Impact of Turbine Inlet Cooling Technologies on Capacity Augmentation and Reduction in Carbon Footprint for Power Production

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Presentation Outline

- Electric Power Generation Carbon Footprint
- Turbine Inlet Cooling (TIC)
- TIC Benefits
- Impact of TIC on Reducing Carbon Footprint
- TIC Technologies
- Impact of TIC Technologies on Capacity Augmentation
- Conclusions

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Carbon Footprint for Electric Power Generation

- **Many organizations, including, power producers are trying to reduce the carbon footprint (reducing emissions of carbon dioxide) of their products**

- **Most of options for reducing the carbon footprint for power production come at a premium costs that ratepayers eventually end up paying**

- **TIC is an attractive option for reducing the carbon footprint as well as the cost of producing power**

Power Demand and Electric Energy Price Rise with Hot Weather

- Price of electric energy goes up significantly during the peak demand periods: as much as 6 times the price during the off-peak periods

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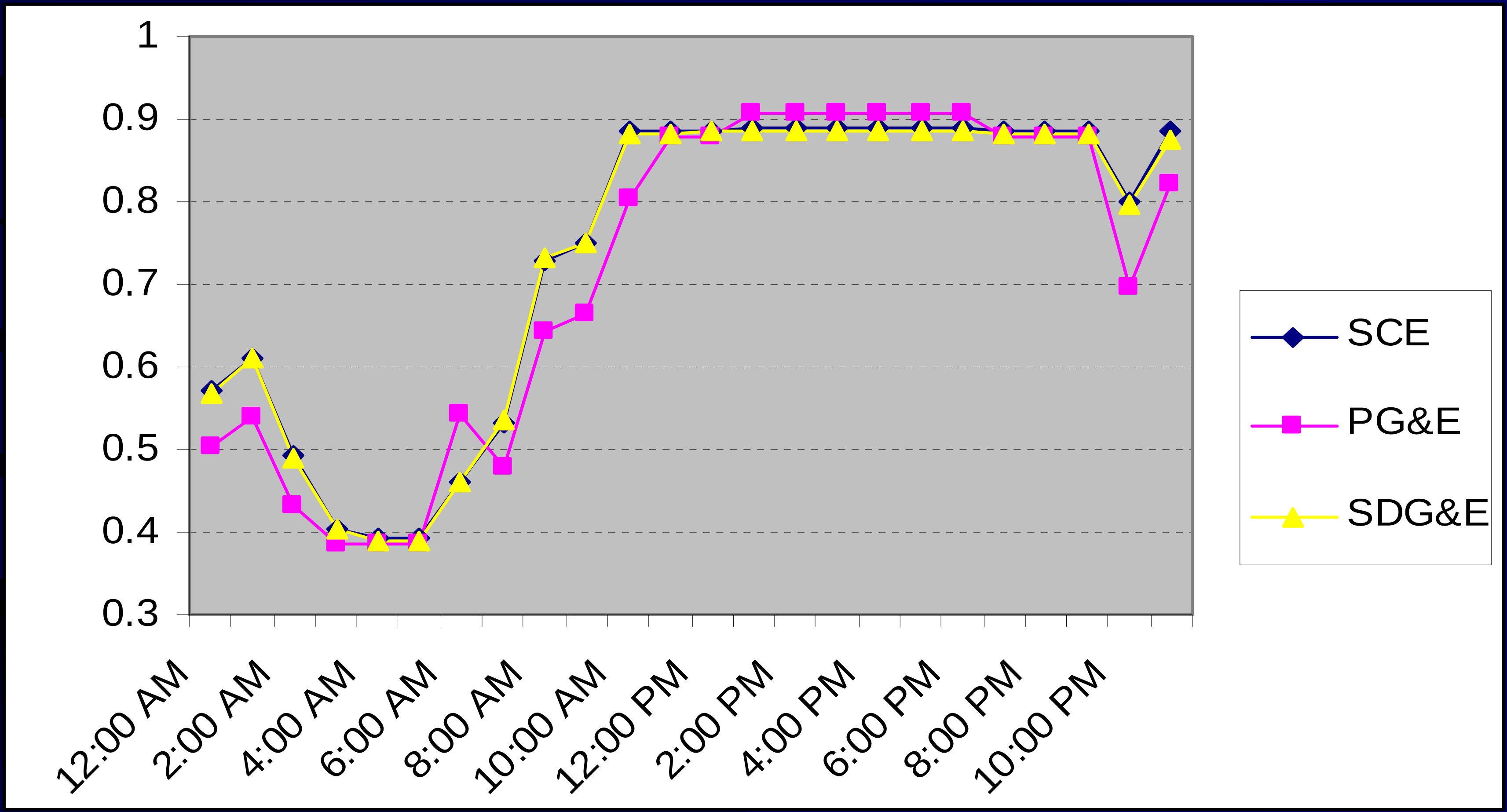
CO_2 Emissions (lbs/kWh) During Summer (California)



Y-Axis Unit: CO_2 Emissions, Lbs/kWh

Source: Scot Duncan Presentation at ASHRAE June 2007

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2004 EPA Carbon Factors, lbs/MWh

State	Average	Non-Baseload
Illinois	1,200	2,200
Indiana	2,100	2,200
Iowa	1,900	2,400
Michigan	1,500	2,000
Minnesota	1500	2,000
Ohio	1,800	2,000
Wisconsin	1,700	2,100

Source: John Kelly Presentation at the Midwest Cogeneration Association Meeting, March 13, 2008

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Power Generation Carbon Footprint

Power System	Heat Rate* (LHV), Btu/kWh	Carbon Footprint
CT in Combined-Cycle	6,500-7000	Lowest
CT in Simple-Cycle	8,000-10,000	
Steam Turbine	12,000-15,000	Highest

Carbon Footprints of Fossil Fuels

* Natural Gas: Lowest

Fuel Oil:

Coal (only applicable to steam turbines): Highest

CT-Based System Characteristic

Increase in Ambient Air Temperature Causes a Triple Whammy:

- **Reduces Power Output, MW**
- **Increases Heat Rate, Btu/MWh**
- **Reduces Thermal Energy in the CT Exhaust Gases, Btu/hr**

