

REINHOLD ENVIRONMENTAL Ltd.



**2018 NO_x-Combustion Round Table
& Expo Presentation**

February 19-20, 2018, in St. Louis, MO / Hosted by Dynegy

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2018 NOx-Combustion-CCR Round Table
February 19-20, 2018

**ASME Research Committee on
Energy, Environment, and Waste
(RCEEW)**

**Power Plant Efficiency:
Annual Heat Rate**

Anthony Licata
Licata Energy & Environmental



Why are we talking about Heat Rate

Heat rate improvements are a good economical and proven method of reducing fuel usage and overall plant emissions. In addition, CO₂ reductions can be achieved by keeping coal plant operating more of the time in a base loaded condition.

EPA's proposed CO₂ rule for existing coal-fired power plants was based on improved plant heat rate of up to 6%. Some claim that no more than a 1% gain can be obtained while others claim that EPA was too conservative.

Heat rates are an important component of reporting emissions - lb/MMBtu

Federal Register /Vol. 82, No. 248 /Thursday, December 28, 2017 / Proposed Rules 61507 Heat Rate

Heat Rate and Plant Efficiency

- RCEEW is looking at Power Plant Efficiency Improvement opportunities in the major component areas of a coal fired power plant.
- Heat rate is a common measure of a power plant's efficiency & Electric utilities are already currently doing *heat rate* improvements.
- Heat rates are an important component for power plant dispatch.
- We are looking at what is the potential feasible *Heat Rate* improvement.
- RCEEW will also look at how the different *heat rate improvement* opportunities interact with each other.
- Finding an industry acceptable standard for measuring **annual** heat rate

Clean Power Plan

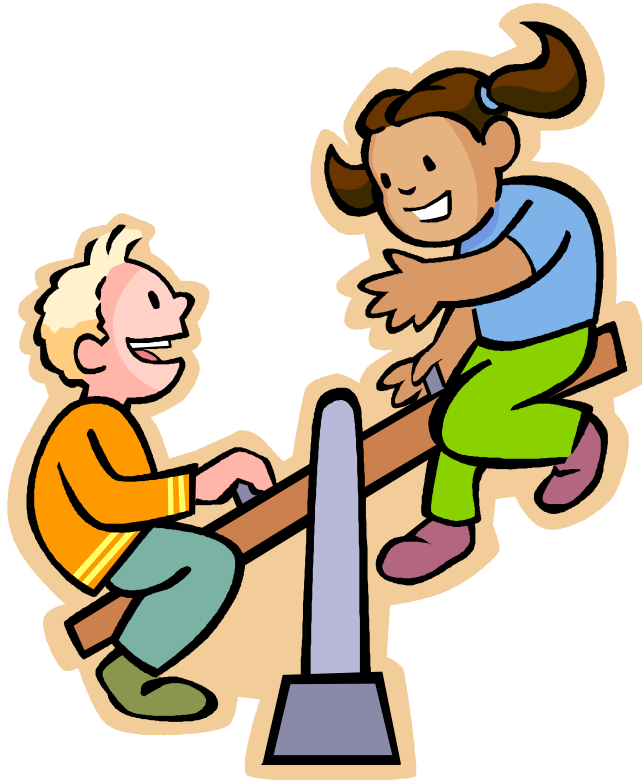
- Dec. 28. 2017 advance notice of proposed rulemaking (ANPRM) response Feb. 26, 2018
- “EPA is considering proposing emission limits for greenhouse gases (GHG) from existing EGUs”
- “EPA seeks comment on this approach to evaluate unit-specific heat rate improvement opportunities”
- “establishing standards of performance for existing sources, reflecting the application of the best system of emission reduction (BSER)”

Heat Rate Definition

- Heat Rate is defined as the amount of energy that is input into the system divided by the electricity generated:
Heat Rate (Btu/kWh) = (Energy Input in Btu/hr.)/(Power Output in kWh)
- Heat rate is reported as either gross or net:
 - Gross: the power output includes all output generated
 - Net: the power output includes only the output that is sent to the power grid
- Another way of ranking performance is Plant Efficiency, the reciprocal of Heat Rate:
Efficiency, (%) = Power Output/(Energy Input) x 100 in consistent units or kWhr./ton of coal
- In this presentation Heat Rate and Plant Efficiency are used interchangeably. When improvement changes are given in percent they are the same. A typical coal-fired power plant has a heat rate of 10,000 Btu/kWh or an Efficiency 34.14%. (3,412Btu/kWh = 100%)

Understanding Heat Rate

Heat Rate
Btu/kWhr.



Plant Efficiency
In % or kWhr./
Ton of coal



Less Fuel burned = lower CO₂ emissions

Heat Rate Reporting Conflicts

- In preparing the Clean Power Plan (CPP) EPA used a method of calculating annual unit heat rate for coal-fired EGUs using data derived from CEMS data (velocity probes) and “F” factors.
- Velocity probes are normally calibrated for two load conditions & not cycling operations. A number of papers have been presented demonstrating potential errors from using this data.
- Accuracy of “F” for fuels.
- EPA stated that the annual gross heat rate Btu/kW for 840 plants in their data base for 2002 to 2012 was 9,754

Heat Rate Reporting Conflicts

- DOE/EIA Reports heat rates in two methods, annual and as test based.
 - As tested shows improved heat rates.
- EIA data based on coal burned.
- EIA data is based on actual operating conditions.
- EIA and EPA data conflict.
- July 25, 2017 DOE reported that the heat rate for coal plants *“The slight rise in the average operating heat rate in coal-fired generation is attributable to the net result of competing factors. Emissions-control investments, which often create significant station loads, were made to almost 205,000 MW of coal capacity from 2006 to 2015. These emissions-control measures increased the operating heat rates for coal-fired generation”*

Combined Heat & Power (CHP)

- **U.S. DOE Southeast CHP Technical Assistance Partnership, NC Clean Energy Technology Center
N.C. State University**

The Problem - Reported by Jeff Quick

Journal of the Air & Waste Management Association, 64(1):73–79, 2014

Annual CO₂ emission tallies for 210 coal-fired power plants during 2009 were more accurately calculated from fuel consumption records reported by the EIA than measurements from CEMS reported by the EPA. Results from these accounting methods for individual plants vary by **+/- 10.8%**. Although the differences systematically vary with the method used to certify flue-gas flow instruments in CEMS, additional sources of CEMS measurement error remain to be identified.

