Benefits of Turbine Inlet Cooling and Thermal Energy Storage for Cogeneration/CHP Systems

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Presented at:

MCA Conference: Implementing Winning Cogeneration/CHP Projects

October 11, 2011

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Outline

- Introduction
- Hot Weather Effects on Combustion Turbine (CT) Systems
- Turbine Inlet Cooling (TIC) and Benefits
- Thermal Energy Storage (TES) and Benefits
- Summary and Conclusions

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Introduction

- **CHP Systems**
  - Installed primarily to **use** electric and thermal energy on site
  - Generally < 50 MW
- **Cogeneration Systems**
  - Installed primarily to **sell** electric power to the grid and use or sell thermal energy
  - Generally >100 MW
- **TIC and TES Allows Optimal Use of Cogeneration and CHP Systems**
  - Improves energy efficiency and economics
  - Reduces emissions

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One Unfortunate Characteristic of Cogeneration and CHP Systems that Use Combustion Turbines: Performance Deteriorates (Relative to Rated Characteristics) in Hot Weather

- Power Generation Capacity Decreases as much as 35%
- Energy Efficiency Decreases as much as 10%
- Thermal Energy in CT Exhaust Gases Decrease as much as 10%

Hot Weather (Summer) Reduces U.S. Power Generation Capacity by Over 31,000 MW

Fuel	Winter Capacity, MW	Summer Capacity, MW	Capacity Loss in Summer, MW
Coal	316,363	314,294	2,069
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 2009 Database

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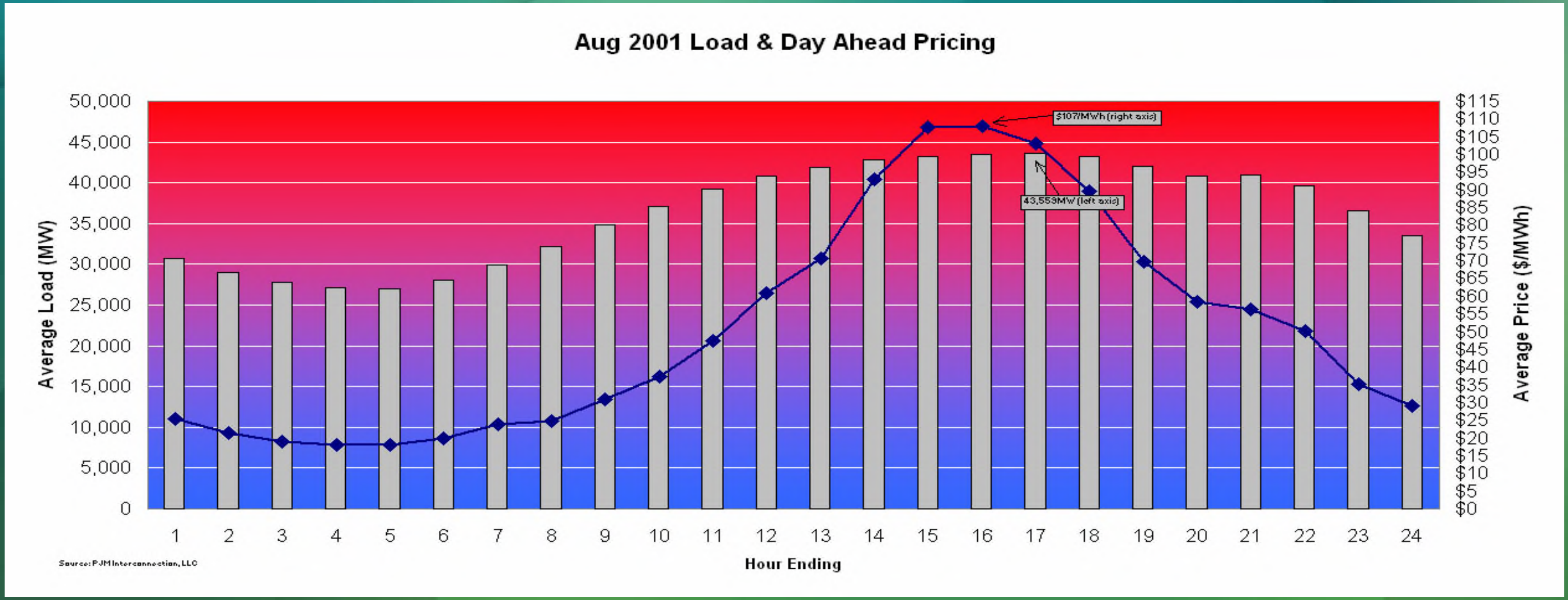
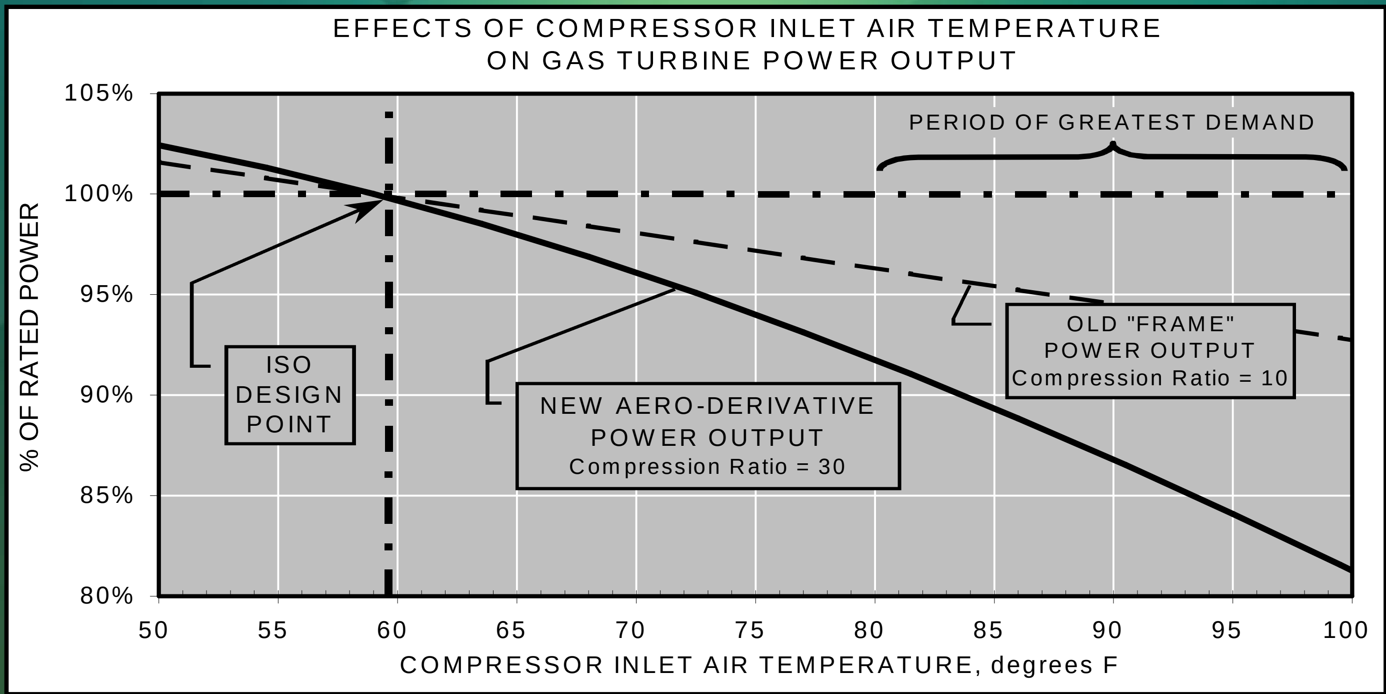
Power Demand and Electric Energy Price Rise with Hot Weather