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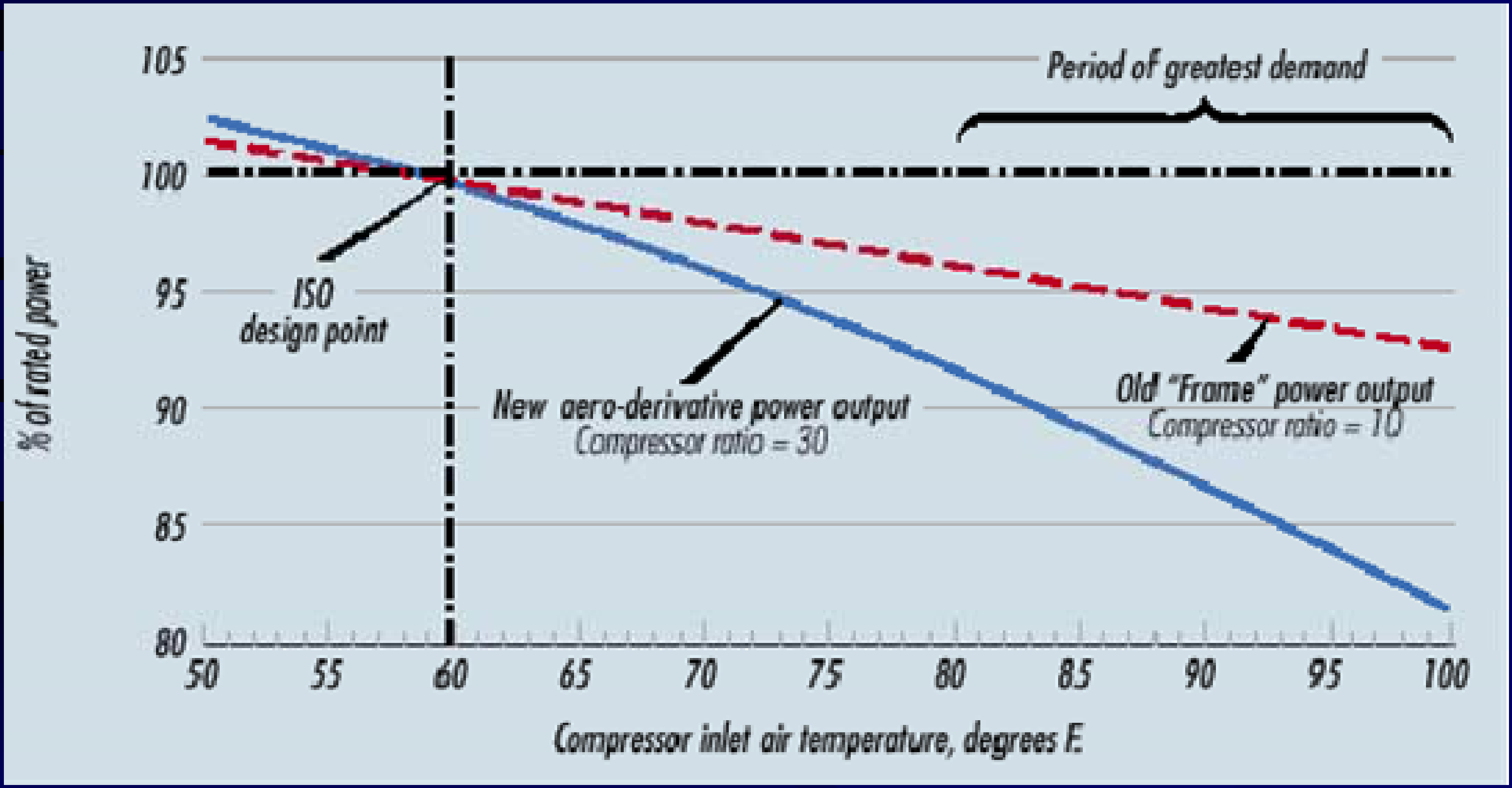
Effect of Inlet Air Temperature on CT Output Capacity

Increase in Inlet Air Temperature Decreases Power Output Capacity



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Reduced Summer Capacity of Combustion Turbine Power Plants is Well Recognized

Fuel	Winter Capacity, MW	Summer Capacity, MW	Lost Summer Capacity, % of Winter Capacity
Coal	315,556	313,380	1
Petroleum	61,171	58,548	9
Natural Gas	412,241	383,061	9

Source: U.S. Department of Energy's Energy Information Agency 2005 Database

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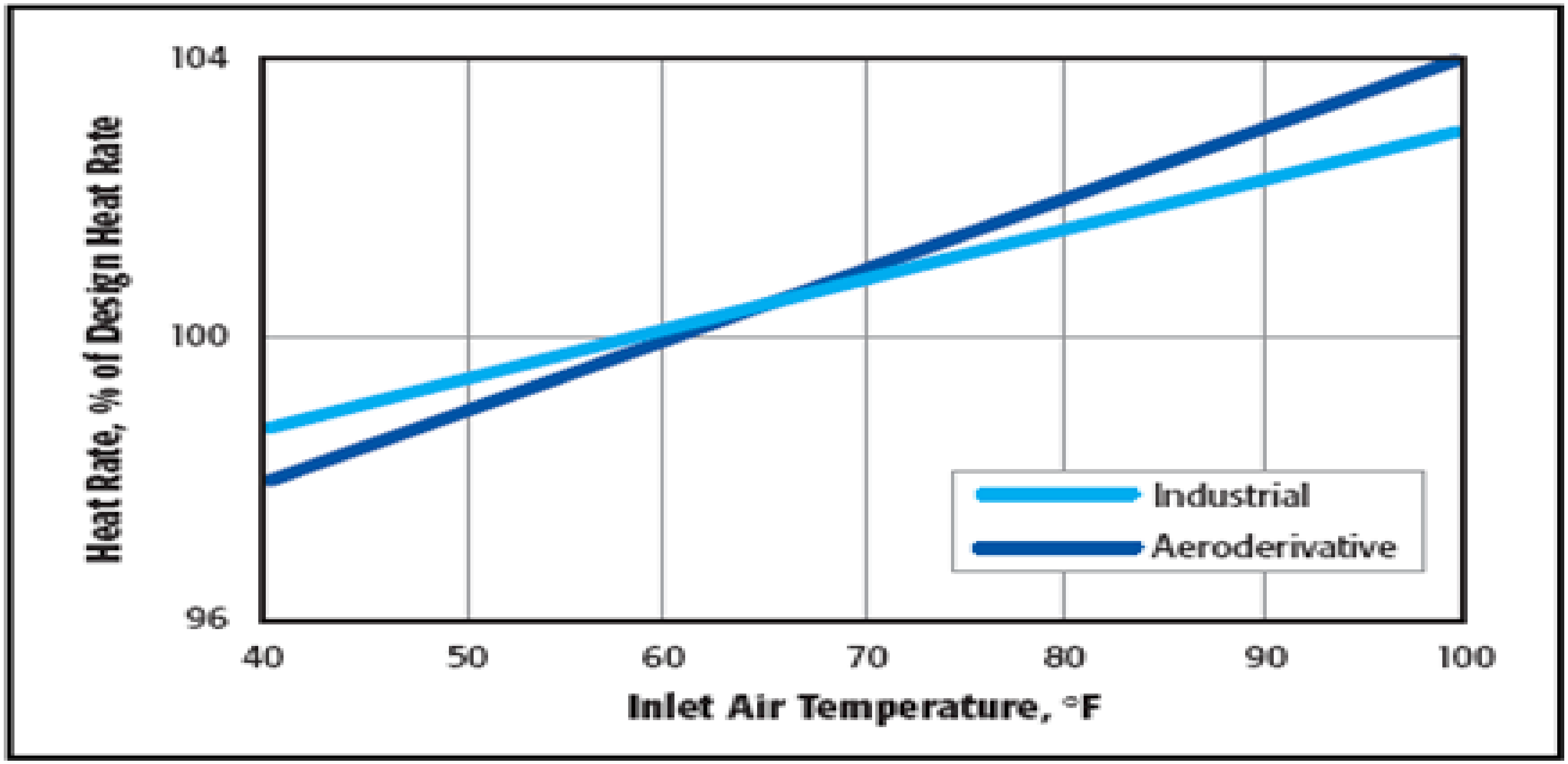
Effect of Inlet Air Temperature on CT Heat Rate

