Technologies and Economics of Turbine Inlet Cooling Application in Cogeneration

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Presentation Outline

- Introduction
- Effects of Ambient Air Temperature on the Performance of Combustion Turbines
- What is Turbine Inlet Cooling (TIC)?
- Benefits of TIC
- TIC Technologies
- Economics of TIC Applications in Cogeneration
- TIC Applications in Cogeneration
- Conclusions

Power Demand and Electric Energy Price Rise with Hot Weather

Price of electric energy goes up during the peak demand periods: as much as 4 times that during the off-peak periods

Source: G.R. Hilberg, *POWER-GEN Asia 2006*

2004 EPA Carbon Factors, lbs/MWh

Carbon Footprints for Power Generation are High During Non-Baseload Periods

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 MCA Meeting, March 13, 2008

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Carbon Footprint Reduction Efforts

- Many organizations, including power producers, are trying various options for reducing the carbon footprint

- Most such options come at premium prices, which ratepayers eventually pay.

Power Generation 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

CT-Based Characteristic

Increase in Ambient Air Temperature Causes a Triple Whammy:

- **Reduces Power Output**
- **Increases Heat Rate**
- **Reduces Thermal Energy in the CT Exhaust Gases**

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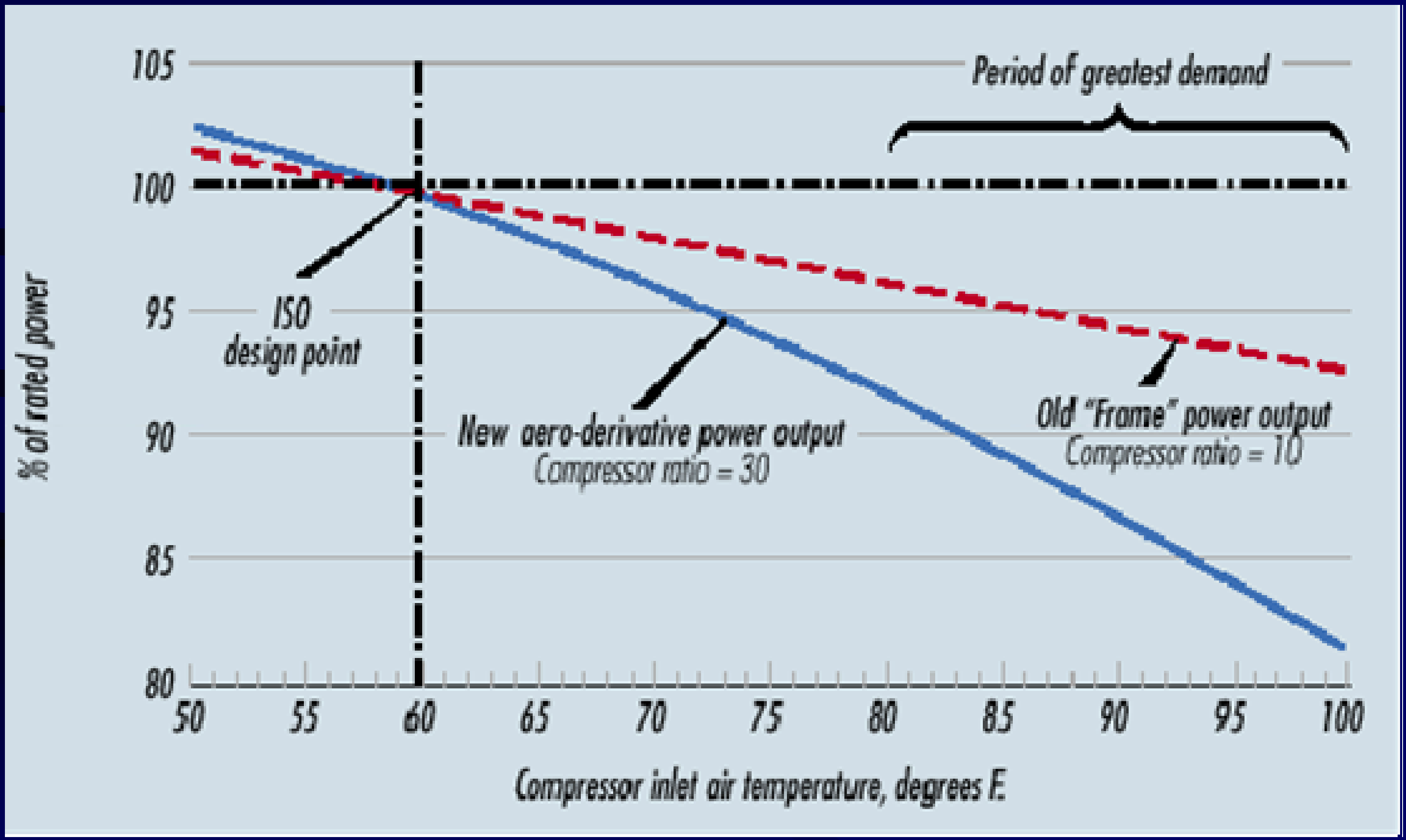
Effect of Inlet Air Temperature on CT Output

