POWER
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COMBUSTION TURBINE INLET COOLING

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UNEARTHING HIDDEN TREASURE

When the weather's hot, there's gold in those combustion turbines, just when you need it the most.

Power shortages commonly occur in the United States and in other parts of the world during peak summer demand. Meanwhile, old plants are retired on a fairly frequent basis. In fact, a recent *Wall Street Journal* story reported that 5,000 to 9,000 MW of installed generation capacity may be retired in the next few years in California alone.

There are two ways to deal with these two facts of life in the power industry. Build new power plants to meet all anticipated power demand. Or utilize the "hidden" capacity of existing gas-fired combustion turbine power plants, thereby only building new power plants to produce the balance of capacity needed. Hidden capacity is the generation potential capacity of a combustion turbine (CT) that becomes unavailable as ambient temperature rises above 59 F. The warmer the weather is, the greater the amount of hidden capacity. This lost potential is due to a basic flaw in all CTs.

Economic and environmental factors dictate that tapping this hidden potential capacity is the preferred approach because it creates a win-win situation for all stakeholders, be they plant owners, ratepayers, the environment and the public at large.

HOT WEATHER DERATES CT CAPACITY

The world has grown to love CTs because they offer so many advantages for power generation. They have made a huge mark in the global power generation market and their popularity will continue. Natural gas and fuel oil prices have risen, new coal plants are entering the generation mix, and new nuclear units may be on the way, but CTs are here to stay. Advanced natural gas production technologies, increased LNG imports, and synthetic gas (syngas) from coal gasification plants will provide enough fuel for these turbines.

But the laws of physics have imposed a major flaw upon all CTs. They lose power output in direct proportion to the increase in outdoor air temperature (Figure 1). This fundamental flaw impacts every CT – some more than others – in the range of 10 to 35 percent of rated output capacity (Figure 2) starting at the point at which outside ambient temperature rises above 59 F. According to a 2003 estimate, there are nearly 2,000 MW of hidden capacity in California alone due to this phenomenon. When applied to CT capacity installed worldwide, the figure represents tens of thousands of hidden MW.

FIGURE 1
DAILY GENERATION PROFILE

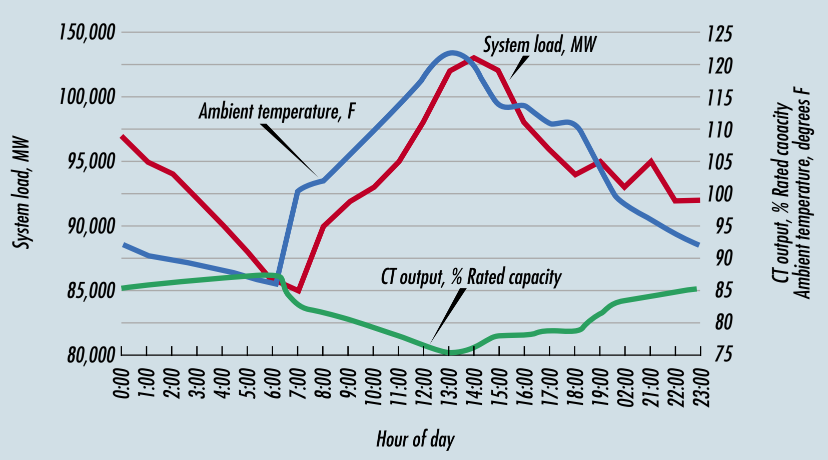
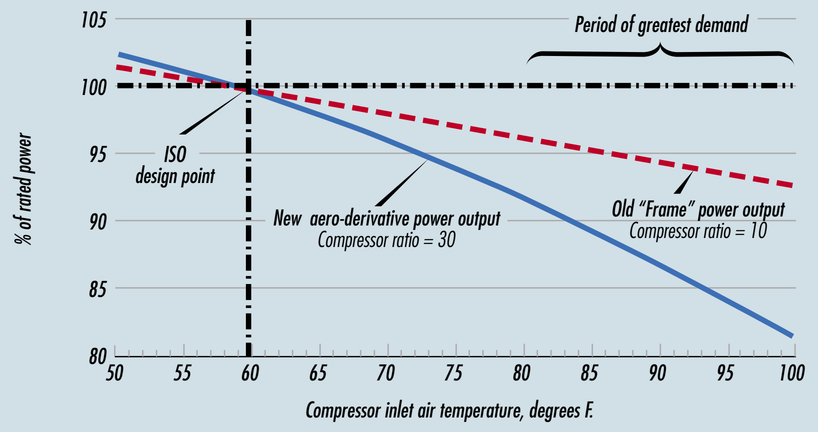