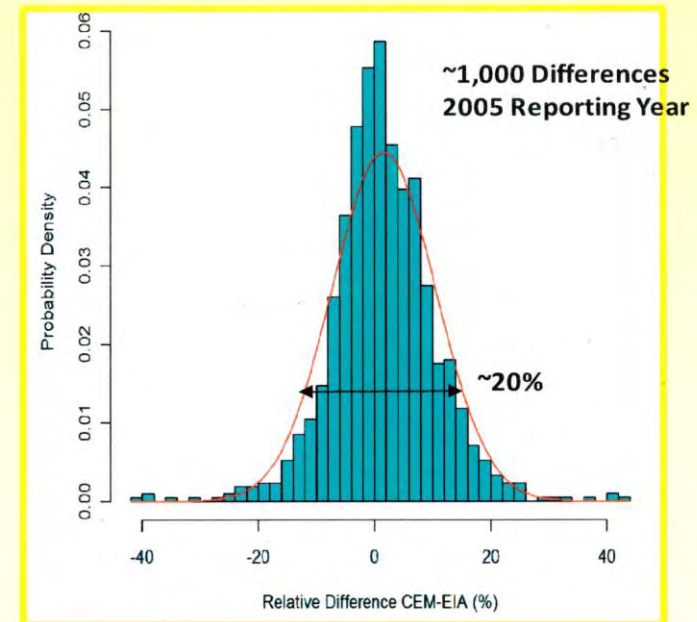
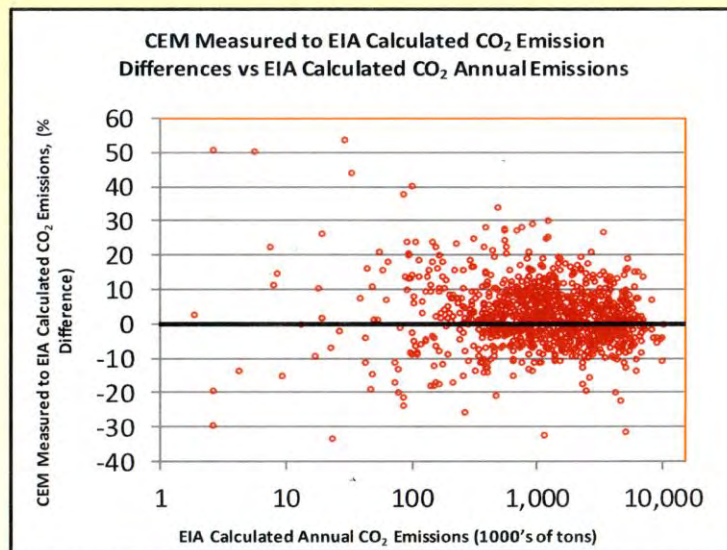
Limitations of the EIA fuel consumption data are also discussed. Consideration of weighing, sample collection, laboratory analysis, emission factor, and stock adjustment errors showed that the minimum error for CO₂ emissions calculated from the fuel consumption data ranged from **+/-1.3% to +/-7.2%** with a plant average of +/- 1.6%. This error might be reduced by 50% if the carbon content of coal delivered to U.S. power plants were reported.

NIST Presentation June 2017

5) Stationary/Point Source Metrology

Agreement between 2 methods of CO₂ emissions reporting?

- 1) Pre-Combustion – Fuel Calculation Method
- 2) Post-Combustion – CO₂ Measurement via CEMS (flow x mole fraction)



Measurement challenges: 1) carbon content of coal, 2) flow measurement in stacks, 3) Pitot velocity measurements, 4) better methods, 5) composition, 5) other?

Heat Rate Origins & Uses by Various Organizations

R. Sommerlad

| Organization | Formulation | Usage | Accuracy |
|--------------|---|---|---|
| ASME | PTC-46 (~8-hr test on a single unit using calibrated instrumentation with CEMS and samples with a specified control volume where all stream entering and leaving control volume are quantified) | Used to show performance guarantees are met among owners and suppliers | High degree of accuracy supported by Uncertainty Analysis |
| EIA | Data provided for entire plant on an annual basis using a prescribed EIA form based on unspecified control volume | Compiled and used as basis of comparison among all US units | Data are on a plant basis and accuracy not verifiable |
| EPA | Based on flue gas flow and flue gas composition using F-Factor for fuel quality | Used to compile fuel usage for local, state, and area emission regulations | Data based on stack measurements so one or more units using same stack are counted as one unit. Accuracy not verifiable |
| EPRI | Generally follow ASME protocols but may use CEMs over timed periods at variable loads | Used to compare units as part of a system and as a guide to maintain good performance | Accuracy is good for periods where load and operating conditions are held constant but Uncertainty Analysis not used |

Heat Rate Impacts

- The plant's design thermodynamic cycle.
- Coal composition and quality – moisture & sulfur.
- Age and size.
- Type & presence of pollution control equipment.
- Operating and maintenance practices.
- Plant component design.
- Geographic location and ambient conditions.
- Cooling/Condenser system -Ambient Conditions.
- Electric grid dispatch requirements.
 - Cycling or base load.

