Turbine Inlet Cooling

A Valuable Tool to

INCREASE

Electric Energy Production

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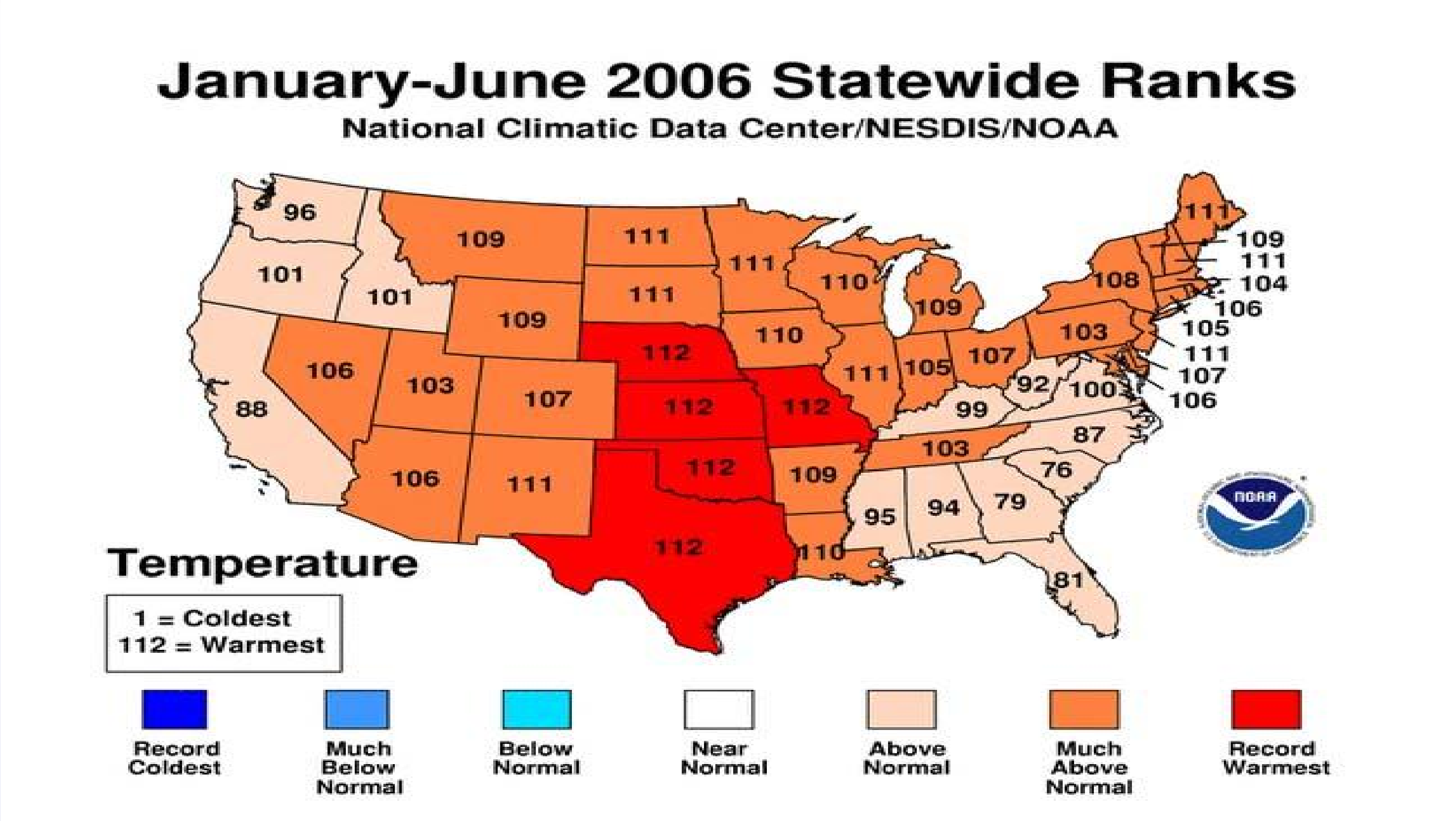
March 2012

Peak Temperatures Are High Across the United States



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Capacity of Combustion Turbine Power Plants is Reduced in Hot Months

Fuel	Winter Capacity, MW	Summer Capacity, MW	MWs Lost in Summer Capacity from Winter Capacity
Coal	319,186	316,800	2,386
Petroleum	59,577	55,647	3,930
Natural Gas	438,727	407,028	31,699

Source: U.S. Department of Energy's
Energy Information Agency 2010 Database

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Major Problem for Regulators

Available electric energy from conventional gas turbine plants is greatly diminished during hot summer months

- According to the U.S. Department of Energy, hot weather reduces electric power generation capacity of gas turbine plants by as much as 31,000 MW
- This supply loss occurs at the very same time when electric power demand is peaking due to increased air conditioning load

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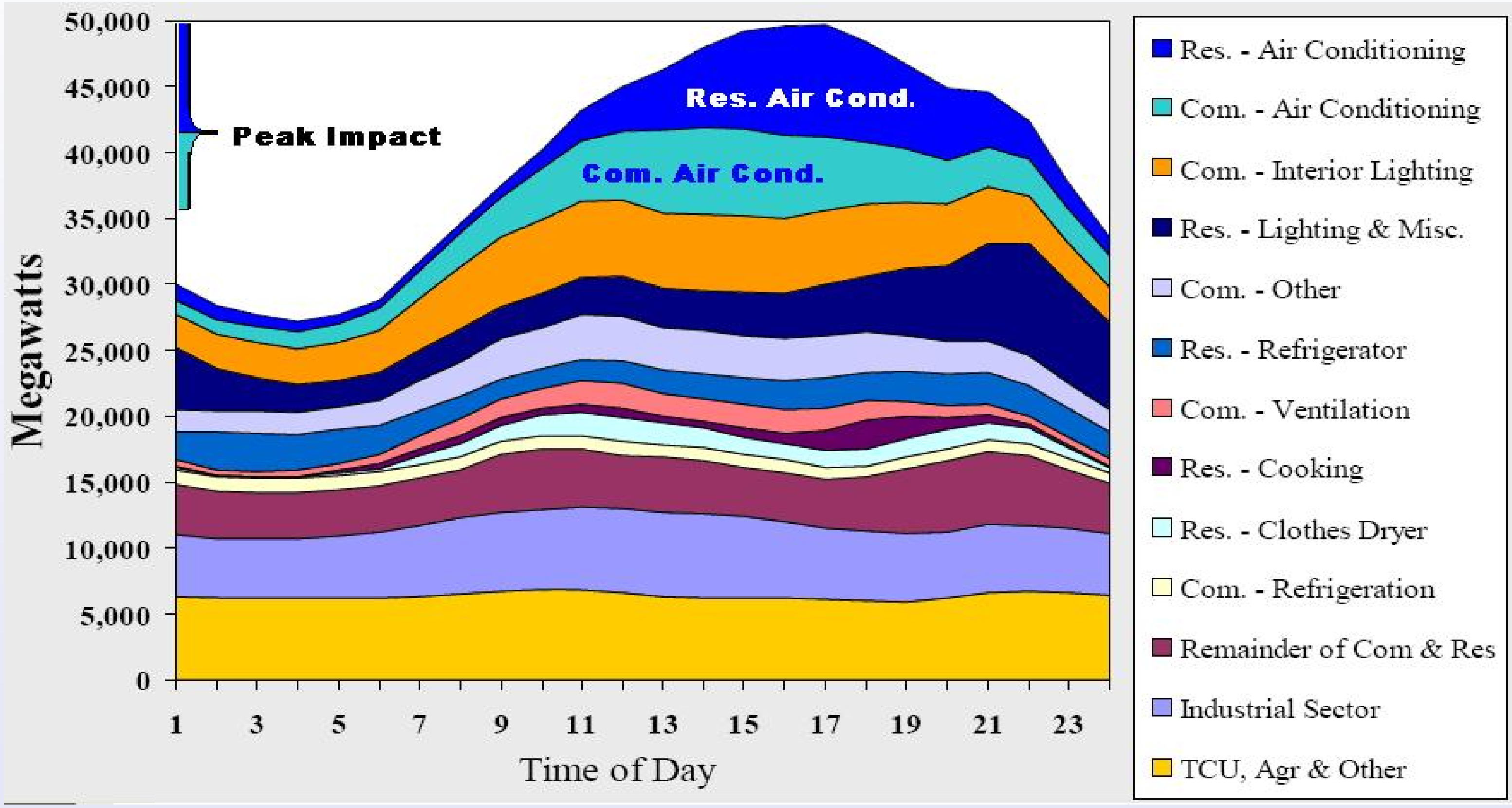
High Air Conditioning Loads are Major Contributors to Peak Demand