FIGURE 2
EFFECTS OF COMPRESSOR INLET AIR TEMPERATURE ON GAS TURBINE POWER OUTPUT



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ARE FIRE BREATHING DRAGONS ATTACKING YOUR TURBINE?

WELL NOT EXACTLY, BUT IF YOU LOOK AT HOW A TURBINE'S MW OUTPUT AND EFFICIENCY DEGRADES ON HOT DAYS, IT CERTAINLY MAY SEEM LIKE IT.

Both simple and combined cycle turbine output degrades up to 20% when ambient temperatures rise above 85° F (29° C). It's a simple relationship, the hotter it gets, the less MWs your plant can produce.

TAME THE DRAGON & RESTORE YOUR BOTTOM LINE

TURBINE INLET COOLING from TAS reduces inlet air temperatures to 50° F (10° C) or lower and restores lost MWs when they are essential – during summertime peak demand. This means your plant can produce more MWs on the hottest days of the year,
which is also when MWs are the most profitable.

Functioning like a virtual peaker, TURBINE INLET COOLING can be installed on new or retrofit plants to restore peak summer output to nameplate capacity.

Small footprints, attractive heat rates, minimal permitting and environmental impacts, highly competitive construction costs and short installation intervals make TURBINE INLET COOLING a simple solution.

Whether you need incremental peak energy or capacity requirements or simply want to maintain grid reliability with load following ancillary services, look to the worldwide leader in providing complete gas turbine inlet cooling solutions.

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Over 280,000 tons of Turbine Inlet Cooling installed and more than 1200 incremental MWs added worldwide.

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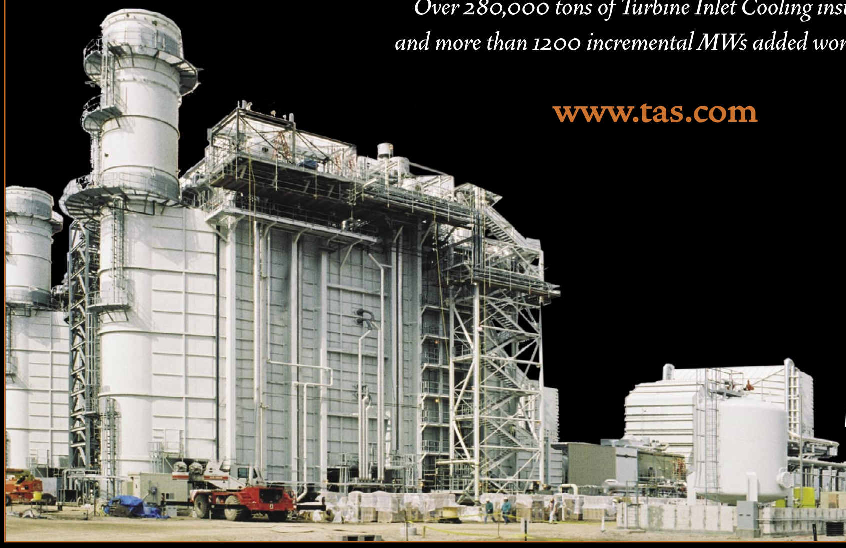