Increase in Inlet Air Temperature Increase Heat Rate



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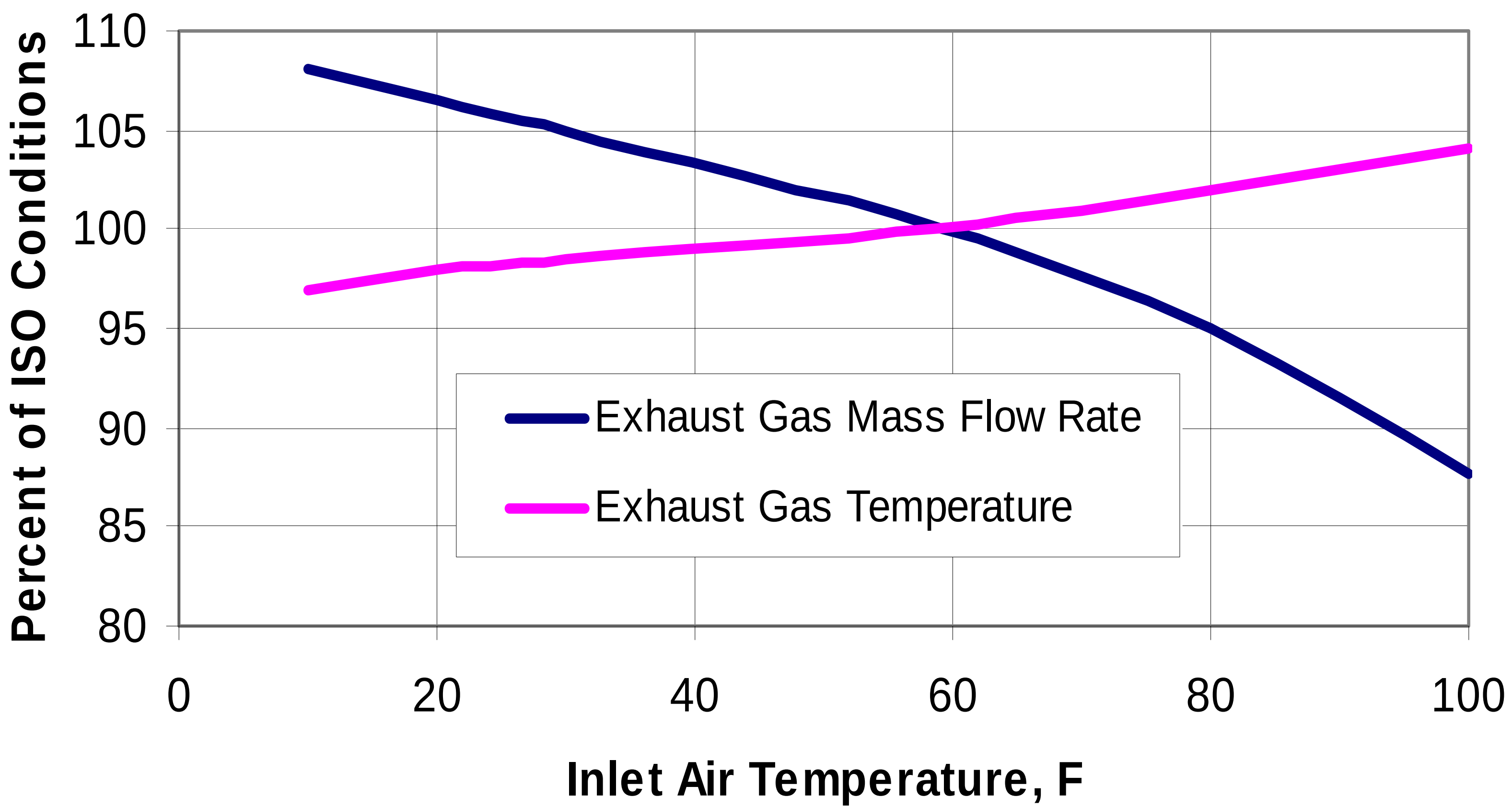
Effect of Inlet Air Temperature on CT Exhaust Gas Mass Flow and Temperature



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Why Cool to the turbine inlet air?

