TURBINE INLET COOLING

A VALUABLE TOOL TO *INCREASE* ELECTRIC ENERGY PRODUCTION

A White Paper

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TURBINE INLET COOLING ASSOCIATION turbineinletcooling.org

427 Prairie Knoll Drive
Naperville, IL 60565 USA
Phone: 630-357-3960
Fax: 630-357-1004
Email: Exedir@turbineinletcooling.org

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ABSTRACT

This paper discusses Turbine Inlet Cooling (TIC) and how it can augment electric power generation by maximizing production from existing combustion turbine (CT) power plants during hot weather. TIC not only increases electric energy production when power demand is high, but it is also commercially-proven to create economic and environmental benefits for plant owners and ratepayers across the globe. During hot weather, without TIC, a CT's power output can drop as much as 35% below its rated capacity (All CTs are rated at 59^{o}F) . The U. S. Department of Energy estimates that capacity of gas turbine plants in the U.S. is diminished by more than 31,000 MW during hot weather, **just when demand is at its peak**. TIC substantially reverses this MW loss by cooling the ambient air at intake and allowing CT plants to run closer to their rated capacities. TIC also improves fuel efficiency of CT plants by as much as 15% which considerably reduces fuel use per MWh. Thus, TIC leads to reduced plant fuel costs and lowers emissions of carbon dioxide and other greenhouse gases (GHG). Moreover, TIC can reduce the need to use less efficient peaking plants to meet power demand. Such peaking plants burn more fuel per MWh and are, therefore, most costly to operate and produce more noxious emissions compared to CT power plants. The related costs and environmental impacts of building new generation capacity are delayed or avoided totally by using TIC. The attention of regulators and policymakers has been diverted from consideration of simple technologies that help resolve basic supply concerns by electric deregulation issues, the worldwide demand to reduce GHGs, and the need to use and integrate renewable energy sources. Nonetheless, electric demand will continue to grow. TIC is a common-sense, cost-effective technology that regulators and policymakers should recognize as a valuable tool to increase electric energy supply during hot weather and quickly help meet growing demand.

BACKGROUND

ELECTRIC POWER DEMAND

Despite challenging economic conditions worldwide, the demand for electricity is increasing. It will continue to escalate as populations and economies grow. Yet, concerns regarding energy stability challenge governments throughout the world as political and armed conflicts create unrest. Major challenges for policymakers and regulators include assuring safe, appropriate energy sources; maintaining an adequate supply; reducing costs; and limiting harmful environmental effects.

Moreover, supplies have been affected by climate issues as leaders have been forced to reduce reliance on coal for environmental concerns. In addition, China's enormous commitment to economic growth requires vast new energy resources directed there. Developing new alternative energy sources, including renewable energy systems, and advancing existing reliable base load sources have become vital considerations to maintain supply. Natural disasters are also a factor as seen with Japan's tsunami, and its forced shutdown of some nuclear reactors. That disaster prompted Germany to commit to closing nuclear facilities and rely totally on other sources, particularly renewables. In the U.S., after many decades of wariness, there seems to be a move toward increasing nuclear power's percentage of energy supply. However, the abandonment of the Yucca Mountain Nuclear Waste Repository, and recent fires and floods in the country that threatened nuclear facilities, serve to renew concerns about expanding nuclear power.

Meeting demand growth is a critical concern for policymakers and regulators everywhere. Choices are complex and each alternative source of supply has limitations. Perhaps, then, the easiest option available is to examine existing generation sources in an effort to expand and capture all megawatts optimally possible. TIC makes this happen.

The Old Regulatory Paradigm

Historically, regulators and owners responsible for assuring electric power generation had one primary concern – adequacy of supply. They focused on developing 10-year plans to meet anticipated demand growth. The regulators were also required to assure that generation growth met the mandated goal of "just and reasonable" costs per kilowatt hour (kWh). However, they expected that ratepayers – those forcing growth – would pay the costs of all new generation. Much has happened since the old supply- and demand- driven days.

Regulators' New Challenges

Today, as a result of deregulation in some markets, generation supply and its future are under the purview of energy companies whose primary goal is maximization of profit. Also, the world has become aware of the need to reduce emissions of GHG and other pollutants and the significance of climate issues. States have mandated Renewable Portfolio Standards (RPS) to broaden supply sources and promote the use of renewable energy over fossil fuels. Hence, policymakers and regulators have had to focus on crafting solutions to these new issues.

However, experts say that even with maximum efforts, the U. S. will rely on coal and other fossil fuels for base load supply well into the future. Therefore, the need to satisfy future demand remains unchanged and is still a perplexing, critical issue. Quick and easy source solutions are not possible and are further complicated by lack of a comprehensive energy policy in the U.S. A patchwork of legislative and regulatory initiatives, as well as court directives, attempts to resolve energy and pollution concerns. Some tax policies and grant programs that promote the development and use of alternative sources such as solar, wind and biomass are helpful. Support exists for efforts to reduce demand through conservation tools such as Energy Star products, Smart Meter, and Smart Grid technologies. **However, the promotion of methods that can maximize production from existing electric power generation sources today is lagging**.

ELECTRIC POWER SUPPLY

Critical energy demands confront policymakers, regulators, and plant owners across the globe. They must reply to this crucial question: How do you meet anticipated demand? One important answer to this supply question that is often overlooked today is "We must maximize electric energy production at existing combustion turbine plants".

Loss of Electric Power Supply

The U. S. Department of Energy has determined that existing CT plants in the U.S. lose over 31,000 MW of generation capacity during peak demand periods due to the deleterious effects of hot weather. Increased temperature of the ambient air reduces the flow of air into the turbine. Thus, a CT can lose as much as 35% in output below its rated capacity (All CTs are rated at 59°F). This fact alone suggests that policymakers and regulators can and should, as part of their supply solutions, seek to identify and utilize technologies that assure maximum production of electric power from existing CT power plants. Any tool that allows for greater kWh of output to the electric grid from existing CT plants during summer peak demand provides huge benefits to plant owners, ratepayers and regulators alike. There is a corollary benefit to the environment as well.

Turbine Inlet Cooling Increases Electric Energy Production

Cool the Air

TIC is a common sense tool that increases electric power production by negating the effects of hot weather on CTs. TIC is easy to implement and helps to maximize electric supply availability, saves fuel, cuts costs, and reduces overall emissions. This is accomplished by **Cooling the Inlet Air** of the CT plants. This cooling process allows the turbine to run more efficiently and function closer to its rated capacity. Therefore, more output is achieved by the turbine using less fuel per MWh. Existing plants become even more important players in meeting heightened electricity demand as temperatures rise.

TIC Reduces Peaking Plant Use

The decreasing order of efficiency of electric power generation and thermal energy use is cogeneration, combined-cycle, simple-cycle and old steam turbine systems. Decreasing efficiency of a system means more fuel is burned with higher emissions of GHG per MWh of electric energy. Employing TIC on higher efficiency systems minimizes the need to operate lower efficiency systems to meet power demand. TIC allows CT plants to produce electric energy in quantities closer to their winter output.

Enhancing the electric energy production from existing high-efficiency CT plants reduces the need to employ peaking power plants that are usually less efficient, more costly and give off greater GHG emissions than CT plants. While peaking plants remain critical to meeting peak demand today, some are targeted for expensive upgrades in order to reduce their enormous outputs of GHG and other noxious pollutants. Others are scheduled to be mothballed due to age and inefficiency. These facts support the need to augment supply from existing power plants to meet peak demands.

TIC is proven to enhance generation capacity as much as 35% and increase energy efficiency by as much as 15% in CT plants during hot weather. When TIC is combined with thermal energy storage (TES), which shifts some of the chillers load to the off-peak hours, additional electric energy is made available due to reduced TIC parasitic load during the on-peak period.

Since the output capacity of CT plants differs so substantially between high output during winter and the lower output during summer, recovering such a large amount of capacity without the use of peakers is a major achievement. Those responsible for assuring supply will meet demand at a just and reasonable price can and should recognize the importance of implementing TIC today and discovering its value.

Further, TIC reduces the need to add new generation capacity thereby avoiding or reducing investment capital for new construction. In turn, the frustrating process for locating sites and the associated environmental effects of new plants are avoided.

TIC Reduces Emissions and Shrinks Carbon Footprint for Power Generation

As major efforts are underway worldwide to reduce carbon footprints and lessen the release of GHGs and pollutants in the atmosphere, TIC technology becomes an important tool in that effort. A report from the President's Council on Science and Technology (November, 2010) regarding the pace of change in technology asked: "Fundamental Question: Can we significantly decrease energy and carbon intensity while accommodating needed economic growth? Is technology the solution?"