Source: Scot Duncan Presentation at ASHRAE June 2007

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Combustion/Gas Turbine Plants Have Two Fundamental Problems

- **During hot weather, CTs' energy output can drop up to 35% below rated capacity (based on 59° F)**
- **High heat causes gas turbines to work harder and lose up to 15% efficiency, thereby increasing fuel use (heat rate) and emissions per kWh**

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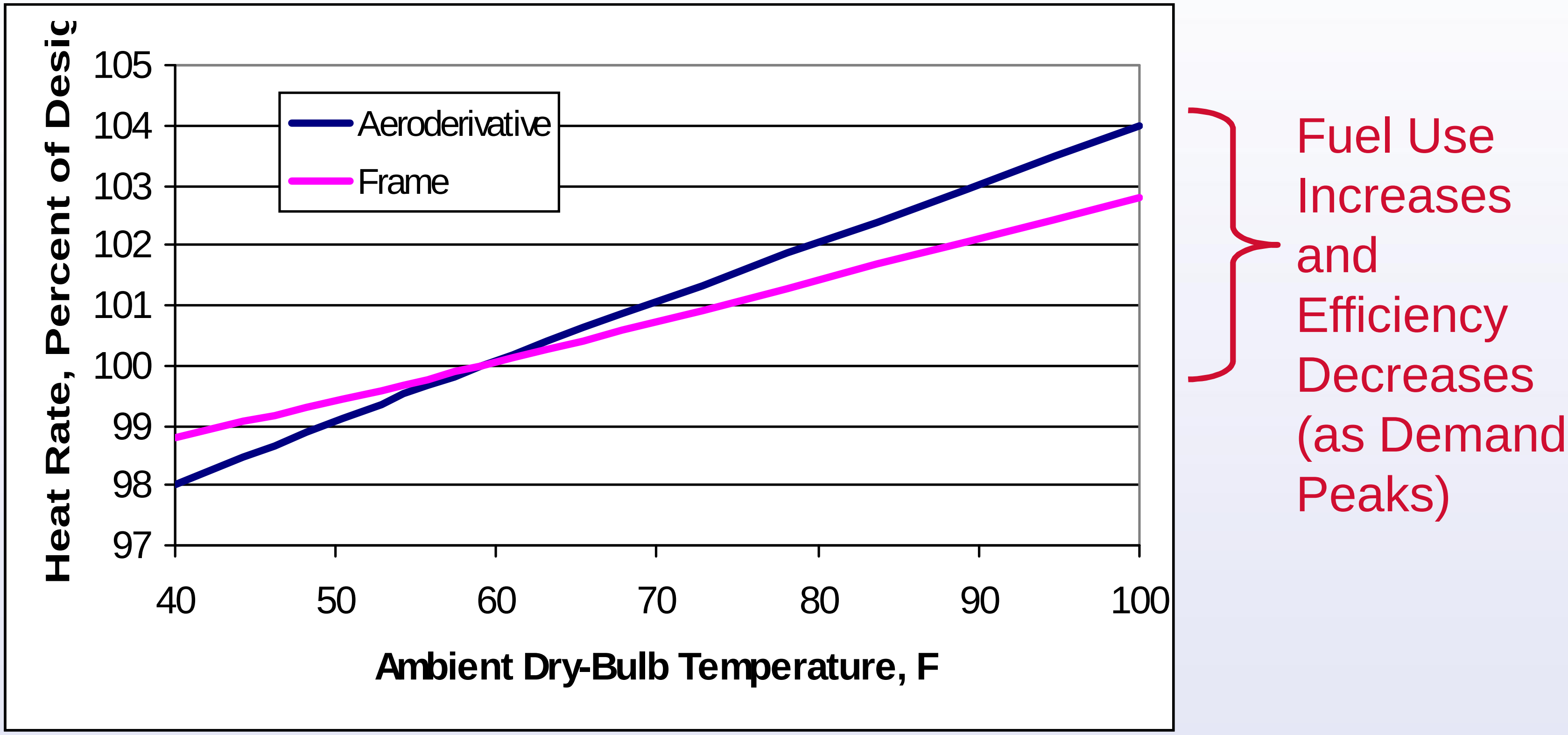
In Hot Weather a CT's Energy Efficiency Goes Down as its Heat Rate Goes Up



Note: Heat rate is directly proportional to fuel used per kWh and inversely proportional to energy efficiency

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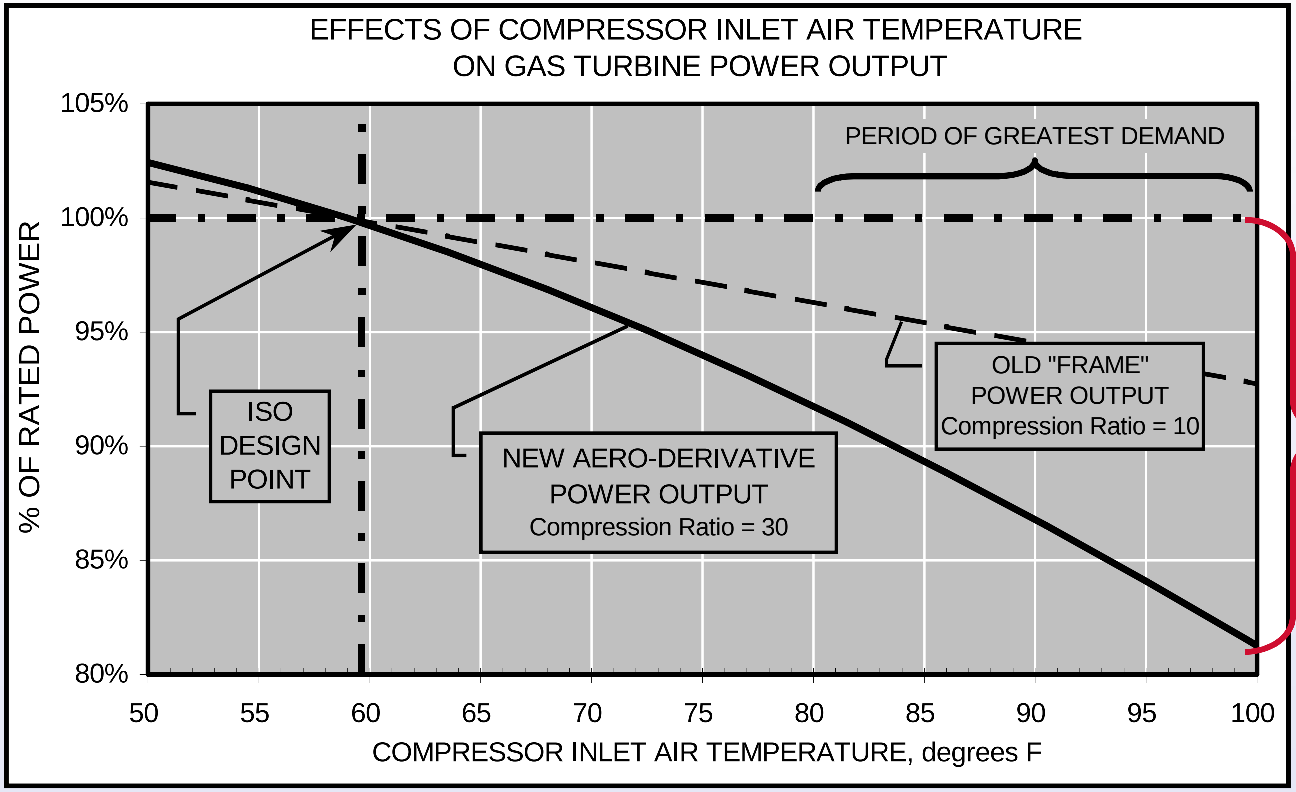
A CT's Generation Capacity Goes Down as Ambient Air Temperature Goes Up