TABLE 1
COMPARISON OF INLET COOLING TECHNOLOGIES

Characteristics	*Wetted Media*	*Fogging*	*Mechanical Chillers*	*Absorption Chillers*	*Thermal Energy Storage*
Advantages					
Low Capital Cost	X	X			
High Capacity Enhancement			X	X	X
Significant Enhancement Even in Humid Weather			X (1)	X (1)	X (1)
Does Not Consume Large Amounts of Water			X	X	X
Low Parasitic Power Need	X	X			
Utilizes Low-Temperature Waste Heat (for producing 15 psig steam or ~200 F water)			X		
Utilizes High-Temperature Waste Heat (for producing 115 psig steam)			X (2)	X	
Allows Cooling Air to the Lowest Temperature (40-42 F)			X		
Disadvantages					
High Capital Cost			X	X	X
Only Limited Enhancement in Humid Weather	X (3)	X (3)			
Consumes Large Amounts of Water	X	X			
Modest Parasitic Power Need				X	
High Parasitic Power Need			X (4)		
Cooled Air Temperature Limited to 48-50 F				X	
Cooled Air Temperature Limited to the Wet-Bulb Temperature	X	X			

Notes:
1. Temperature of cooled air is not limited by the wet-bulb temperature
2. Temperature of cooling air is limited by the wet-bulb temperature
3. If steam turbine is used for running the compressor
4. If electric motor is used for operating the compressor

Unfortunately, as the weather gets hotter, the need for air conditioning increases power demand. Demand charges raise the price of electricity during peak periods when most of the hot weather occurs. So just when output is needed most, CT output decreases. In cogeneration and combined heat and power (CHP) systems, a rise in ambient temperature not only reduces power output, it also reduces the total thermal energy available in the CT exhaust gases, thereby decreasing the output capacities of heating or cooling (using absorption chillers) systems downstream of the CT.

CT DERATING SOLUTION

The solution to CT derates at high temperatures is amazingly simple: cool the air before it enters the gas turbine. The concept of turbine inlet cooling (TIC) is not only simple, the technology needed is also available and well-proven. Intuitively, TIC might appear to be a wrong approach because it adds more cooling load, thus increasing power demand. Fortunately, it is the correct approach because the increased CT power output derived from inlet cooling is far greater than the power needed to cool the air that enters it.

The magnitude of the power boost depends on the characteristics of the turbine, ambient temperature and humidity, and on the TIC technology used. Several TIC technologies are available, including wetted media, fogging, mechanical chillers (driven by electric power, steam turbines, or gas engines), absorption chillers, and thermal energy storage. All of these technologies have been commercially used in many power plants worldwide. Each exhibits certain advantages and disadvantages, summarized in Table 1 (page 64). A discussion on each of these technologies is available at the Technology Overview section of the Turbine Inlet Cooling Association website (www.turbineinletcooling.org) and in a number of publications listed in the website's library section. The website also features about 100 examples of power plants using TIC.

TIC technology can be used with all CT applications – simple and combined cycles, cogeneration, or combined heat and power (CHP), and integrated coal gasification combined cycle (IGCC). It can be retrofitted to existing plants or implemented in new plants. TIC technology can also be used to enhance the performance and economics of duct firing for CT power plants.

The primary economic benefit of all TIC technologies is that they provide additional power capacity from existing plants at a fraction of the cost per MW of a new gas turbine plant without TIC. The actual economic benefit of each technology depends on weather conditions at a specific plant location and the CT characteristics.