TIC technologies offer such a solution by reducing fuel use which lessens the release of carbon dioxide and other GHG. The net effect is to shrink carbon footprints of electric power generation. TIC is also extremely useful as it helps avoid the use of less efficient and higher emission peaking plants and delays the need for new capacity construction fraught with environmental issues.

TIC is an Important Tool for Regulators, Plant Owners and Ratepayers

TIC Increases Electric Energy Production

Speaking to the Energy Conference of the Energy Information Administration in 2011, an EPA official said "The overall goal is to provide positive environmental outcomes for the public and provide industry with greater certainty using common sense and flexible solutions that are reasonable and achievable". TIC does provide certainty. For those challenged with the responsibility of assuring that supply meets demand and carbon impact and emissions are limited, TIC technology is worth pursuing.

TIC suppliers are available to discuss how TIC reduces costs and augments power sources, and they can determine which TIC option best meets the needs of a particular plant. Policymakers, regulators, plant owners and ratepayers are encouraged to understand the value of TIC technology. It is a **WIN*WIN*WIN** !

DISCUSSION

THE PROBLEM OF DEMAND and SUPPLY

Most of the world experiences power shortages sometimes. Generally, these shortages occur during hot weather. The criticality of demand and the relentless need for supply is most evident during hot summer months. According to the U.S. Department of Energy, over 31,000 MW of electric power generation capacity is lost during summer, as shown in Table 1, as compared to winter capacity.

Over 31,000 MW of Electric Power Capacity LOST During Summer

Fuel	Winter Capacity, MW	Summer Capacity, MW	Loss in Summer Capacity, Relative to Winter Capacity, MW
Coal	316,363	314,294	2,069
Petroleum	60,878	56,781	4,097
Natural Gas	432,309	401,272	31,037

Table 1 U.S. Power Generation Capacity during Winter and Summer (EIA 2009)

CT- based generation plants also lose up to 15% operational efficiency during hot weather. The effects of the hot air prevent the plants from performing up to their winter standard. Reducing the negative effects of ambient air increases by cooling air at intake during hot summer months makes sense. Such cooling can restore the lost MWs and make available to the grid much of the capacity that is normally available in winter.

Thus, TIC facilitates increasing supply from existing CT plants in order to meet peak demand. This means that if TIC were installed on all CTs in the United States, new construction would not be necessary to augment the existing generation fleet to meet present summer demand. **Up to 31,000 MW of lost supply can become readily available by the use of TIC.**

Summer Peak Loads

There continues to be increased demand for electricity. During summer, hot ambient air and high humidity result in large electric power demand due to increased load caused by air conditioners for space cooling. These heat-related effects also result in decreased output of electric capacity by up to 35% for all CT systems. Thus, high ambient air temperature is the causative factor for both the need to use air conditioning and the decreased ability of CTs to provide their rated capacity.

Figure 1 shows a typical hourly electric power demand profile for a day in the state of California. It reveals how the various types of power demand loads contribute to almost **doubling demand** from the early morning to the late afternoon peak. The air conditioning load can be seen as the largest "adder" to the power demand during the peak period. Similar hourly electric power load profiles are likely in other parts of the U.S. and, indeed, the world.

Air Conditioning Load is Largest Adder to Peak Demand

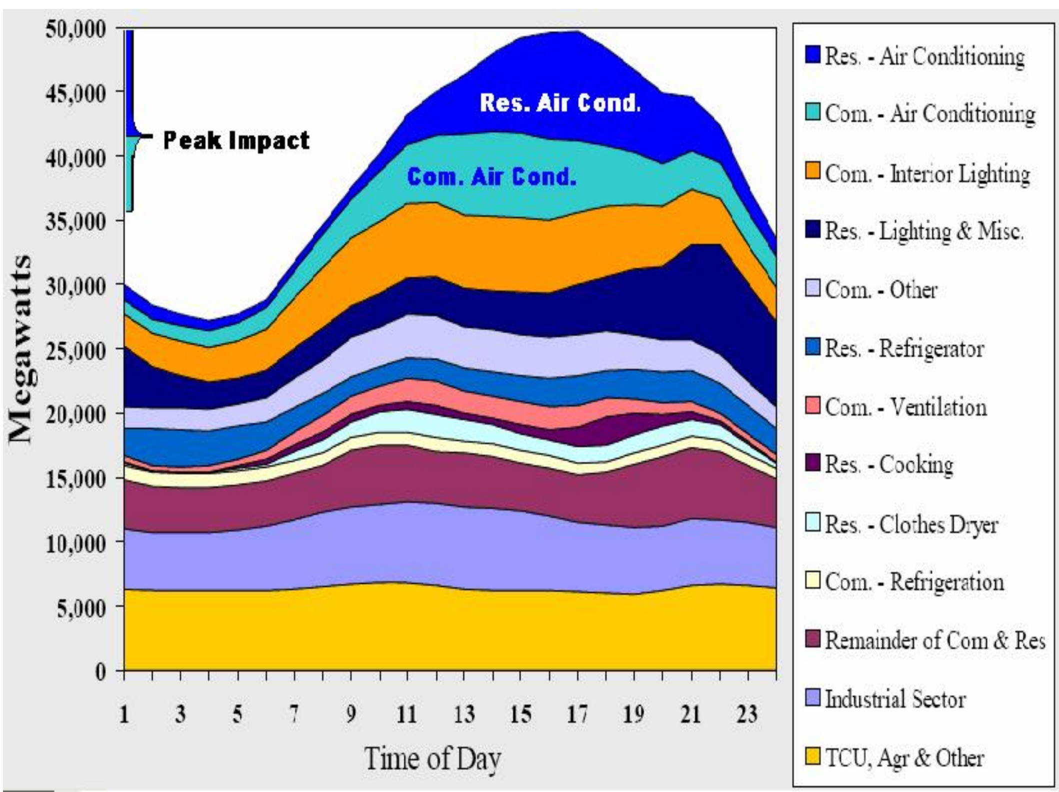

Figure 1 Typical Hourly Load Profile in California (Duncan 2007)

Most of the reduced electric power generation capacity is lost due to the operating characteristics of CT plants. Even though CT power plants can be very energy efficient as discussed earlier, they do have one unfortunate characteristic: **Their output and efficiency decrease with increases in ambient air temperature, as shown in Figure 2.**

It shows that generation characteristics of the CT cause a widening gap between generation capacity and power demand as the ambient temperature rises. Power supply capacity is lost when demand is the greatest.

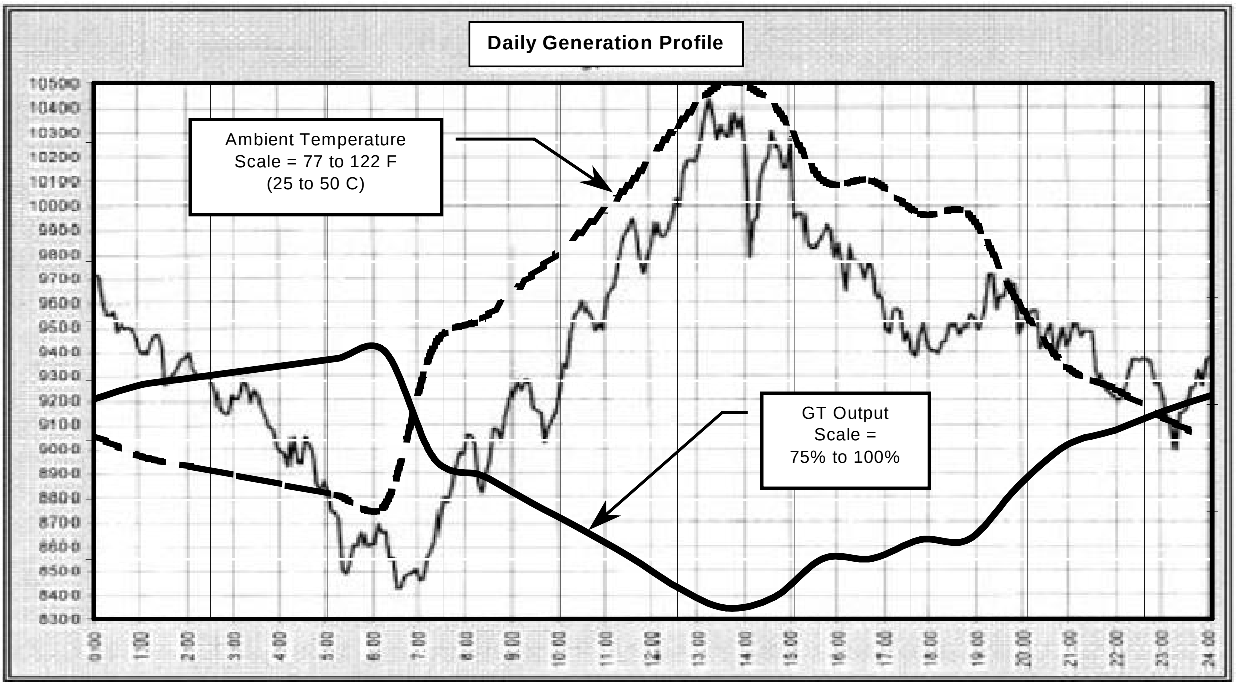

Figure 2 Typical Hourly Profiles for Power Generation by CTs and Power Demand (Punwani 2005)

At the most critical time when ambient air temperature is high, all CT systems confront decreased output and cannot achieve their rated capacity. Heated ambient air reduces a CTs generation capacity by as much as 35% of its rated capacity.