- Market price of electric energy goes up during the peak demand period: as much as 4 times the value during the off-peak periods in this example.

CT Generation Capacity Decreases with Increase in Ambient Temperature

(CTs Rated at 59ºF, 60% RH at Sea Level; Temperature Impact Depends on the CT Design)



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

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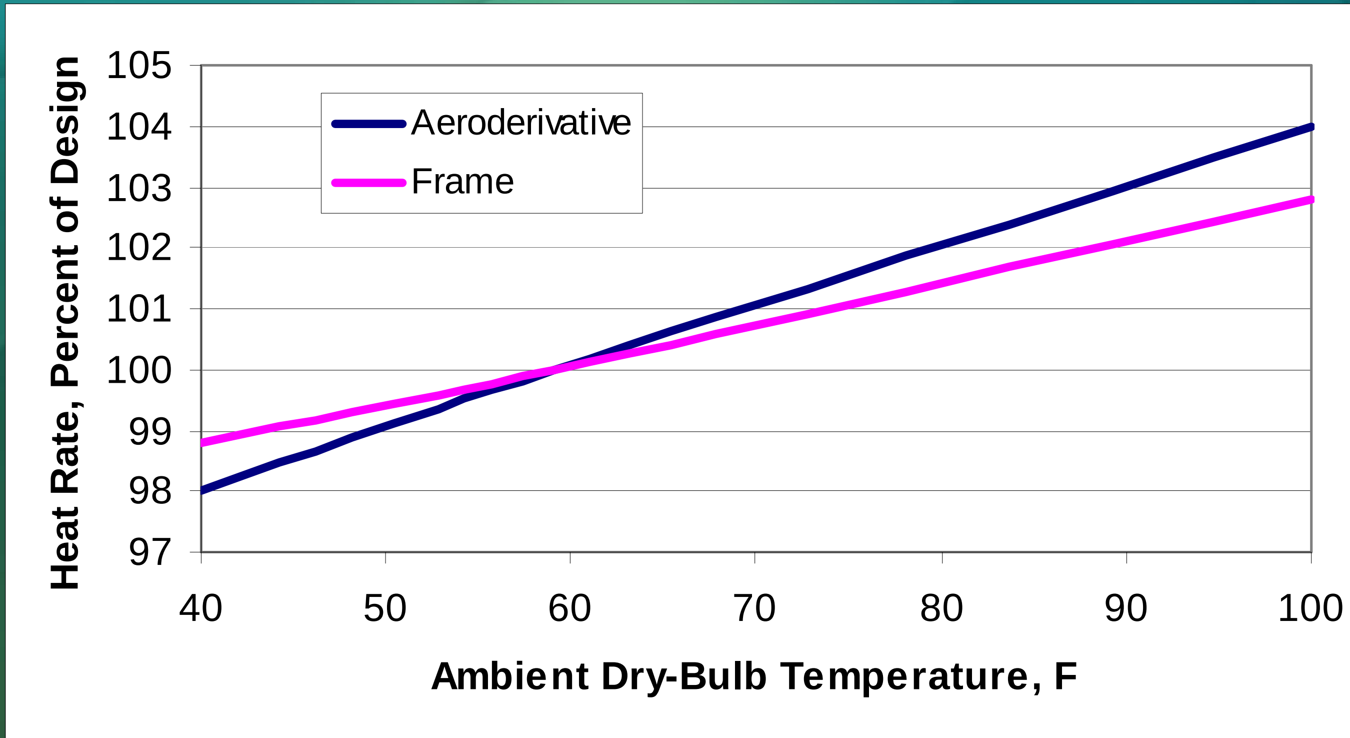
Increase in Ambient Temperature Increases Heat Rate (Btu/kWh)