Increase in Inlet Air Temperature Decreases Power Output



Source: Punwani, D.V. and Hurlbert, C. M., *Power Engineering*, Nov. 2005

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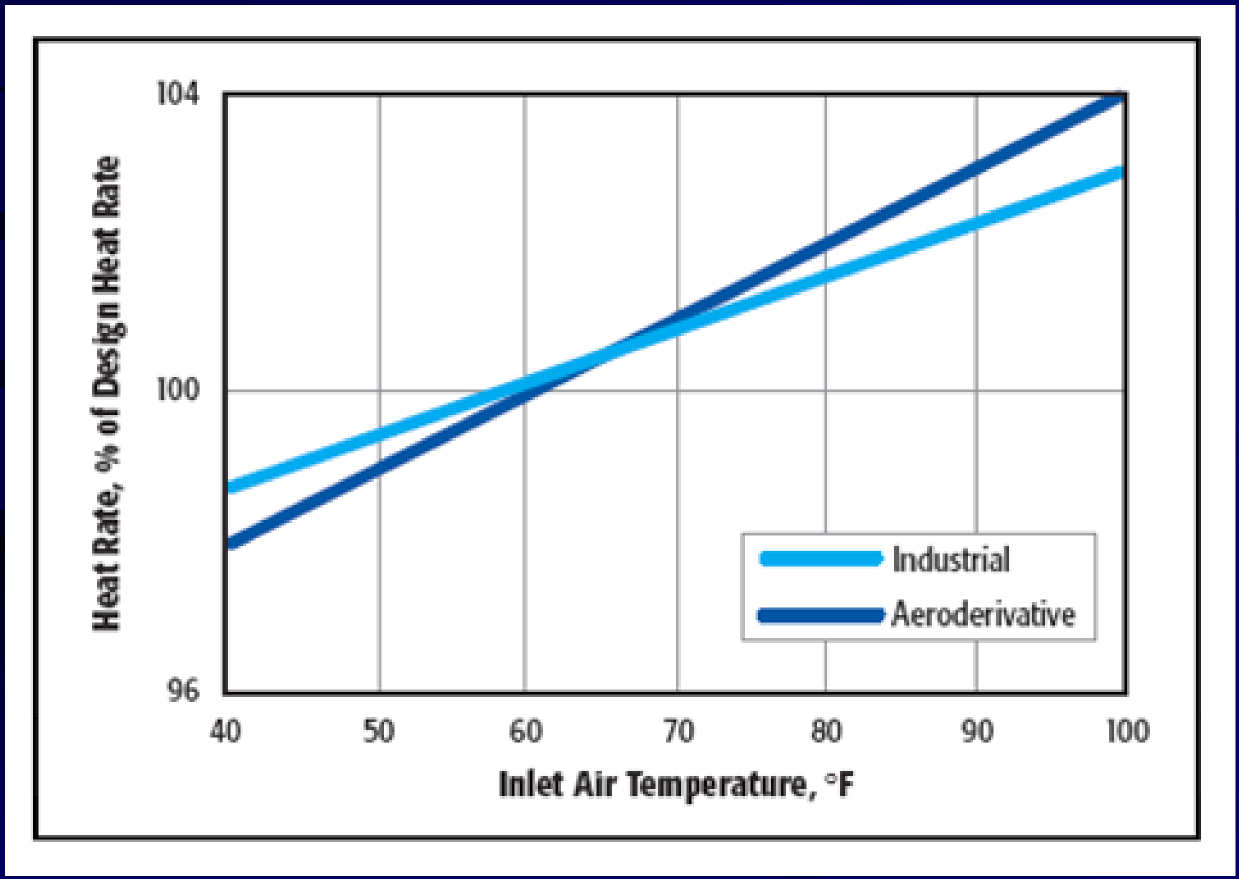
Effect of Inlet Air Temperature on CT Heat Rate

Increase in Inlet Air Temperature Increases Heat Rate (i.e. Decreases Energy Efficiency and Increases Emissions)



Source: D.V. Punwani, *Energy-Tech*, December 2003

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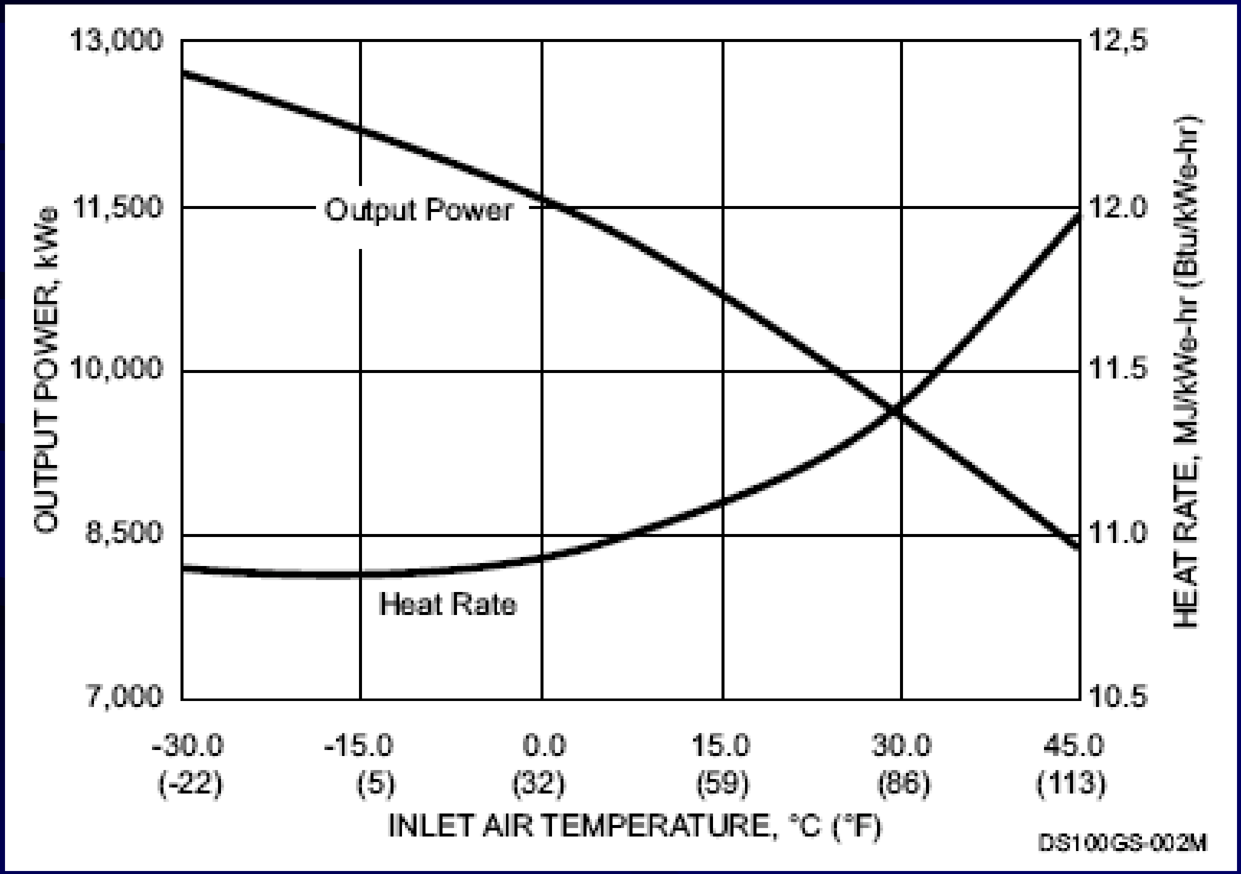
Effect of Inlet Air Temperature on CT Output (Small Turbines)