High summer temperatures also reduce energy efficiency of a CT by as much as 15% of its rated efficiency. Therefore, any technology that can intervene in this scenario to allow CTs to run closer to their rated capacity and efficiency should be welcomed by plant owners, regulators, policymakers and ratepayers alike.

TIC is a Solution

TIC is such a technology and is readily available for installation. If TIC were installed on all CTs in the United States, the construction of up to 31,000 MW of new capacity to augment the existing generation fleet could be avoided.

Generation Supply

The net effect of hot ambient air is that it increases power demand but reduces generation capacity of CT plants. In order to rapidly meet that need and provide supply, base load generators must be augmented by bringing peaking plants online. Most electric power in the U.S. is generated by fossil fuels: coal, oil or natural gas. The majority of these power plants either:

- Burn natural gas or oil directly in a CT that is connected to an electric generator, or
- First burn natural gas, oil or coal in a boiler to produce steam that is used to operate a steam turbine connected to an electric generator

CT power plants can be significantly more energy efficient than steam-turbine based plants. Electric power producers usually bring their most energy efficient power plants online first. However, to meet peak demand during summer, even the most inefficient power generation systems must also be activated. How different power generation resources are used on a typical day in California is shown in Figure 3. In states that do not have as much hydro power as California, more inefficient peaking power plants must be used.

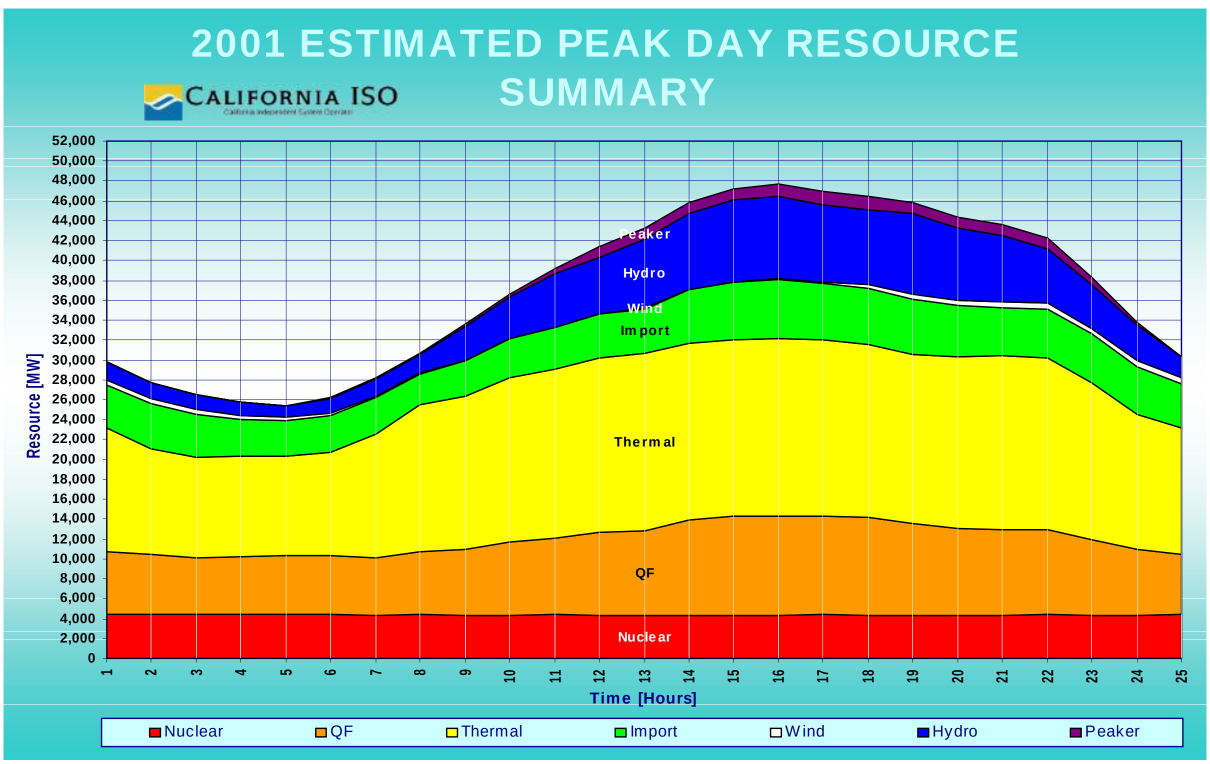

Figure 3 Contributions of Various Power Generation Technologies for Meeting Power Demand (Duncan 2007)

TIC is a Solution

TIC can relieve the need to bring peaking plants on line to assist in meeting peak demand. Existing generation capacity can be augmented by up to 31,000 MW during the hot summer months merely by adopting the TIC technology. It is both cost-effective and results in less emissions.

The PROBLEMS OF EFFICIENCY and EMISSIONS

Energy Efficiency

Power plants that use CTs are designed for operation in simple cycle, combined cycle or as cogeneration. In a simple-cycle system, the exhaust gases of the CT are vented to the atmosphere. In a combined-cycle system, the thermal energy in the turbine exhaust gases is recovered for producing steam that is used for operating steam turbines that produce additional electric energy. In a cogeneration system, also known as combined heat and power (CHP) system, some of the thermal energy in the CT exhaust gases is utilized directly as a source of heat at or near the site of the power plant.

Energy efficiency is the highest for CHP systems, followed by combined-cycle systems, simple-cycle and steam turbine systems. Hence, CHP systems have the smallest carbon footprint of any power generation system, and it is the largest for steam turbine systems.

Energy efficiencies of the various power plants:

- CHP/Cogeneration ranges are 65% to 75%
- Combined-cycle ranges are 48% to 52% or heat rates of 6,500-7,000 Btu/kWh
- Simple-cycle ranges are 34% to 42% or heat rates of 8,000 to 10,000 Btu/kWh
- Steam-turbines ranges are 23% to 42% or heat rates of 8,100 to 15,000 Btu/kWh

Generally, older plants have higher heat rates.

Higher heat rates = higher fuel use, greater cost, greater emissions.

Emissions and Carbon Footprints

Power generation by fossil fuels (coal, oil and natural gas) is one of the largest sources of GHG including carbon dioxide and other air pollutants.. A generation plant's emissions are proportional to the fuel burned per unit of electric energy. Higher energy efficiency power plants burn less fuel per unit of energy i.e. lower heat rate. Improving plant efficiency achieves two important goals: lower fuel cost and lower emissions.

TIC Reduces Emissions Cost-Effectively

	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
Thermal 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.

Table 2 Typical Carbon Emissions for Various Power Plants (EPA and Pasteris Energy, Inc.)