This CT shows up to 19% capacity loss at peak demand

Punwani 2005

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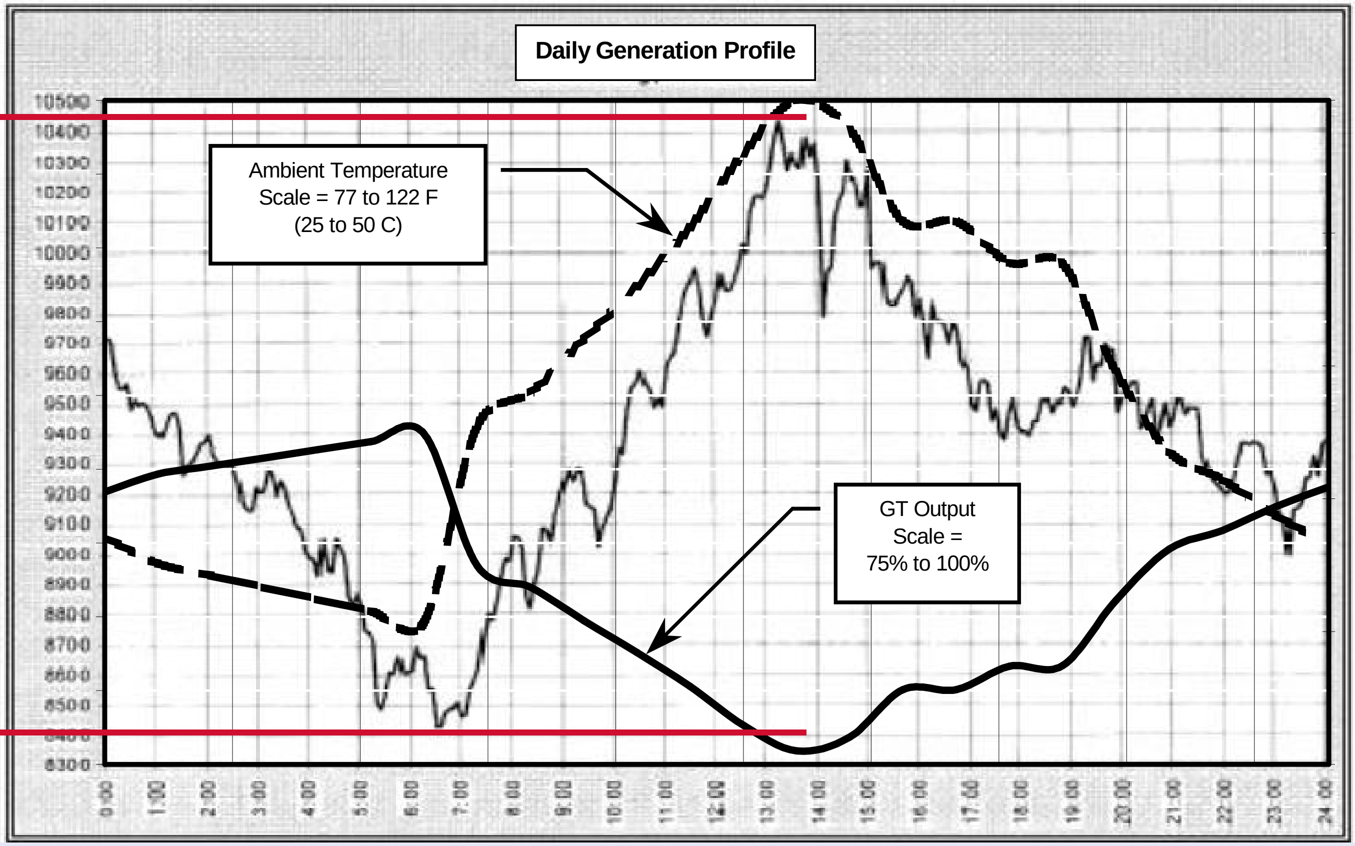
Generation Capacity Loss Coincides with Peak Demand

Peak Power Demand

Lowest Generation Capacity



Punwani 2005

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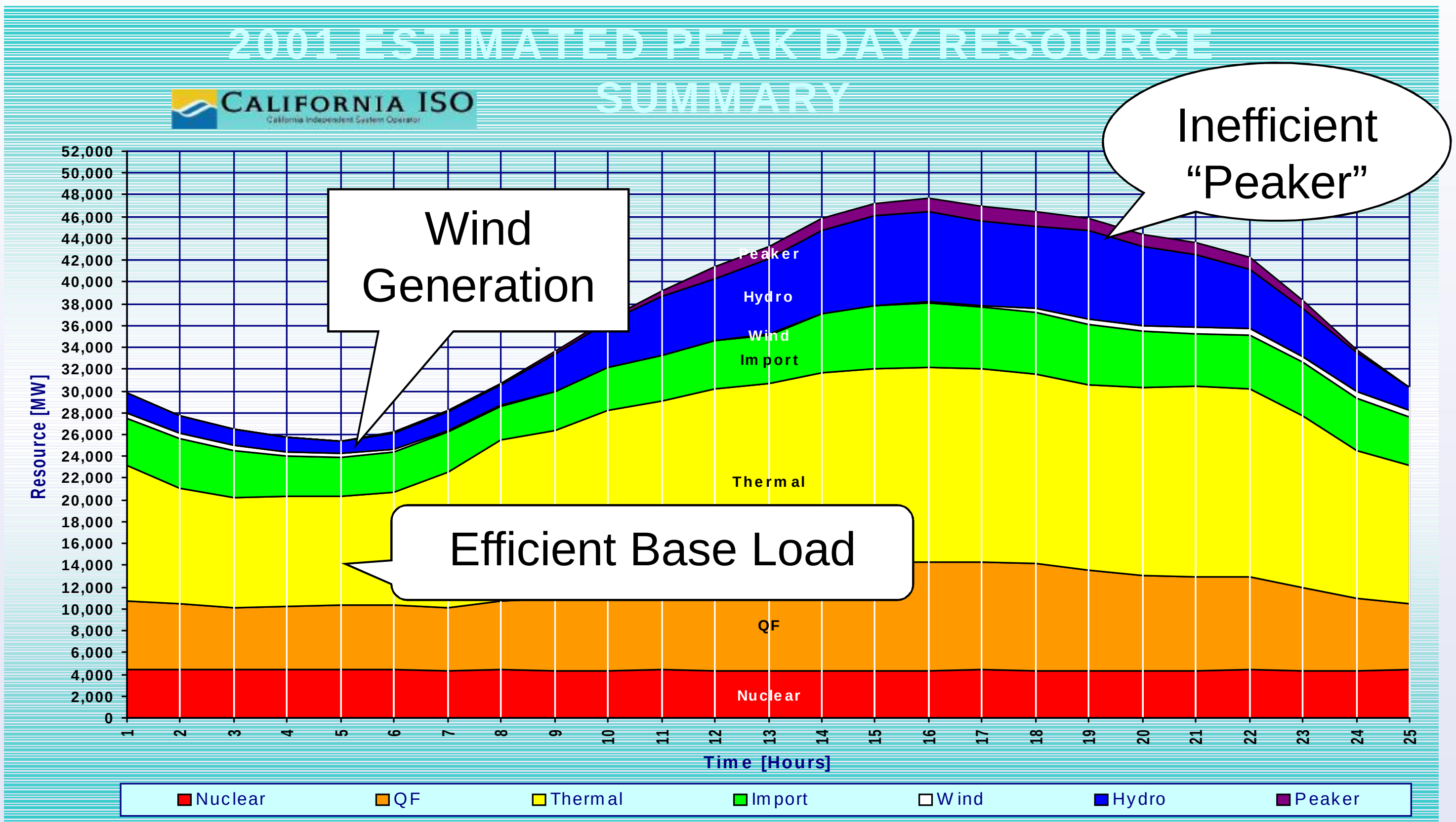
Losing CT Generation Capacity and Efficiency Due to Hot Weather also Means

- **Other plants must be brought online. Usually, such peaking plants are:**
  - **Less efficient than gas turbine plants**
  - **More costly to operate than gas turbine plants**
  - **Emitters of larger amounts of greenhouse gases than gas turbine plants**