Overcome all three detrimental effects of increase in inlet air temperature on the CT performance:

1. Decrease in power generation capacity

2. Increase in Heat Rate

3. Decrease in enthalpy of the CT exhaust gases

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TIC Provides Two Types of Benefits

- Environmental
- Economic

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TIC Environmental Benefits

Reduced* Emissions of GHG and pollutants

- Displaced / eliminated operation* of less efficient and higher emission power plants
- Increased efficiency of fuel utilization

Reduced* Need for Siting New Generation Capacity

———————————————

* Equivalent to the capacity enhancement of CT-based power plants (Combined-Cycle and Simple-Cycle)

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TIC Economic Benefits

- Generates more electric energy and revenue during hot weather when power demand and electric energy value are high
- Reduces capital cost per unit of the increased generation capacity compared to new uncooled power plants
- Reduces cost of electric energy generation compared to the less energy efficiency "peakers"

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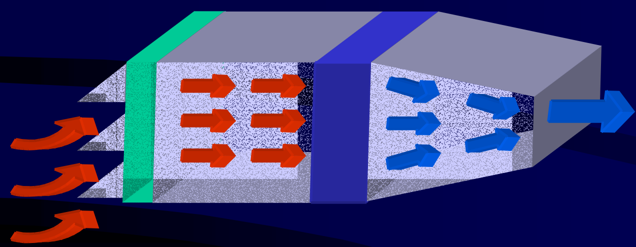
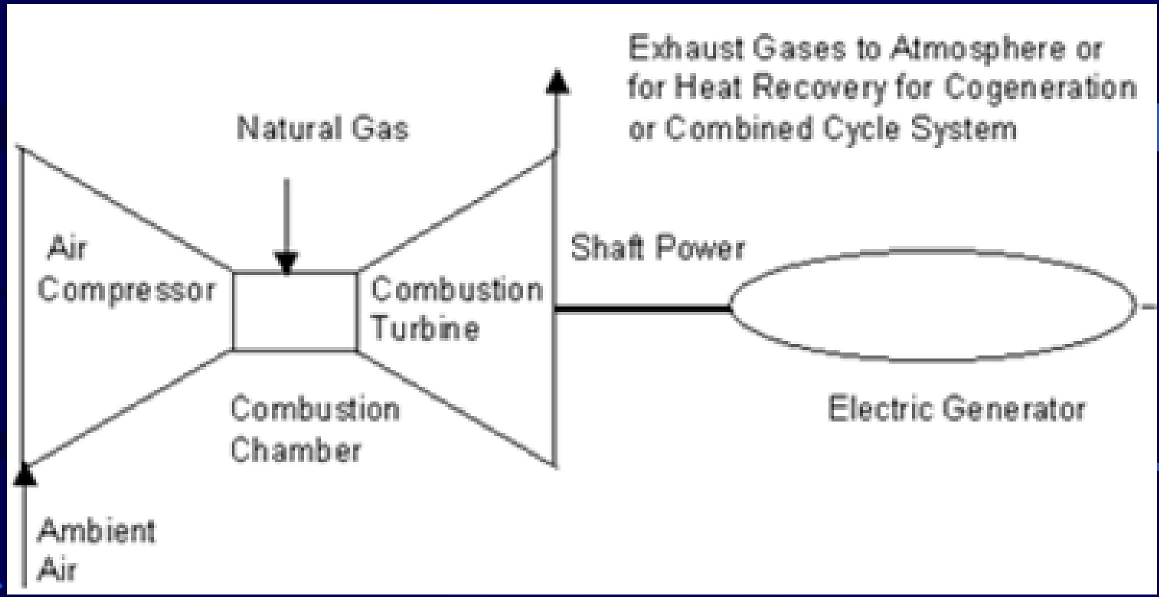
Turbine Inlet Cooling (TIC)





- Cooling the inlet air to the compressor that supplies the high-pressure compressed air to the combustor of a combustion turbine

Disadvantages of TIC

- Permanent higher CT inlet pressure drop
- Magnitude of inlet pressure drop varies with the cooling technology:

  0.1 to 1.0 WC

- Increased inlet pressure drop results in small drop in CT output capacity even when inlet cooling is not being used:(~0.025 to 0.25% of the CT Output)
- Additional maintenance cost of the cooling equipment

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TIC Technologies

- Evaporative Systems
- Chiller Systems
- LNG Vaporization System
- Hybrid Systems

TIC Technologies

Evaporative Systems

- Direct Evaporative Cooling
- Indirect Evaporative Cooling

TIC Technologies

Direct Evaporative Cooling

- Cooling is produced by evaporation of the water added to the inlet air

- Most used TIC technology option

- Its limitation: Cannot cool the air to below the ambient wet-bulb temperature and therefore, its effectiveness decreases as the ambient relative humidity goes up

- Generation capacity of the CT varies with the ambient temperatures

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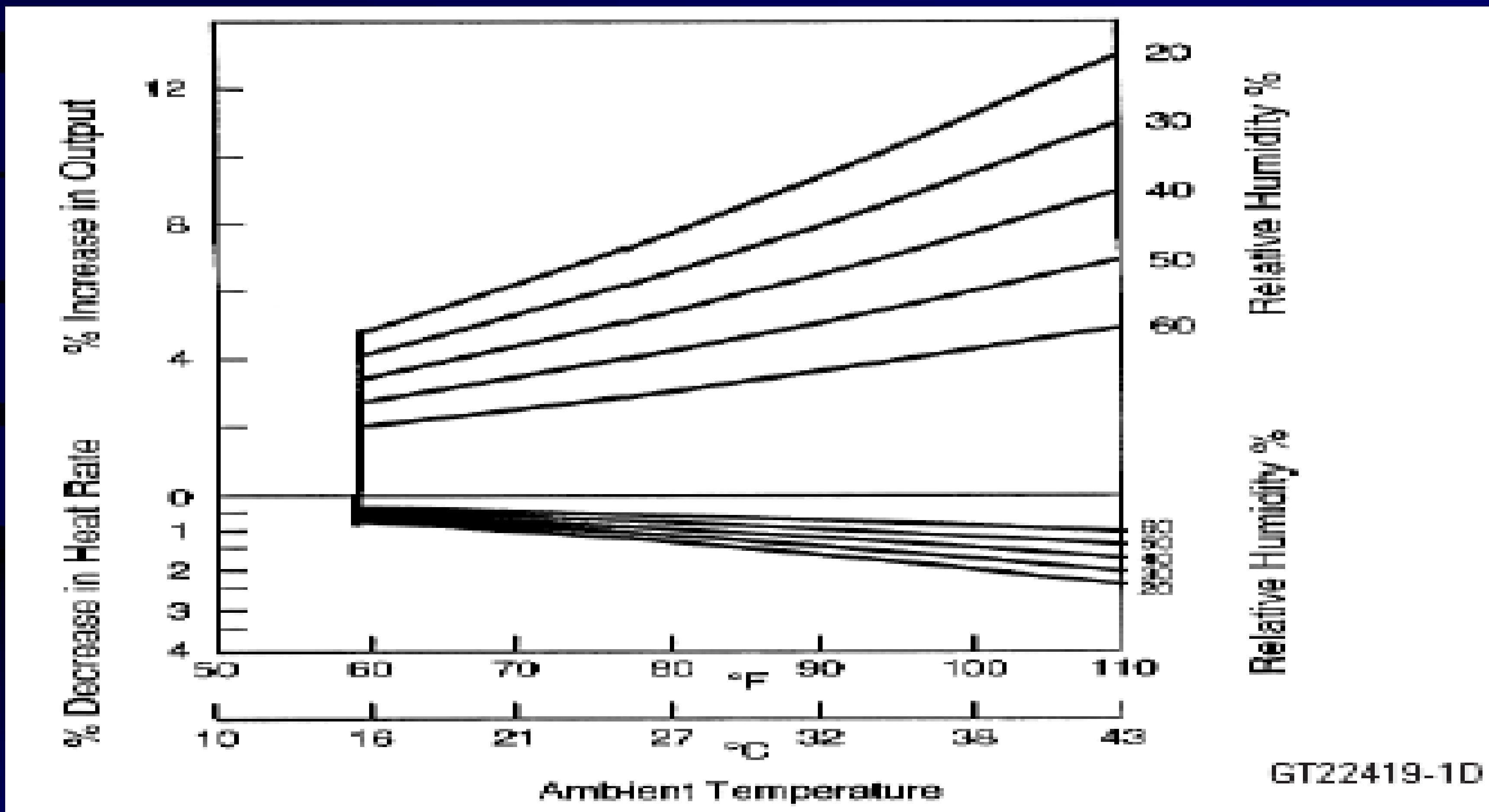
TIC Technologies