Table 2 shows typical carbon emissions from various power plants that utilize natural gas as a fuel. It shows that all CT-based power plants are more energy efficient than the old steam turbine system and the steam turbine system produces 29.3 Tons/hr. vs. 17.0 Tons/hr. for the CHP/Cogeneration system for the example in Table 2. Consequently, it shows that the less efficient old steam turbine power plant produces as much as **72% more emissions than a CHP/Cogeneration system.**

Figure 4 shows carbon emissions during a day in California. Even with California's large amount of hydro power added, the **carbon footprint of electric energy generated during on-peak is more than doubled when compared to off-peak.**

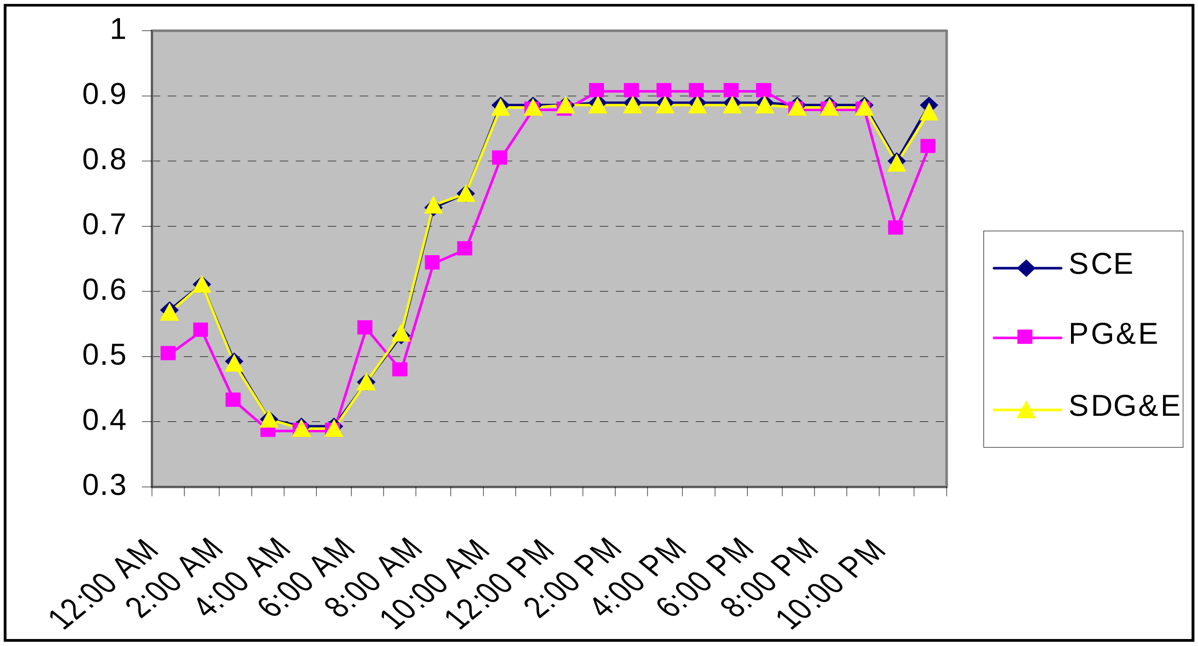

Figure 4 Carbon Dioxide Emissions for Electric Energy Generation during a Typical Summer Day (Duncan 2007) Note: Y-Axis Scale Shows lb. of CO_2/Kwh

TIC… Reduces Carbon Footprint

The reason carbon emissions are higher during on-peak is that low-efficiency peaking power plants are brought online to meet demand. To minimize emissions of carbon and reduce carbon footprints, the preferred order of operating fossil fuel power plants is cogeneration (CHP), combined-cycle, simple-cycle and steam turbine systems. This order reduces fuel use and related costs. Thus, to keep high carbon footprint steam turbine systems offline, it is important to prevent loss of generation capacity of efficient systems. Using TIC on CT-based systems during hot weather accomplishes that goal.

TIC is a Solution

After the recent UN Climate Change talks in Bonn and discussions about after the Kyoto Protocol expires in 2012, C. Brandon Fletcher noted "Many… are attempting to find a solution that has a quick return on investment, is financially viable in the current economic downtrend, and offers a strong reduction in energy costs." He supports utilizing "energy efficiency as the primary source of reducing GHG emissions in a manner that offers a return on investment in 3 years or less that can be a shared financed project". **TIC perfectly meets the description of such a technology**. The proposed U.S. Power Act of 2010 would regulate GHG using market-based mechanisms, efficiency programs and other economic incentives. Since TIC is proven to reduce emissions cost-effectively, it is a worthy candidate for federal incentives.

THE PROBLEM OF HIGH PEAKING COST TO RATEPAYERS LESSENED BY TIC

Use of inefficient plants also results in higher costs of electric energy to ratepayers. An example of the hourly power demand and electric energy profiles for markets where electric energy is deregulated, is seen in Figure 5. It shows that doubling the power demand from off-peak to the on-peak period increases electric energy price by a **factor of four**. This shows day-ahead market pricing for energy payment only.

Figure 5 An Example of Hourly Power Demand and Electric Energy Price Profile (Data Source: PJM Interconnection LLC)

For some deregulated generation markets, to balance the supply needed to meet unforeseen shortfalls, even larger variations between off-peak and on-peak prices are seen. The high price for balancing power is normally for a short period, but the price can exceed $4,000/MWh as in ERCOT in 2008. One reason market prices can be volatile is due to less efficient peaking power plants that burn more fuel per MWh. **TIC reduces the need to operate these plants, cuts fuel use, helps reduce costs and peak prices.**

COMBUSTION TURBINE SYSTEM PERFORMANCE

CT-based systems are the preferred choice among fossil fuel power plants to minimize fuel cost and emissions and enhance efficiency. Numerous installations of these systems exist worldwide. However, all CT systems have a major drawback: when temperatures go **UP**, generation capacity goes **DOWN**, as shown in Figure 6.

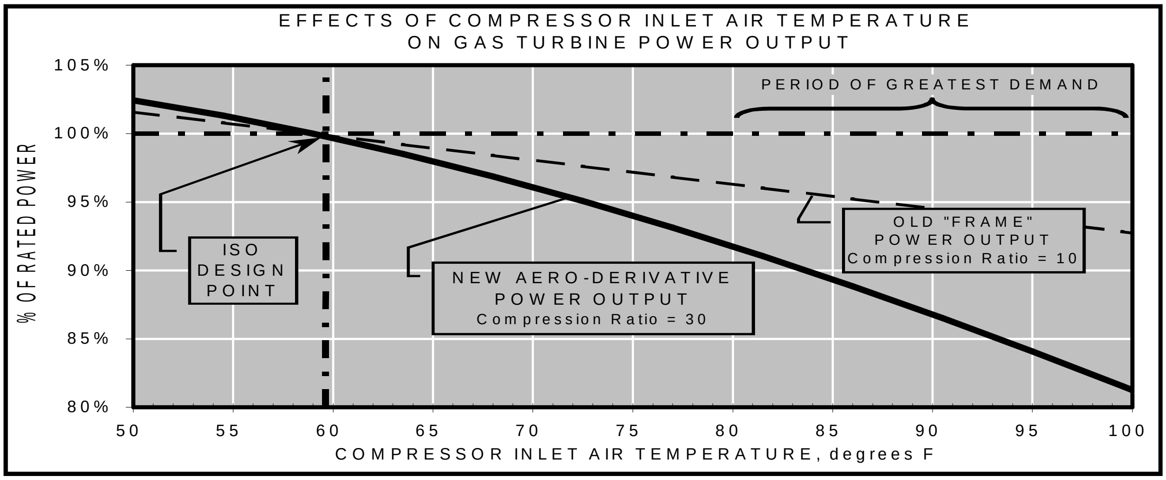

Figure 6 Effect of Ambient Air Temperature on CT Power Generation Capacity (Punwani 2005)

Typical effects of ambient air temperature on CT heat rate (efficiency) are shown in Figure 7 for two classes of turbines: frame and aeroderivative. The effects of higher temperature are readily seen in these figures.

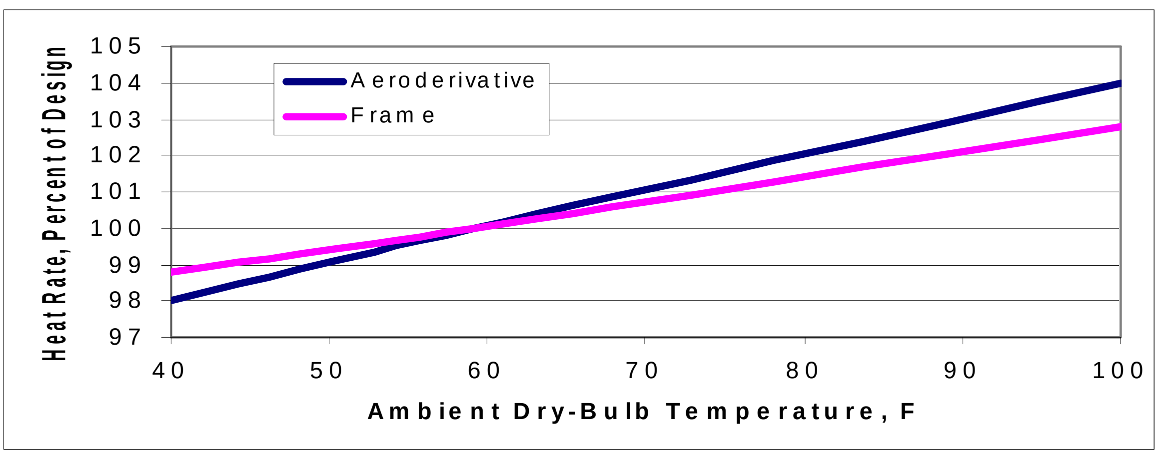

Figure 7 Effect of Ambient Air Temperature on CT Heat Rate (Efficiency) (Punwani 2005)

Hot Weather Affects Combustion Turbine Operations

Each CT is designed to intake a fixed maximum volumetric flow rate of ambient air. **CT energy output is dependent on the mass flow rate of the inlet air to the system**. Anything that decreases that flow rate disrupts energy output.

