EXHIBIT D

Applying the Fundamentals for Best Heat Rate Performance of Pulverized Coal Fueled Boilers

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Abstract:

Often overlooked are the factors that boiler combustion and performance play in the overall heat rate performance of pulverized coal plants. For example; a large utility boiler can be tested and found to be meeting the original design boiler efficiency by completing an ASME boiler heat loss method performance test. Yet the unit heat rate may be off design by over 300 Btu's per kWh due to the non optimization of airflows, air in leakage, high desuperheating spray water flows to the reheater and superheater, auxiliary power consumption and/or non optimum steam temperatures [2, 3, 4, 5, 7, 23]. In fact, there are at least twenty two operations and maintenance controllable heat rate factors that are controllable by excellence in O&M at the boiler [2]. The top ten of these boiler operations and maintenance controllable variables (based on our experience) are:

1. Air in-leakage into the boiler setting
2. Pulverizer fineness, mechanical tolerances and tuning optimization
3. Optimization of Primary, overfire air and secondary airflow measurement and control.
4. Balanced fuel and air distribution into the burner belt
5. Air heater leakage
6. Reheater sprays
7. Reheater steam temperature
8. Superheat sprays
9. Superheater Steam Temperature
10. Carbon in Ash

It has been the author's experience that the average large coal fueled utility steam unit, on a given day, has about 300 to 500 Btu's per kWh heat rate improvement potential [2, 3].

This presentation will review some experiences and case studies of typical coal plants where the fundamentals of optimizing furnace performance have led to significant heat rate improvements.

1.0 <u>Introduction</u>

Old coal fueled power plants are still the backbone of America's base load power generation. The average age of the American coal fueled fleet is about 35 years. In 2007, coal fueled power plants produced about 49% of the total electric power generation of the United States. The plants are amongst the lowest cost of generation of electric power and are likely to be depended on for years to come. Reasonable cost electricity is an important factor for America's economy and for industrial competitiveness. Therefore the efficiency of these old plants should be improved upon to be the best attainable.

It has been the authors' experience that many plants have significant opportunity for improvement in heat rate. This is illustrated by Figure 1, which has been taken from the July 23, 2008 report by the

DOE/NETL, entitled "Reducing CO_2 Emissions by Improving the Efficiency of the Existing Coal-Fired Power Plant Fleet". [24]
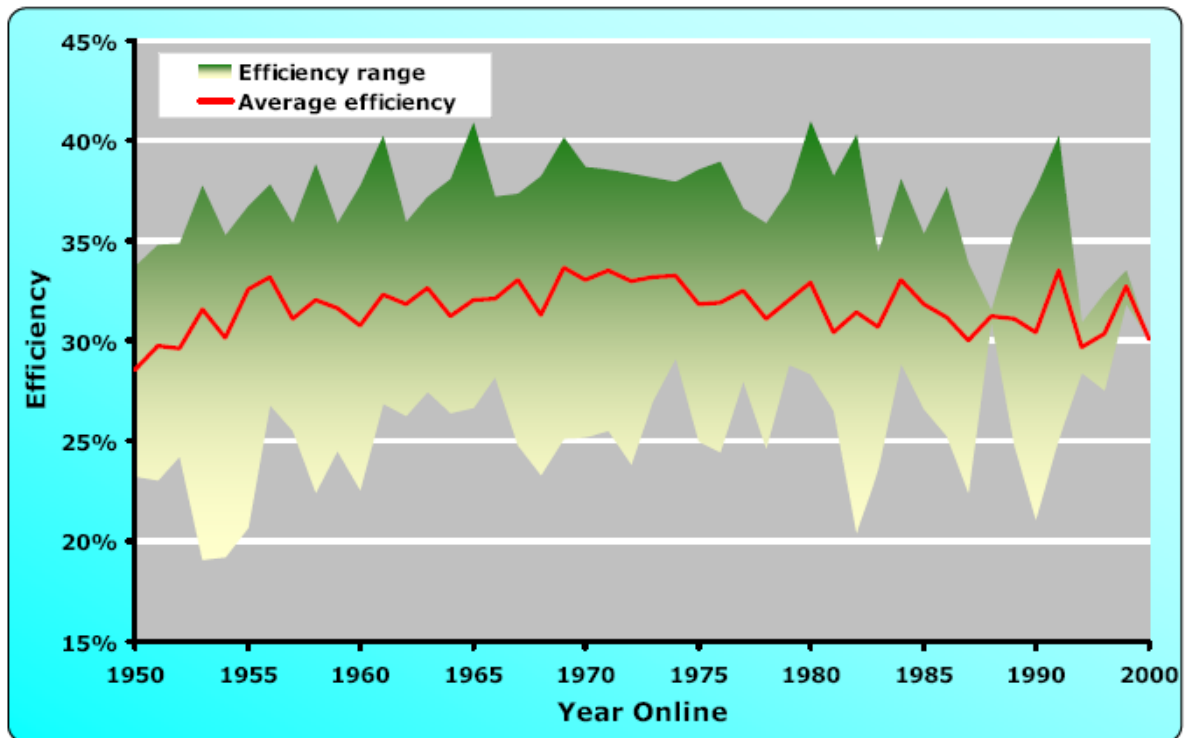
Figure 1

This figure indicates a wide spread between the "Best" and the "Worst" performing plant heat rates.