Various Power Generation Technologies Help Meet Power Demand



Source: Scot Duncan Presentation at ASHRAE June 2007

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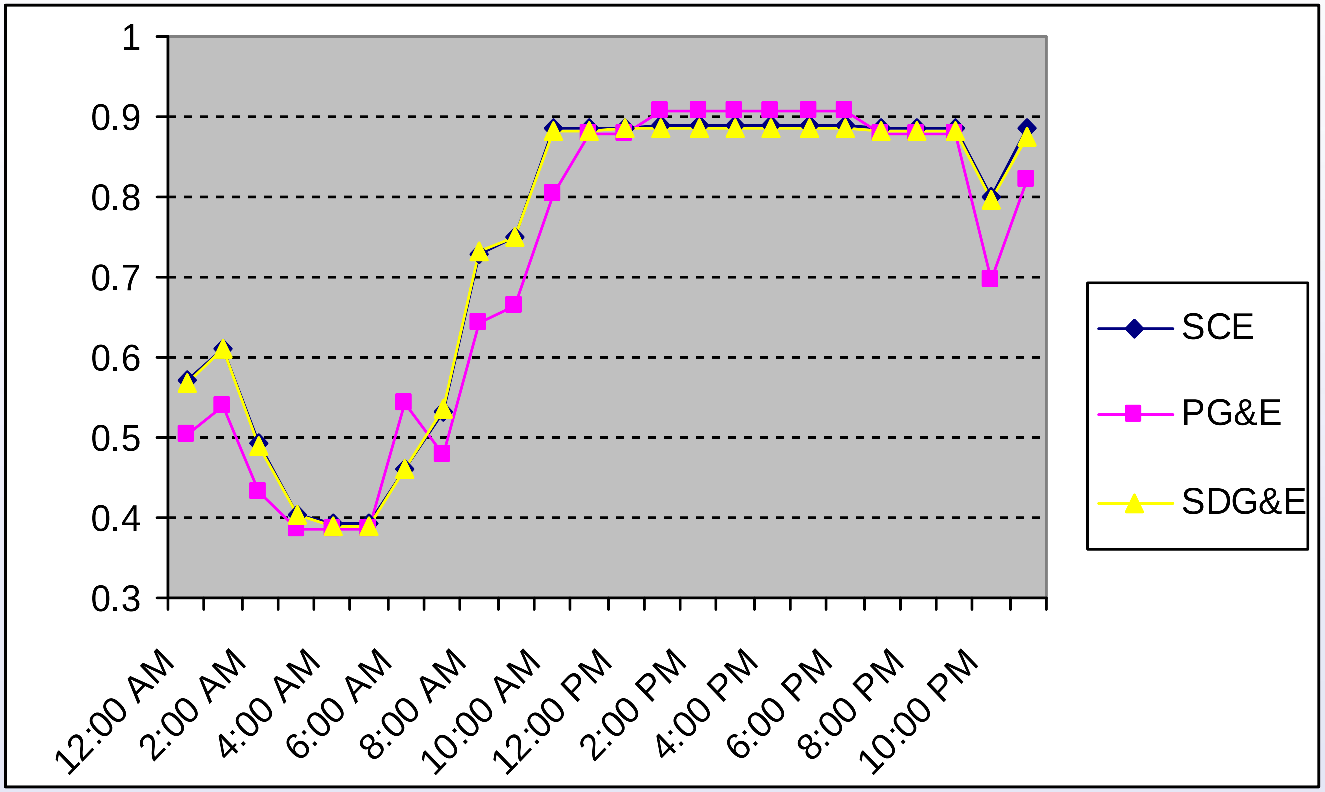
Summer Emissions (lbs/kWh) of CO_2 (California)



Y-Axis Unit: CO_2 Emissions, Lbs/kWh

Source: Scot Duncan Presentation at ASHRAE June 2007

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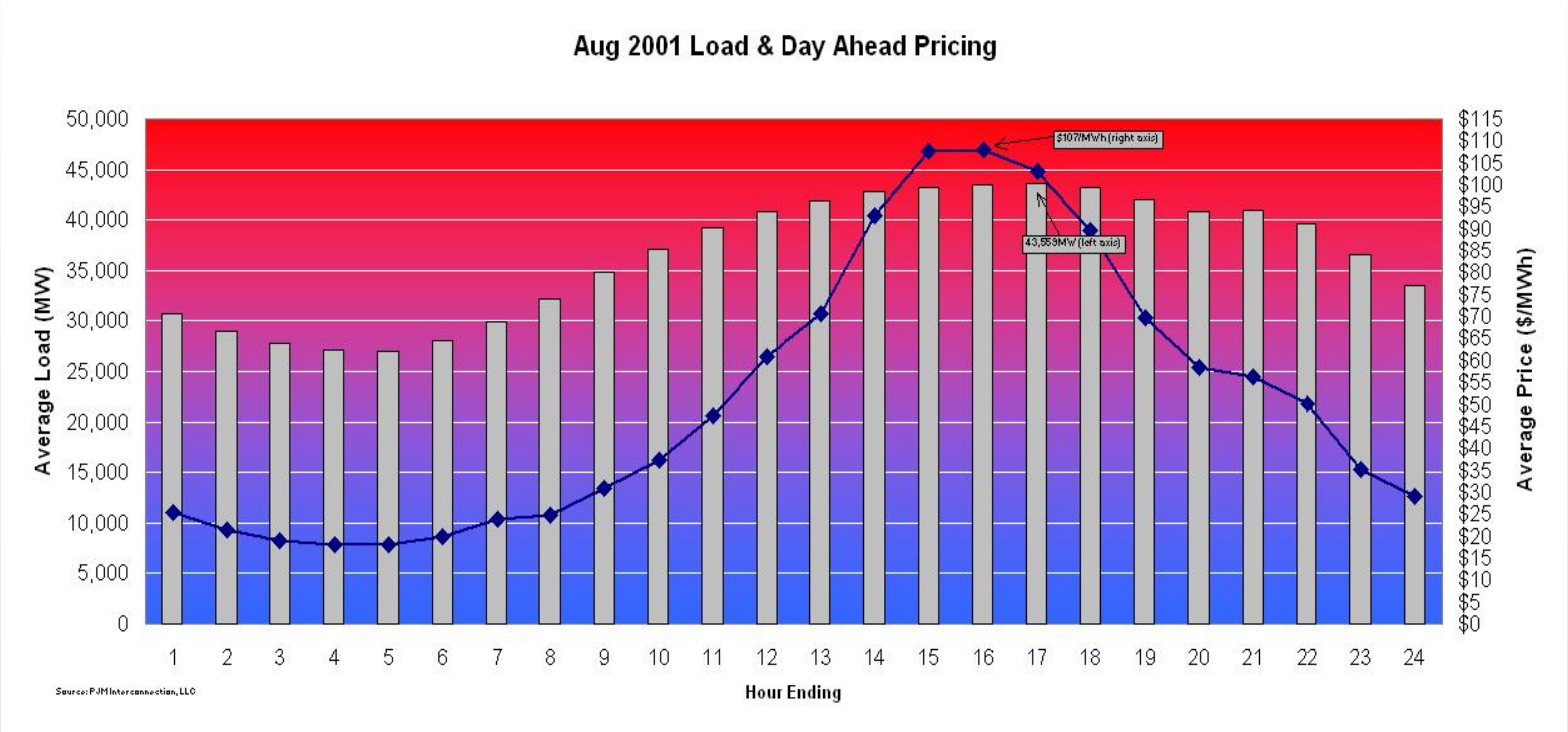
As Power Demand Increases During Hot Weather Electricity Prices Go Up



This example shows the cost of electricity can be up to 4 times higher in peak periods as in off-peak . Rates can be even higher depending on scarcity of supply.

