Turbine Inlet Cooling: Increased Energy Efficiency & Reduced Carbon Footprint Aspects for District Energy Systems

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Presentation Outline

- Ambient Temperature Impacts on CT-Based Systems
- What is TIC Cooling?
- TIC Technologies
- Benefits of TIC
- Economics of TIC
- TIC Examples in District Energy Systems
- Conclusions

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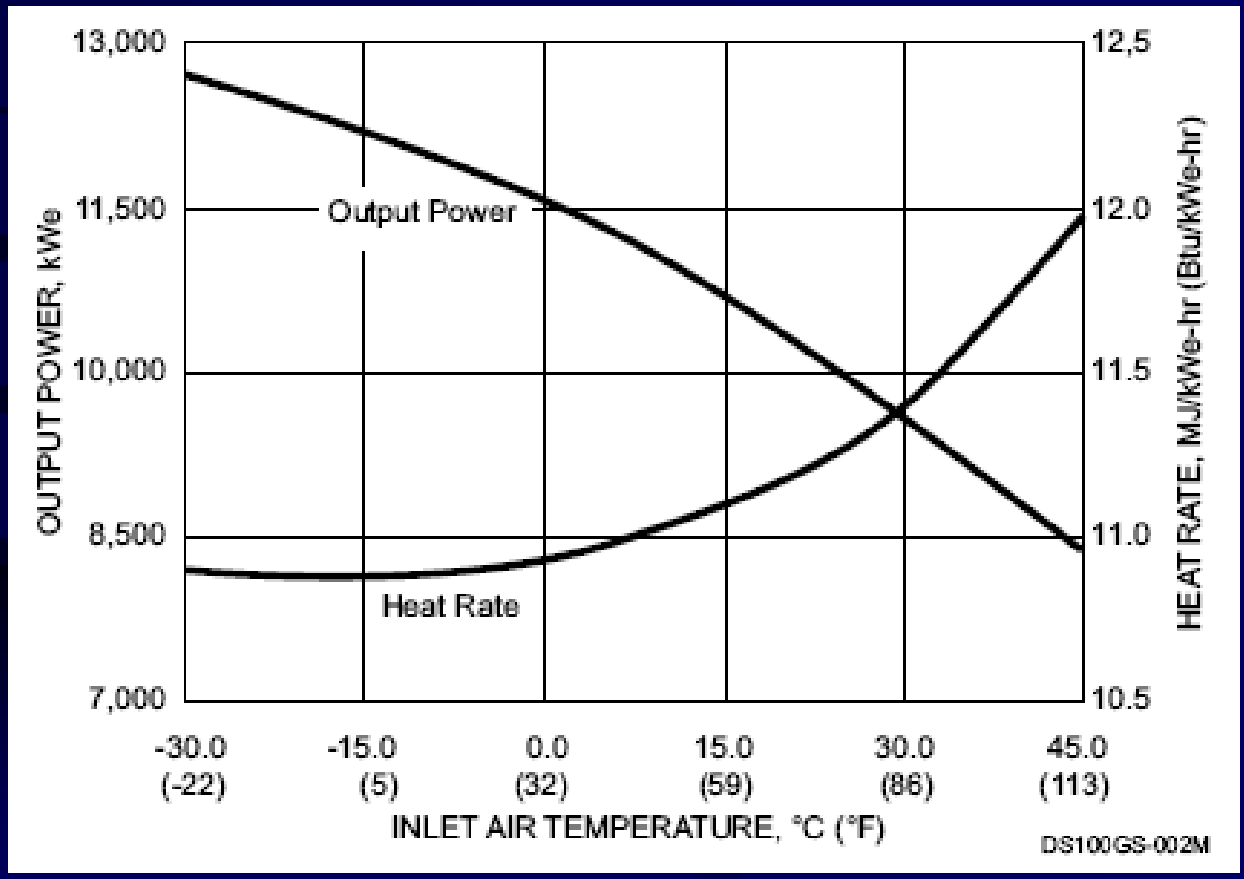
Ambient Temperature Impacts on CT Output Heat Rate

Increase in Temperature Decreases Power Output and Increases Heat Rate (Decreases Energy Efficiency)