The purpose of this presentation is to show the opportunity to apply the fundamentals and achieve significant improvement in overall plant efficiency.

Figure 2 on the next page is a figure that Storm Technologies, Inc. has used for years to illustrate the potential improvements by applying excellence in operations and maintenance.[3] This slide compares the design of the ASME historical power plant, Eddystone No. 1, which was designed for an overall thermal efficiency of about 41% to several periods from 1957 to present day. The world's best most efficient plants even with extreme clean coal stack clean up auxiliaries are approaching 41% again. Yet, we depend on an aging fleet of about 1400 old coal plants that could achieve heat rates of about 10,000 Btu/kWh or better, but often operate at about 10,500 Btu's/KWh or about 32.5% thermal efficiency.
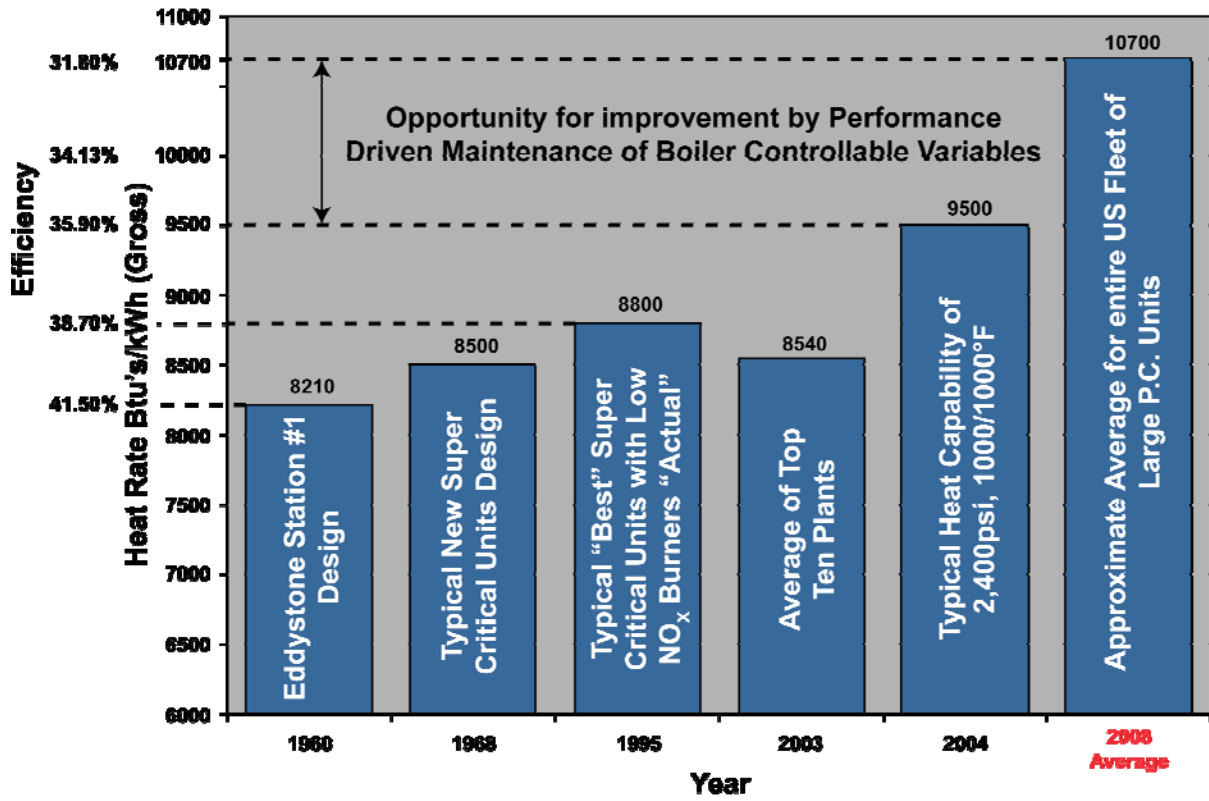
There is Potential for Improvement