Heat Rate Impacts where you have no control

Heat Rate Improvement Applications

Impact on Heat Rate

Ambient temperature

minor

Temperature of cooling water

major

Snow and rain

minor

Environmental regulations

major

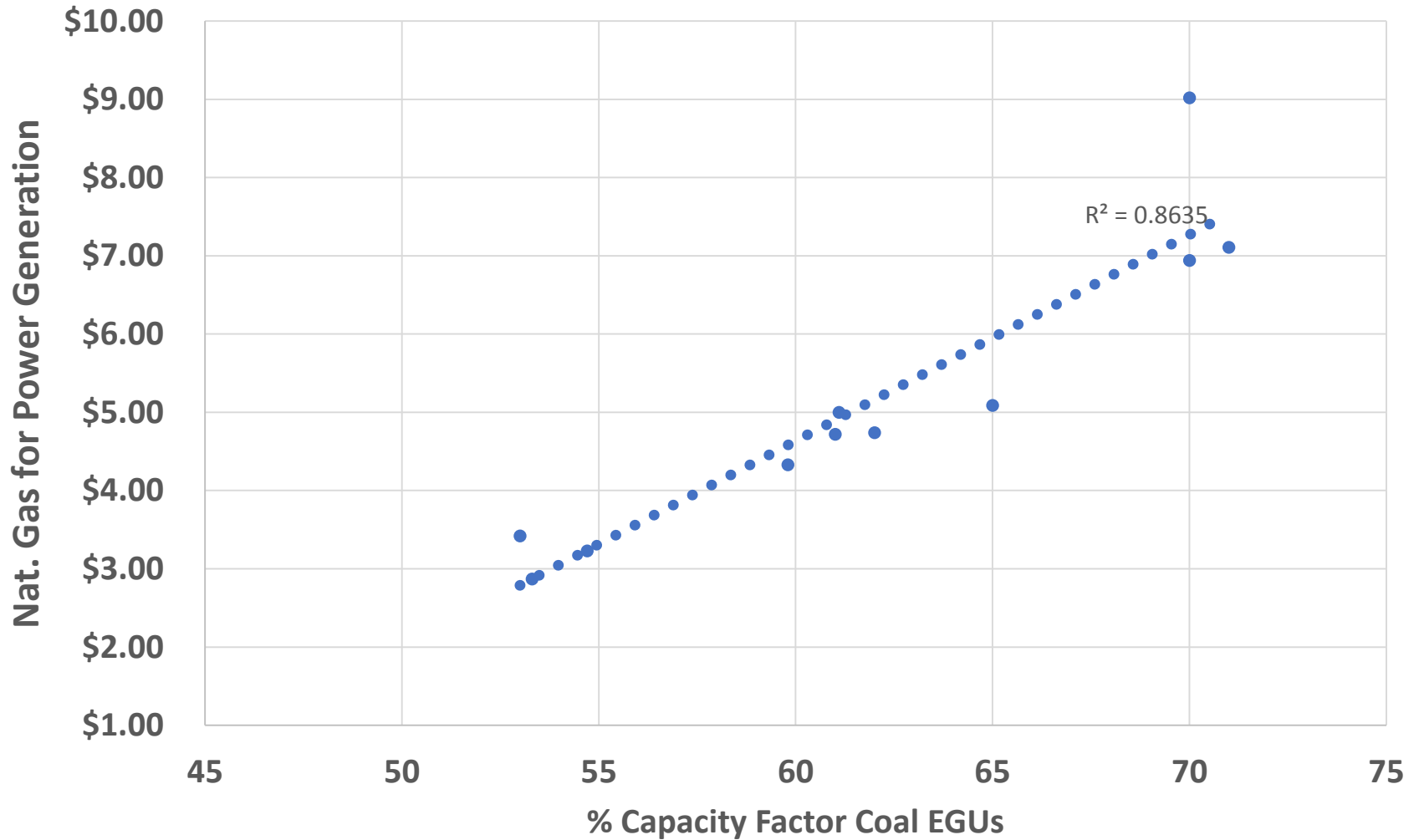
Plant age and size

major

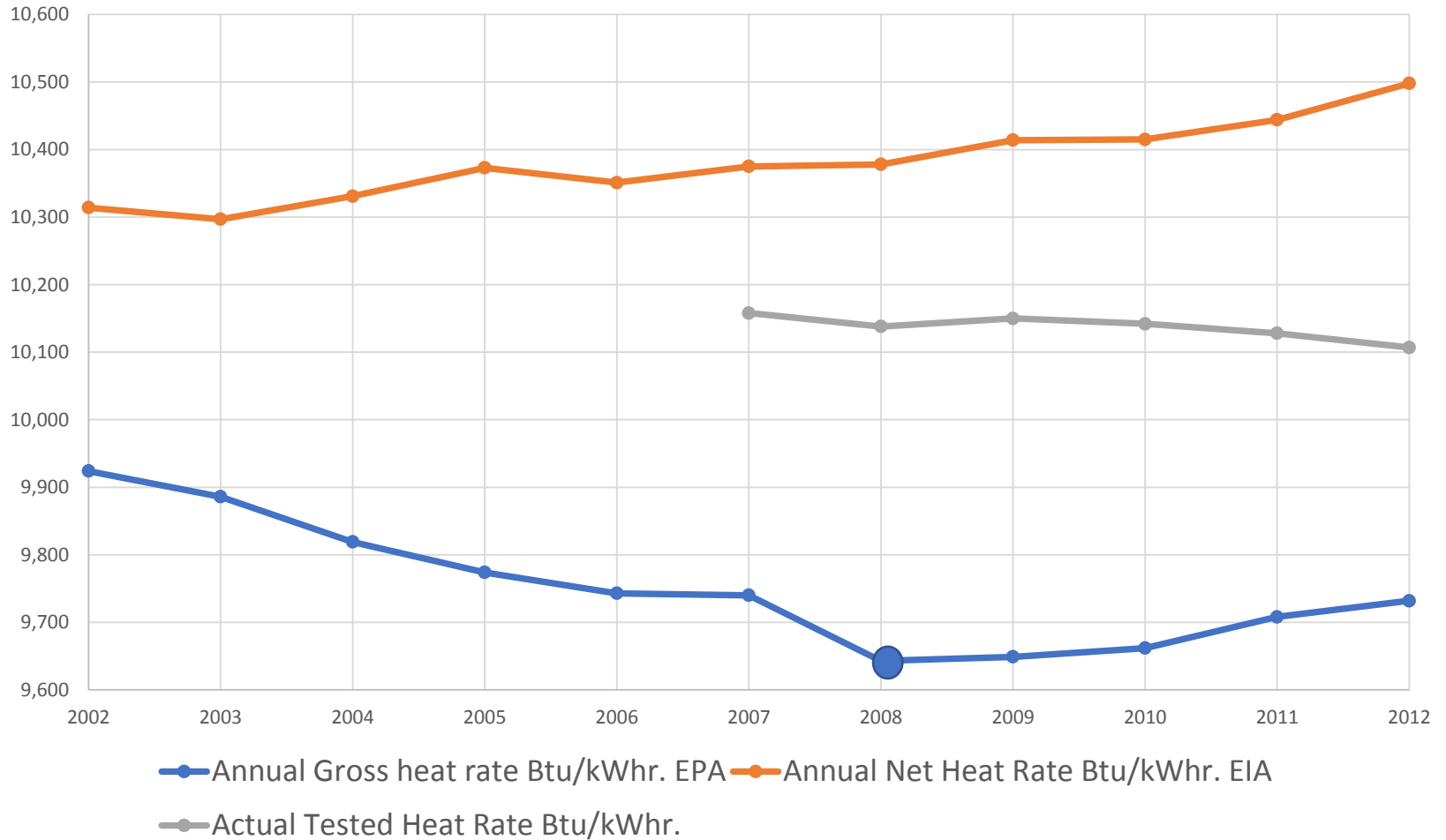
| Year | Annual Gross Heat Rate Btu/kW hr. EPA | Annual Net Heat Rate Btu/kW hr. EIA | Actual Tested Net Heat Rate Btu/kW hr Full load. EIA | Capacity Factor % | Nat. Gas for Power \$/MMBtu |
|------|--|--|---|-------------------|--------------------------------|
| 2002 | 9,924 | 10,314 | | 68 | |
| 2003 | 9,886 | 10,297 | | 69 | |
| 2004 | 9,819 | 10,331 | | 70 | |
| 2005 | 9,774 | 10,373 | | 71 | |
| 2006 | 9,743 | 10,351 | | 70 | \$ 6.94 |
| 2007 | 9,740 | 10,375 | 10,158 | 71 | \$ 7.11 |
| 2008 | 9,643 | 10,378 | 10,138 | 70 | \$ 9.02 |
| 2009 | 9,649 | 10,414 | 10,150 | 62 | \$ 4.74 |
| 2010 | 9,662 | 10,415 | 10,142 | 65 | \$ 5.09 |
| 2011 | 9,708 | 10,444 | 10,128 | 61 | \$ 4.72 |
| 2012 | 9,732 | 10,498 | 10,107 | 53 | \$ 3.42 |
| 2013 | | 10,459 | 10,089 | 60 | \$ 4.33 |
| 2014 | | 10,428 | 10,080 | 61 | \$ 5.00 |
| 2015 | | 10,495 | 10,059 | 55 | \$ 3.23 |
| 2016 | | 10,493 | 10,045 | 53 | \$ 2.87 |