Source: Solar Turbines

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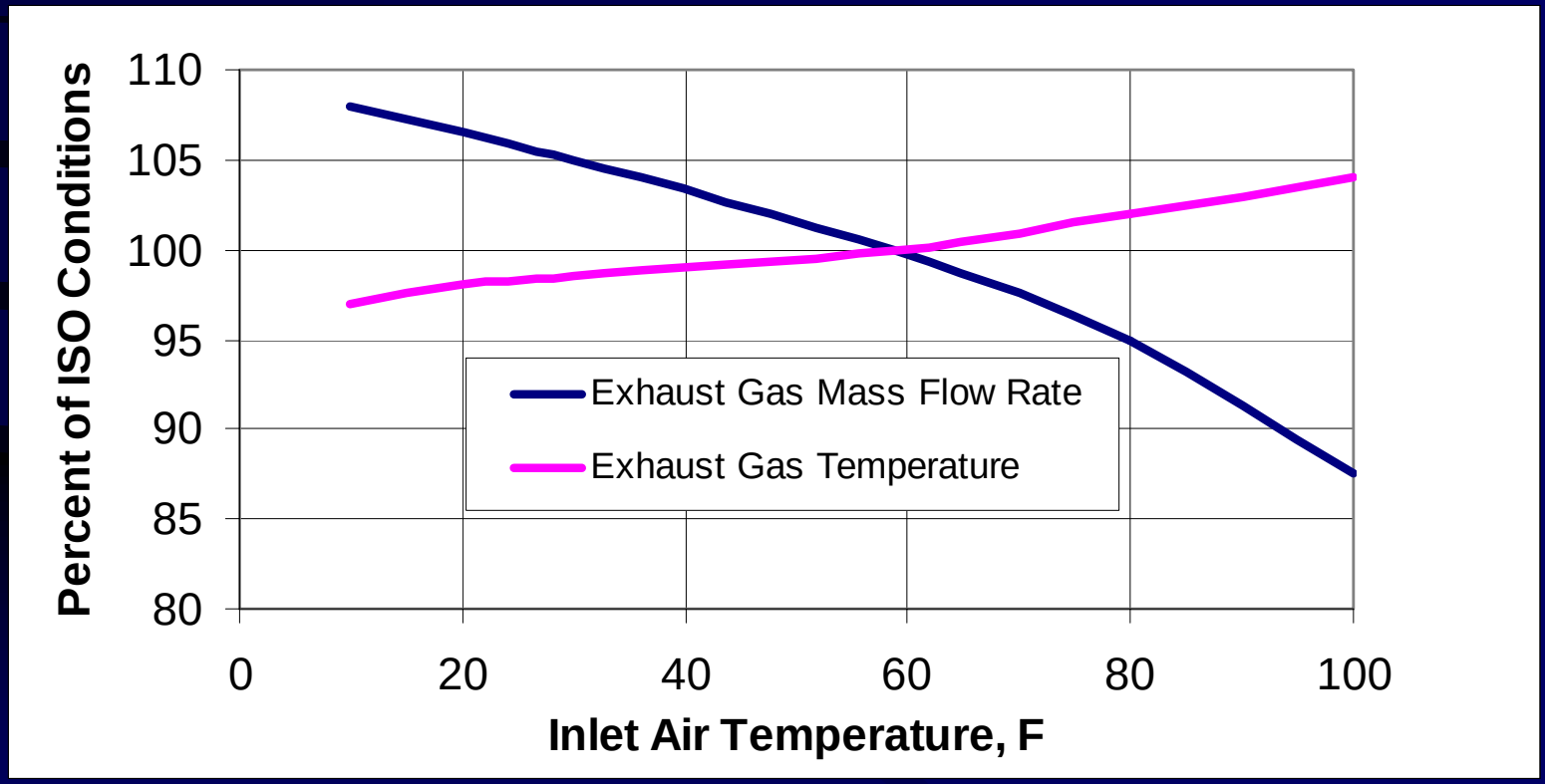
Ambient Temperature Impact on Thermal Energy in CT Exhaust Gases

Increase in Temperature Decreases Flow Rate, Increases Temperature and Decreases Total Thermal Energy Available in Exhaust Gases



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

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Impacts of Hot Weather on the Performance of CT-Based District Energy Systems

1. **Reduces power generation capacity** *(Big Impact)*
   - Increases cost of buying electric energy from the grid or increases the fuel cost for starting up a less energy efficient system at the facility
   - Increases power demand from the grid
   - Increases use of less efficient systems to meet grid demand and prevent power outage
   - Increases carbon dioxide and other emissions

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Impacts of Hot Weather on the Performance of CT-Based District Energy Systems