Figure 2

With this background established of the potential improvement by applying the fundamentals, a few examples will be reviewed of the results that may be (and have been) attained by Applying the Fundamentals (2, 3, 5, 7, 10, 12, 15, 16, 18, 19, 20, 22, 23).
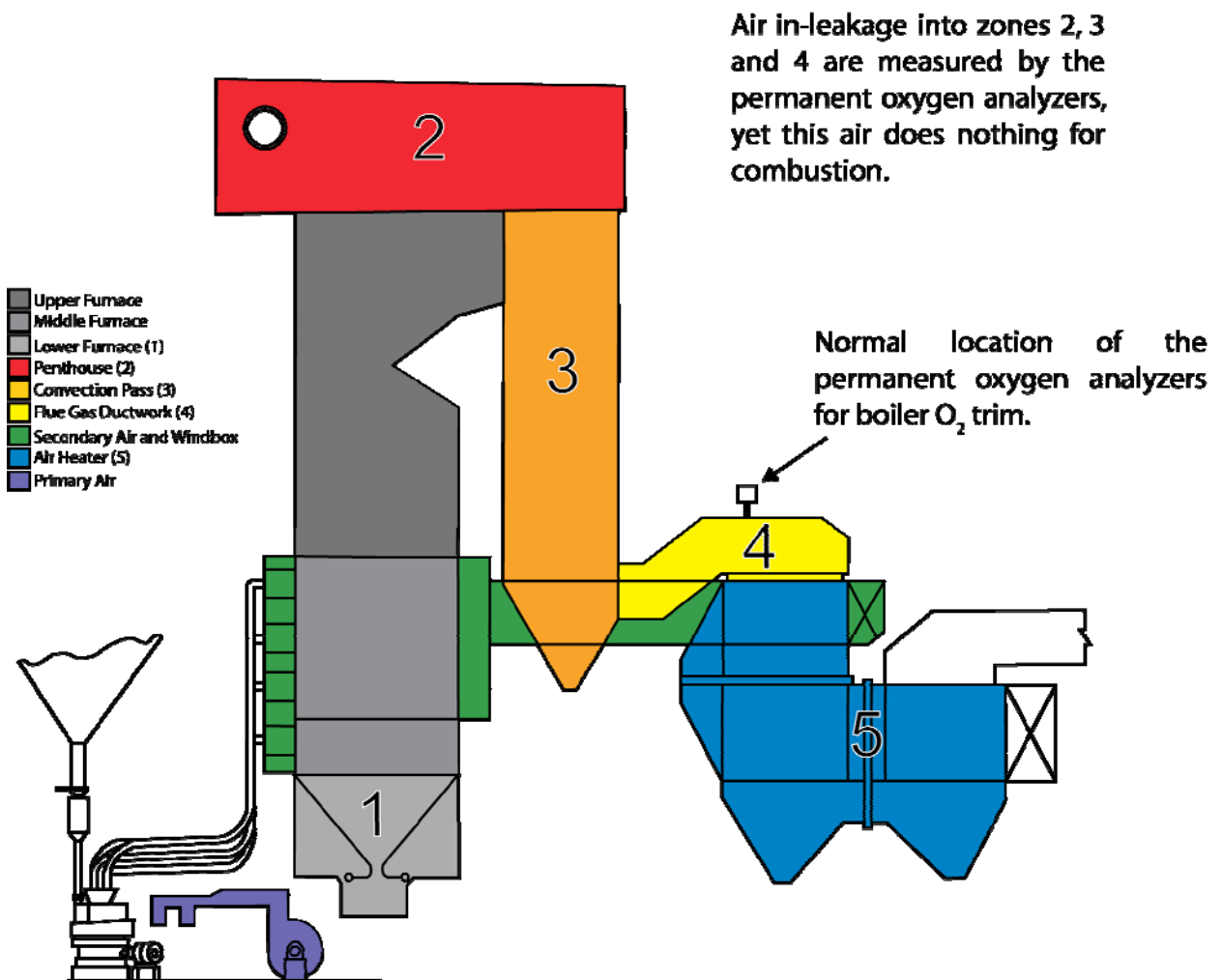
Improved Heat Rate Results should begin with the optimization of the combustion process.

2.0 Air In-Leakage – The Number 1 Stealth Heat Rate Penalty

Of course, this only applies to balanced draft systems. In our experiences, we occasionally are involved with pressurized furnaces, but I estimate that 90% plus of the pulverized coal boilers in operation, are balanced draft.

Figure 3 – Combustion Airflow should be precisely measured and controlled. Any air that leaks into the setting after the furnace exit is of no value to combustion and is a loss in efficiency. The overall unit efficiency losses tend to compound one another and accumulate to very significant levels.

Total equivalent leakages of air, from the furnace to the air heaters, has been documented to the range of 20% of the equivalent total air required for full load operation. See Figure 3 for typical locations of air in-leakage (3).

Air in-leakage into zones 2, 3 and 4 are measured by the permanent oxygen analyzers, yet this air does nothing for combustion.

Normal location of the permanent oxygen analyzers for boiler O_2 trim.

Legend:
- Upper Furnace
- Middle Furnace
- Lower Furnace (1)
- Penthouse (2)
- Convection Pass (3)
- Flue Gas Ductwork (4)
- Secondary Air and Windbox
- Air Heater (5)
- Primary Air

Figure 3 – Typical Locations for Air In-Leakage

This air in-leakage has resulted in significant heat rate penalties. Air in leakage and the resultant oxygen starved furnace further contributes to loss of capacity and reliability from the high furnace exit gas temperatures. Furnace oxygen starvation creates the reducing atmosphere which increases slagging, fouling and water wall metal wastage.