PJM Interconnection LLC

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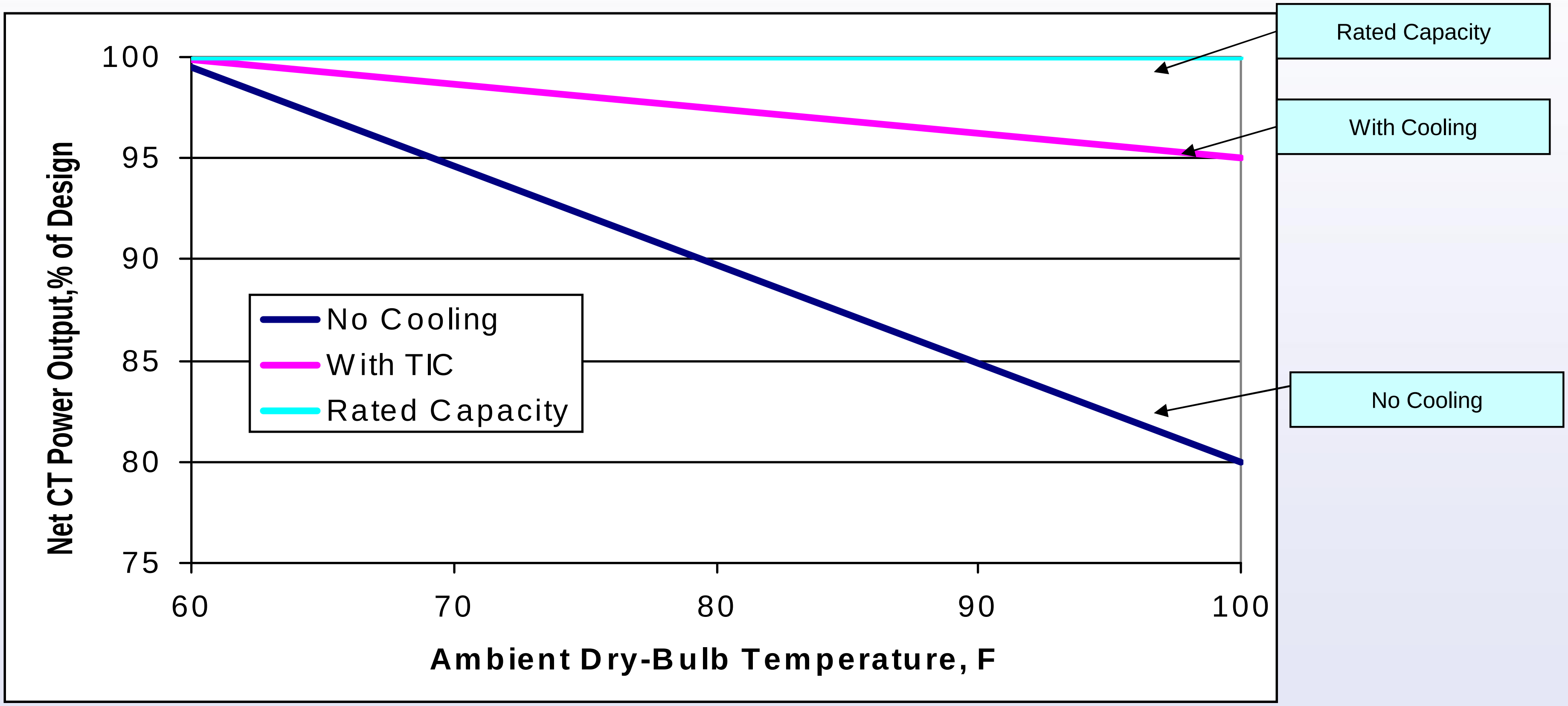
Turbine Inlet Cooling (TIC) Overcomes the Effects of Hot Weather on CT Plants



Punwani 2005

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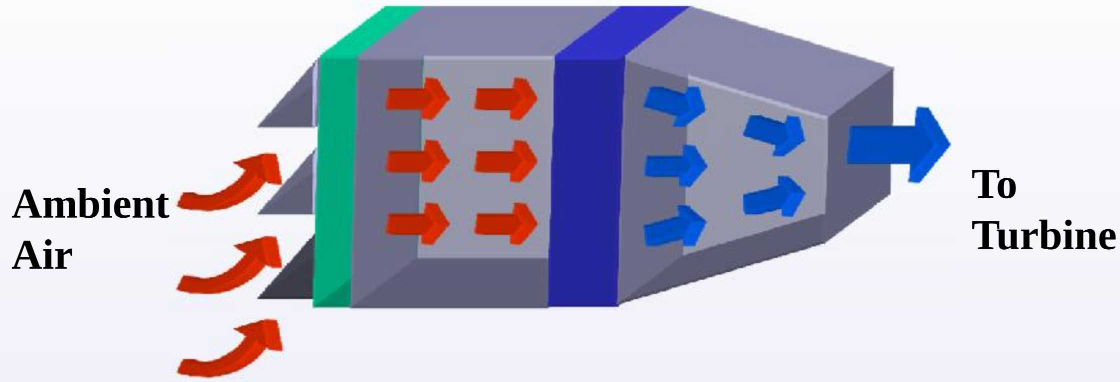
TIC Technologies are Simple and Proven



- **TIC is simple**
  - Cool the ambient air before it enters the turbine
  - Same process as cooling air before it enters buildings
- **TIC technologies are proven as thousands of plants worldwide utilize TIC**
  - TICA website shows plants benefiting from TIC

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TIC Technology Options

- **Evaporative Systems**
  - Wetted Media, Fogging or Indirect
- **Chiller Systems**
  - Mechanical or Absorption
- **Chillers + Thermal Energy Storage**
- **Wet Compression System**
- **LNG Vaporization System***
- **Hybrid Systems**

***Where Liquefied Natural Gas (LNG) is available**

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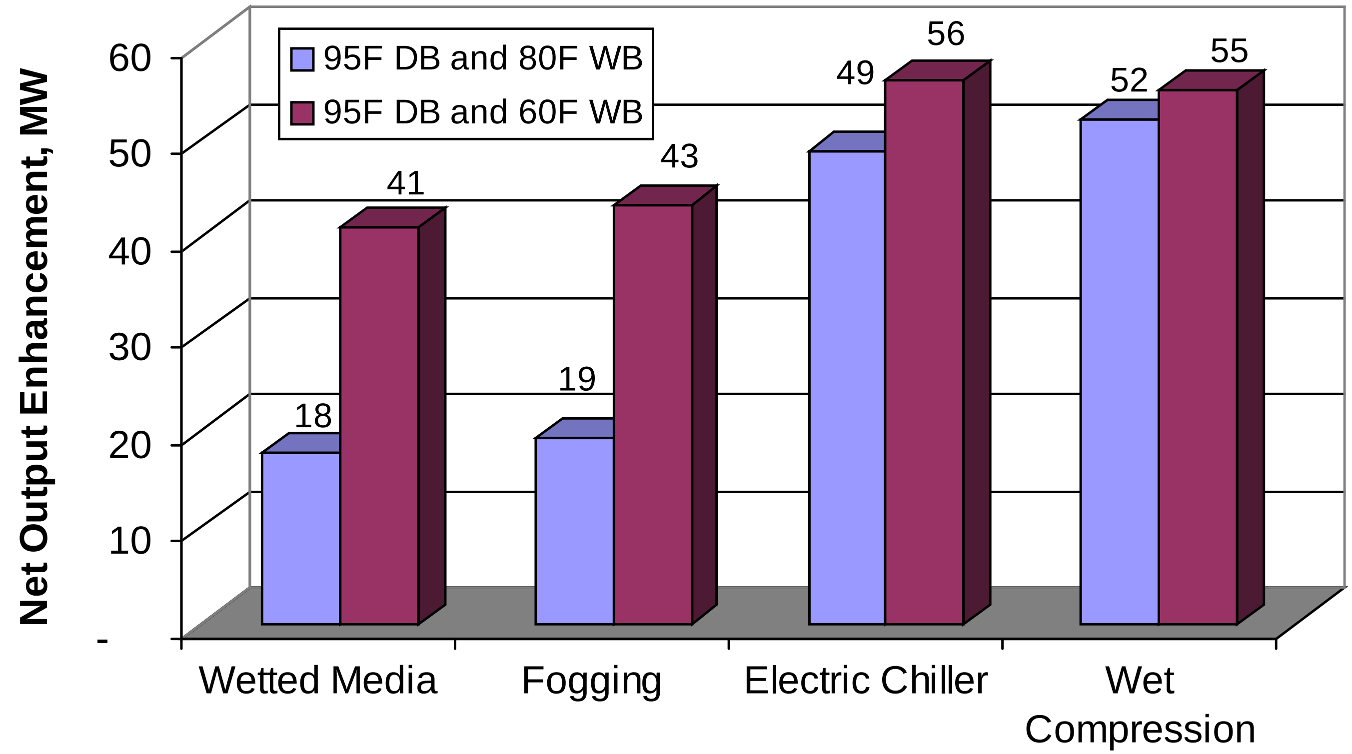
Examples of how TIC Technology Enhances Energy Output



Combined-Cycle System: Two 501FD1 and one ST

Sources:

Wet Compression: Caldwell Energy, Inc.