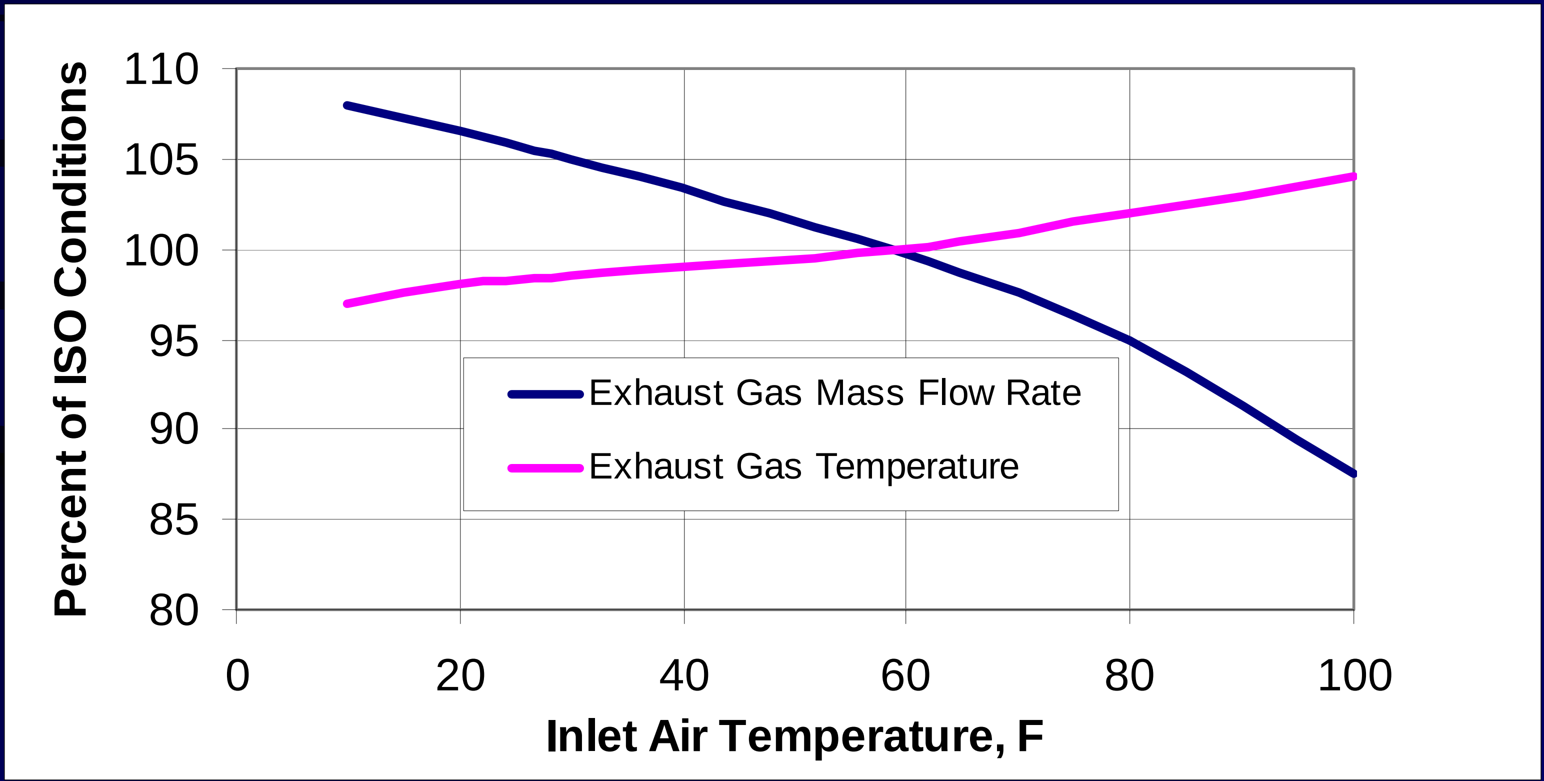
Increase in Inlet Air Temperature Decreases Power Output



Source: Solar Turbines

CT-Based CHP System Characteristic

Increase in Ambient Air Temperature Decreases Exhaust Gas Flow Rate and Increases Temperature (Total Available Energy Decreases)



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

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Economic Impacts of Increase in Ambient Temperature on CT-Based Systems

- Increases the cost of buying power and thermal energy (to make up for the lost CT output), if the Cogen owner is using its output for meeting its own needs, or
- Reduces revenue potential from the sale of power and thermal energy, if the cogen owner is selling these energies to others

Environmental Impacts of Increase in Ambient Temperature on CT-Based Systems

- Increases the carbon footprint for power generation at the generation facility
- Increases the carbon footprint of power generation for the grid system connected to the generation facility (because somewhere a less efficient system has to be brought online to meet the demand to prevent power outage)

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

TIC Economic Benefits

- Increases CT output (MWh and thermal energy) and thus, saves cost of buying or reduces revenue for selling these energies during on-peak demand periods when electric energy demand and price are highest

- Reduces cost of electric energy generation compared to the less energy efficiency “peakers”