In our experience, the heat rate penalty for excessive air in-leakage alone is often over 300 Btu/kWh.

3.0 Combustion Airflow Optimization

Modern low NO_X combustion systems typically have at least three air flow paths (excluding tramp air in-leakage). These are: Primary Airflow, Secondary Airflow and Overfire Airflow. The secondary airflow paths are often divided into at least two or more paths, of inner air or core air and peripheral air in a two air zone low NO_X burner as shown in the figures below.
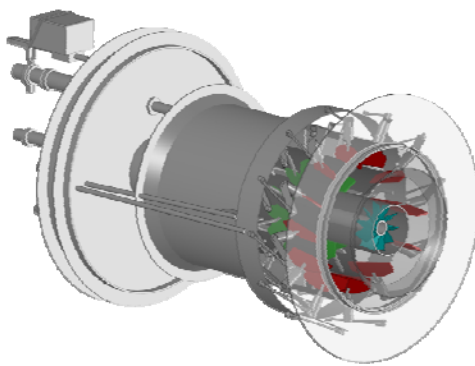
All modern low NO_X burner designs internally stage combustion by deliberate separations of the air and fuel into zones. This separation of the airflow streams purposely reduces the flame intensity and lengthens the flames.
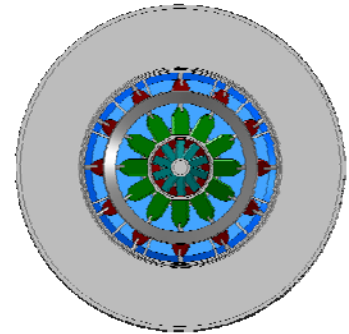
Figure 3A

Some new generation low NO_X burners have three or four secondary air zones, and some boilers utilize underfire air or boundary air for partial admission of portions of the combustion airflow to the burner belt.
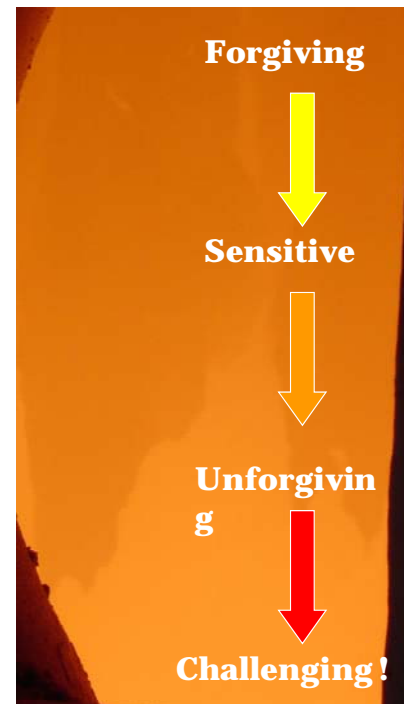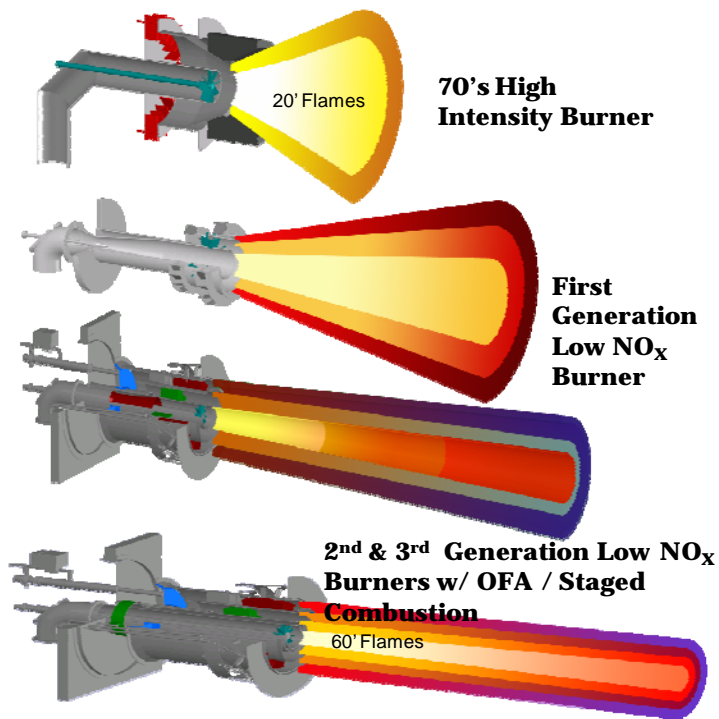
20' Flames

70's High Intensity Burner

First Generation Low NO_X Burner

2nd & 3rd Generation Low NO_X Burners w/ OFA / Staged Combustion

60' Flames

Forgiving

Sensitive

Unforgiving

Challenging!