As an example, consider a plant in Houston consisting of two identical frame CTs, each rated 170 MW (gross); one 172 MW (gross) steam turbine; and a total plant parasitic load of 11.5 MW (Figure 3). Net plant production at ISO conditions is 501 MW. When the ambient temperature in Houston is 95 F dry-bulb and the coincident

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  - operate chillers in off-peak conditions
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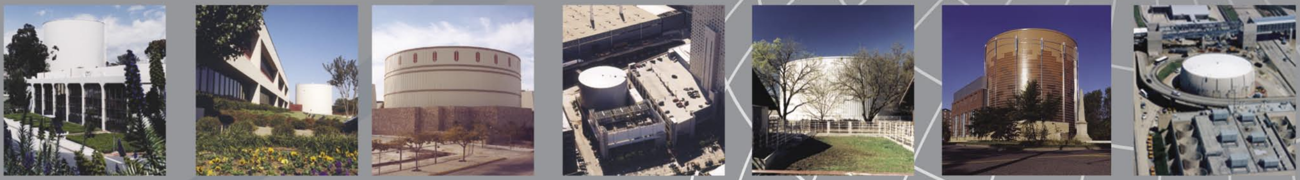


wet-bulb temperature is 80 F, plant output without inlet cooling drops from 501 MW to about 448 MW – a loss of 53 MW, which is more than 10 percent of rated capacity at ISO conditions. Data indicate that ambient temperature increases reduce the power output of both the CT and the steam turbine downstream (due to reduced CT exhaust gas mass flow).

Modeling plant operation using GateCycle software, widely accepted for this type of analysis, begins by assuming an approach of 90 percent of the difference between the dry-bulb and wet-bulb temperatures for the wetted-media case, and 98 percent for the fogging system. These two technologies can cool the inlet air to 81.4 F and 80.2 F respectively for this situation.

The electric-chiller case assumes a system designed for cooling the inlet air to 50 F. Such a chiller would require a total cooling capacity of 13,288 refrigeration tons (RT – removal of 12,000 Btu/hr). Power requirements for the chiller plant would be approximately 0.65 kW/RT for the chiller plus an additional 0.16 kW/RT for chilled-water, condenser-water and cooling-tower pumps, yielding a total chiller-plant demand of 10,763 kW. In this case, the electric chiller maximizes power output, even after accounting for its significant parasitic power load. Compared to the uncooled base case, the CT cooled by wetted media, fogging and electric chiller increase power output by 21 MW (4.6 percent), 23 MW (5.1 percent), and 47 MW (10.5 percent), respectively.

The impact of cooling technology on the installed cost of the incremental capacity enhancement reflect the following assumptions for installed costs:

- *Building a new uncooled CT combined cycle, $350/kW at ISO conditions*
  - *Wetted media, $4/kW of CT capacity at ISO*
  - *Fogging system, $4/kW of CT capacity at ISO*
  - *Electric chiller system (including the inlet cooling coil), $800/RT*

Wetted media and fogging system costs are relatively independent of ambient temperature. Chiller costs, on the other hand, depend significantly on the ambient dry-bulb and wet-bulb temperatures. For the same capacity, chiller costs will be higher for the plant location where dry-bulb and web-bulb temperatures are higher.

In this case, fogging and electric chiller systems provide capacity enhancement at less than one-sixth and slightly more than one-half, respectively, the cost of a new or existing gas turbine-based cogeneration plant without TIC (Figure 4). The final selection of an optimum TIC technology for a specific plant requires further analysis for determining the net present value (NPV) for the system. Such an analysis requires hourly data for all 8,760 hours of the year for estimating the net annual production of electrical energy (MWh) and steam, and their respective market value and annual operating and maintenance costs.

Because of the compelling economic benefits of TIC, a 1996 DOE report prepared by Pacific Northwest National Laboratory ("A Comparative Assessment of Alternative Combustion Turbine Inlet Air Cooling Systems") recommends that "inlet air cooling