2. **Decreases efficiency of power generation i.e. increases heat rate** *(Smaller Impact)*
   - Increases fuel consumption and cost per kWh
   - Increases carbon dioxide and other emissions

3. **Decreases thermal energy of the CT exhaust gases in CHP systems** *(Small Impact)*
   - Increases fuel or electric energy consumption and cost
   - Increases carbon dioxide and other emissions

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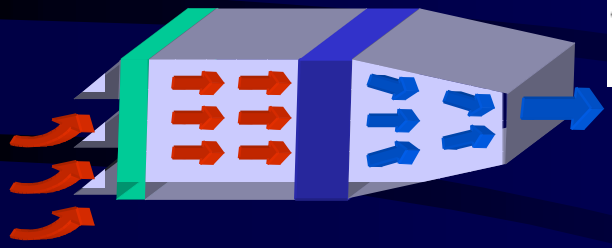
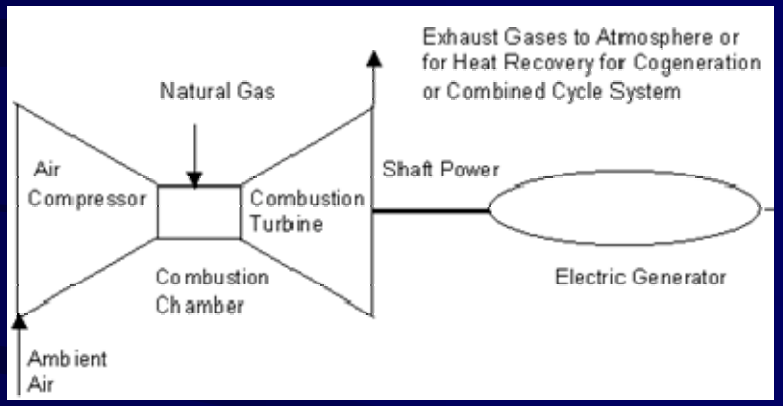
Turbine Inlet Cooling

The only cure for overcoming all three detrimental effects of increased ambient temperature on the CT performance

What is Turbine Inlet Cooling?





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

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Turbine Inlet Cooling

History

- Commercially available for over 20 years
- Over a thousand power plants already using it
- Some district energy and CHP systems also incorporate TIC

Today

- Increasing energy efficiency is more important
- Reducing carbon emissions (carbon footprint) more desirable
- Impact of TIC on energy efficiency and emissions is better understood
- Availability of new hybrid and packaged systems may make TIC economically more attractive

Power Generation and Carbon Emissions

- Higher energy efficiency reduces fuel consumption and emissions
- Carbon emissions for power generation across a grid system depend on the mix of power generation technologies deployed by the system
- Generally, carbon emissions during non-baseload period are higher than the average emissions
- Carbon emissions during non-based load period are higher because less energy efficient power plants have to be brought online to meet increased power demand during peak and shoulder periods
- Higher ambient temperature generally results in increased power demand and higher price of electric energy
- Increased use of higher efficiency power plants during hot weather will minimize the use of less efficient plants and help reduce fuel consumption and carbon emissions

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Increase in Ambient Temperature Increases Power Demand and May Lead to Increased Electric Energy Prices