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

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Ability of TIC to Enhance a CT's Energy Output Depends on Several Factors

- CT Design, Location, and Altitude, among others
- Weather Data (dry-bulb and coincident wet-bulb temperatures) for the geographic location of the CT
- Selected ambient design conditions
- The TIC Technology selected
- Selected cooled air temperature (if allowed by the TIC technology)
- TIC parasitic load
- Pressure drop across the component inserted upstream of the compressor (insertion loss)

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Power Plants that Burn Fossil Fuels

- **Are significant producers of carbon dioxide and other GHGs and pollutants**
- **There are two types of fossil fuel power plants:**

  1. Burn fuel to produce steam for steam turbines ~~to produce electric power~~ or
  2. Burn oil or gas directly in combustion turbines (CTs) ~~to produce electric power~~

- Power plants that burn coal produce the most emissions (lbs/MWh)
- Power plants that use natural gas in CTs produce the least emissions (lbs/MWh)

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Emissions of Various Power Plants

	TIC Candidates			Existing Older Plants
Unit Type	CHP/Cogeneration	Combined-Cycle CT	Simple-Cycle CT	Boiler + Steam Turbine (STG)
Prime Mover	Frame CT	Frame CT- STG	Frame CT	Condensing STG
Fuel	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Plant Age (Yrs)	< 5	< 5	< 5	> 30
CT Heat Rate (Btu/kWh)	10,750	7,000	10,750	13,000
Generation Capacity (MW)	100	100	100	100
Hours of Operation	1	1	1	1
Themal Energy Need, MMBtu	465	465	465	465
Fuel Use, MMBtu				
Power Generation	1,075	700	1,075	1,300
Thermal Use (1)	0	547	547	547
Total	1,075	1,247	1,622	1,847
Energy Efficiency, %				
Electric Power Generation	32	49	32	26
Overall Energy Efficiency, %	75	71	55	48
Carbon Emissions, Tons	17.0	19.8	25.7	29.3

Notes

1. CHP provides thermal energy from the CT Exhaust without using additional; Other systems use 85% efficiency boilers for providing thermal energy needs.

Source: EPA and Pasteris Energy, Inc.

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Power Plant Priority of Use to Reduce Emissions

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

1. CT in combined-cycle system - lowest heat rate/highest energy efficiency
2. CT in simple-cycle system
3. Old steam turbine system - highest heat rate/ lowest energy efficiency

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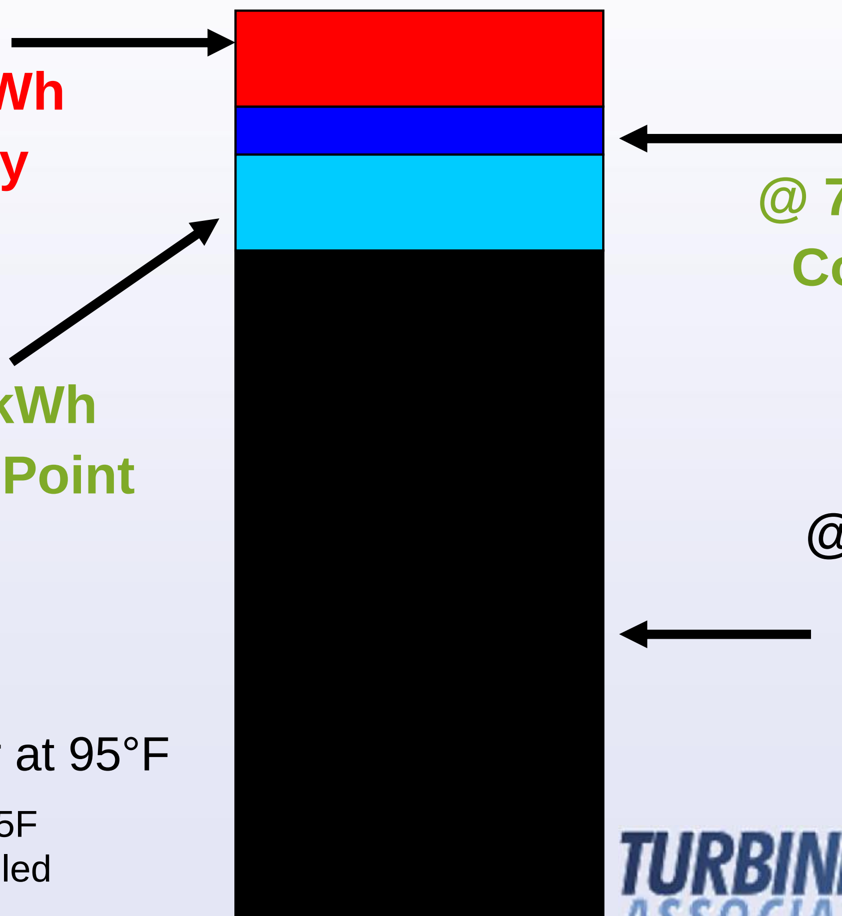
Preferred Dispatch Order for a Combined-Cycle System using TIC



73,394 kW
@ 8,440 Btu / kWh
Supplementary
Duct Firing

16,874 kW
@ 7,894 Btu / kWh
Cooling to 50°F

36,865kW
@ 6,799 Btu / kWh
Cooling to Dew Point

452,183 KW
@ 6,371 Btu / kWh
Base Case

Dispatch Order at 95°F

Basis: GT pro model at 95F DB/78F WB with inlet chilled 207FA.
Source: TAS

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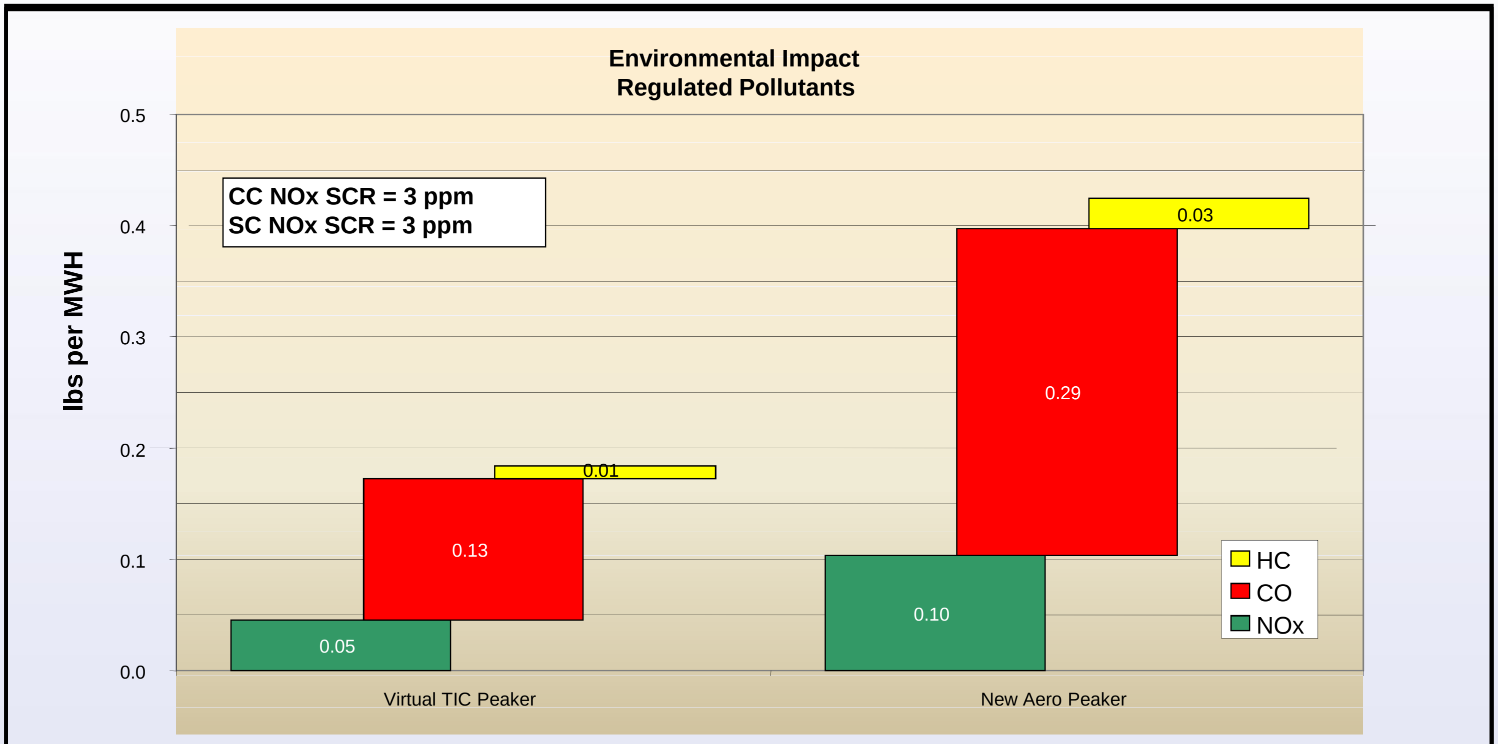
TIC Reduces Regulated Pollutant Emissions