Impact of Nat. Gas on Plant Capacity Factor

2006-2016 EIA data



Heat Rate Comparisons



Impact of Cycling Loads/Capacity



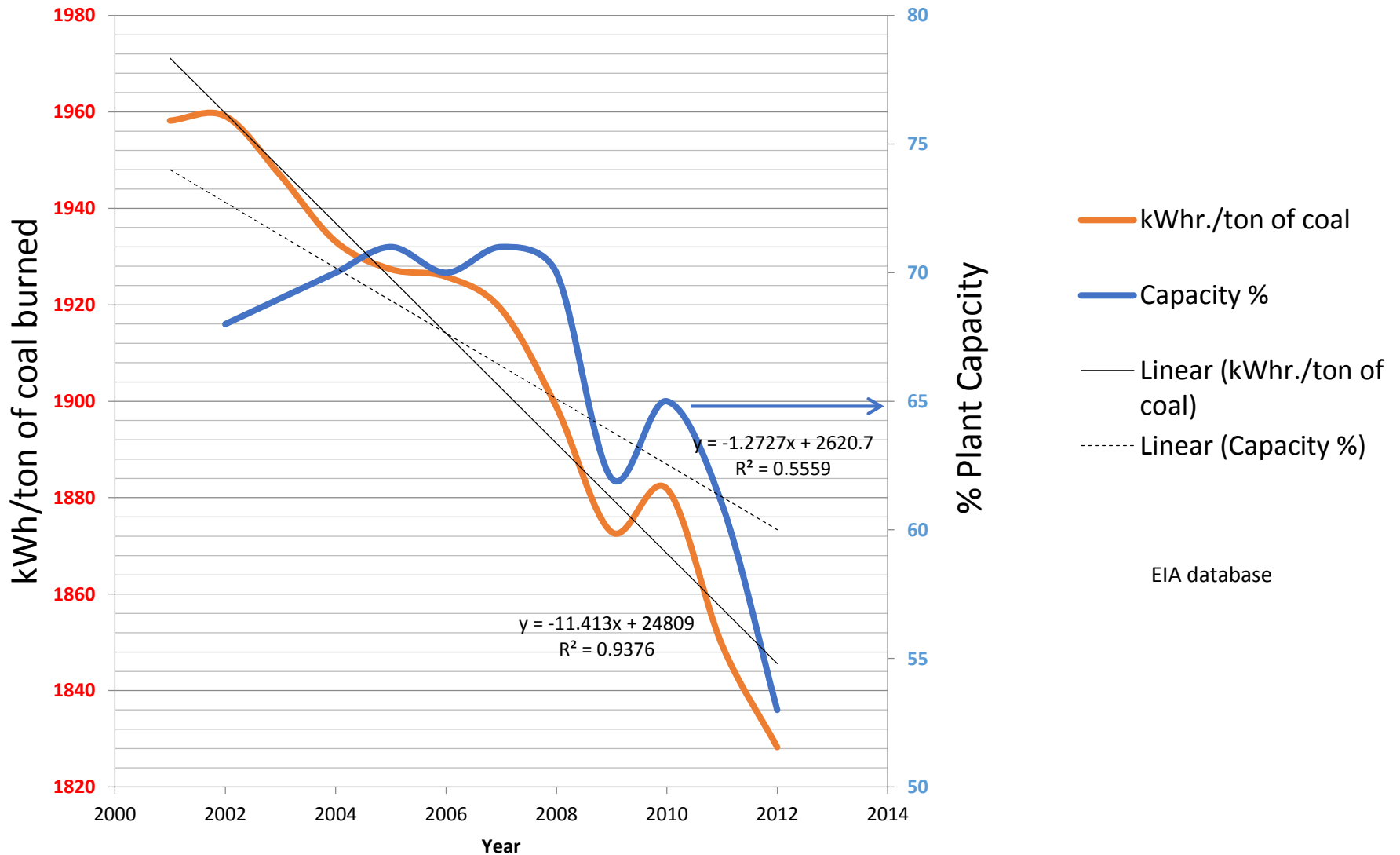
Plant Capacity



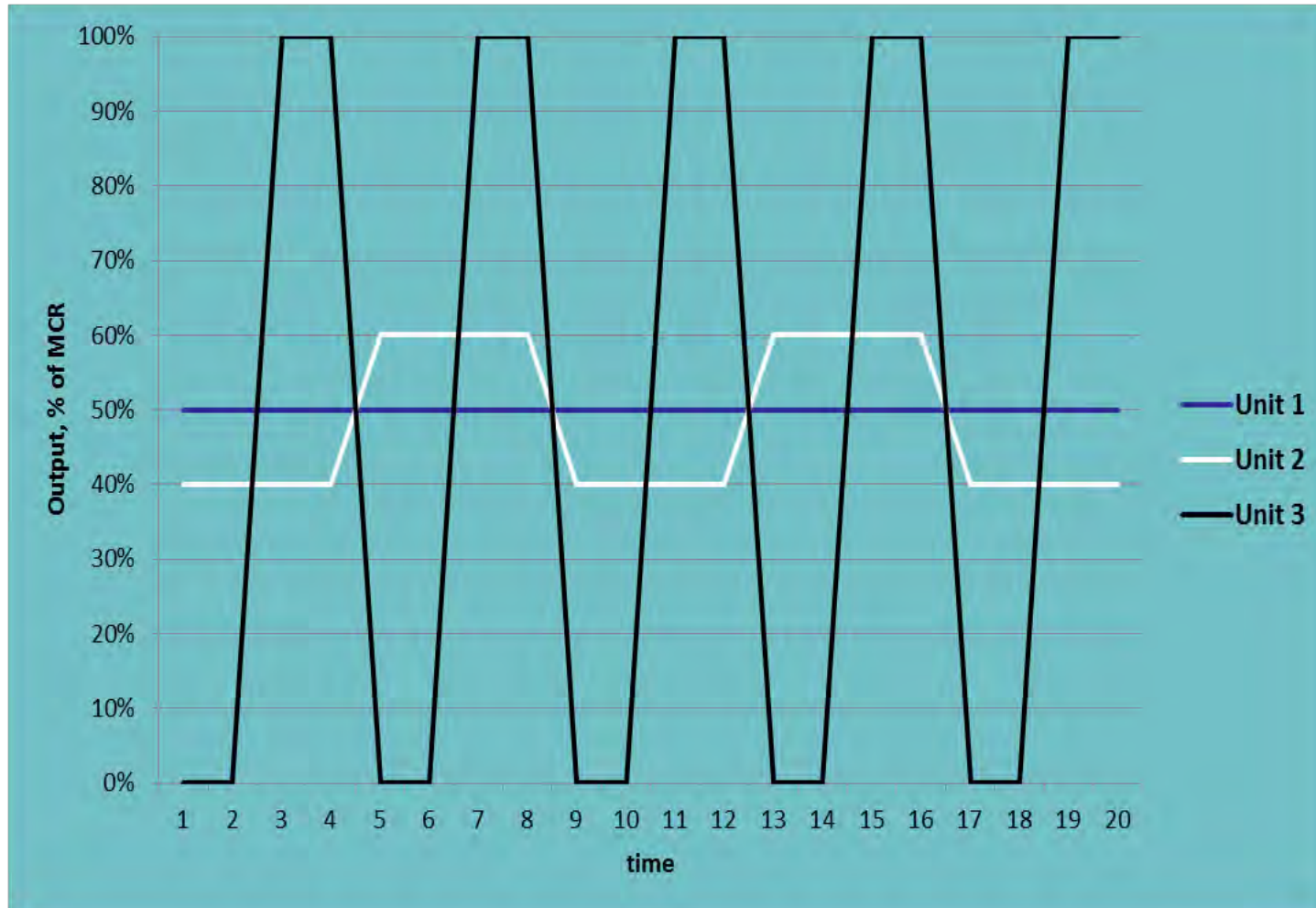