- Requires less investment per unit ($/kW) of the increased generation capacity compared to new power plants

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TIC Environmental Benefits

Reduced Emissions of GHG and pollutants

- Displaced/eliminated operation (up to 30 % of the CT capacity*) of less efficient and higher emission power plants
- Increased efficiency of fuel utilization

Reduced Need for Siting New Generation Capacity for Meeting Power Demand During Hot Weather

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* During hot weather

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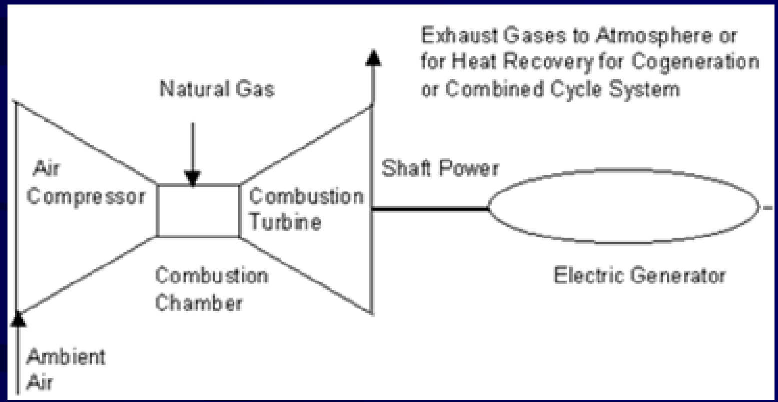
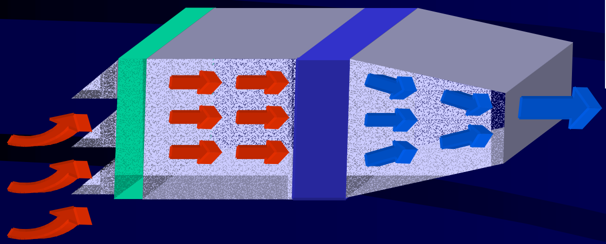
What is Turbine Inlet Cooling?





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

TIC Commercial Experience

- Over thousand plants are already using one of the TIC technologies
- TIC systems are available from multiple suppliers

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TIC Technologies

- Evaporative Cooling
  - Wetted Media
  - Fogging
- Chillers
  - Mechanical (Electric- or Steam-Driven)
  - Absorption Chillers
  - With Thermal Energy Storage