Up to 4% loss in Energy Efficiency

Increase in Heat Rate Increase Fuel Consumption and Cost for Power Generation

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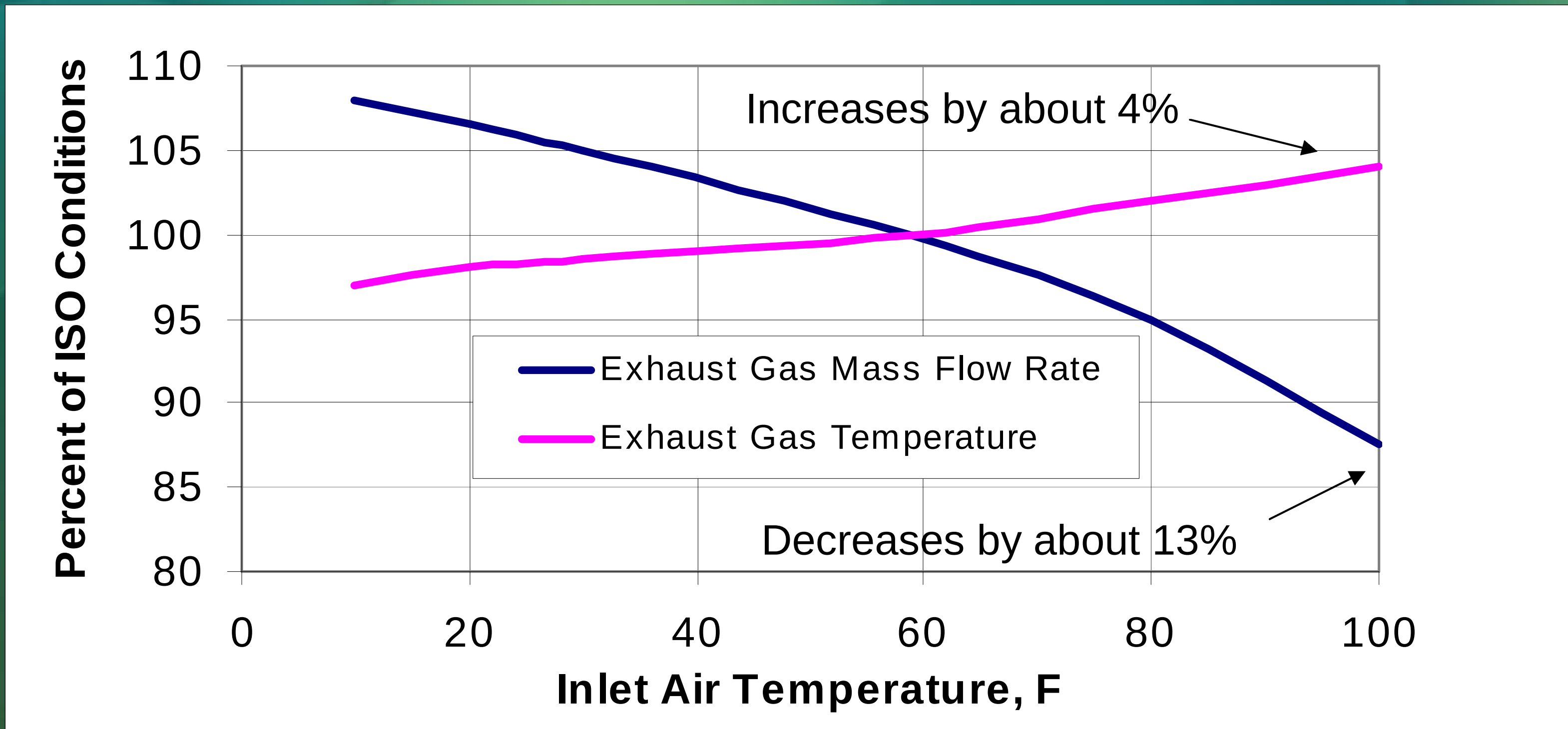
Increase in Ambient Air Temperature Leads to Reduced Thermal Energy in the CT Exhaust Gases