FIGURE 3

CAPACITY ENHANCEMENT FROM TIC

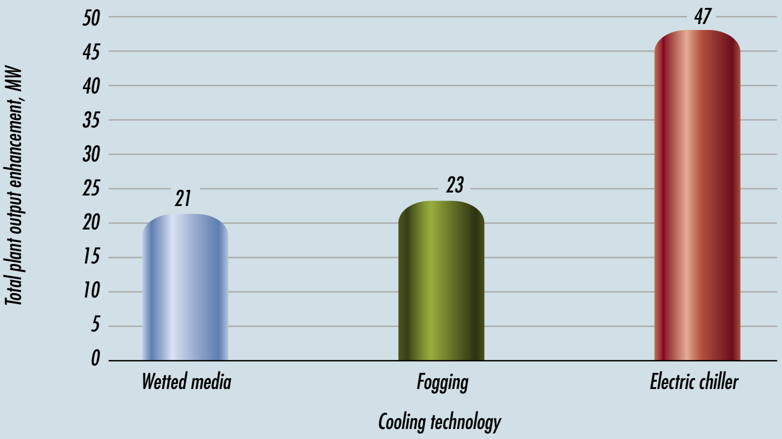
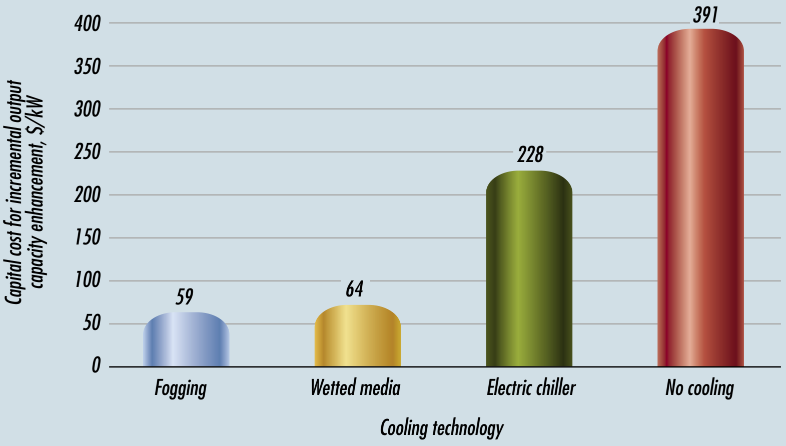
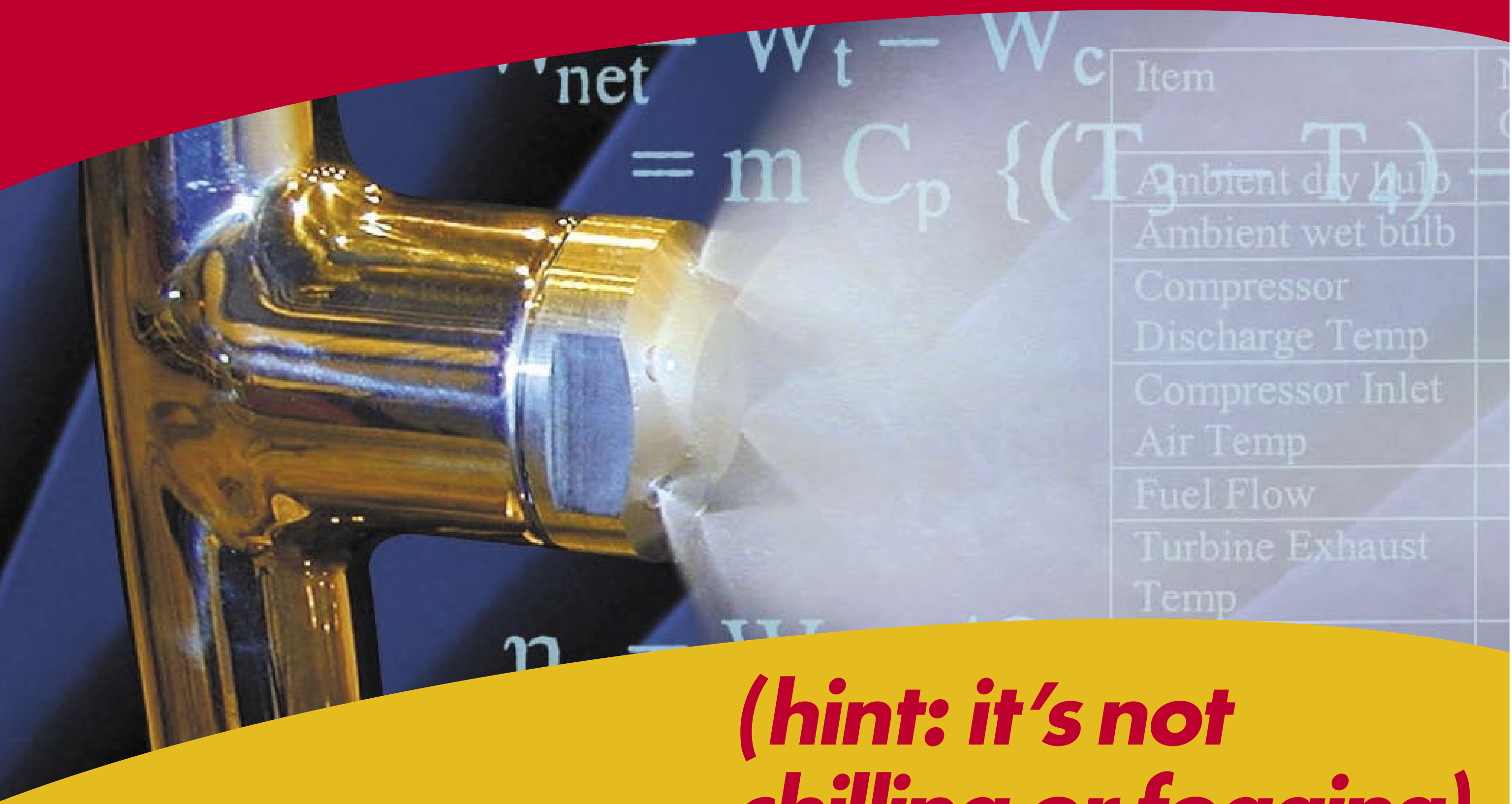


