

EXHIBIT E

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REDUCING HEAT RATES OF COAL-FIRED POWER PLANTS

Improving the heat rates of their coal-fired generating units has become a priority for many power generation companies. Sharp increases in the cost of coal has led many in the industry to search for ways to reduce their annual fuel bills. In addition, some companies are placing increased emphasis on heat rate reductions in preparation for possible future CO₂ regulations. Research projects at the ERC are developing new techniques for reducing heat rate as well as developing an information-base on heat rate reduction options for existing coal-fired power plants.

Edward Levy explains, "Heat rate improvement opportunities for existing units include reductions in heat rate due to process optimization, more aggressive maintenance practice and equipment design modifications. Opportunities exist in the boiler, turbine cycle and heat rejection system. The overall level of heat rate improvement which can be achieved varies with unit design, maintenance condition, operating conditions, and type of coal."

The Energy Research Center has been working on research projects dealing with heat rate improvements in coal-fired power plants since the 1980's. These projects cover a wide range of heat rate-related topics extending from optimization of combustion and sootblowing practice to development of methods to accurately measure changes in unit heat rate. Center researchers who have been involved in this area of research include Harun Bilirgen, Edward Levy, Carlos Romero and Nenad Sarunac. This article summarizes findings from some of these projects.

Optimizing Combustion. The boiler is often a good place to begin to look for heat rate improvements. The operating conditions of a typical pulverized coal boiler can be controlled by adjusting fuel and air flow rates among burners,

Examples of Heat Rate Improvement Opportunities: Bituminous, Subbituminous and Lignite Coals

	Potential Heat Rate Reductions (%)	
	Lignite and PRB	Bituminous
BOILER AND FUEL MOISTURE		
• Optimize Combustion and Sootblowing	1 to 2	1 to 2
• Upgrade Air Preheater Seals	0.5	0.5
• (a) Pre-dry High Moisture Coals	2 to 4 (a)	-----
and Reduce Stack Temperature to 140°F	1.5 (a)	1.5 (a)
or		
(b) Reduce Stack Temperature to 100°F	1.5 to 3.5 (b)	1.5 (b)
TURBINE CYCLE AND HEAT REJECTION SYSTEM		
• Install Advanced Steam Turbine Blading and Seals	2 to 3	2 to 3
• Upgrade Steam Temperature Control Capabilities	1	1
• Upgrade Cooling System Performance	1 to 3	1 to 3
Note: Use either (a) or (b) above, but not both		

adjusting mixing patterns of coal and combustion air and adjusting economizer O₂ level. Changes to these parameters affect quantities such as combustion efficiency, steam temperatures, slagging and fouling patterns and furnace heat absorption, which in many boilers have significant effects on unit heat rate. There are systematic procedures which can be used to identify the combinations of boiler control settings which minimize unit heat rate. Referred to as "Combustion Optimization" these procedures typically involve use of intelligent software to assist in the optimization process. The Energy Research Center has optimized combustion at over 25 coal-fired units at which achievable heat rate reductions in the 0.5 to 1.5% range were identified.

Sootblowing Optimization. Slagging and fouling deposits from coal ash accumulation on heat exchanger tubes affect boiler heat absorption patterns,

steam temperatures and unit heat rate. Sootblowing optimization is used to identify sootblowing strategies which prevent uncontrolled buildup of slag and soot deposits and minimize heat rate. The Center has developed test procedures to determine optimal sootblowing schedules and has also developed adaptive intelligent software to automate the sootblowing process. The Center's recent sootblowing projects indicate potential heat rate improvements in the 0.25 to 1% range.

Steam Temperature Control. One of the techniques used to prevent excessively high steam temperatures at the inlets to the HP and IP turbines is to spray liquid H₂O into the steam. Referred to as attemperating spray, these liquid flows are taken from the turbine cycle and result in increased heat rate. Consequently, attemperating spray flow rates should be the lowest flow rates

needed to control steam temperatures to design levels. The table below shows data from a unit in which the steam temperatures were lower than desired, while both main steam and hot reheat steam attemperating sprays were in operation. This resulted in heat rate penalties due to low steam temperatures and the use of attemperation when it was not needed. The total heat rate penalty was 89 Btu/kWhr or approximately 0.8%. An upgrade to the steam temperature controls and perhaps repair of leaking flow control valves would be needed to prevent this type of loss.