(Because of decreased mass flow rate of exhaust gases, even though its temperature is slightly higher)



Source: Punwani, D.V. and Andrepont, J.S., *POWER-GEN International 2005*

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Economic and Environmental Effects of Hot Weather on CT-Based Cogen and CHP Systems

- **Reduced Electric Power Output**
  - Increased cost of buying grid power at premium price for CHP users
  - Reduced revenue for the seller of power
- **Reduced Energy Efficiency**
  - Increased fuel cost, $/kWh
  - Increased environmental emissions, lb/kWh
- **Reduced Thermal Energy in Combustion Turbine Exhaust**
  - Reduced thermal energy available for heating, cooling or dehumidification, Btu/h
  - Increased fuel cost for meeting thermal energy needs
  - Reduced revenue for the seller of thermal energy

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Carbon Footprint (lbs/MWh) for Power Generation is 5 to 83% Higher than Average During Non-Baseload Period

(Because of the need to use lower-efficiency peaking power plants during peak demand period)

State	Average	Non-Baseload
Illinois	1,200	2,200
Indiana	2,100	2,200
Iowa	1,900	2,400
Michigan	1,400	2,000
Minnesota	1,500	2,000
Ohio	1,800	2,000
Wisconsin	1,700	2,100

Source: John Kelly Presentation at the MCA Meeting, March 13, 2008

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Carbon Footprint of Fuel Use* is the Lowest for Cogen/CHP Systems

System	Carbon Footprint
Cogeneration/CHP	Smallest
CT in Combined-Cycle	
CT in Simple-Cycle	
Steam-Turbine	Largest**

* Total fuel used for generating electric and thermal energy

** Old plants used primarily for peak shaving

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TIC Reduces Need for Operating Less Efficient or Building New Power Plants

- TIC in combined-cycle (CC) systems reduces the need to operate simple-cycle (SC) systems

  - Example: TIC for a 500 MW CC plant eliminates the need for operating or building a new 40-50 MW SC peaking plant; Also eliminates higher emissions of SC compared to those from CC

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TIC Benefits

- Reduced detrimental impacts of hot weather on CT system performance
- Reduced CHP user costs for buying grid power and fuel
- Increased revenues for the seller of power and thermal energy
- Reduced grid-wide emissions by minimizing the need to operate lower-efficiency peaking power generation systems
- Reduced need to site and build new power plants

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Midwest Ambient Temperature Characteristics

- Annual Number of Hours Temperatures in the Midwest are over 59ºF

  Range from over 2,500 to 3,800

State	Capital	Annual Hours > 59ºF
Illinois	Springfiled	3,867
Indiana	Indianapolis	3,528
Iowa	Des Moine	3,597
Kansas	Topica	3,730
Michigan	Lansing	2,912
Minnesota	St Paul	2,836
Missouri	Columbia	3,932
Nebraska	Lincoln	3,621
North Dakota	Bismark	2,511
Ohio	Columbus	3,565
South Dakota	Pierre	3,045
Wisconsin	Madison	2,876