Therefore, the reason a CT's power generation capacity decreases with increased ambient temperature is because hotter temperatures decrease air density. The same volumetric intake of air has a decreased mass flow rate and reduces the plant's energy production capacity.

Power generation capacity and the heat rate of a CT always depend on ambient air temperature. Thus, each CT has a rated capacity to generate energy that is based on an ambient dry-bulb temperature of 59°F at 60% relative humidity at sea level and an atmospheric pressure of 14.7 psia with zero pressure drops in the inlet and exhaust system. These rating conditions were selected by the International Standards Organization (ISO) and are accepted worldwide. There are additional characteristics of each plant that can also affect CT efficiency.

TURBINE INLET COOLING == INCREASED OUTPUT

To negate the adverse effects of increased ambient air temperature on a CT's performance, the solution is simple:

Cool Air - IN *Output* - UP

The use of TIC on efficient combined-cycle plants allows them to produce more electric energy at higher fuel efficiencies on hot days, rather than securing costlier electricity by dispatching an uncooled simple-cycle aero-derivative CT "peaker." Plus, when TIC is combined with thermal energy storage, there is a shift of some of the chiller's electric load to off-peak hours. Thus, additional electricity is made available during the peak period due to a reduced TIC parasitic load.

A typical effect of TIC on the power generation capacity of a CT when compared with an uncooled CT and its rated capacities is seen in Figure 8. TIC significantly overcomes the derating of the CT output capacity.

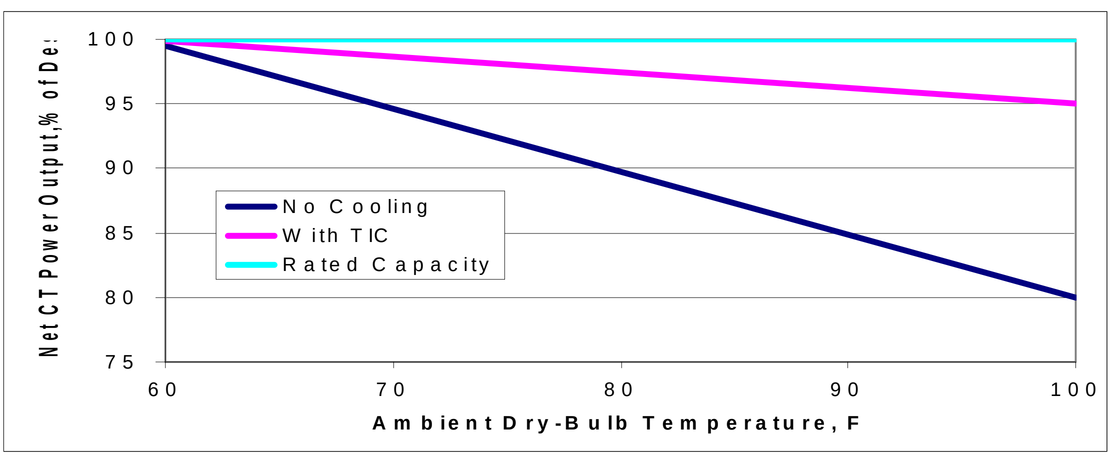

Figure 8 Effect of TIC Technology on a CT Power Generation Capacity (Punwani 2005)

TIC TECHNOLOGIES

The concept of TIC is very simple: ***Cool the Air*!**

Many companies provide a number of commercially-proven TIC technology options. The major TIC options are:

- Evaporative Cooling: wetted-media, fogging, or indirect
- Chillers: mechanical/electrical or absorption
- Chillers: with thermal energy storage
- Wet Compression
- Liquefied Natural Gas (LNG) Vaporization (applicable where LNG is available and can be vaporized)
- Hybrid

Each technology has its advantages. TIC provides power augmentation that can be used alone or together with other complementary augmentation technologies such as wet compression (Kraft 2006). Selection of the best technology for each plant requires evaluation on the basis of plant characteristics, location, fuel cost and market values of the electric energy and generation capacity.

TIC POWER CAPACITY ENHANCEMENTS and ECONOMICS

Considerable expertise is needed to select the TIC option that provides the best solution. The potential of TIC capacity enhancement and economics depends on:

- CT design and characteristics, including the impacts of inlet air temperature and ambient design conditions
- Pressure drop across the component inserted upstream of the compressor (insertion loss)
- Water usage and cost
- Hourly weather data, dry-bulb and coincident wet-bulb temperatures
- Hourly market value of electric energy and plant capacity
- Selected cooled air temperature upstream of compressor
- Fuel use and cost
- Power demand profile

TIC AT WORK REDUCING COSTS

TIC effectiveness in enhancing the capacity potential of a typical 500 MW combined-cycle system is seen in Figure 9. Evaporative cooling produces more capacity enhancement when relative humidity of the ambient air is lower. The chiller option provides the most capacity enhancement regardless of ambient air relative humidity.

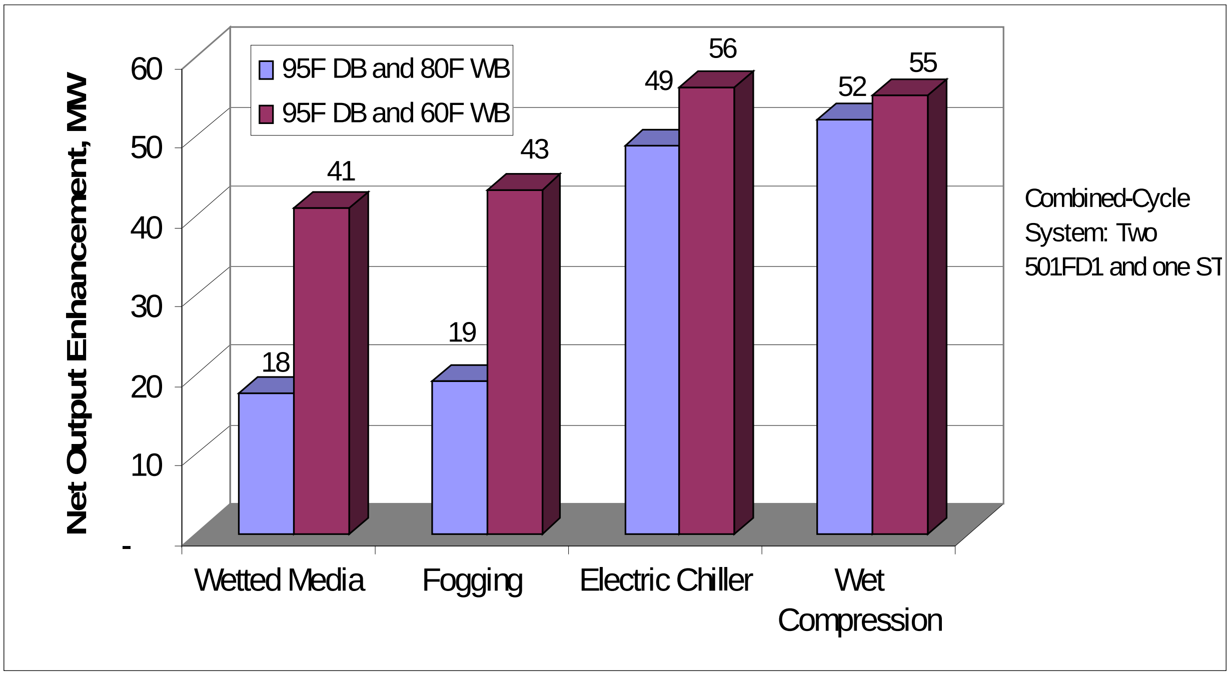

Figure 9 Effects of TIC Technology on Capacity Enhancement Potential (Source for Wet Compression: Caldwell Energy Company; Source for all others: Punwani 2008)

The preliminary estimates of TIC net capacity enhancements, shown in Figure 9, by evaporative cooling and chiller without thermal energy storage are made using ASHRAE calculation procedures (ASHRAE 2008), based on several rules of thumb. More accurate estimates may require sophisticated CT models as well as site-specific cost analyses.