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*

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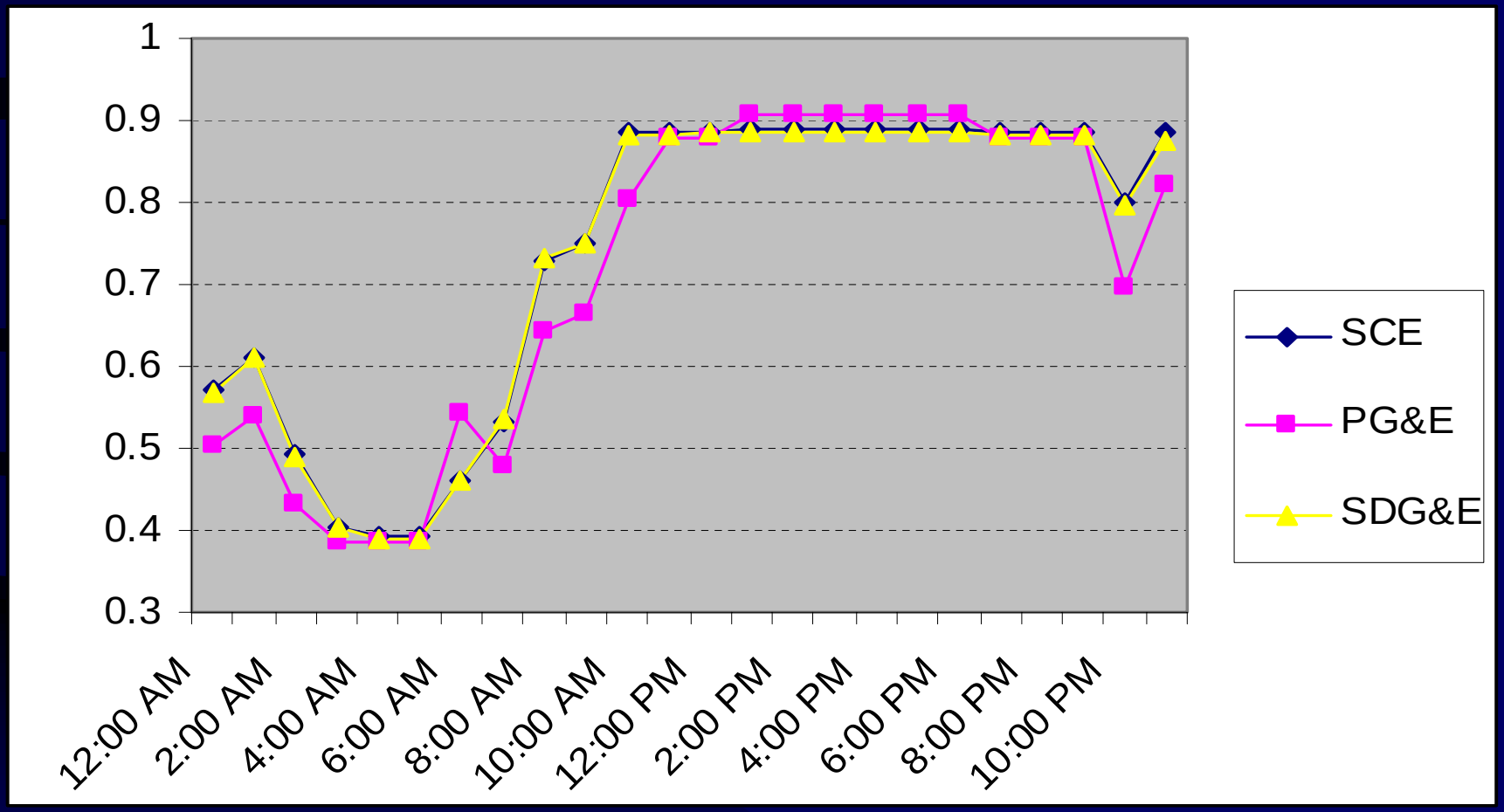
CO_2 Emissions (lbs/kWh) During Peak Period
California Summer Example



Y-Axis Unit: CO_2 Emissions, Lbs/kWh

Source: Scot Duncan Presentation at ASHRAE June 2007

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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

Information on Carbon Factors by zip code and state:
www.epa.gov/cleanenergy/energy-resources/egrid/index.html

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Power Generation Carbon Footprint

Power System	Heat Rate (LHV), Btu/kWh	Carbon Footprint
CT in Combined-Cycle	~7000	Lowest
CT in Simple-Cycle	8,000-12,000	
Steam-Turbine	8,100-15,000*	Highest

* The higher heat rate is for the old plants used primarily for peak shaving

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Fuel Use* Carbon Footprint

System	Carbon Footprint
CT in CHP	Lowest**
CT in Combined-Cycle	
CT in Simple-Cycle	
Steam-Turbine	Highest***

* Total fuel used for generating electric and thermal energy

** Utilizes thermal energy in the CT exhaust to meet some of the thermal energy needs

*** Old plants used primarily for peak shaving

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Strategy for Reducing Carbon Footprint

- Maximize the use of newer high-efficiency CHP, combined-cycle and simple-cycle systems that use CT
- Minimize the use of older low-efficiency systems that use steam turbines and fuel oil
- Maximizing the use of high efficiency district energy systems helps minimize the use of less efficient system somewhere in the connected grid system

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TIC Benefits

- District Energy System Owners
- Grid Systems
- Environment & Natural Resources

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TIC Benefits During Hot Weather

District Energy System Owners

- Reduced cost for buying electric and thermal (in CHP systems) energy or
- Reduced need to operate lower efficiency systems and thus, reduced fuel cost