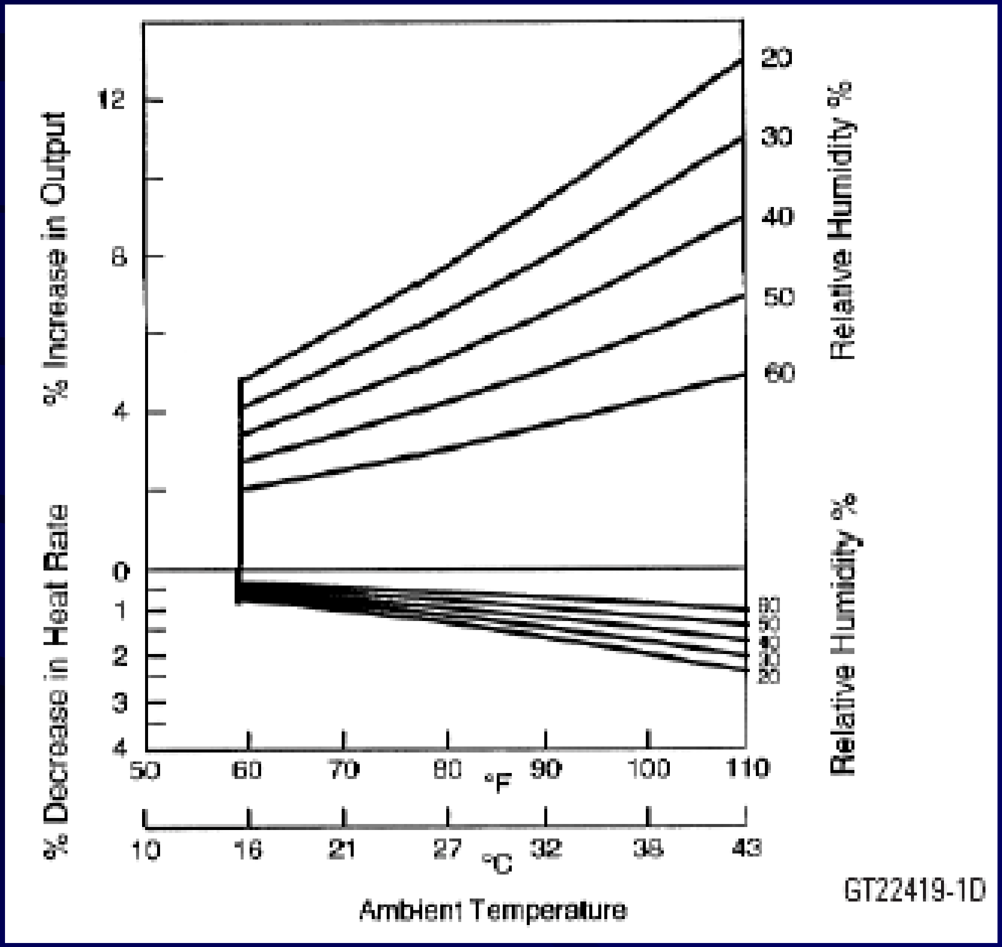
TIC Technologies

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

TIC Technologies

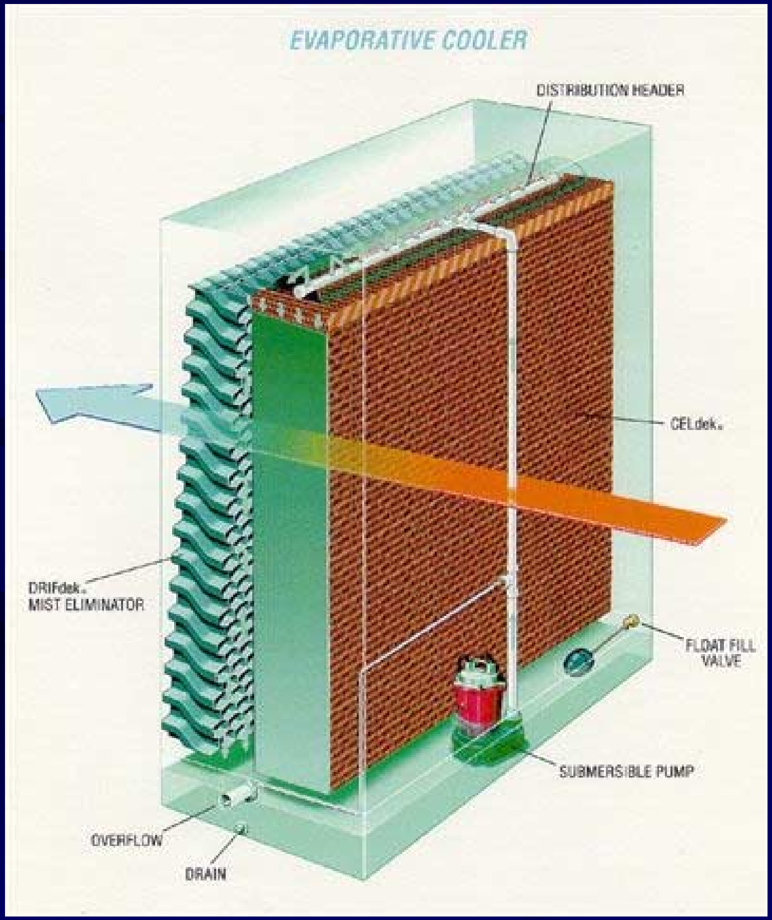
Direct Evaporative Cooling



Source: GE Power Systems

TIC Technologies

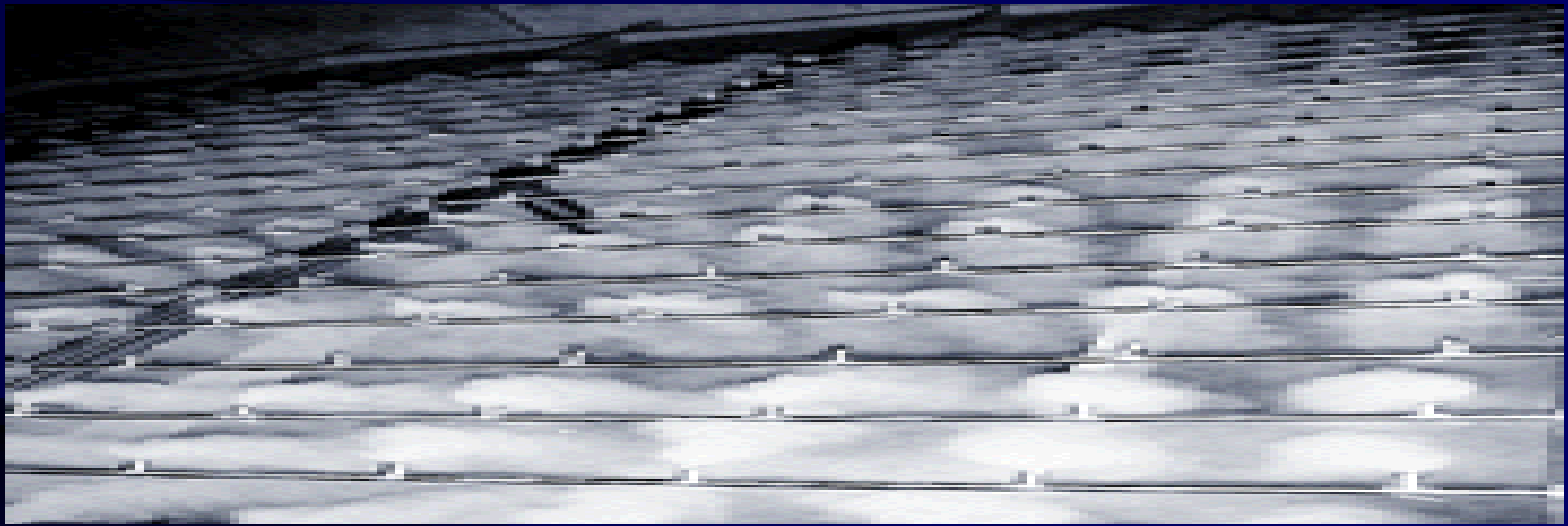
Wetted Media Systems



Source: Munters Corporation

TIC Technologies

Fogging Systems



TIC Technologies

Chiller System

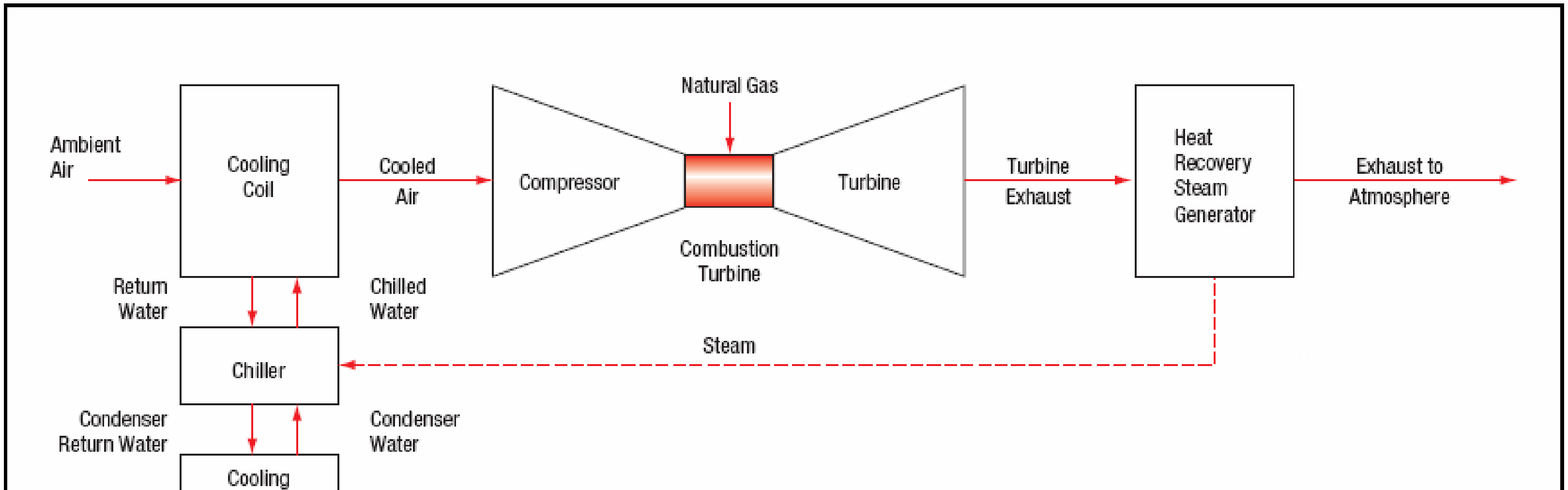


Figure 1: Schematic Flow Diagram for a Combustion Turbine Plant Using Chillers for TIC

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

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

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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 even below the wet-bulb temperature to as low as 42F (Even lower if the ambient air is very dry)
- Can maintain constant CT output irrespective of the ambient temperatures

TIC Technologies

Chiller Systems

- Many types of chillers are applicable and commercially used:

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

  ABSORPTION: Aqua-Ammonia or Lithium Bromide-Water

- With or without thermal energy storage (TES)

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TIC Technologies