Figure 10 shows how the implementation of some TIC options actually serves to greatly enhance the economics of a 316 MW cogeneration plant that is operational and located in Pasadena, Texas.

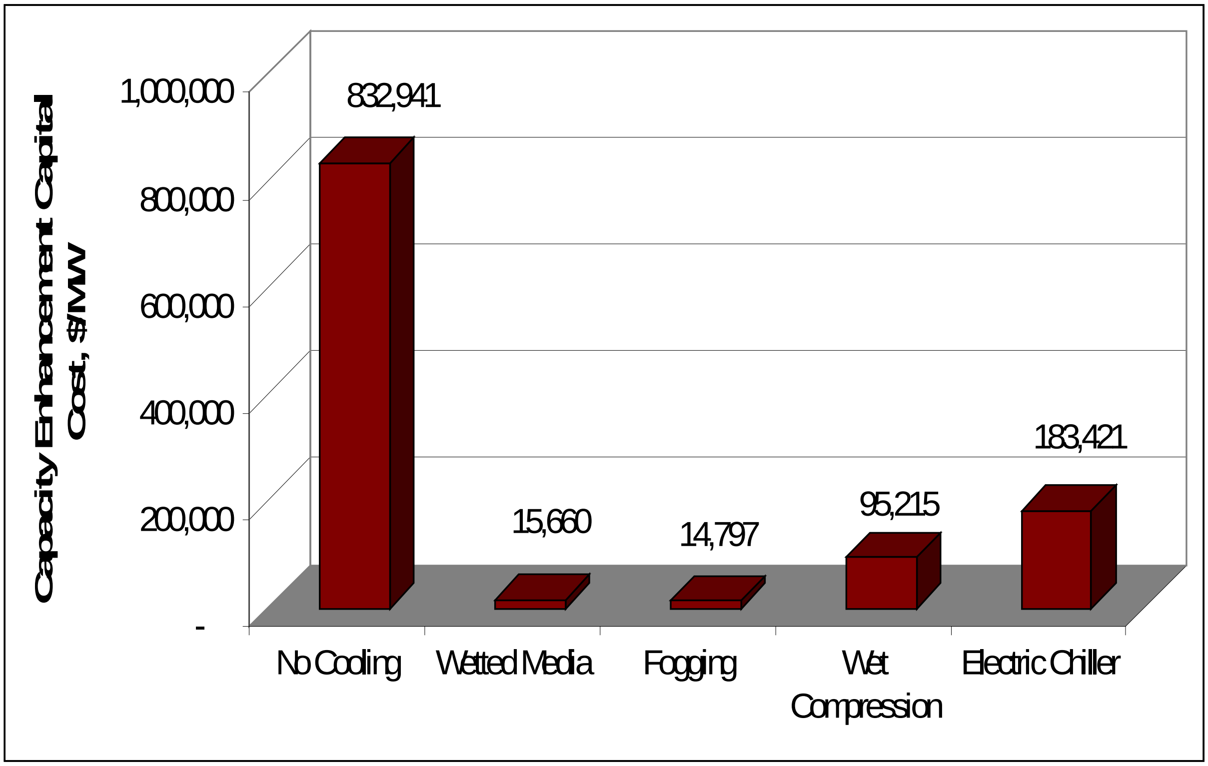

Figure 10 An Example of the Effects of TIC Technology on the Capital Cost of Capacity Enhancement

(Source of Wet Compression: Caldwell Energy; Source for All Others: www.turbineinletcooling.org)

The capital investment required per unit of incremental capacity is lowest for evaporative cooling technologies and highest for chillers systems. However, this Figure shows that the capital cost of all of these TIC technologies is just a small fraction of the cost of that for all the un-cooled systems. **The cost-effectiveness of adopting each TIC option is readily seen and clearly reflects the value of TIC.**

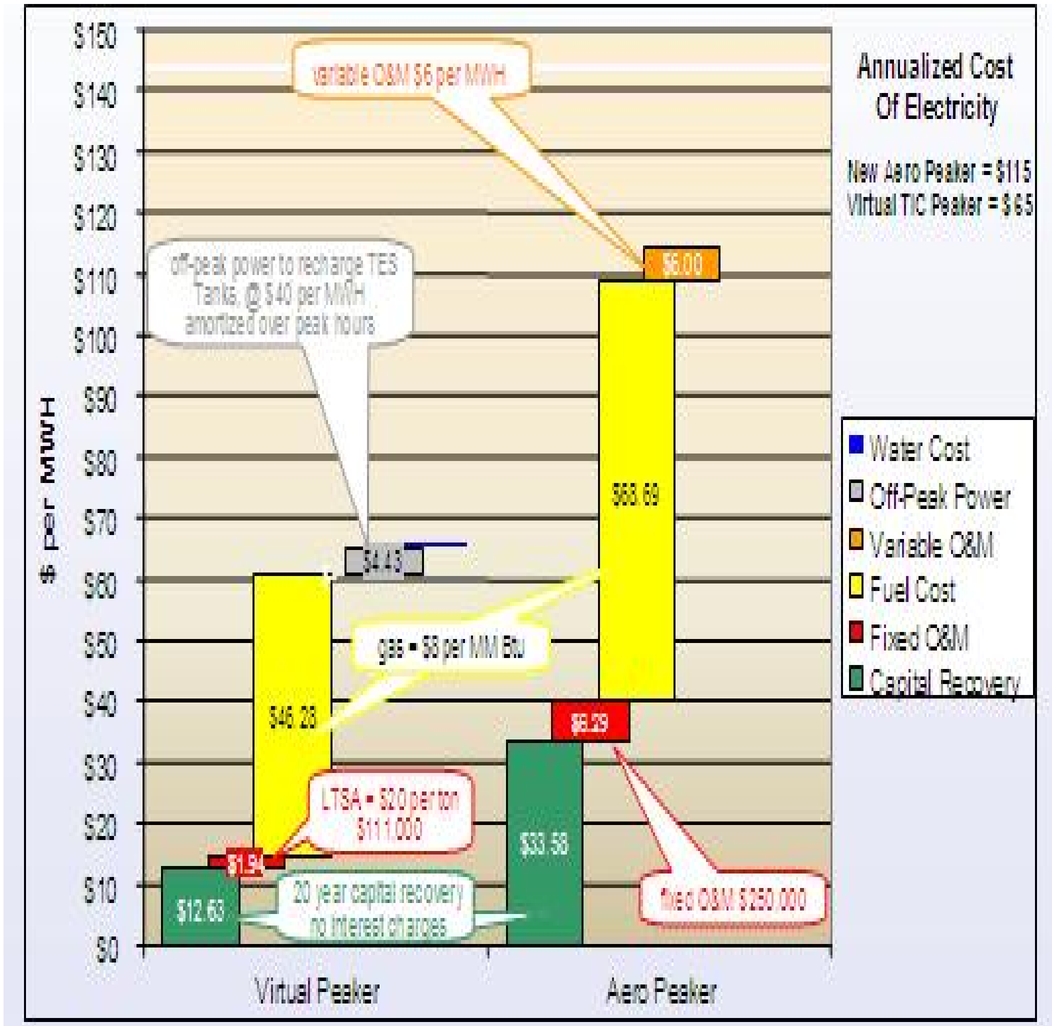

Figure 11 A Comparison of Turbine Inlet Cooling Economic Benefits
(Source: TAS)

Basis: LM6000PC-Sprint with hot SCR & TIC vs. incremental MWH from Combined cycle 207FA with TIC added.

The cost of incremental electric energy provided by a combined-cycle system using TIC is less than that for an un-cooled simple-cycle peaker. The major portion of the cost savings from employing TIC comes from reduced cost of fuel.

Figure 12 shows the preferred order of dispatching electric energy from a combined-cycle system that incorporates duct-firing and TIC. It is readily seen that the use of TIC for supplying incremental electric energy saves fuel compared to that supplied by duct firing.