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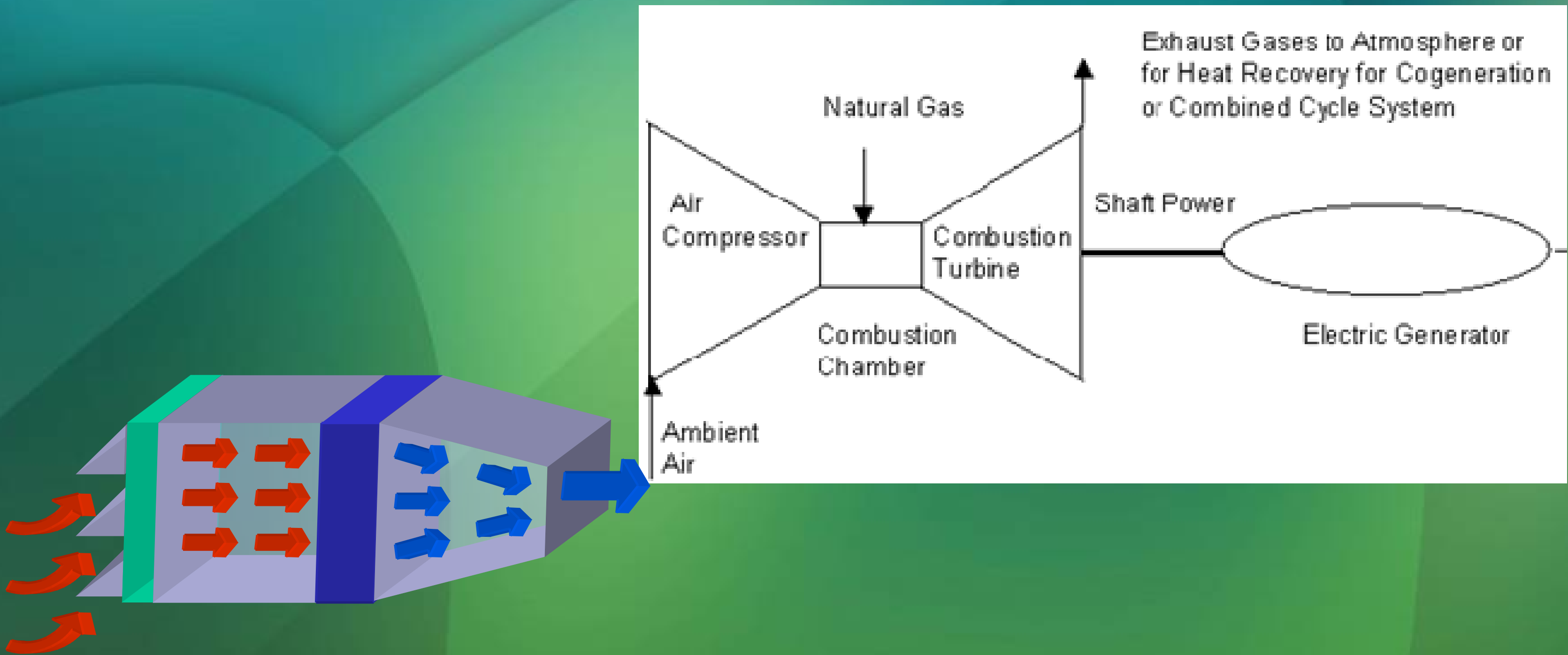
Turbine Inlet Cooling



- Cooling the inlet air before or during compression in the compressor

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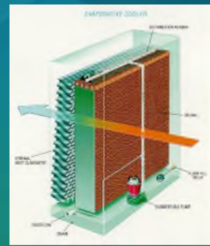
TIC Technologies



- **Direct Evaporation**
  - Wetted Media, Fogging
- **Indirect Evaporation**

- **Chilled Fluid using mechanical or absorption chillers**
  - Indirect or Direct Heat Exchange

- **Thermal Energy Storage (TES)**
  - Chilled Fluid or Ice

- **Hybrid**
  - Some combination of two or more cooling technologies
- **LNG Vaporization**
- **Wet Compression**

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TIC Technology Characteristics

- Sensitivity of degrees of cooling to the ambient humidity
- Power requirement
- Water quality and flow rate requirements
- Pressure drop
- Capital and O&M costs