Grid Systems

- Reduced demand on the grid from the district energy systems using TIC
- Reduced need to operate less efficient power plants to makeup for the lost CT capacity

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TIC Benefits During Hot Weather

Environment & Natural Resources

- Less fuel consumed at a district energy facility or somewhere in the grid system
- Less carbon and other emissions

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TIC Technologies

Direct Evaporative Cooling

- Wetted Media
- Fogging

Chillers

- Mechanical (Electric- or Steam-Driven)
- Absorption Chillers
- With Thermal Energy Storage

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TIC Technologies

Hybrid (Newer)

- Indirect Evaporative Cooling followed by Direct Evaporative Cooling
- Indirect Evaporative Cooling followed by Chiller
- Chiller followed by Direct Evaporative Cooling
- Direct Evaporative Cooling followed by Chiller

Pseudo-Hybrid (Newer)

- Allow switching between direct evaporative cooling and direct-contact chilled water cooling

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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**
- **CT Characteristics**

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*** 8,760 Hours**

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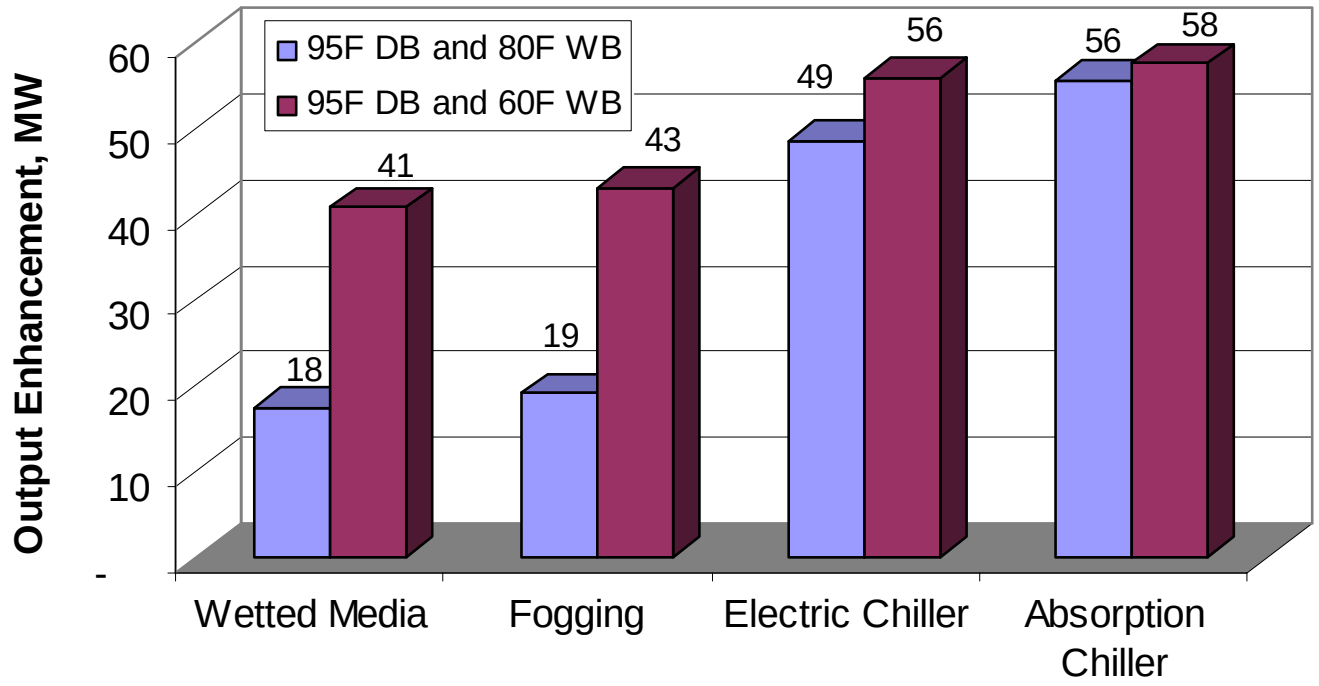
Effect of TIC Technology on Net Capacity Enhancement