Figure 3B

The point attempted to be made here is the combustion airflow should be measured and controlled to each point of admission into the furnace. Or at least, know the total quantities of airflow being supplied to each major flow path; primary, secondary and overfire. The reason for knowing the exact airflow proportions is that there is limited time to complete combustion. Only one or two seconds. [1, 3, 4, 5, 7, 8, 9, 11, 15, 19]

The residence time to combust pulverized coal fuel is only one to two seconds from the time a coal particle enters the furnace (from the uppermost burners), until the de-volatilized particles are quenched below the carbon char ignition temperature of 1,400° F as shown on Figure 4 below.
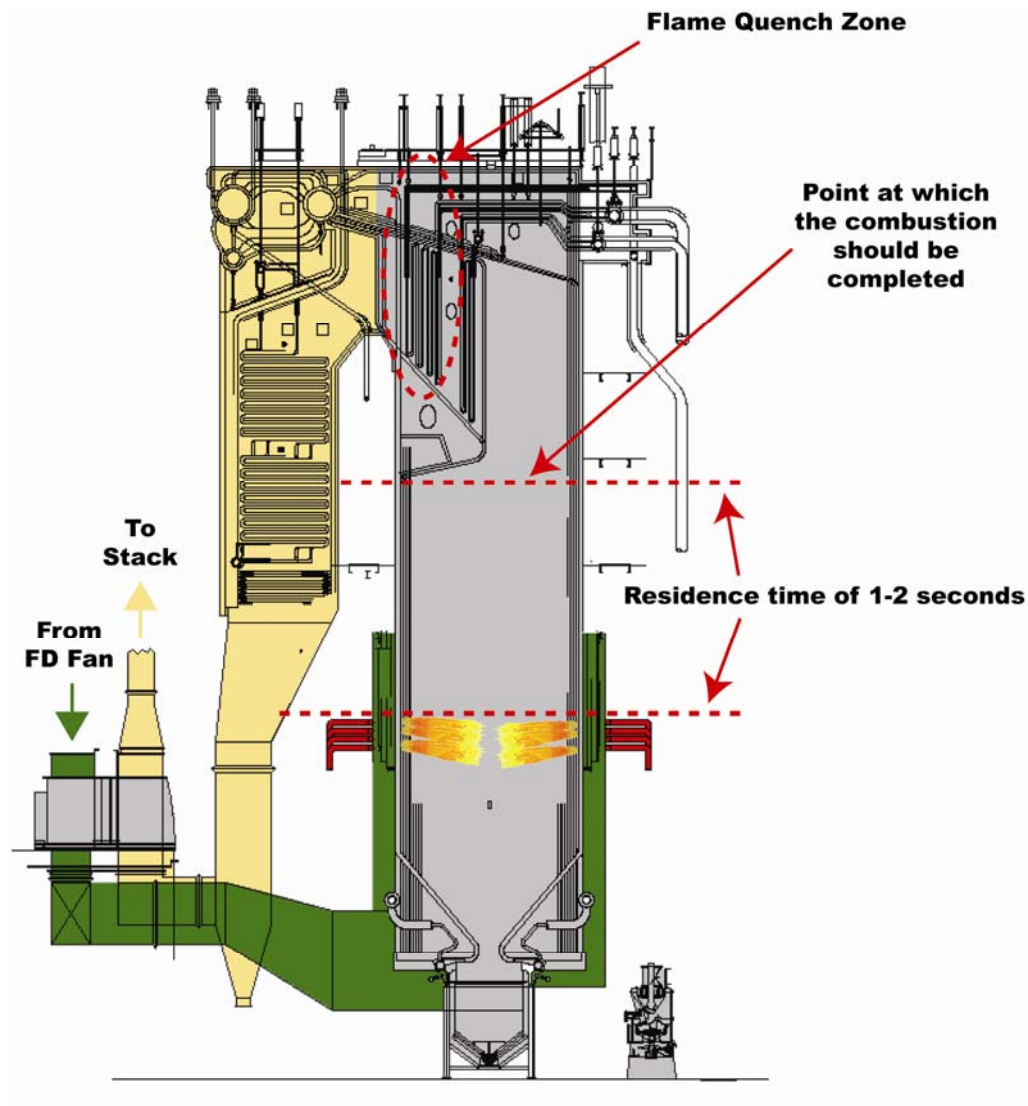
Figure 4

Because of this short time to completely combust the pulverized coal at a NO_X compliant level, the airflow paths must be precisely measured and controlled. The schematic of typical airflow paths is shown on Figure 5.