FIGURE 4

COST OF CAPACITY ENHANCEMENT FROM TIC



What Technology Has 1/3 the Cost and 3x the Output?



(hint: it's not chilling or fogging)

visit www.caldwellenergy.com/thefacts.pdf

At Caldwell Energy, our expert engineers focus solely on how to optimize the output and efficiency of combustion turbines. We completely understand combustion turbines and will maintain their integrity, reliability and availability. Sure, you can find folks that will spray fog into your turbines, but oftentimes their solutions just don't add up.

- Over 250,000 fired hours of wet compression technology.
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- Engineering staff has over 100 years of combustion turbine design and power augmentation experience.

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Caldwell Energy Company is ISO9001 Certified should be considered a standard practice to be incorporated with combustion turbine installation."

In the restructured energy markets of many U.S. states, independent system operators (ISOs) responsible for electric power reliability in their respective regions invite bids from power plant owners for bringing their plants online when needed. The ISOs pay power plant owners for making their power generation capacity available for their regions. The ISOs make capacity payments to the plant owners, whether or not the plant is brought online during the contract period.

Since TIC enables the plant owner to utilize the hidden capacity at much lower cost than building new plants, the owners that implement TIC in their plants will be able to submit lower bids for their generation capacity. That means the ISOs will have to make lower capacity payments, which in turn helps reduce cost to the ratepayers in the ISO regions.

At present, when power demand rises beyond the capacities of baseload power plants, ISOs allow operation of peaking plants, typically simple-cycle units. Such peaking plants are not the most energy efficient and produce high emissions per unit of electric energy. The cost of electricity produced by these plants is also high. Therefore, these peaking plants not only cost ratepayers more, but also create more pollution. The use of TIC in the more efficient baseload power plants will reduce and postpone the use of peaking plants and thus, help reduce cost to ratepayers and minimize pollution for the general public too.