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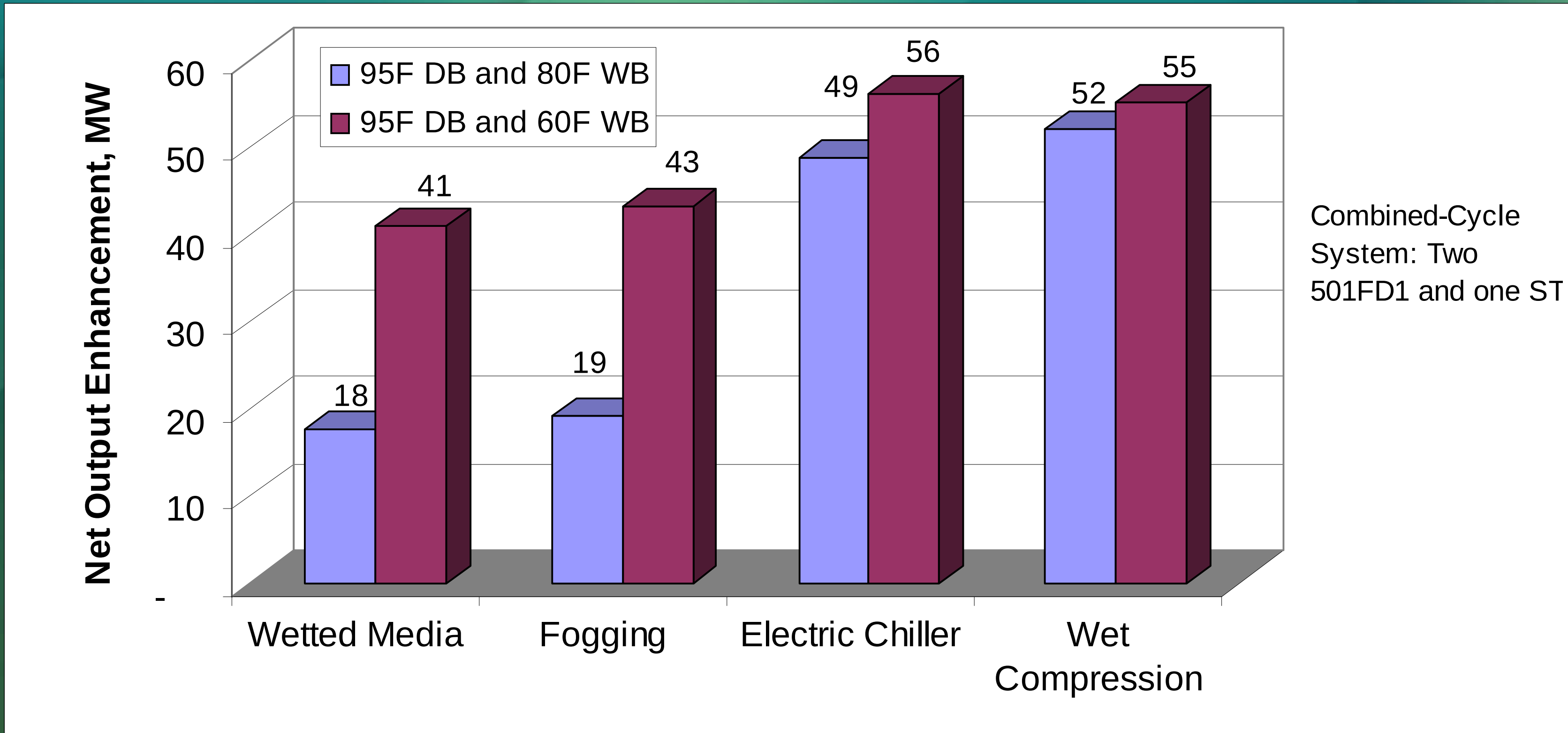
TIC Technologies

- All technologies have their pros and cons
- No one technology is best for all applications
- Each technology has commercial applications

Effect of TIC Technology and Ambient Humidity on Net Capacity Enhancement



Source: White Paper of the Turbine Inlet Cooling Association (2009)

Example of Comparative Performances of TIC Technologies in the Midwest (Illinois)

Location: Springfield, IL; 93.4^{o}F DB and 46% RH (ASHRAE 0.4% Ambient)

GT: 7.0 MW ISO Capacity; 0.5% Change in Capacity Per ^{o}F;

15,000 lb/hr/MW Inlet Air Flow Rate

	Inlet Air Temperature, ^{o}F	Gas Turbine Capacity, MW	Capacity Gain by TIC , % of No TIC
No TIC	93.4	5.8	NA
Wetted Media	77.8	6.3	10
Fogging	77.0	6.4	10
Electric Chiller	50.0	7.1	22

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TIC Calculator

Available on the Website of TICA:

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

For Preliminary Comparative Estimates of Capacity Enhancement, and Fuel and Water Needs by Three TIC Technologies:

Wetted-Media, Fogging and Chillers at a selected ambient air condition

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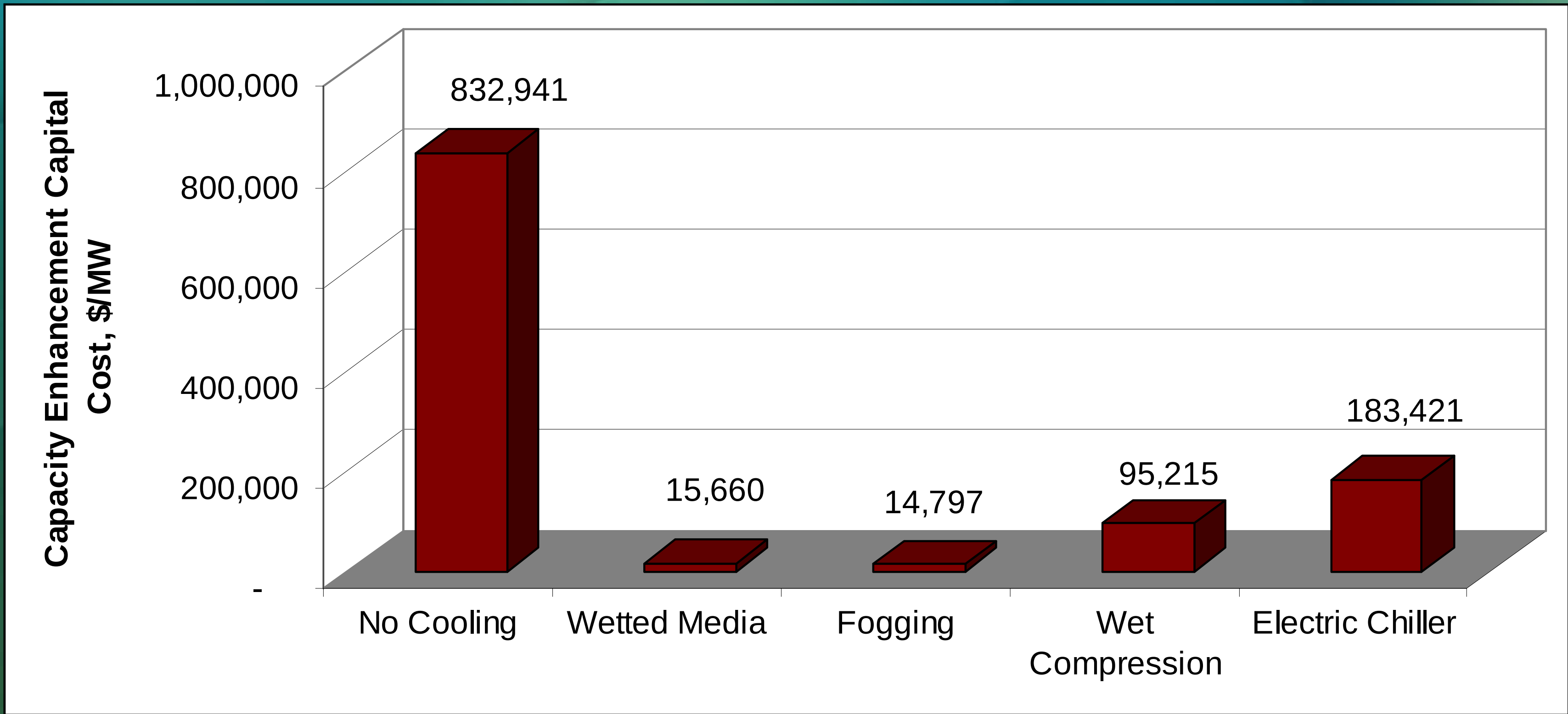
Effect of TIC Technology on Capital Cost for Incremental Capacity



317 MW Cogeneration System Snapshot at 95ºF DB and 80ºF WB

Source: White Paper of the Turbine Inlet Cooling Association (2009)

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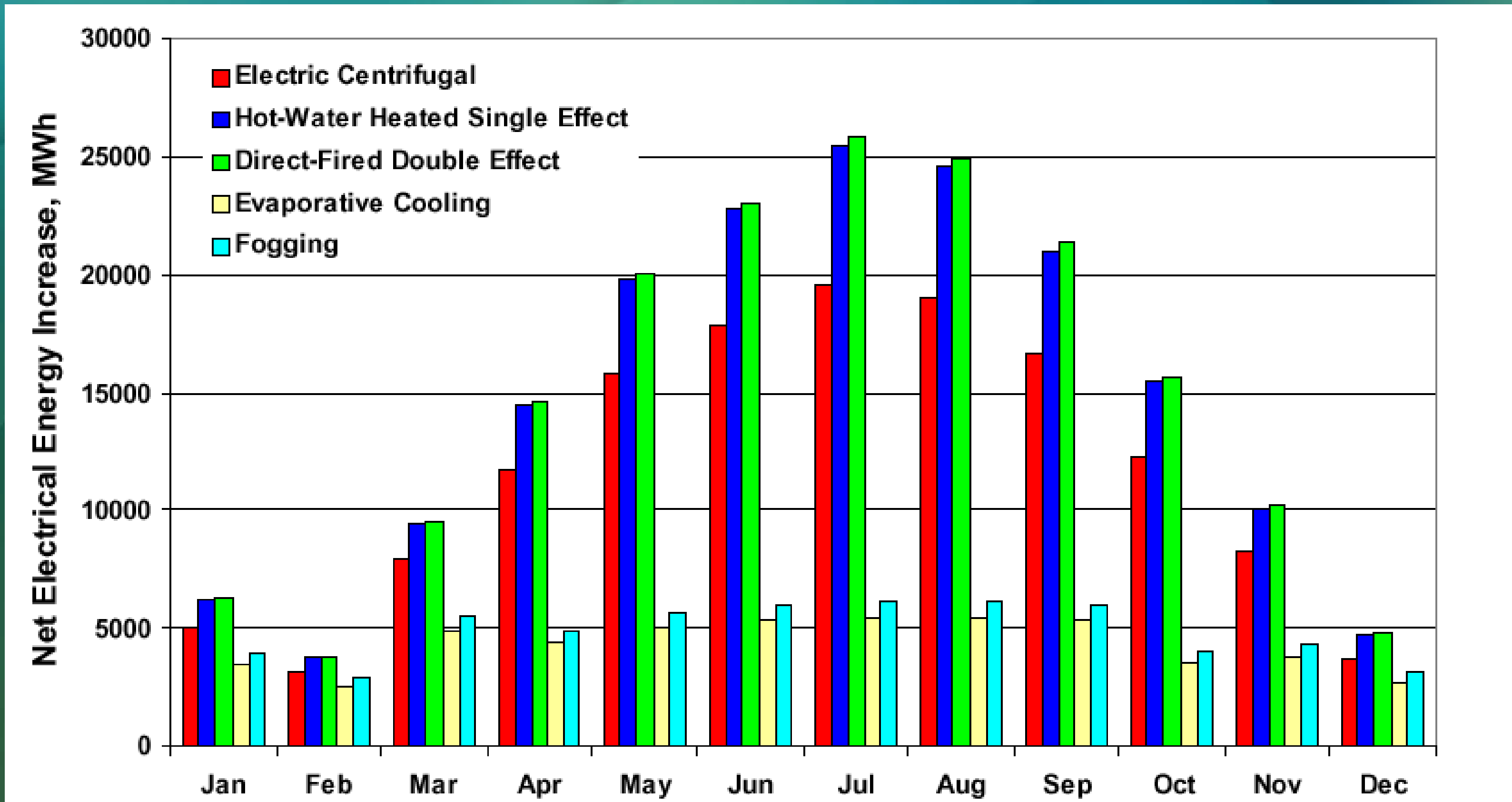
Evaluation of TIC Economics Requires an Estimate of Annual Net Increase in Electric Energy Production