Direct Evaporative Cooling



Source: GE Power Systems

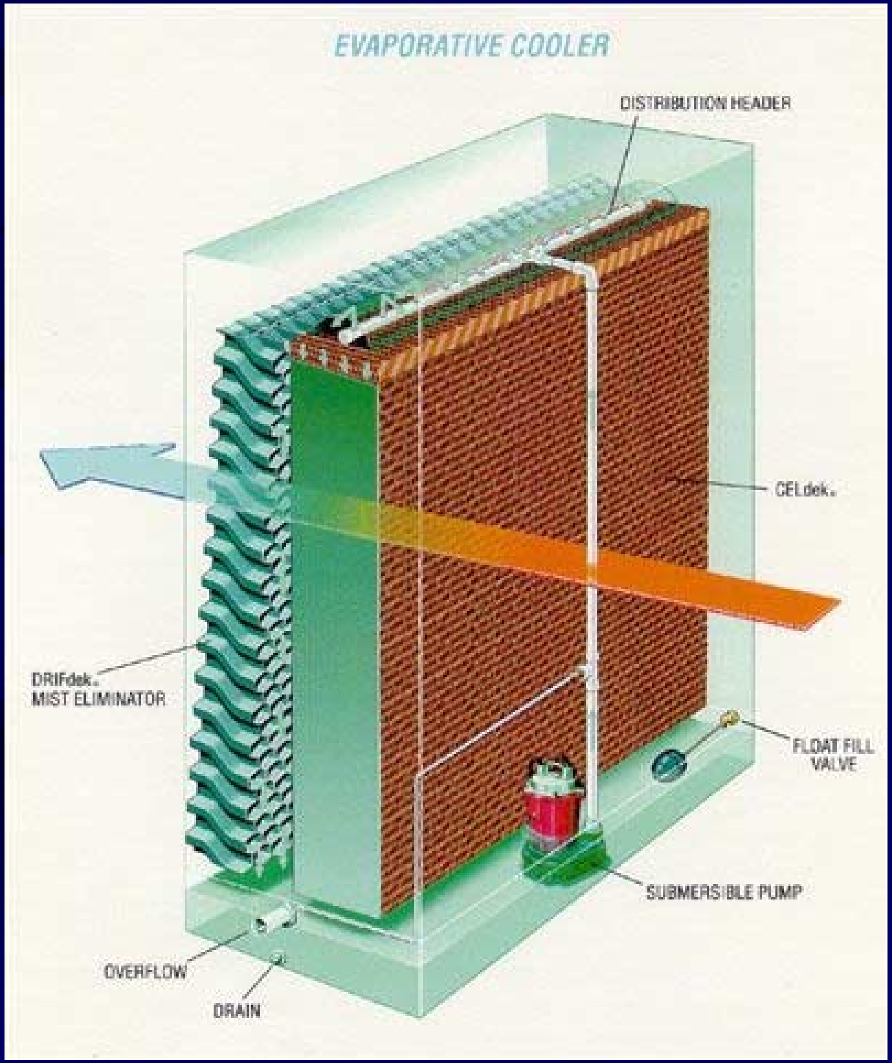
TIC Technologies

Direct Evaporative Systems

- Wetted Media
- Fogging

TIC Technologies

Wetted Media Systems



Source: Munters Corporation

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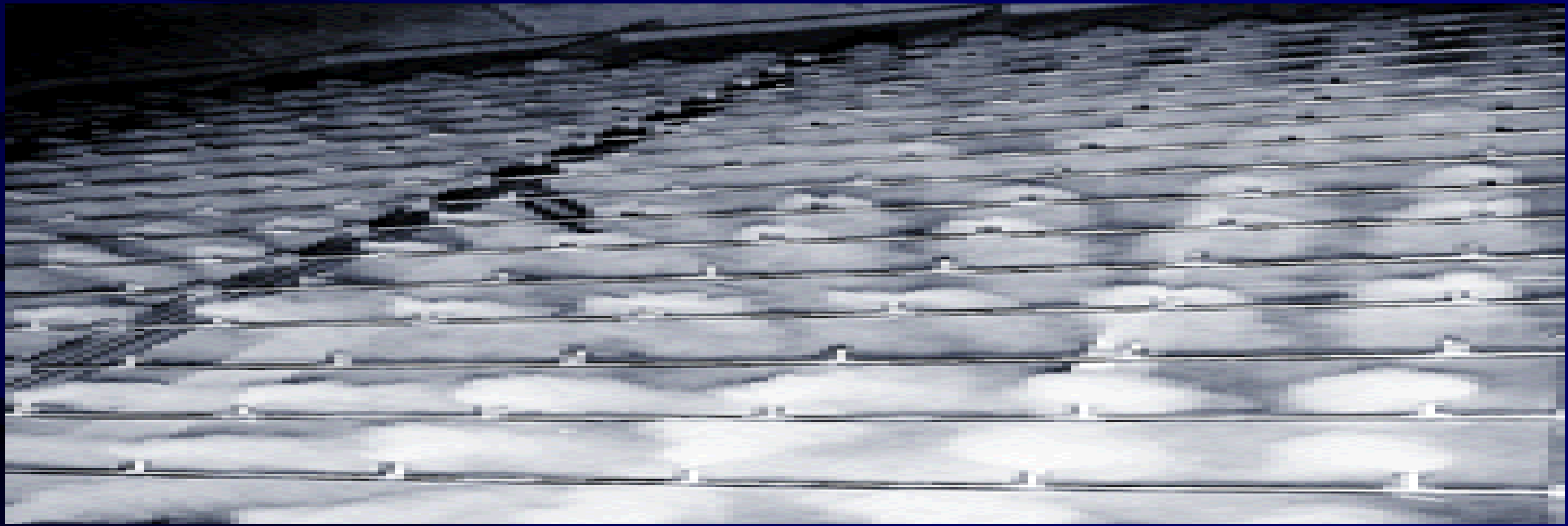
Fogging Systems