TIC Reduces Total Emissions (lbs/MWh) by Over 50%

Basis: Total of all pollutants (lbs/MWh), LM6000PC-Sprint with hot SCR & TIC vs. incremental MWH from combined cycle 207FA with TIC added (Source: TAS)

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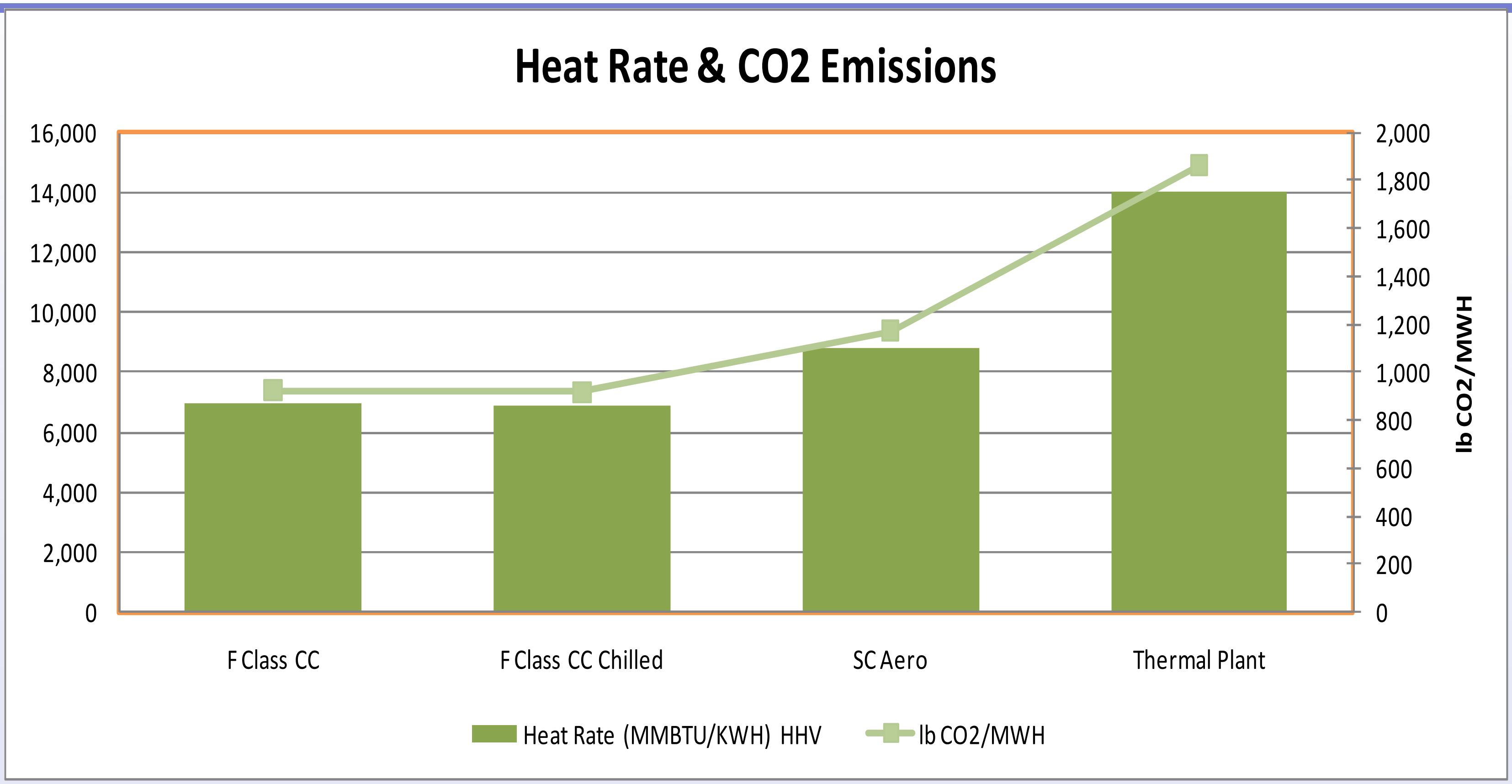
Turbine Inlet Cooling Reduces CO_2 Emissions



Basis: 95°F DB and 78°F WB

Source: TAS

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Turbine Inlet Cooling Environmental Benefits

- **Reduces need to run less efficient peaking plants that have greater emissions than gas turbine plants**
  - Reduces carbon footprints for the grid
  - Reduces emissions of greenhouse gases including carbon dioxide (CO_2) and other pollutants
- **Minimizes the need for new generation capacity**
  - Delays or avoids environmental impacts of siting and construction
  - Delays or avoids a new source of emissions

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Turbine Inlet Cooling
Reduces Need for New Power Plants

- **TIC used on CTs in combined-cycle (CC) systems reduces the need to operate CTs in simple-cycle (SC) systems**
- For example, TIC used in a 500 MW CC plant eliminates the need for a 40-50 MW SC peaking plant
- TIC eliminates costs associated with siting, construction and interconnection of a new plant

Turbine Inlet Cooling Economic Benefits

- Generates more MWhs during peak demand in hot weather
- Reduces the amount of fuel used per kWh by up to 15%
- Increases electric power output which reduces effective capital cost per unit of capacity as compared to constructing a new power plant
- Reduces use of peaking plants that are generally more costly to operate (due to lower efficiency) and produce more emissions than gas turbine systems using TIC
- Reduces ratepayer costs since lower capacity payments are required from independent system operators (ISOs) to power producers
- Increases baseload supply which enhances economic development