Mechanical Chillers

- Refrigerant: HCFCs, HFCs or Ammonia
- Water-Cooled or Air-Cooled
- Can cool the air to any desired temperature

TIC Technologies

Lithium Bromide–Water Absorption Chillers

- Refrigerant: Water
- Water-Cooled
- Two Types
  - Single-Effect
  - Double-Effect

- Cannot cool the air to much below 50F

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TIC Technologies

Lithium Bromide–Water Absorption Chillers

Primary Energy Source Options

- **Single-Effect**
  - Steam (15 psig): 18lb/h ton
  - Hot Water (at least 180F)

- **Double-Effect**
  - Steam (115 psig): 10lb/ ton
  - Natural Gas or Exhaust Gases

TIC Technologies

Chillers and 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

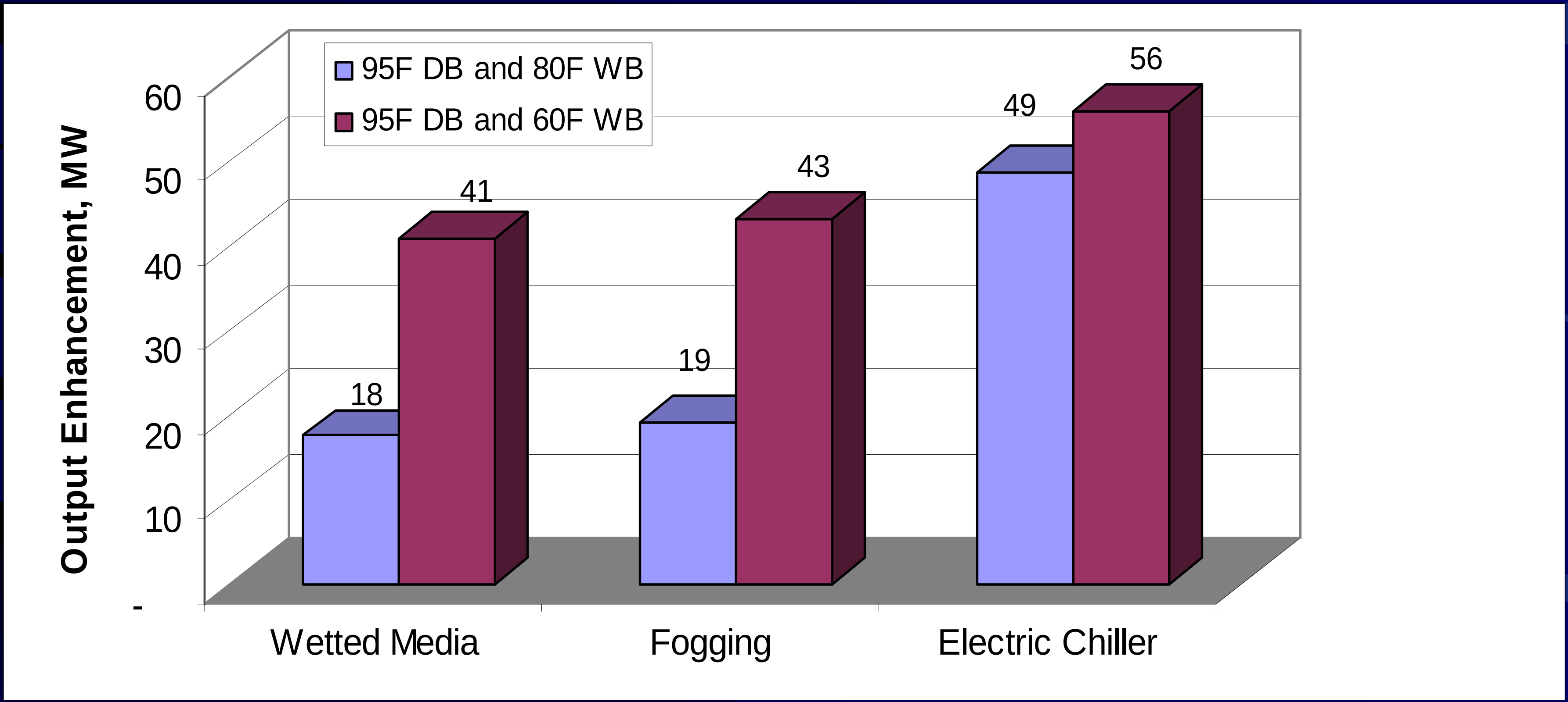
Chillers and Thermal Energy Storage (TES)

TES system options:

1. Full-Shift: Chillers not operated during on-peak

2. Partial-Shift: Chillers also operated during on-peak to complement the cooling capacity available from the stored chilled water or ice

Effect of TIC Technology on Net Capacity Enhancement



For a nominal 500 MW Combined-Cycle System

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TIC Economics

Is TIC Cost Effective?