For a nominal 500 MW Combined-Cycle System

Source: Punwani, Electric Power 2008

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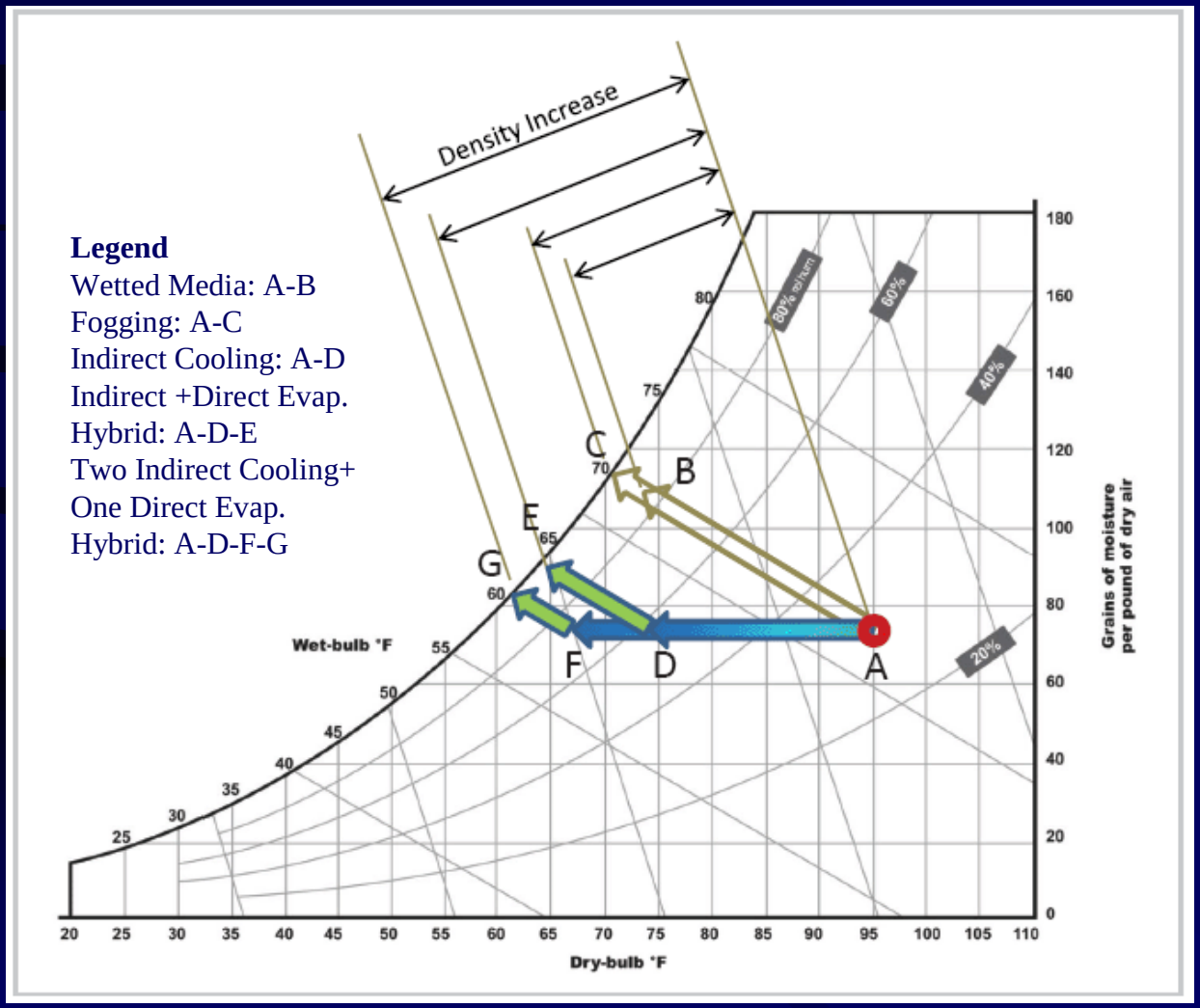
Pyschrometric Chart for Some TIC Examples