(Requires Calculations for all 8,760 hours/year of weather data)



Increased Annual Net Electric Energy Generation Relative to No TIC

Source: Punwani *et al* ASHRAE Winter Meeting, January 2001

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Factors Affecting TIC System Economics

- Market value of additional power generation capacity and electric energy produced by TIC
- 8,760 hours/year weather data for the plant location
- TIC Technology
- CT model
- TIC system capital cost
- Cost of purchased fuel

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CHP Systems Using TIC

- **McCormick Place Exposition Center, Chicago, IL**
  3.3 MW (3 X 1.1 MW gas turbines) system
  uses indirect heat exchange with liquid ammonia
  from ammonia chillers

- **Caterpillar, Inc. Aurora, IL**
  15 MW (2 X 7.5 MW) system uses wetted-media
  direct evaporative cooling

- **A Food Processing Company, Bakersfield, CA**
  5 MW system uses hybrid cooling: Indirect + Direct evaporative
  Cooling

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Large Cogeneration Systems Using TIC

- **Calpine Clear Lake Cogeneration, Pasadena, TX**
  318 MW (3 x 106 MW) system uses six hot-water heated absorption chillers (8,300 Tons) in series with an electric chiller (1,200 Tons) and chilled water TES (107,000 Ton-hr)

- **Mulberry Cogeneration, Bartow, FL**
  127 MW (85 MW CT in Combined-Cycle) system uses 4,000-Ton ammonia chiller

- **Las Vegas Cogeneration, Las Vegas, NV**
  164 MW (4 X 41 MW) system uses hybrid cooling: fogging + absorption chiller

Calpine Clear Lake Cogeneration

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Resource for More Examples

Experience Database of the
Turbine Inlet Cooling Association (TICA):
http://www.turbineinletcooling.org/data/ticadatap.pdf

Shows information about hundreds of CT-based power plants already benefiting from TIC

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TES Need and Benefits for CHP Systems

- **Non-uniformity of Electric and Thermal Loads**
  - Often, electric and thermal loads on CHP system are not uniform 24x7
  - Electric and thermal loads are not in sync
  - Non-uniform loads adversely affect efficiency and economics

- **TES Systems**
  - Store excess thermal energy (from prime mover) during low demand and make it available during high demand

- **TES Benefits**
  - Minimizes waste of thermal energy
  - Improves overall system efficiency
  - Properly sized TES also improves system economics

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TES Technologies

- **Hot-Water Storage**

  - Stores sensible thermal energy

- **Chilled-Fluid Storage**
  - Directly stores sensible heat and indirectly stores electric energy as stored cooling

- **Ice Storage**
  - Directly stores latent heat and indirectly stores electric energy as stored cooling

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TES Economics

Factors Affecting the Economics

- Cost of purchased fuel
- Difference between the on-peak and off-peak charge for power demand and electric energy
- 24-hour “design day” thermal load profile
- Capital cost of the TES system

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TES Example

Princeton University, Princeton, NJ

- 40,000 Ton-hr Chilled-Fluid TES System
- 14.6 MW simple-cycle CT in CHP service
- TES serves Campus Cooling Network and TIC

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Summary & Conclusions

- TIC prevents De-rating of CT Power Capacity During Hot Weather, when Power is Most Needed and is Most Highly Valued
- TIC Costs Less for Providing Hot-Weather Capacity than a CT plant Without TIC
- TIC also Helps Reduce Emissions by Reducing or Eliminating the Need for Operating Lower-Efficiency Peaking Plants
- TES can improve the efficiency and economics of CHP systems with fluctuating thermal loads
- Multiple TIC & TES Technology Options are Commercially Available
- Each TIC & TES Technology has its Pros and Cons
- Thousands of plants are already successfully deploying TIC & TES

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For Questions or Follow-up

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