Plant Heat Rate



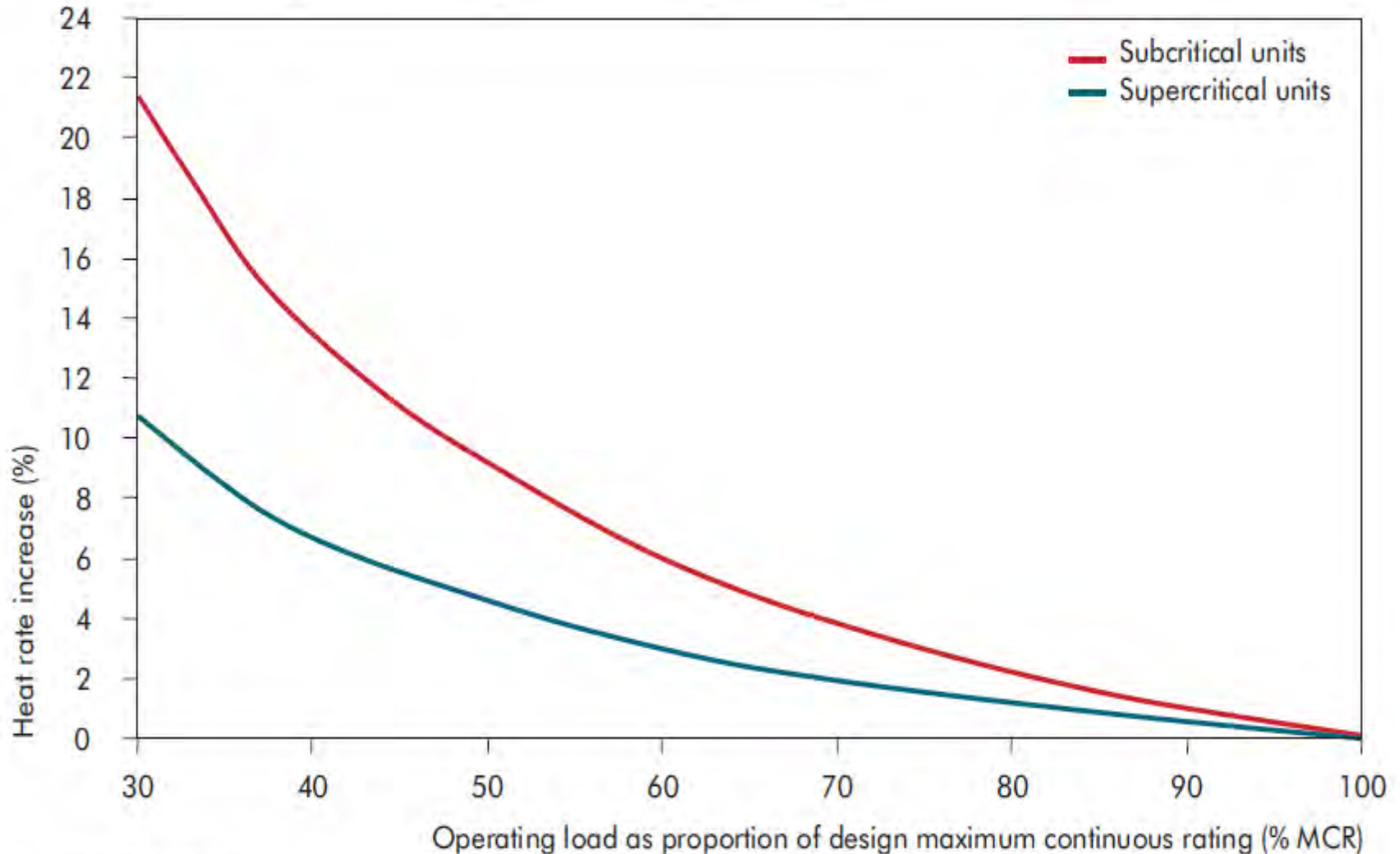
Impact of Capacity on Plant Efficiency



Units 1, 2, and 3 all have 50% capacity factor although their operation is very different.