Source: Schlom, L.A. , *Energy-Tech* June 2009

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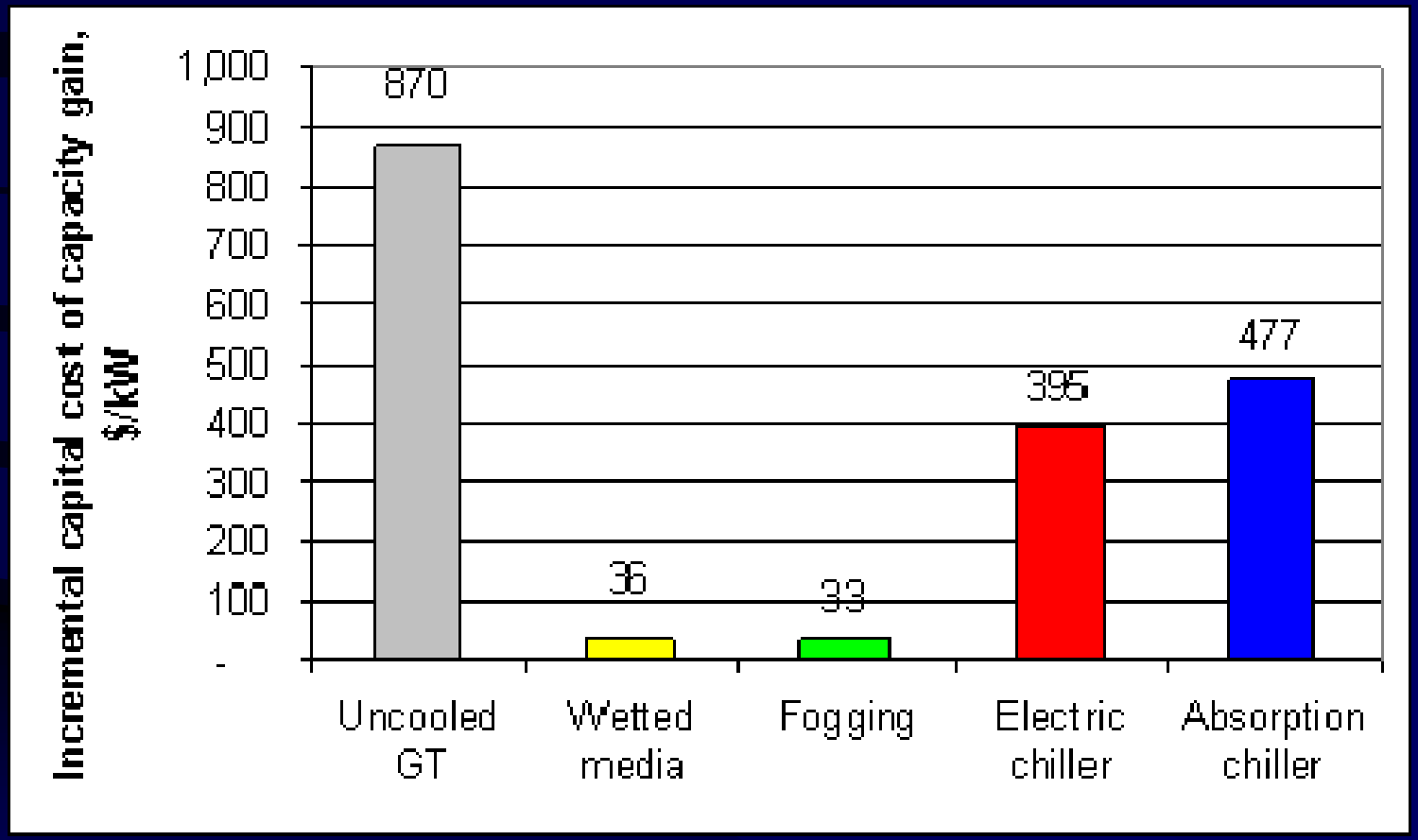
Effect of TIC Technology on Capital Cost for Incremental Capacity Enhancement