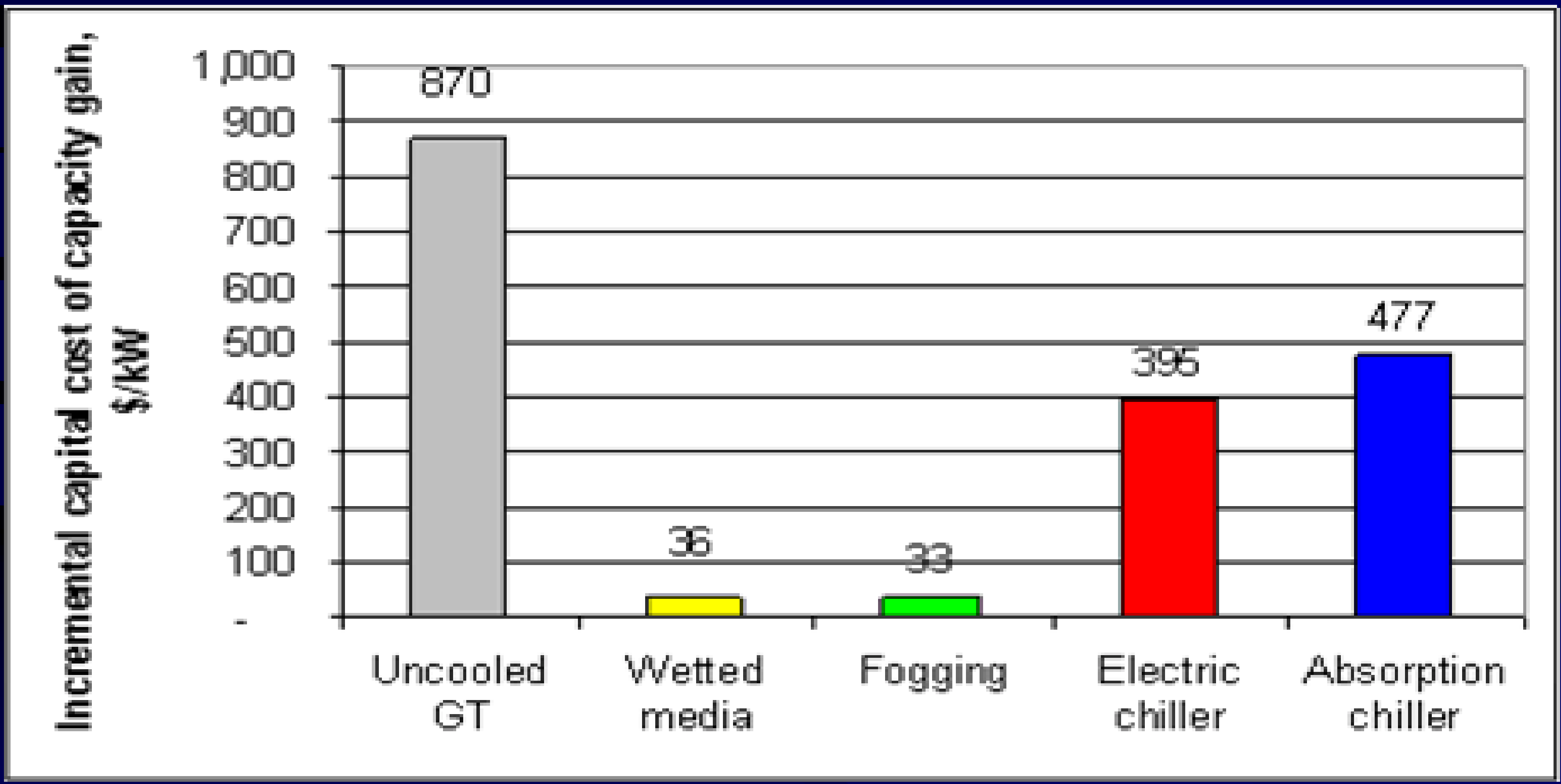
Depends on many factors, including:

- Weather data for the plant location*
- Market value / price of electric energy
- Cost of fuel