OPPORTUNITY FOR POLICY MAKERS AND REGULATORS

Despite DOE's recommendations in 1996, TIC has not become a standard practice. Possible reasons include:

- *Existing long-term power purchase agreements (PPAs) that limit output and/or are based on a flat-rate (independent of time-of-day) for electric energy*
- *Environmental/permitting regulations: Retrofitting a plant with TIC triggers environmental re-permitting*
- *Lack of structure for paying for value of power during hot weather*
- *CT OEMs who would rather sell more or larger capacity CTs*
- *Lack of knowledge/understanding and incentives for the engineering and construction companies to incorporate TIC*

While the Turbine Inlet Cooling Association plans to work with OEMs, plant owners and engineering companies, there is an opportunity for policy makers and regulators to revise policies and regulations that would maximize the benefits of TIC to ratepayers and the general public.

The key to encouraging investment for TIC retrofits is the creation of a hot-day capacity market. States like California could make standard offer contracts available that are essentially PPAs defining how and when power owners get paid for generating power. Under these PPAs, the states pay for power only when they need it, which is during the hot periods. Through these contracts, the states tell the market, "We want your hot-day capacity, and we will make a capacity payment for you to make that investment." Once such contracts are in place, asset managers will rush proposals for TIC.

All power plants are currently permitted to emit up to certain annual weight of pollutants. If a plant does not incorporate TIC, the environmental permit is based on the reduced annual electric energy production (MWh) during hot weather. Total environmental emissions per unit of electricity produced would be lower for plants retrofitted with TIC than those without TIC. However, total annual emissions for the retrofitted plants would be higher than those for the plants with TIC because of much higher annual production of electric energy. Current regulations require re-permitting for such plants. Such policies discourage plant owners from retrofitting TIC systems. The Turbine Inlet Cooling Association believes retrofitting existing power plants with TIC should be exempted from environmental re-permitting.

Furthermore, the electric power industry must seriously re-think the way it operates. It should conduct the kind of reassessment undertaken in the late 1970s with the passage of PURPA, which created the IPP business and forced the industry out of the "utility" mindset. The entire purpose of PURPA was to benefit the ratepayer, which it did. It is time to put the end user in mind globally.

While the basic flaw of CTs can't be fixed, TIC offers an economical and environmentally sound option for reducing the detrimental impact of that flaw. It's a win-win option for the power plant owner, ratepayers and the environment. It also helps achieve three goals of President Bush's energy policy: Better use of technology for conserving energy; innovative and environmentally sensitive ways to make the most of existing energy resources; and helping the growing number of energy consumers overseas apply new technologies to use energy more efficiently and reduce global demand for fossil fuels.

A few changes in state policies and regulations would help the states minimize construction of new plants and the related costs and siting issues. PE

Authors

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Turbine Inlet Cooling (TIC) Benefits

A substantial number of new power plants in the world would not need to be built if TIC is utilized for capturing the hidden capacity of existing and new combustion turbine plants. TIC provides economic as well as environmental benefits. These benefits are good for the combustion turbine plant owners, the ratepayers and the general public.

Economic Benefits of TIC

I. Captures "hidden" capacity when most needed and most valuable

II. Enhances combustion turbine asset value:

  a. Reduces capital cost per MW of capacity gain produced (Also lowers total blended capacity cost)

  b. Improves heat rate (Lower fuel use and cost per kWh)

  c. Provides faster capital cost payback (Higher return on investment)

  d. Improves net present value

III. Reduces cost for ratepayers / electricity users

Environmental Benefits of TIC

IV. Allows minimum use of inefficient and polluting power plants by allowing maximum use of efficient and cleaner combustion turbine plants

  a. Conserves nation's natural fuel resources

  b. Reduces emissions of pollutants (SOx, NOx, particulates)

  c. Reduces emissions of global warming/climate change gas (CO2)

V. Minimizes (or may even eliminate) siting of new power plants

Note: Emissions reductions result from TIC displacing very high heat rate peakers. No significant emissions reduction necessarily occur at the plants that use TIC.