
Examples of the Effect of TIC Technology and Ambient Temperature on Capacity Enhancement



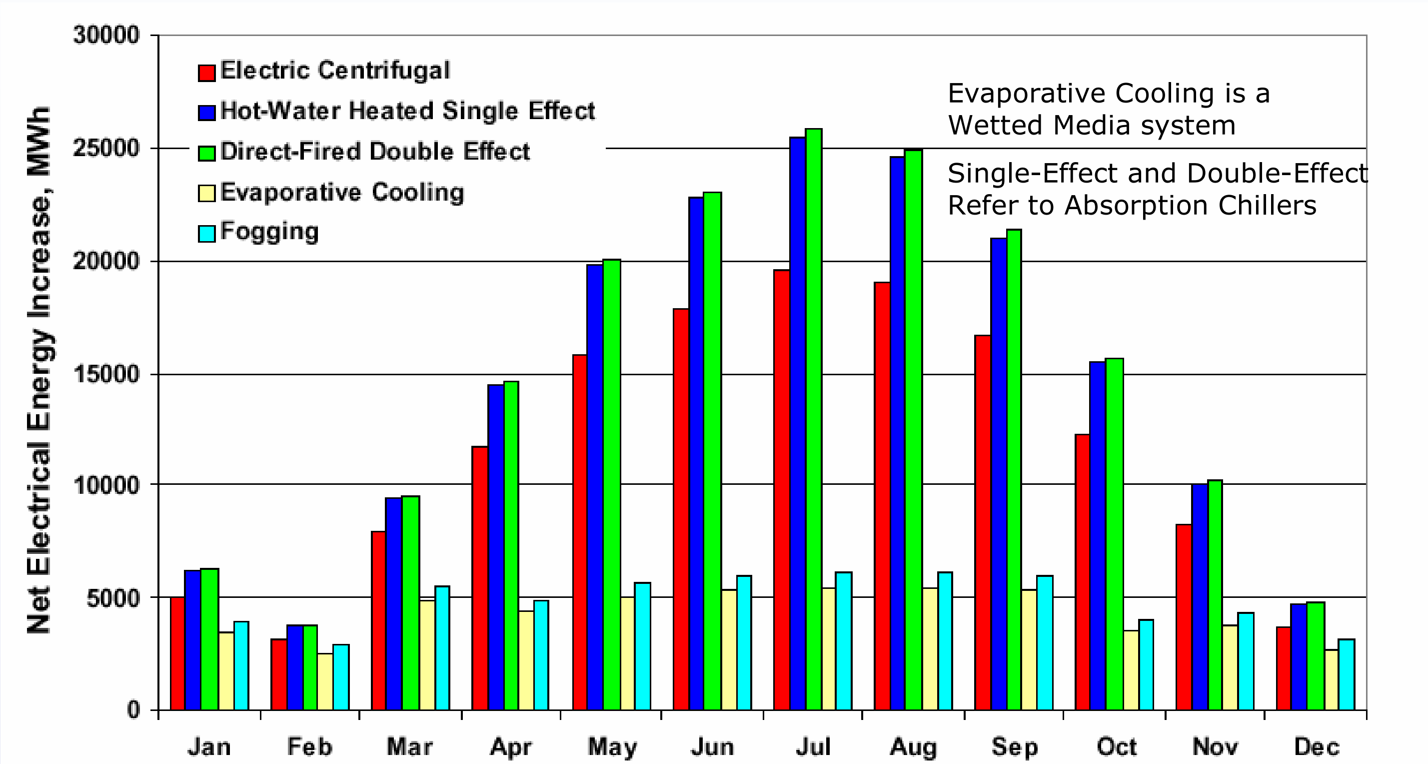
Sources:

Wet Compression: Caldwell Energy, Inc.

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

Example of Monthly Incremental 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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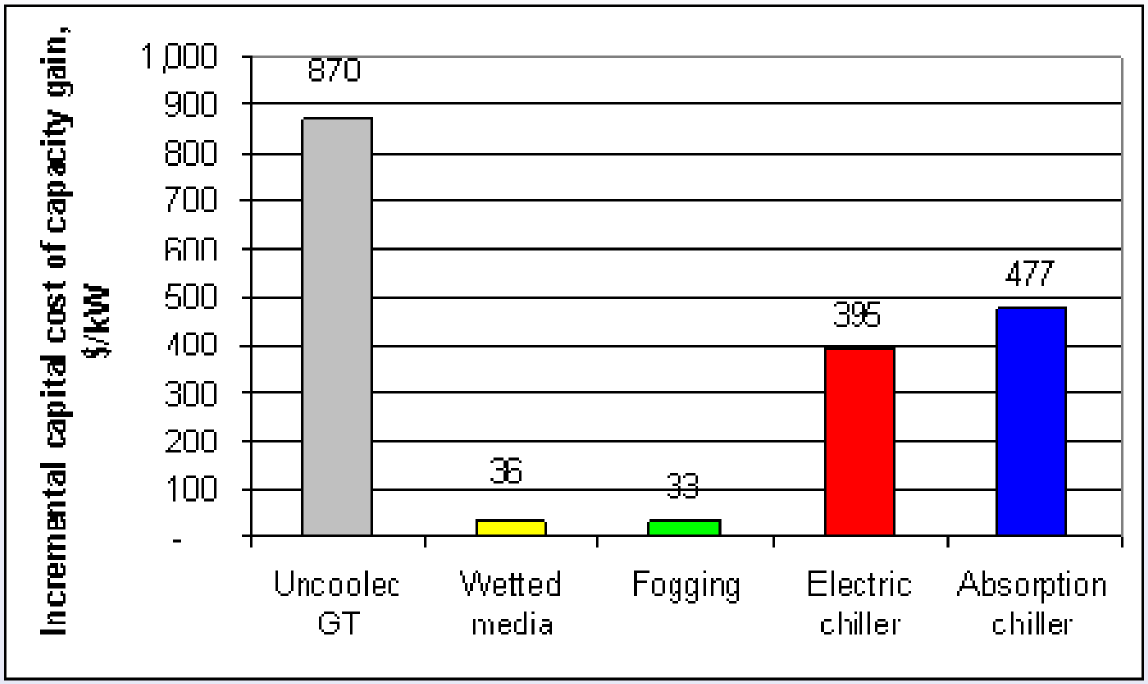
Factors Affecting the Economics of TIC

- TIC Technology
- CT Characteristics
- Weather Data for the Geographic Location of the CT
- Market Value of the Additional Electric Energy Produced
- Fuel Cost

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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Turbine Inlet Cooling Economic Benefits

- Generates more MWh and revenue during peak demand periods when electric energy value and price are high
- Reduces capital cost per unit of the increased generation capacity compared to new power plants
- Reduces cost of electric energy generation compared to the low energy efficiency "peakers"
- Reduces cost for ratepayers by allowing lower capacity payments by the independent system operators (ISOs) to power producers

Suggested Changes To Regulatory Structure

- **Realize full potential of existing combustion turbines plants**
  - Require addition of TIC before allowing new plants to be built
- **Exempt TIC from environmental re-permitting**
  - Impact of TIC is similar to ambient temperature naturally going down during winter (i.e. TIC yields winter performance in summer)
- **Calculate capacity payments for plant owners on the basis of systems incorporating TIC**
  - Consistent with the PJM affidavit made to the FERC in August 2005

TIC Summary

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

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Contact Information

Dharam V. Punwani

dpunwani@avalonconsulting.com

1- 630-998-0883