TIC Technologies

Indirect Evaporative Cooling

- Cools the air to even below the wet-bulb temperature
- A couple of technology options are at various stages of development
- Not yet commercially proven

TIC Technologies

Chiller Systems

- Cool the air by exchanging heat through a cold fluid produced by a chiller
- Can cool the inlet air to any desired temperature to as low as 42F*
- Can maintain constant CT output irrespective of the ambient temperatures

* Any lower temperature may result in ice formation downstream of the compressor bell-mouth in which up 10F temperature drop may occur.

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TIC Technologies

Chiller System

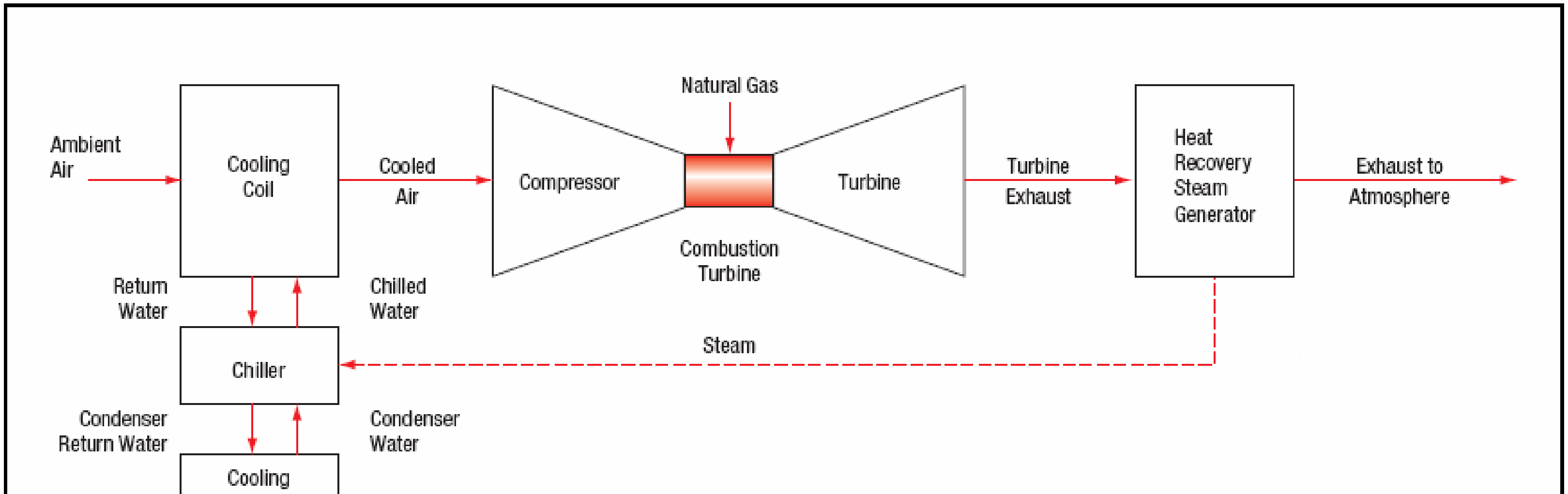

Figure 1: Schematic Flow Diagram for a Combustion Turbine Plant Using Chillers for TIC

Figure Correction: There should be a stream for steam leaving the HRSG for use in steam turbine or other heat applications

Source: Punwani, D.V. Energy-Tech, June 2004

TIC Technologies

Chiller Systems

- Many types of chillers are applicable and commercially used:

  MECHANICAL: MECHANICAL: Electric-, Steam-Turbine or Engine-Driven

  ABSORPTION: Aqua-Ammonia or Lithium Bromide-Water

- With or without thermal energy storage (TES)

TIC Technologies

Chiller Systems

Indirect Heat Exchange

- Heat exchange between the chilled fluid and the inlet air is through a cooling coil

Direct Heat Exchange

- Heat exchange between the chilled water and the inlet air is by direct contact between the two streams

TIC Technologies

Direct Heat Exchange With Chilled Water

- Uses chilled water over wetted media, instead of ambient temperature water used for evaporative cooling
- Allows the flexibility of using water without or with chilling
- Removes particulate and dissolved gases from the inlet air just as in direct evaporative systems
- Use substantially more wetted media and thus, higher pressure drop than that for wetted-media evaporative cooling
- One commercial plant (Three GE Frame 6B) in Australia has been using it since 1998

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TIC Technologies

Chillers with Thermal Energy Storage (TES)

- Increase power output capacity and revenues during on-peak periods
- Desirable if TIC is needed only during a small number of hours per day
- Incorporate tank (s) that store chilled water or ice which is produced chillers or refrigeration systems during off-peak period
- TES can reduce total TIC system capital cost by reducing the chiller capacity required to achieve the same instantaneous on-peak cooling demand
- Disadvantage: Need bigger site footprint

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TIC Technologies

LNG Vaporization Systems

- Useful when power plant is located near a liquefied natural gas (LNG) import facility
- Heat needed for the vaporization of LNG can be derived from inlet air which gets cooled in the process
- Commercially used in a few power plants

TIC Technologies

Hybrid Systems

Indirect Heat Exchange Chilling (Stage 1 cooling) followed by Evaporative Cooling (Stage 2 Cooling)

- Cooling load is shared by the chiller and the evaporative cooling
- Advantage: Reduced electric parasitic load of chillers
- Disadvantage: Higher inlet air-side pressure drop and higher installed cost than that for the individual cooling options
- At least one commercial plant operating in the U.S.