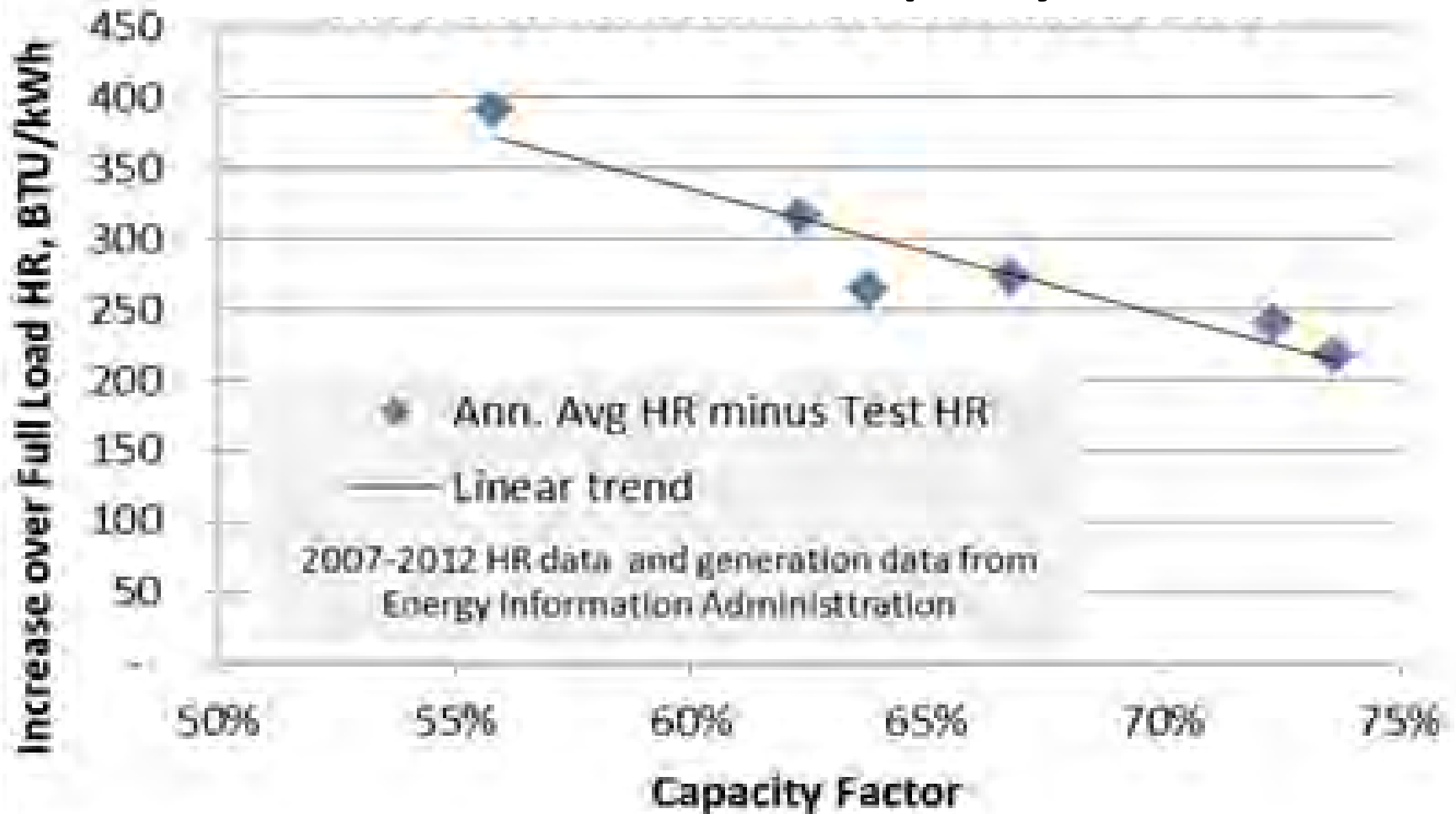


Supercritical plants are more efficient than conventional subcritical plants, especially at low loads (capacity)