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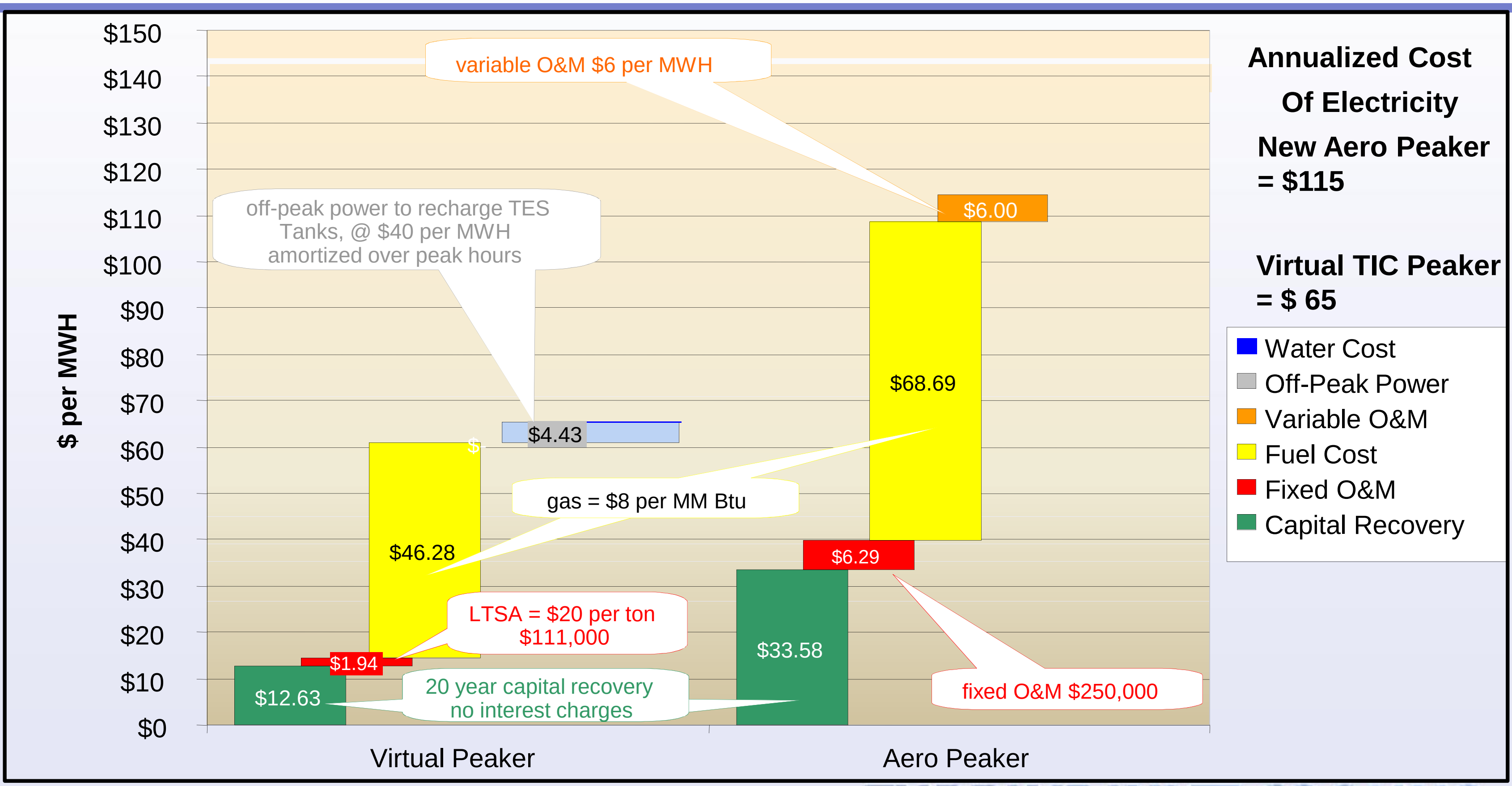
A Comparison of Turbine Inlet Cooling Economic Benefits



Basis: LM6000PC-Sprint with hot SCR & TIC vs. incremental MWH from combined cycle 207FA with TIC added. (Source: TAS)

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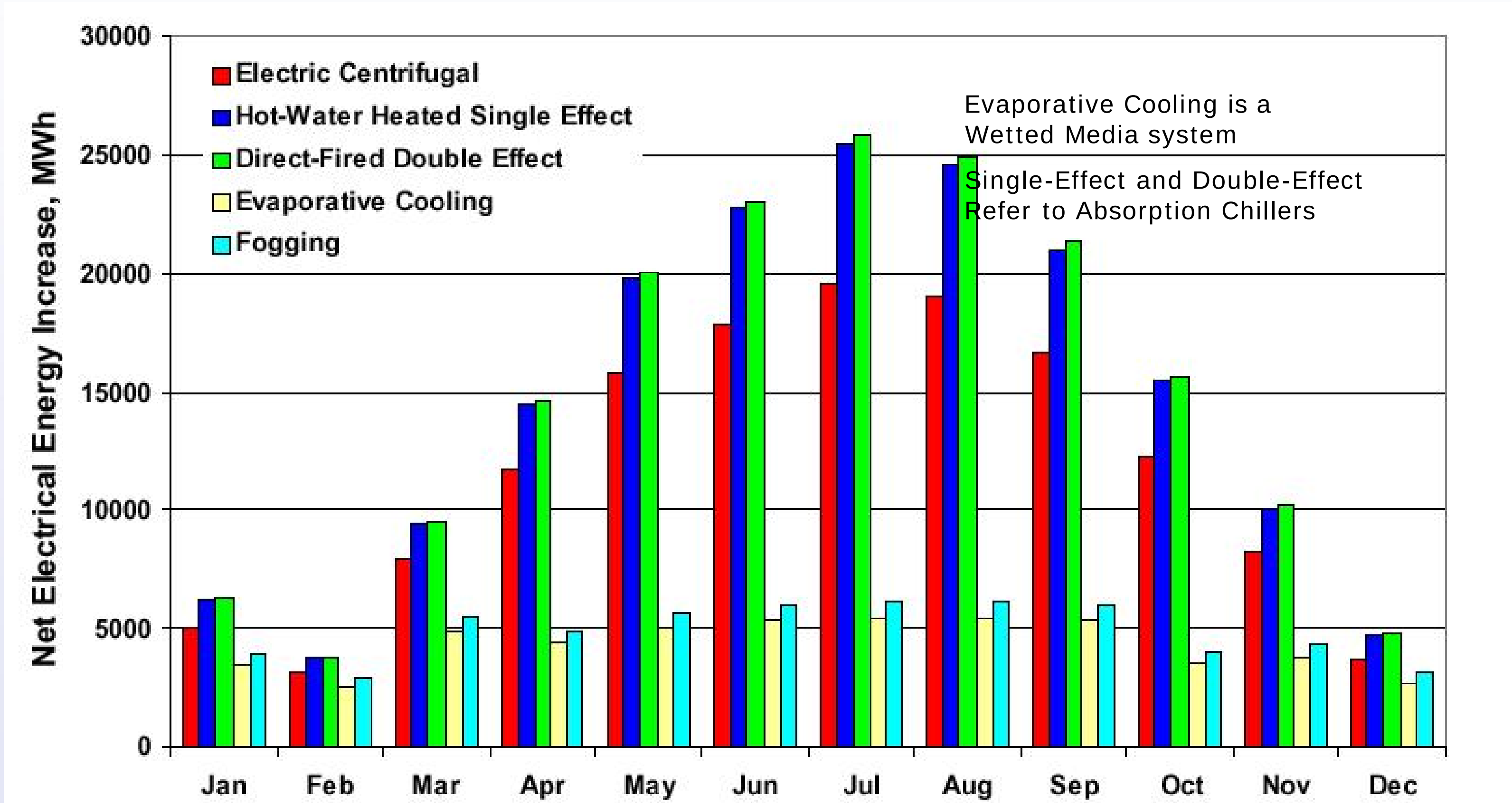
Monthly Incremental Electric Energy Provided by Some TIC Technologies
(316 MW Cogeneration Plant Near Houston, TX)



Source: D.V. Punwani et. al. Presented at ASHARE 2001

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Overall Benefits of TIC

TIC increases electric energy production during hot weather and reduces emissions of GHGs per unit of electricity produced. Plus TIC:

- **Provides the grid with up to 31,000 MW more electric power by generating more electricity from combined heat & power (CHP), combined-cycle (CC) and simple-cycle (SC) plants**
- **Is readily implemented within 6-18 months**
- **Reduces generation costs saving money for producers and ratepayers**

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Suggested Regulatory and Policy Positions

- ✓ **Regulators should recognize TIC is a valuable solution to their supply problem during hot weather and**
  - **Use** the full potential of existing combustion turbines plants
  - **Require** TIC use before allowing construction of new capacity
  - **Ensure** capacity payments provide appropriate returns for systems using TIC
- ✓ **Policymakers should recognize the value of TIC and**
  - **Exempt** plants that retrofit with TIC from environmental re-permitting since TIC results in plant emissions similar to those in winter (TIC yields winter performance in summer) so no permit changes should be necessary
  - **Create** incentives for plant owners to use TIC technology

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Conclusions

TIC is a valuable tool to increase electric energy production during hot weather

TIC provides regulators an important, easy to implement tool that quickly adds supply to meet demand

TIC provides economic and environmental benefits

TIC is a useful tool for ratepayers, the environment, plant owners and regulators

Cooling the air to gas turbines makes good sense

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