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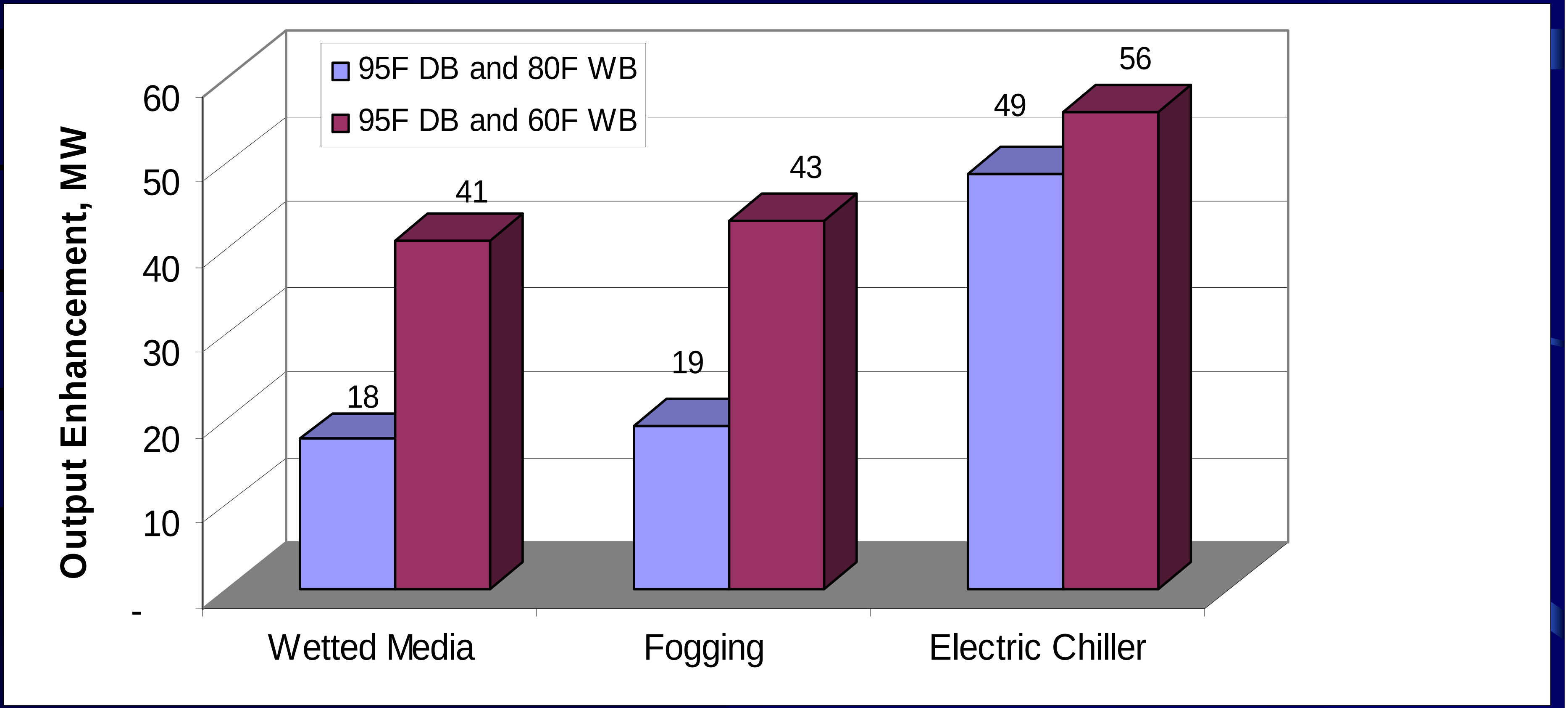
Effect of TIC Technology on Net Capacity Enhancement



For a nominal 500 MW Combined-Cycle System

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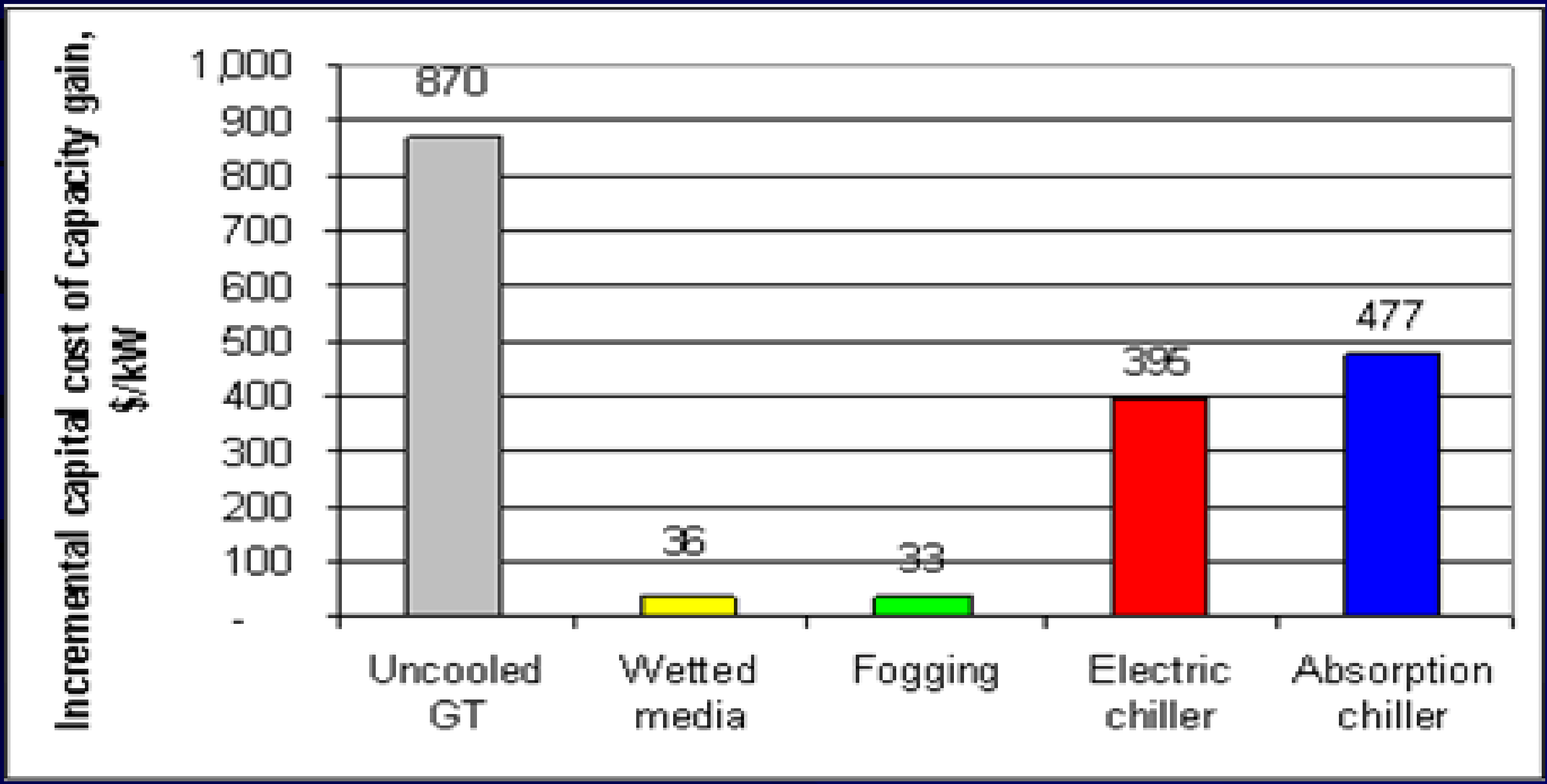
Effect of TIC Technology on Incremental Capital Cost for Capacity Enhancement