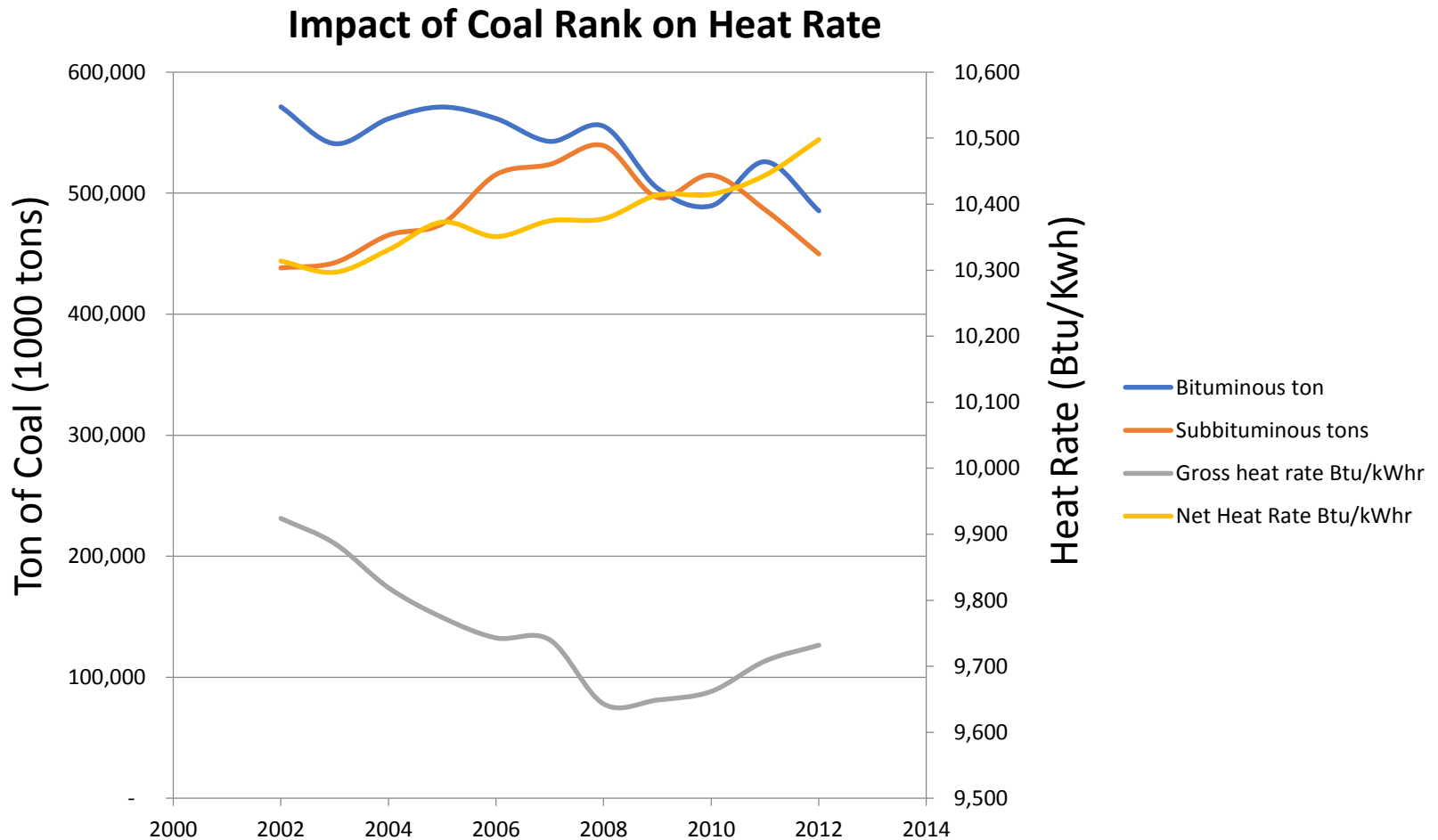


Source: E.ON UK plc.

Heat rate increases when plants operate at less than full capacity



Net heat rate increased from 2002 to 2012 with increasing use of lower rank, subbituminous coal



Air Pollution Controls Increase the Heat Rate

| | High Sulfur Coal | | PRB Coal | |
|-----------------------|------------------|----------|----------|----------|
| Initial Heat Rate | 10,500 | Btu/kWhr | 10,500 | Btu/kWhr |
| | | | | |
| Wet Limestone FGD | 289 | Btu/kWhr | 184 | Btu/kWhr |
| | | | | |
| Typical SCR | 79 | Btu/kWhr | 79 | Btu/kWhr |
| | | | | |
| New Heat Rate | 10,868 | Btu/kWhr | 10,763 | Btu/kWhr |
| | | | | |
| Increase in Heat Rate | 3.5% | | 2.5% | |

Capital cost items where impacts can be made

| Heat Rate Improvement Applications | Impact on Heat Rate | Cost* | Current Utility Practice |
|---|---------------------|-------------|--------------------------|
| Fuel Delivery System | significant | significant | None |
| Feeders (Replace) | | | |
| Pulverizers (Retrofit Dynamic Classifiers | | | |
| Burner Mods (LNBS & OFA) | | | |
| Burner Control System (Neural Network) | | | |
| Superheater, reheater and economizer upgrades (i.e., restoring to original design) | small | major | |
| Add surface area to boiler (Modify design) | small | major | |
| Intelligent soot blowing | significant | significant | yes |
| Add Sliding Pressure operation (if applicable) | small | major | None |
| Air heater upgrades | significant | significant | yes |
| Application of VFD motors | significant | significant | yes |
| Turbine upgrades | significant | major | |
| Condenser upgrades | minor | major | |
| Cooling tower modifications | minor | significant | |
| Feedwater heater upgrade | minor | significant | |
| Condenser water intake modifications if possible (i.e., to get cooler water) in open loop systems | | | |

Operational and maintenance practices where impacts can be made

| Heat Rate Improvement Applications | Impact on Heat Rate | Cost* | Current Utility Practice |
|---|---------------------|-------|--------------------------|
| Fuel switch (low moisture coal or natural gas) | significant | | yes |
| Coal grind adjustments | minor | | yes |
| Burner adjustments | | | yes |
| Air leakage (Casings & expansion joints) | | | |
| Cleaning of wall and tube surface | | | |
| Combustion and steam controls for cycling units | | | |
| Air heater repairs | | | |
| Seals and baskets | significant | | yes |
| Additives | ? | ? | yes |
| Water side fouling | | | |
| Condenser fouling | | | |
| Air pollution control system optimization | minor | minor | yes |
| Cooling tower operation and packing if present | | | |
| Enhance Existing Training | minor | minor | yes |
| Shut down of unused equipment | minor | minor | yes |
| Increase Economic incentives | minor | minor | yes |

Impacts where you may have limited ability to influence

| Heat Rate Improvement Applications | Impact on Heat Rate | Cost* | Current Utility Practice |
|--|---------------------|-------|--------------------------|
| Dispatch cycling and shutdowns | significant | | |
| Fuel purchase | | | |
| High moisture | high | | yes |
| Low Btu | high | | yes |
| Ash content and composition | minor | | |
| The plant's design thermodynamic cycle | | | |
| Plant component design | | | |
| Economic life of the plant | | | |
| New Source Review/PSD | major | | |
| Turbine and condenser efficiency including condenser back pressure | major | | |
| Plant/unit load | | | |

Impact by Fuel, Boiler Technology, & Boiler Size

| | Subcritical | | Supercritical | |
|------------|-------------|---------------|---------------|---------------|
| | Bituminous | Subbituminous | Bituminous | Subbituminous |
| 100-200 MW | 10,663 | 11,051 | | |
| 200-500 MW | 10,470 | 10,642 | 10,364 | |
| 500+ MW | 10,121 | 10,374 | 9,868 | 10,582 |
| Lignite | 11,091 | | | |

Boiler Technology

| Plant Design | Heat Rate BTU/KWhr | Efficiency | CO2 Emissions | Reduction in CO2 |
|------------------------------|-----------------------|------------|--|------------------|
| Subcritical | 10,700 | 32% | 2105 lbs CO2/MW _{hr} _{gross} | Base |
| Supercritical | 9500 | 36% | 1869 lbs CO2/MW _{hr} _{gross} | 11.2% |
| Ultra-supercritical | 8979 | 38% | 1767 lbs CO2/MW _{hr} _{gross} | 16.0% |
| Advanced Ultra-supercritical | 7500 | 45.5% | 1476 lbs CO2/MW _{hr} _{gross} | 30.0% |