Steam Turbine Maintenance. The performance of HP, IP and LP turbine stages deteriorates over time due to factors such as nozzle and blade erosion and seal leakage and periodic turbine outages are used to restore degraded turbine components to as-new condition. However, a new generation of aerodynamically improved turbine stage designs with nozzles and blades made from more erosion resistant materials have been made available by steam turbine vendors. For older units, these designs make it possible to produce 2 to 3% more gross power than can be produced by the original steam turbines.

Condenser Back Pressure. LP steam turbines are designed to operate with specific values of turbine back pressure. The turbine back pressure increases above the design value as the steam temperature in the condenser increases above the design value, which results in a reduction in MW produced and leads to increases in turbine cycle and unit heat rates. For units which reject heat to river water, increases in condenser pressure can occur due to factors such as an increase in river water temperature and/or condenser fouling. For units equipped with cooling towers, factors such as condenser fouling, maintenance related cooling tower performance deterioration, and increases in ambient temperature and humidity can all cause increases in back pressure. For full-load operation, increases in turbine cycle heat rate of more than 2% are typical for an increase in exhaust pressure of 2 inches Hg above design. It is not uncommon to find units operating with turbine back pressures approaching 5 inches Hg, which results in even larger heat rate penalties.

Pre-dry High Moisture Coal and/or Reduce Stack Temperature. High fuel moisture levels found in low rank coals have several adverse impacts on the operation of a pulverized coal generating

Example of Steam Temperature Control Impacts on Unit Heat Rate

	<u>Design</u>	<u>Actual</u>	<u>ΔHR (Btu/kWh)</u>
$T_{MS}^{\circ F}$	1005	996	8
$T_{RHT}^{\circ F}$	1000	985	20
$\dot{m}_{MS,spray} \text{ (lb/h)}$	0	20,000	5
$\dot{m}_{RHT,spray} \text{ (lb/h)}$	0	22,500	56
		TOTAL	89

unit, for they can result in fuel handling problems and they affect heat rate, stack emissions and maintenance costs. ERC research has shown that use of power plant waste heat to reduce coal moisture before pulverizing the coal can provide heat rate and emissions benefits. The degree to which performance improves depends strongly on the degree of drying, with heat rate gains expected to be in the 2 to 4% range.

Opportunities also exist to condense moisture from flue gas by reducing flue gas exit temperature. Captured sensible and latent heat can be used to improve unit heat rate through efficiency improvements both in the boiler and turbine cycle.

Summary. The potential for improvement in unit heat rate for a given unit will depend on fuel type because of the added flexibility to reduce heat rate for units firing high moisture low-rank coals. The table on page 4 lists examples of opportunities to improve heat rate for units fired with bituminous, subbituminous and lignite coals. If improvements could be made in all possible areas, the net improvement in heat rate would approach 10% for bituminous and 15% for PRB and lignite coals. While it would not be possible to take full advantage of all possible improvements on every coal-fired unit, the table nevertheless shows there is potential for making significant heat rate improvements to the fleet of coal-fired units.

Levy adds, "Center researchers are working on analyses of the heat rate-related factors which would affect the cost and performance of CO₂ capture systems for controlling CO₂ emissions from pulverized coal power plants. The initial results are quantifying the impacts of unit heat rate improvements on the physical size of back-end CO₂ scrubbers and on the thermal efficiency penalties which would result from adding CO₂ capture capabilities. We plan to estimate the impacts of heat rate improvements on the cost of carbon capture, once these analyses are complete." ■

RESEARCHERS' PROFILES

- **Dr. Harun Bilirgen** is a Senior Research Scientist in the Energy Research Center and his research focuses on emissions control and performance improvement of coal-fired power plants.
- **Dr. Edward Levy** is Professor of Mechanical Engineering and Mechanics and Director of the Energy Research Center. His research deals with emissions control and performance improvement in coal-fired power plants.
- **Dr. Carlos Romero** is an Associate Director of the Energy Research Center. He is a specialist in combustion kinetics and emissions control.
- **Dr. Nenad Sarunac** is Associate Director of the Energy Research Center. His research focuses on power plant heat rate improvement, emissions control and process optimization.
- **Dr. Eugenio Schuster** is an Assistant Professor of Mechanical Engineering and Mechanics. His research focuses on dynamic modeling and control of electric power generation systems.
- **Mr. Zheng Yao** is a Research Scientist in the Energy Research Center. His research deals with optimization of power plant operations.

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