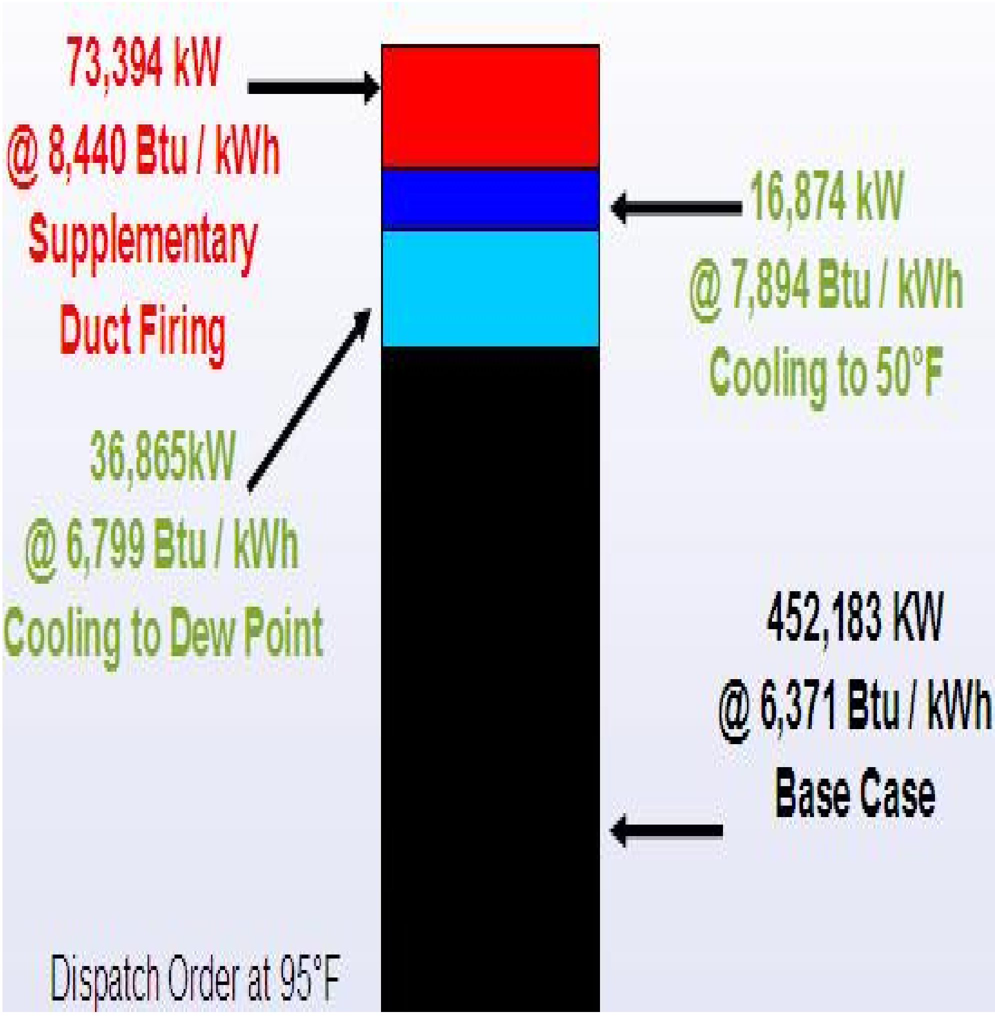

Figure 12 Preferred Order for Providing Electric Power from a Combined-Cycle System Incorporating TIC and Duct Firing (TAS)

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

Estimates of the payback period and/or internal rate of return require analyses based on hourly weather data for plant location, costs of fuel and water, and market value of the incremental electric energy. An example of the results of hourly analyses for a 316 MW cogeneration plant in Pasadena, Texas using TIC options is shown in Figure 13. TIC significantly increases electric energy output during hot weather.

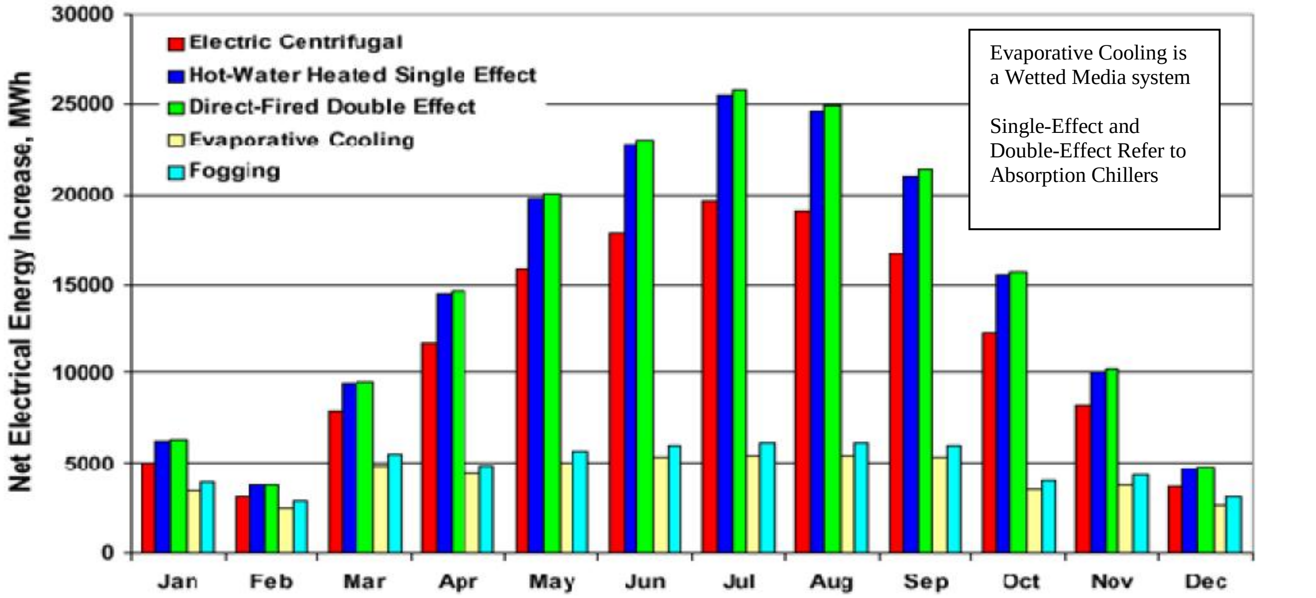

Figure 13 An Example of Monthly Incremental Electric Energy Provided by Various TIC Options for a 316-MW Cogeneration System in Pasadena, TX. (Punwani 2001)

TIC AT WORK REDUCING EMISSIONS

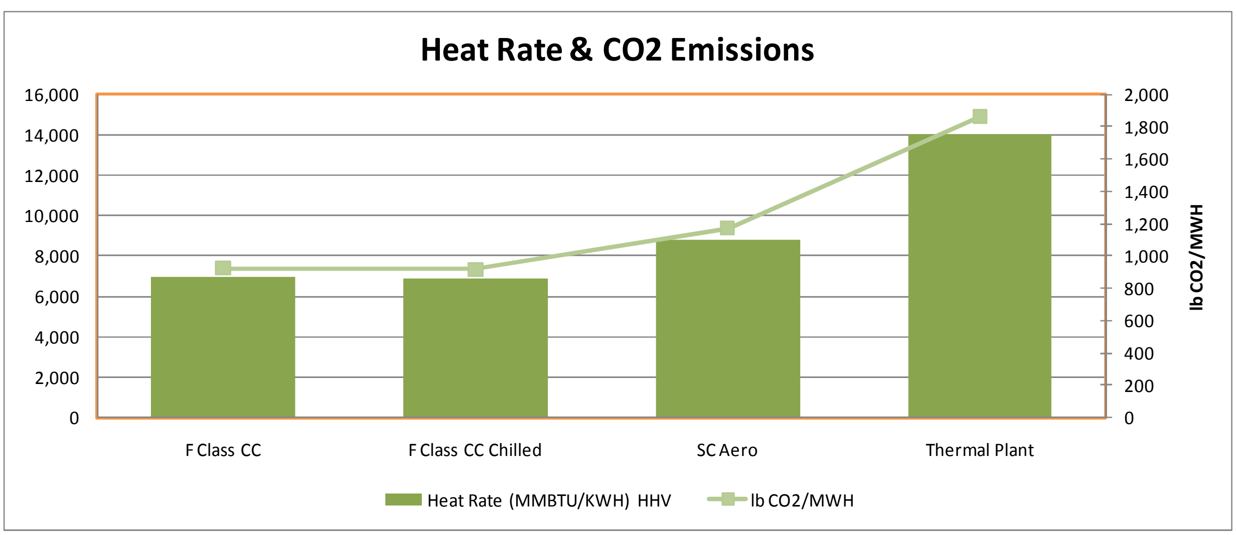

Figure 14 Comparison of Heat Rate and Carbon Dioxide Emissions from Combined- Cycle, Simple-Cycle & Thermal Plants (Ambient Air at 95oF Dry-Bulb and 78°F Wet Bulb) (TAS)

Figure 14 shows carbon dioxide emissions per MWh unit of electric energy available from using TIC in a typical combined-cycle plant is only about 800 lbs. This is significantly less than the over 1,100 lb. for a peaking simple-cycle plant. It is a huge reduction from the over 1,900 lb. of carbon dioxide from a steam turbine thermal plant.