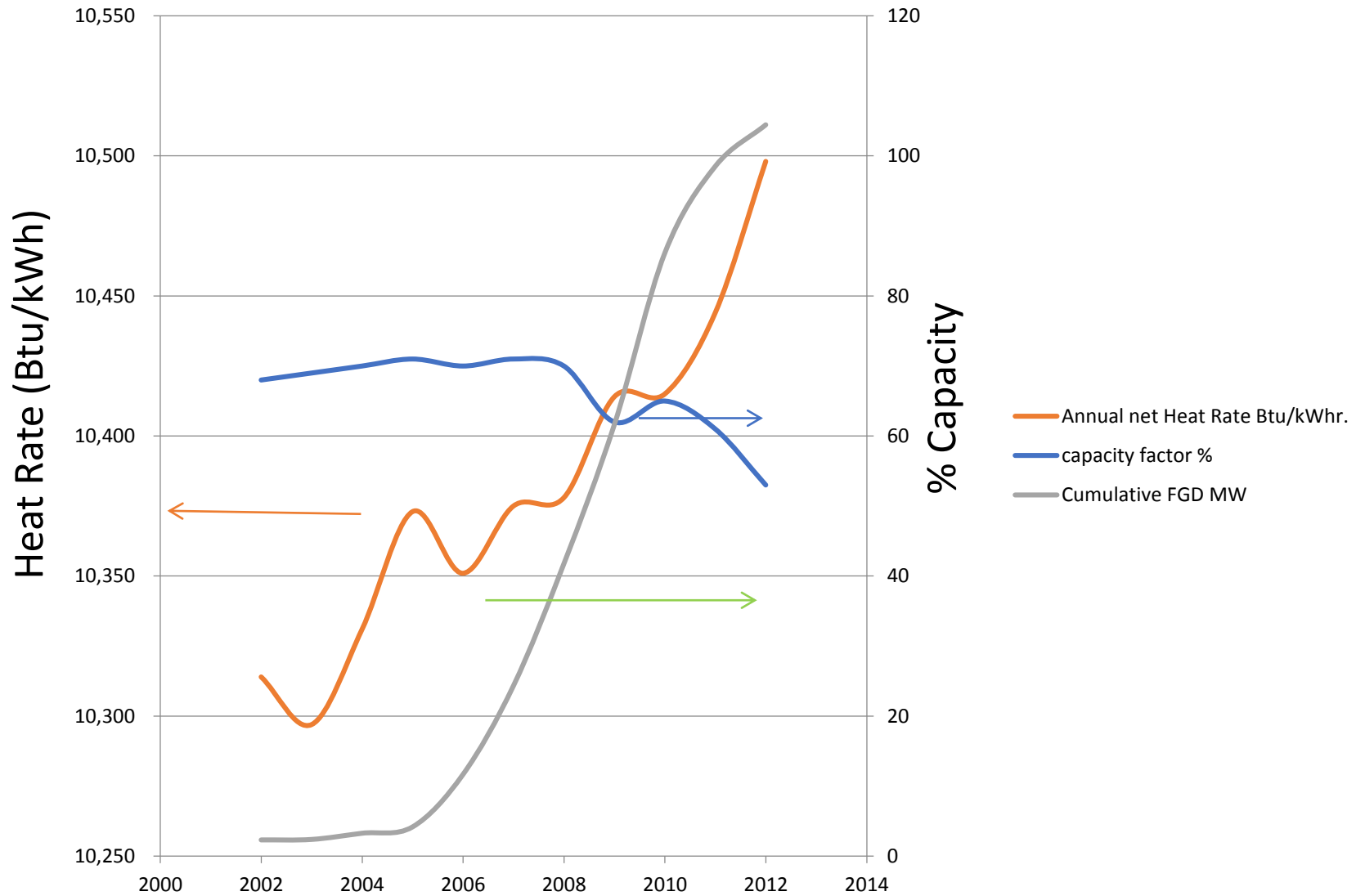
| Parameter | Change | Heat Rate Change*, % |
|-----------------------|------------------|----------------------|
| Main Steam Temp. | - 10 °F | +0.17 |
| Hot Reheat Temp. | - 10 °F | +0.16 |
| Main Steam Press. | - 1% | +0.06 |
| Feedwater Temp. | -10 °F | +0.27 |
| SH Spray Flow | 1% of steam flow | 0.025 |
| RH Spray Flow | 1% of steam flow | 0.4 |
| Aux. Steam Flow | 0.5% of cold RH | 0.35 |
| Excess O ₂ | + 5% | -0.2 |
| APH Exit Temp. | +10 °F | -0.25 |

* Assumed a 10,000 Btu/kWh net heat rate

APC Equipment Installations -DOE

| Year | Flue Gas Desulfurization Systems | | Select Catalytic and Non-Catalytic Reduction Systems | |
|------|----------------------------------|-------------------------------------|--|-------------------------------------|
| | Number of Installations | Associated Net Summer Capacity (MW) | Number of Installations | Associated Net Summer Capacity (MW) |
| 2005 | 555 | 113,573 | 1,068 | 236,689 |
| 2006 | 554 | 116,899 | 1,151 | 255,923 |
| 2007 | 582 | 130,815 | 1,186 | 264,851 |
| 2008 | 629 | 150,835 | 1,238 | 276,010 |
| 2009 | 669 | 174,090 | 1,311 | 298,441 |
| 2010 | 708 | 200,368 | 1,348 | 313,656 |
| 2011 | 721 | 210,878 | 1,396 | 329,676 |
| 2012 | 716 | 218,285 | 1,438 | 343,233 |
| 2013 | 691 | 218,121 | 1,445 | 349,727 |
| 2014 | 689 | 222,626 | 1,459 | 356,920 |
| 2015 | 680 | 222,919 | 1,464 | 358,007 |

FGD Installation Impact on Heat Rate



Efficiency Upgrades and NSR Issues

- Projects with No NSR
 - Neutral networks (FL)
 - Clean condensers
 - Boiler feed pump replacements
 - Cooling tower upgrades
 - Combustion system optimization (FL)
 - Coal drying
 - Steam leaks
- Projects with NSR Violations
 - Economizer replacements
 - Air heater/duct leakage
 - Steam turbine upgrades
 - AQCS upgrades
 - Feed water heater upgrades

Key Question for Energy Efficiency Improvements

- **NSR?**

- Can we make energy efficiency improvements without clarifications to NSR.
- In order to implement energy efficiency & reliability projects on exist EGUs there needs to be a legislative change to the current NSR rule.
- Provide an exemption for energy efficiency and reliability projects.
- Corrosion.

Conclusions & Recommendations

- Heat rate measurements are an important factor in plant economics, energy efficiency and calculating emissions.
- Industry needs to have DOE and EPA working on a compatible basis.
- Need NSR changes to implement heat rate improvement projects.
- DOE/ASME Study to recommend method for annual heat rate.
 - Need your input and help.
 - tonylicataleec@aol.com
 - : <https://www.nist.gov/news-events/events/2017/06/improving-measurement-smokestack-emissions>