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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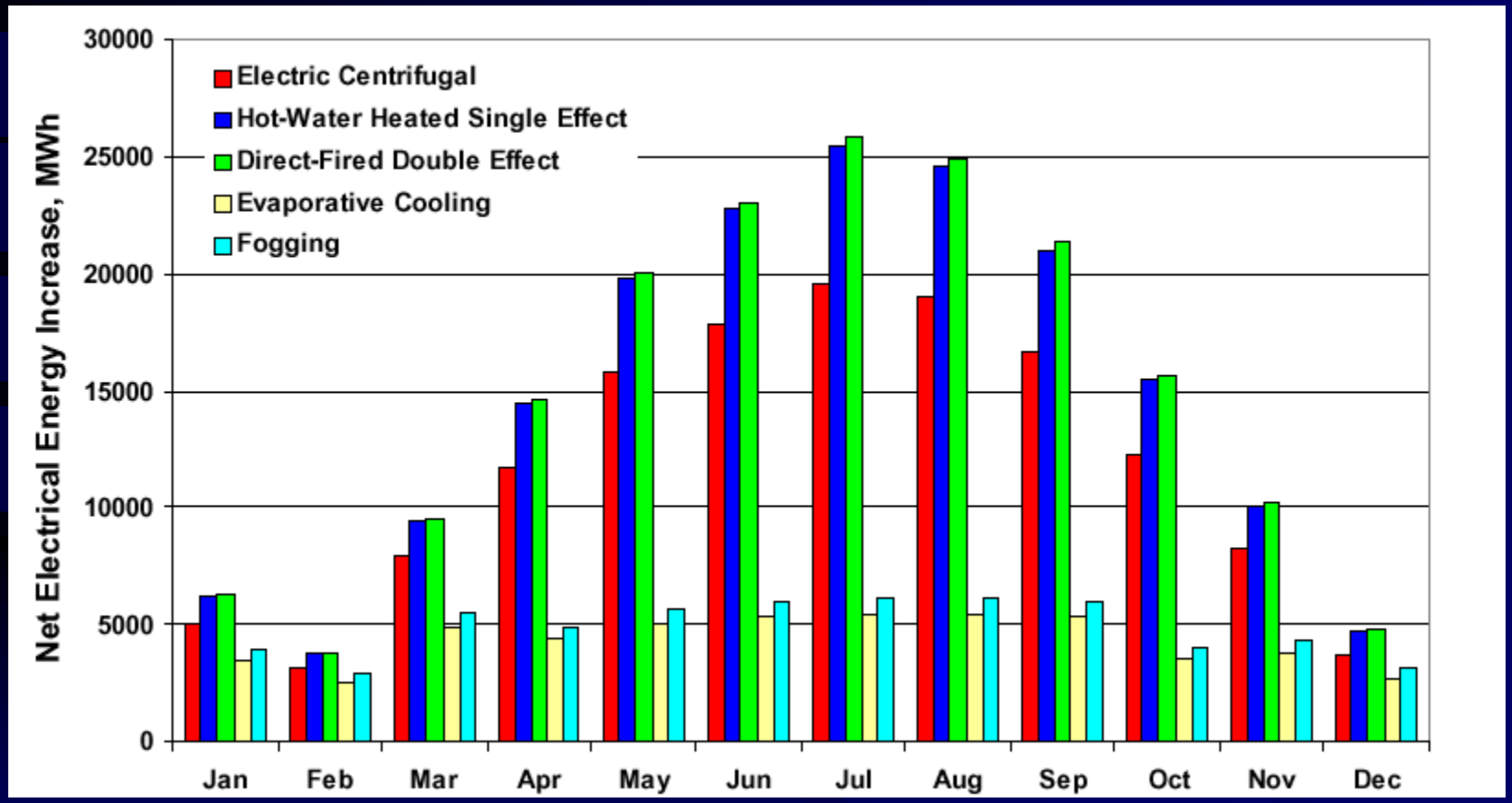
Effect of TIC Technology on Ne6t Increase in Electric Energy Output



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

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

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Examples* of District Energy Systems Using TIC

System Owner Name & Location	Startup Year	CT Capacity (ISO), MW
Trigen Energy (Oklahoma City, OK)	1992	1.1
Trigen Energy (Tulsa, OK)	1992	1.1
KIAC Partners (JFK Int'l. Airport, NY)	1994	85.0
Trigen Energy (Garden City, NY)	1997	42.0
McCormick Place (Chicago, IL)	1997	3.3
Reedy Creek (Disney World, FL)	1998	32.0
Trigen Energy (Philadelphia, PA)	1998	120.0
Climaespaco (Lisbon, Portugal)	1998	5.2
Austin Energy (Austin, TX)	2004	4.5
U.S. Army (Fort Bragg, NC)	2005	5.5
Princeton University (Princeton, NJ)	2005	14.6
Arizona State University (Tempe, AZ)	2005	6.8
University of California (Irvine, CA)	2008	13.5
Cornell University	2009	30.0

- No database available to determine the number of district energy system using TIC

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Conclusions

- TIC could improve the economics of district energy systems
- TIC installed in district energy systems about 20 years ago are still doing well
- TIC helps reduce carbon footprint for power generation for the district energy systems or the connected grid
- Think of TIC as the “Other” Clean Energy technology without the premium cost
- CT-based district energy systems that do not yet have TIC, should consider evaluating the economic benefits of all TIC options: both mature and newer (hybrid and packaged) systems

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