* Chicago area has over 3,360 when temperature is above 59F

Effect of TIC Technology on Incremental Capital Cost for Capacity Enhancement

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

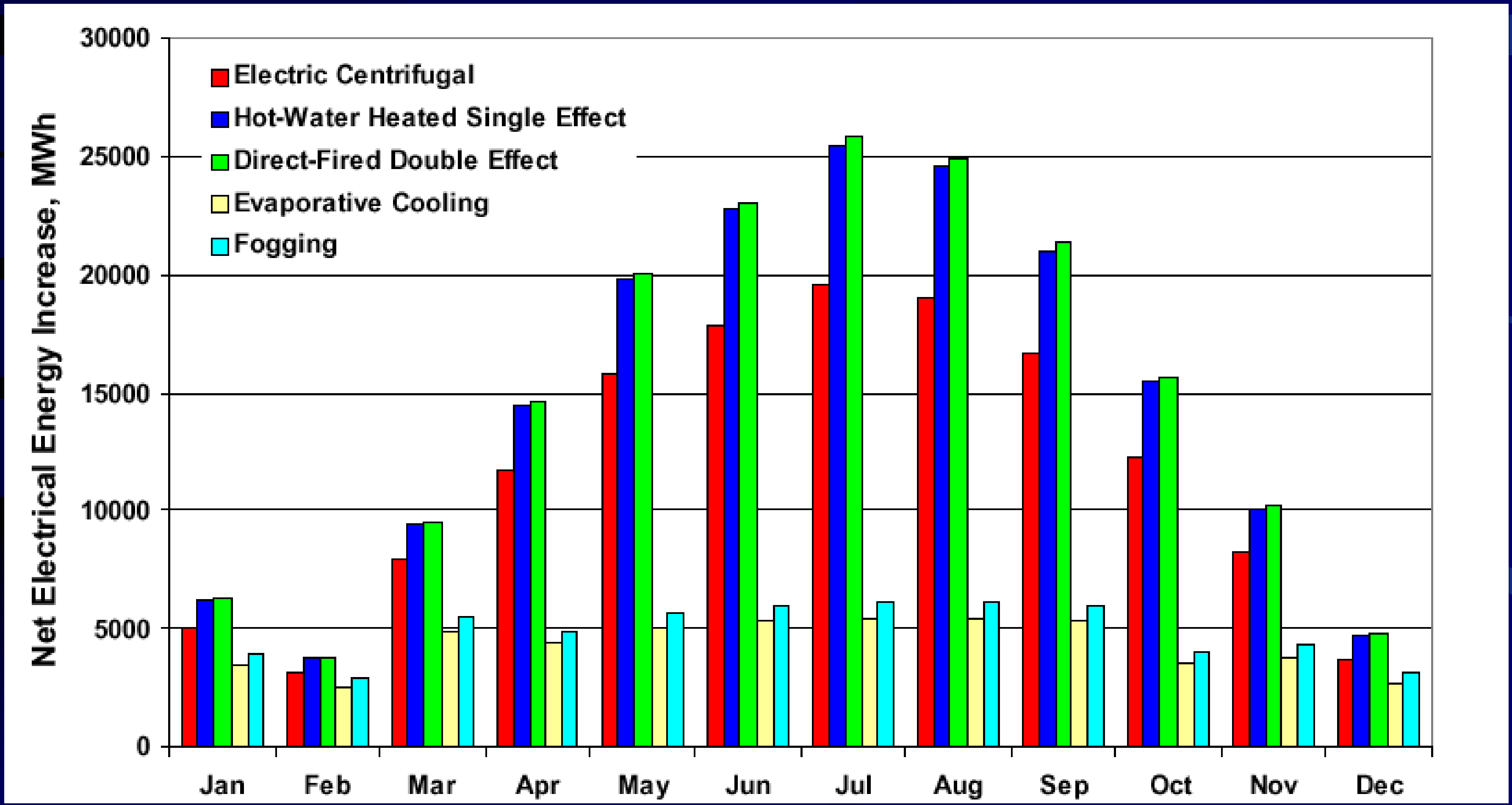


Source: Punwani *et al* ASHRAE Winter Meeting, January 2001

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

Effect of TIC Technology on Increase in Electric Energy Produced

(317 MW Cogeneration Plant; 95F DB and 80F WB)



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

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DOE Survey* of CHP Installations with TIC

Results: Geographical Distribution

State	Number of Systems	% of Total
California	11	38
Texas	4	14
Florida	3	11
New York	3	11
Oklahoma	2	7
Colorado	1	3
Hawaii	1	3
Illinois	1	3
Maryland	1	3
Nevada	1	3
Pennsylvania	1	3
Total	29	100

* Performed by the Cool Solutions Company and Avalon Consulting, Inc (2004)

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DOE Survey* of CHP Installations with TIC

Results: Applications Served

Application	Total Number	% of Total
Industrial	18	38
District Energy	8	17
Commercial	6	13
Government	6	13
Educational Facilities	5	10
Medical	3	6
Airport	1	2
Other	1	2
Total**	48	100

* Performed by the Cool Solutions Company and Avalon Consulting, Inc (2004)

** Total Applications are higher than the number of installations because of many the installations serve multiple facilities

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DOE Survey* of CHP Installations with TIC

Results: TIC Technologies

Technology	Number of CHP Systems	% of Total
Chillers	21	73
Ammonia Evaporation in Coil	4	14
Wetted Media	2	7
Fogging	1	3
Over-Spray Fogging (Wet Compression)	1	3
Total	29	100

* Performed by the Cool Solutions Company and Avalon Consulting, Inc (2004)

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McCormick Place Cogen* with TIC, Chicago, IL

East Exhibit Hall ----
4,000 T (1994)
North Exhibit Hall ---
4,000 T (1994)

Internet "hotel" ----
3,000 T (2000)

--- **South Exhibit Hall**
8,000 T (1997)
--- **32-story hotel**
1,000 T (1998)

--- **Gov't office space**
1,000 T (2000)

*** Metropolitan Pier & Exposition Authority (Originally owned and operated by Trigen-Peoples District Energy)**

Source: Andrepont, J.S., ASHRAE Winter Meeting, January 2006

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McCormick Place Cogen* with TIC, Chicago, IL

- Three CTs (1.1 MW each)
- Each CT drives an induction-motor generator and a 2,200 Ton ammonia screw chiller
- Side-stream of ammonia refrigerant used for cooling inlet air to 50°F
- CT Exhaust heat exhaust recovered for steam production used for space heating or absorption cooling
- 123,000 Ton-hours (8.5 million gallons) of TES (127 ft Diameter x 90 ft High

Source: Andrepont, J.S., ASHRAE Winter Meeting, January 2006

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Recent Cogen Installations with TIC

- 5-MW System at Lafarge Gypsum Division, Sliver Grove, KY (2004)
- 4.5-MW System at the Domain Power Park Austin, TX (2004)
- 5.5 MW-System at the U.S. Army, Fort Bragg, NC (2005)

For More Information See: Punwani, D.V. and Andrepont, J.S., POWER-GEN International, 2005

Conclusions

- TIC Improves the Economics of Power Generation
- TIC Reduces Carbon Footprint for Power Generation
- Therefore, TIC is Good the Environment, Rate Payers and Plant Owners

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Any Questions?

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