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The fundamental fact of coal combustion, especially for bituminous coals is that the de-volatilized carbon char particles remaining after a pulverized coal particle enters the furnace will require a minimum of 1400°F and an oxidizing environment to complete combustion. Therefore, combustion must be completed before the burning carbon char particles enter the convective heat transfer section of the boiler.
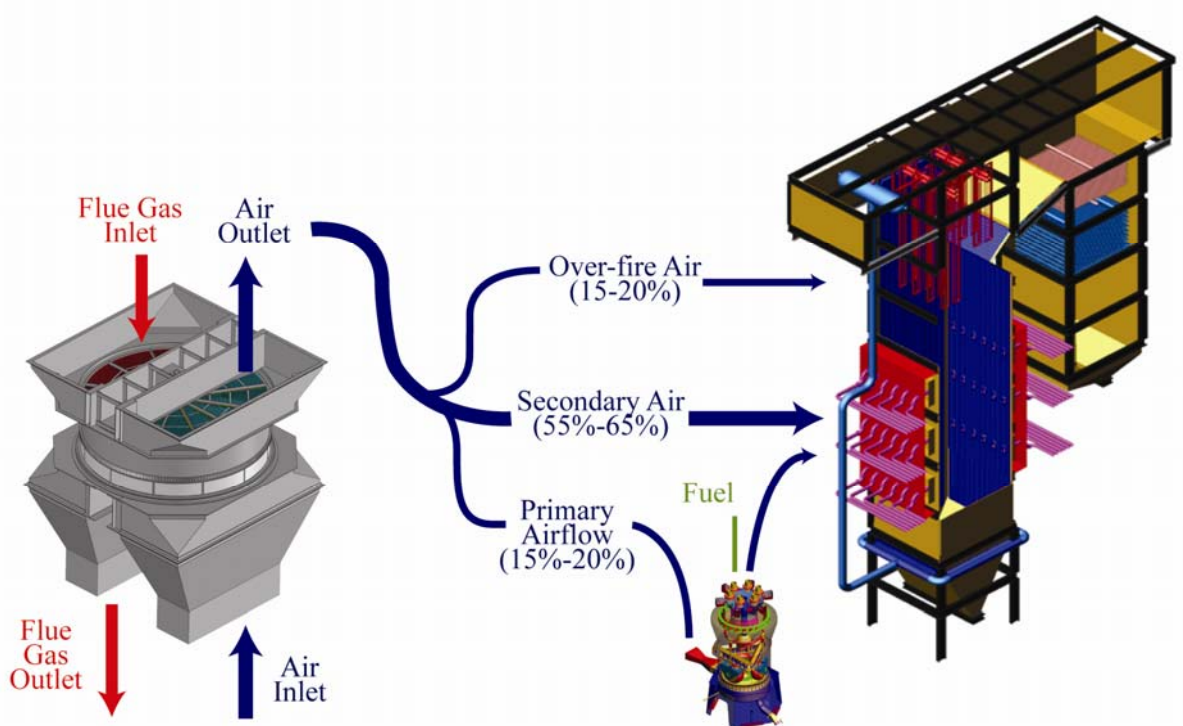
Figure 5 – Typical Air Flow Paths

So what does airflow management have to do with heat rate? Plenty! Here are a few examples:

- High primary airflow harms heat rate. This is especially true for bituminous fuels (total fuel moisture less than 10%) where significant tempering airflow is utilized as a component for primary air.

- Why? Because the tempering airflow bypasses the air heater and in so doing, gives up the heat transfer of the exiting flue gas to exchange heat to that amount of combustion air in the primary airflow path. In essence, this is an increase in the stack dry gas loss, due to a slightly elevated flue gas exit temperature

Even greater losses in efficiency from non-optimized primary airflow show up as high furnace exit gas temperatures which create heat rate penalties from a myriad of affects including: [1, 3, 4, 16, 19, 21, 22, 23]

  ➢ High de-superheating spray water flows

  ➢ Increased slagging and fouling which requires more frequent sootblowing

  ➢ Increased ash cinder (popcorn) ash deposits to foul or plug the SCR or APH. These fouled surfaces then increase draft losses and increased fan power

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consumption, in addition to the increased frequency of soot blowing. Higher airheater differential also induces more airheater leakage.

➢ High primary airflow usually creates poor fuel fineness and poor fuel distribution which contribute to the above. Plus higher than optimum carbon in ash.

➢ The unit heat rate Performance deterioration tends to be compounded from the high furnace temperatures. The high temperatures promote slagging and fouling, which increases draft losses, which increase soot blowing, which create more SCR or ApH fouling which increases draft losses and thereby increases the air heater leakage and higher duct negative pressures create more in-leakage of tramp air. Fan power is increased, etc. Many factors do in fact, tend to multiply.

Secondary airflows and overfire airflows are also important to be measured and controlled for best furnace performance. [4, 21, 23] Another subject is fuels flexibility. The more precise the airflow measurement and control is, the more tolerant a furnace is of fuels with lower fusion levels that accompany higher sulfur and iron levels. [5, 6]

The typical heat rate improvement opportunity for optimizing combustion airflow is in the magnitude of 50-200 Btu's/kWh. Not insignificant and at today's fuel costs there is both financial and environmental incentives.

4.0 What does Flyash Unburned Carbon Have to do with Heat Rate?

The heat rate penalty for Bituminous Flyash LOI (or Loss on Ignition) is roughly accepted to be about 0.10% in efficiency for every 1.0% change in flyash LOI. In other words, if a boiler firing Central Appalachian coal with a 12,000 Btu/pound HHV and 10% ash has a 15% flyash LOI, the losses due to LOI when calculated by the ASME code will come out real close to 1.5 % in efficiency loss of the boiler for the heat loss component attributed to carbon in ash. If the steam plant is operating at a heat rate of 10,000 Btu's/kWh, then the penalty could be expressed as 150 Btu's per kWh. Seems simple enough. Now, if combustion optimization is applied to the pulverizers, mechanical tolerances and airflow, and the flyash LOI is reduced to about 5%, then the heat rate improvement would be roughly about 100 Btu's right? Well maybe.