Figure 15 shows a similar reduction in the emissions of the regulated pollutants (SOx, NOx, and others) by adopting the use of TIC.

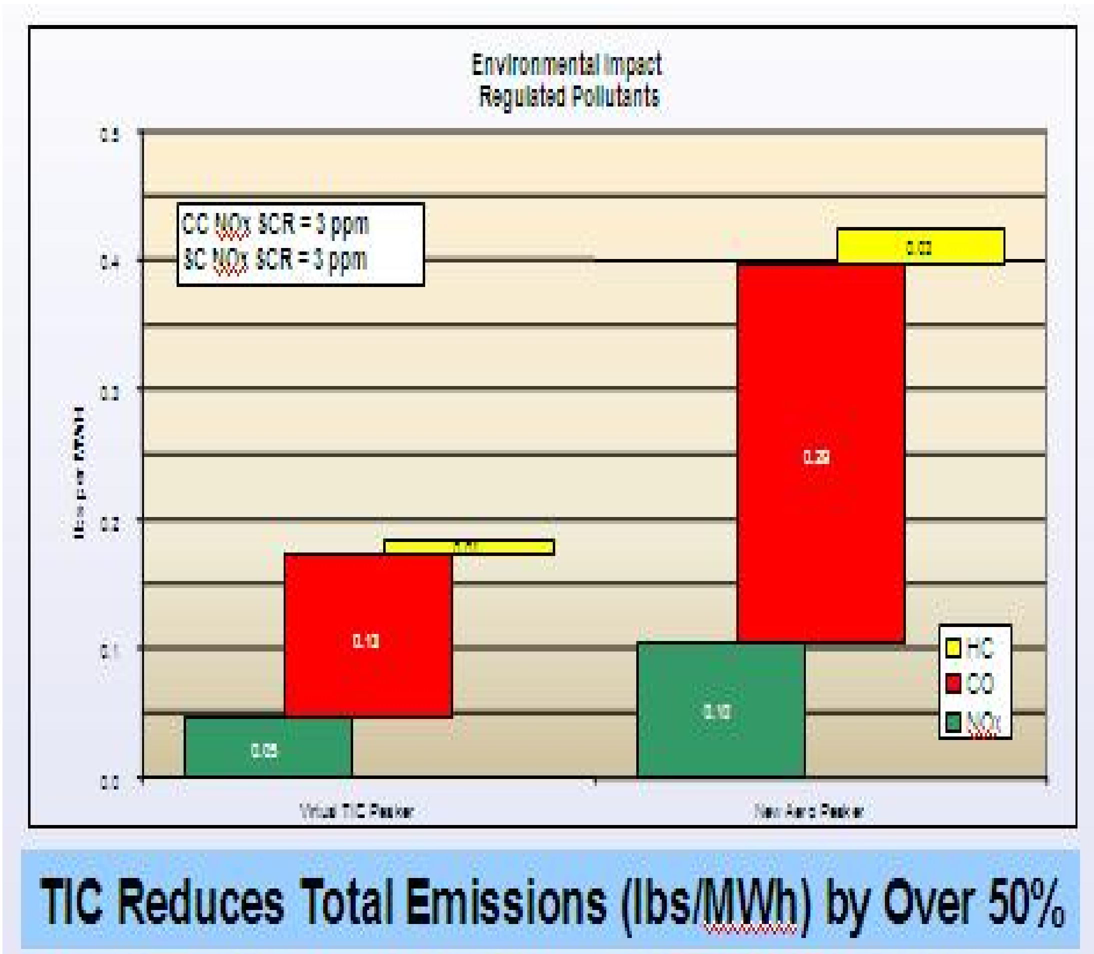

Figure 15 A Comparison of Regulated Pollutants Emission from the Incremental Electric Energy Produced by TIC Cooling of a Combined-Cycle System with a Single-Cycle Peaking Plant (TAS)

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

SUMMARY OF ENVIRONMENTAL AND ECONOMIC BENEFITS

Environmental

TIC allows for minimizing the use of inefficient and higher emission peaking power plants by maximizing the use of higher efficiency and cleaner CT plants. TIC reduces the emissions of carbon dioxide – a major GHG and results in carbon footprint reduction for the grid. Other noxious pollutants such as NOx and SOx are also reduced. Achieving these objectives is good for plant owners, regulators and for the environment as efforts to reduce emissions and their impact on the environment are accelerating.

Unearthing the treasure of hidden capacity of CT power plants during hot weather also allows regulators and owners the opportunity to minimize or avoid altogether the need to site and construct new generation capacity. It also furthers the opportunity to develop renewable sources by using CT plants as the backup generation capacity. This assists regulators with meeting RPS milestones. Hence, TIC leads to additional substantial environmental and economic benefits for all concerned.

Economic

Economic benefits shown in Figures 10 through12, make clear that installation of TIC on all CTs would enhance electric power generation capacity during times when ambient air temperature increases and just when demand for power is high. TIC provides the increased generation capacity at a lower capital cost than uncooled CT plants.

An independent analysis conducted for PJM Interconnection LLC (PJM 2005) showed that the capital cost for the additional capacity provided by TIC is only $216 per kW. This compares favorably to construction of an uncooled CT which the study shows costs almost double at $391 per kW. Ratepayer costs decline since lower capacity payments are due from the independent system operators (ISOs) to power producers.

TIC results in less fuel used and thus, reduces fuel cost. Plus, today TIC can eliminate or delay the need to site and build new power capacity by as much as 31,000 MW. In summary TIC provides many economic benefits:

- Captures the “hidden” power generation capacity (during hot weather) when most needed and most valuable
- Enhances CT asset value
- Lowers capital cost per MW capacity gain produced (also lowers total blended capacity cost)
- Improves heat rate and lowers fuel cost per MWh
- Expedites capital cost payback (higher return on investment or net present value)
- Reduces costs to ratepayer resulting in lower rates

REGULATORY AND POLICY RECOMMENDATIONS

Regulators and policymakers are urged to consider the adoption of a policy that **requires the use of TIC** to increase electric energy production from existing generation systems. Information in this paper clearly demonstrates the cost-effectiveness of TIC and how it provides numerous benefits to plant owners, ratepayers and the environment. It is readily seen how valuable a tool TIC can be for regulators as well. The Turbine Inlet Cooling Association (TICA) believes that:

- Regulators should recognize that TIC is a valuable solution to their supply problem during hot weather
- Regulators should use the full potential of existing CT plants by
  - Requiring the use of TIC before allowing construction of new capacity and
  - Ensuring capacity payments provide appropriate returns for systems using TIC
- Policymakers should recognize the value of TIC by
  - Recognizing that TIC actually helps reduce emissions by minimizing the need to operate power plants less efficient than CTs
  - Exempting an existing plant retrofitting with TIC from environmental re-permitting since using TIC results in plant emissions similar to those in winter and no permit change should be needed
  - Creating incentives for plant owners to use TIC technology similar to provisions found in the proposed Electric Power Act proposed in Congress in 2010

CONCLUSIONS

TIC is a valuable tool to increase electric energy production during hot weather. It helps meet demand at lower cost with reduced carbon dioxide emissions. TIC also effectively reduces emissions of GHGs per unit of electricity produced. The benefits of TIC include:

- Maximum production of electric energy from highly efficient CT-based cogeneration/CHP, combined-cycle and simple-cycle plants
- Minimized fuel use by increasing efficiency of ~~uncooled~~ CT systems by up to 15% and up to ~~72~~ 85% by preventing the use of less efficient peaking plants
- 31,000 MW of additional generation capacity from the existing CT plants during hot weather
- Reduced overall carbon footprint for power generation
- Reduced need for constructing new power plants and their related cost, siting and environmental issues
- Reduced fuel cost of power production
- Cost-effective power supply made available to meet demand
- Readily implemented within 6-18 months
- Proven technology with no implementation risks

COOLING THE AIR

TO GAS TURBINES

WITH TIC

MAKES

GOOD SENSE

For more information on Turbine Inlet Cooling visit (http://www.turbineinletcooling.org) or e-mail exedir@turbineinletcooling.org

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Descriptions of all TIC technologies are available at the Website of the Turbine Inlet Cooling Association (http://www.turbineinletcooling.org/technologies.html) and in many publications - Andrepont 2005, ASHRAE 2008, Cho 2003, Farmer 2007, Kraft 2004, Punwani 2008, and Stewart 1999).