(317 MW Cogeneration Plant; 95F BD & 80F WB)



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

***Absorption chiller cost also includes the cost of the heat recovery equipment**

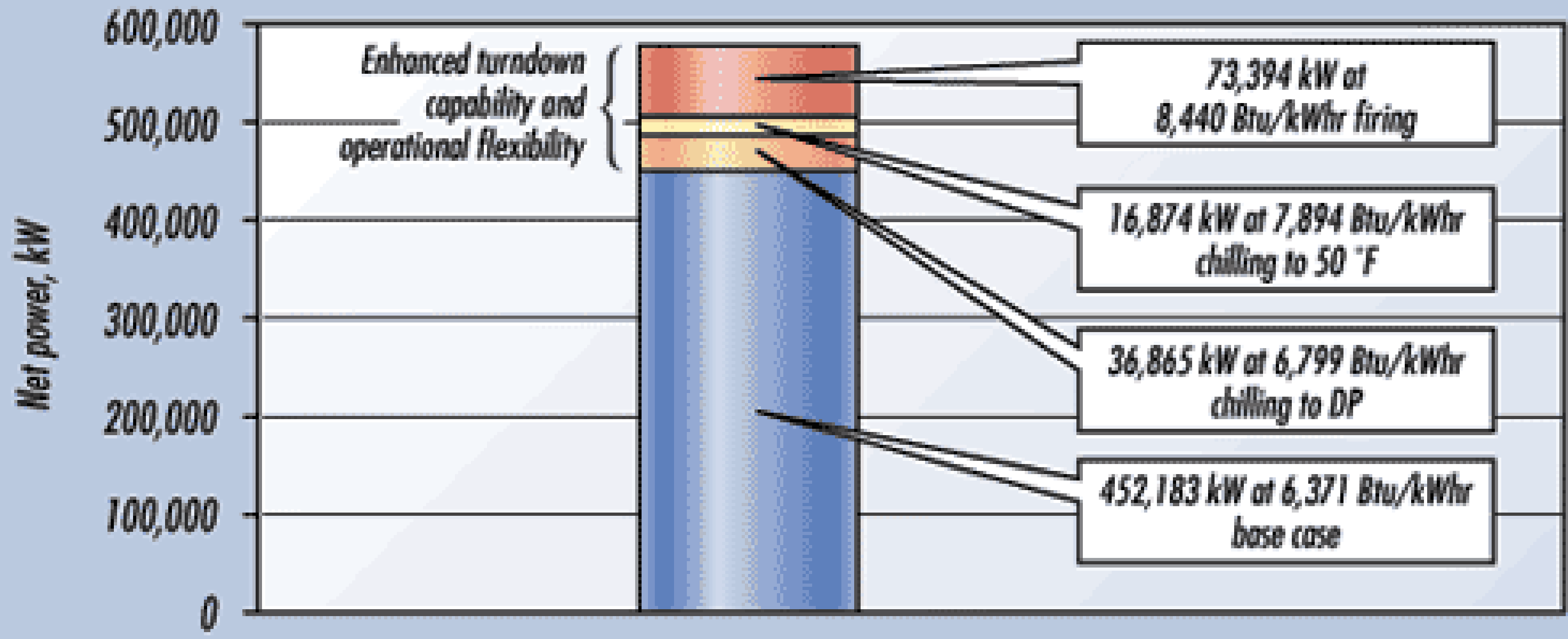
TIC Could also be Used in Combination with Other Power Augmentation Technologies

Such as:

- **Wet Compression**
- **STIG**
- **Duct-firing**

Preferred Dispatch Order for a Combined-Cycle System with TIC

FIGURE 3
PREFERRED DISPATCH ORDER FOR A TYPICAL COMBINED-CYCLE SYSTEM



Source: Punwani, D.V. and Hurlbert, C.M., *Power Engineering*, Feb. 2006

Conclusions

- TIC Reduces the Carbon Footprint for Power Generation for the Power Grid
- TIC Reduces the Fuel Cost of Power Generation for the Power Grid
- TIC Requires Less Investment for Increasing the Generation Capacity
- Therefore, TIC is Good for the Environment, Ratepayers and Plant Owners

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Regulatory Changes Deserving Consideration

- **Require retrofitting of TIC before permitting construction of new plants**
- **Exempt TIC from environmental re-permitting**
- **Calculate capacity payments for plant owners on the basis of systems incorporating TIC***
- **Allow Tradable Carbon Credits for TIC**

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* Consistent with the PJM affidavit made to the FERC in August 2005: http://pjm.com/documents/ferc/documents/2005/20050831-er05-___-part-5.pdf

PJM: PJM Interconnection, LLC

FERC: Federal Energy Regulatory Commission

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Any Questions?

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