It has been our experience that when the flyash LOI is reduced significantly, as in this example, the heat rate improvement is often far better than the expected 100 Btu's/kWh. Why? I have seen this many times and the explanation is this. When the pulverizer adjustments are made, the airflow proportions corrected, leakage repaired, and slagging reduced. Then there are a number of compounding factors that work in the favor of better heat rate. Among them:

- Less soot blowing, so there is a reduction in steam consumption and steam cycle losses.

- Less draft losses from cinders plugging the SCR or the Air Preheaters. So, there is less auxiliary horsepower required for the fans.

- Less draft losses create less air heater differential between the entering air and leaving gas. This reduced delta of static pressures reduces airheater leakage rates.

- As the fires are lowered in the furnace and active combustion is lowered down and out of the superheater and reheater, then there are less de-superheating water spray flows which are in themselves a large unit heat rate penalty.

- Operations and maintenance personnel when working to reduce the flyash LOI become more aware of the other 21 O&M Controllable factors at the boiler and the overall heat rate improvement using flyash LOI as a precursor can yield improvements that exceed expectations from flyash carbon loss alone.

5.0 Summary of Opportunities for Improvement

There are two lists that Storm uses as check lists to optimize combustion. They are the Thirteen Essentials and the 22 Heat Rate Factors Controllable by O & M.

22 Heat Rate Variables

1. Flyash Loss On Ignition (LOI)
2. Bottom ash carbon content
3. Boiler and ductwork air in-leakage
4. More precise primary airflow measurement and control, by reducing tempering air
5. Reducing pulverizer air in-leakage on suction fired mills
6. Pulverizer throat size and geometry optimization to reduce coal rejects and compliment operation at lower primary airflows
7. Secondary airflow measurement and control for more precise control of furnace stoichiometry, especially important for low NO_X operation
8. Reduction of extremely high upper furnace exit (FEGT) peak temperatures, which contribute to "Popcorn Ash" carryover to the SCR's and ApH's, High spray water flows, Boiler slagging and fouling, and high draft losses due to fouling. The high draft losses cause increased in-leakage, increased fan auxiliary power wastage and increased associated losses with the high spray water flows
9. High de-superheating spray water flow to the superheater
10. High de-superheating spray water flow to the reheater
11. High air heater leakage (note: Ljungstrom regenerative airheaters should and can be less than 9% leakage)
12. Auxiliary power consumption/optimization i.e., fan

clearances, duct leakage, primary air system optimization, etc
13. Superheater outlet temperature
14. Reheater outlet temperature
15. Airheater outlet temperature
16. Airheater exit gas temperature, corrected to a "no leakage" basis, and brought to the optimum level
17. Burner "inputs" tuning for lowest possible excess oxygen at the boiler outlet and satisfactory NO_X and LOI. Applying the "Thirteen Essentials"
18. Boiler exit (economizer exit) gas temperatures ideally between 650°F to 750°F, with zero air in-leakage (no dilution!)
19. Cycle losses due to valve leak through – i.e. spray water valves, reheater drains to the condenser, superheater and re-heater drains and vents, and especially any low point drains to the condenser or to the hot well
20. "Soot blowing" Optimization – or smart soot blowing based on excellence in power plant operation. (Remember, soot blowing medium is a heat rate cost, whether compressed air or steam)
21. Feed water heater level controls and steam cycle attention to detail
22. Steam purity and the costly impact of turbine deposits on heat rate and capacity

Thirteen Essentials of Optimum Combustion for Low NO$_X$ Burners

1. Furnace exit must be oxidizing preferably, 3%.
2. Fuel lines balanced to each burner by "Clean Air" test ±2% or better.
3. Fuel lines balanced by "Dirty Air" test, using a Dirty Air Velocity Probe, to ±5% or better.
4. Fuel lines balanced in fuel flow to ±10% or better.
5. Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.
6. Primary airflow shall be accurately measured & controlled to ±3% accuracy.
7. Overfire air shall be accurately measured & controlled to ±3% accuracy.
8. Primary air/fuel ratio shall be accurately controlled when above minimum.
9. Fuel line minimum velocities shall be 3,300 fpm.
10. Mechanical tolerances of burners and dampers shall be ±1/4" or better.
11. Secondary air distribution to burners should be within ±5% to ±10%.
12. Fuel feed to the pulverizers should be smooth during load changes and measured and controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred.
13. Fuel feed quality and size should be consistent. Consistent raw coal sizing of feed to pulverizers is a good start.

Myself and others in our company have presented numerous presentations, written articles for magazines and technical publications on the Storm approach to getting the "furnace inputs right" so I will not repeat the details here. The reference list at the end of this paper lists 23 publications or presentations on the subject "Optimizing Furnace Inputs". Suffice it to say, we know they work and we have obtained good results by applying the fundamentals.

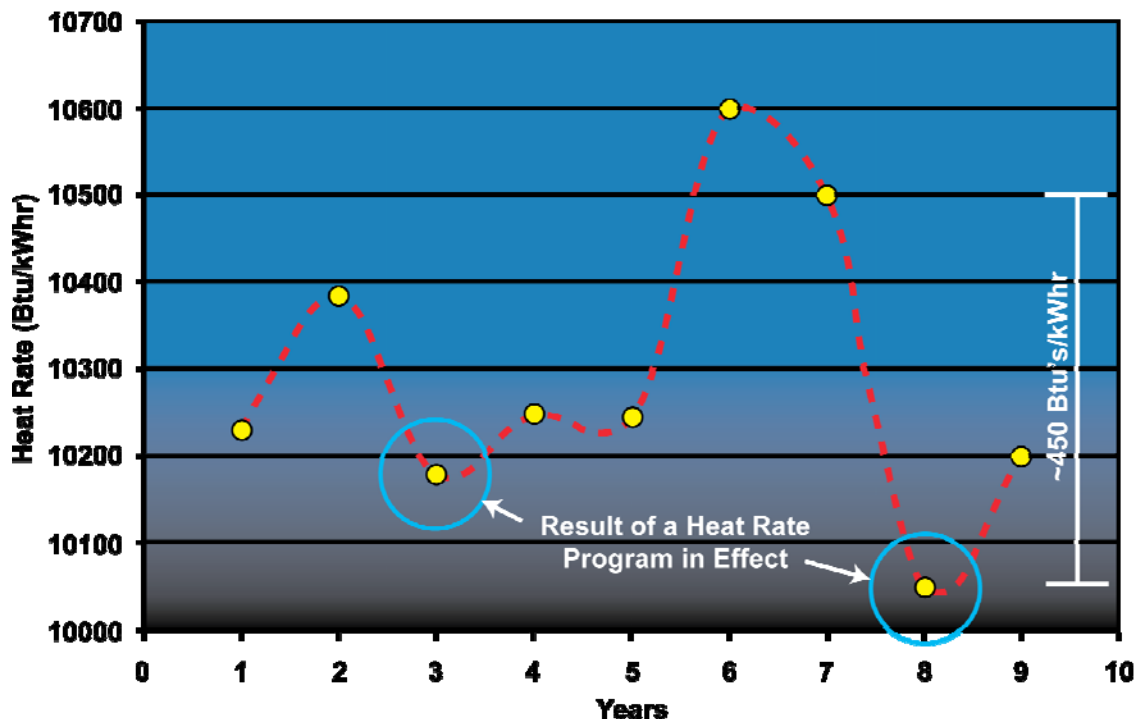A typical approach is shown on the Heat Rate Curve, Figure 6.

Figure 6

Figure 6 represents an actual case study of a 650MW, wall fired 2400 psi/1000°F/1,000°F unit. This was a coordinated effort by all of the O & M team, and Storm Technologies personnel using our testing and diagnostic techniques. Basically, the Heat Rate was improved overall by over 500 Btu's/kWh by a comprehensive approach to getting the boiler inputs optimized , feedwater cycle, condenser, cooling tower and balance of plant. By teamwork, the overall heat rate was improved significantly on two occasions. The high peaks were when attention was not applied to the boiler.

I have been involved in many such successes as shown on Figure 6. Our approach works, when the O & M team all buys in and applies the fundamentals.

How does a plant get started?

Begin with a comprehensive diagnostic testing program that includes at least seven variables for measurement, then plan and execute the required maintenance operations to achieve results. See Figure 7a.

Item	Description	Outage Provisions
1.0	**Pulverizer & Fuel Line Performance**	Test Ports Must be Installed
1.1	Clean Airflow Balance	
1.2	Dirty Airflow Balance	
1.3	Fuel Flow Balance	
1.4	Air-Fuel Ratios	
1.5	Pulverized Coal Fineness	
2.0	**Primary Airflow Calibration**	
3.0	**Secondary Airflow Distribution & Control**	Accessibility & Testing Ports are Required
4.0	**Excess O_2 Probe Measurement Accuracy**	Multi-point test probes are Preferred
5.0	**Furnace Exit Gas Temperature & Flue Gas Measurement**	Water & Air Supply Hoses & Fittings will need to be prepared; Safe Test Platforms; Test Ports (test ports - bent tube openings with observation / test door assemblies)
6.0	**Boiler Exit to Stack Flue Gas Measurements;** Air Heater Performance; Boiler Efficiency & Total System Air In-leakage Measurement	Accessibility & Testing Ports are Required
7.0	**Insitu Flyash Sampling & Analyses** for Sizing & unburned carbon	Accessibility & Testing Ports are required; Multi-Point Emission Sampling Systems by STORM TECHNOLOGIES are suggested for ease of testing/daily measurements

Figure 7A
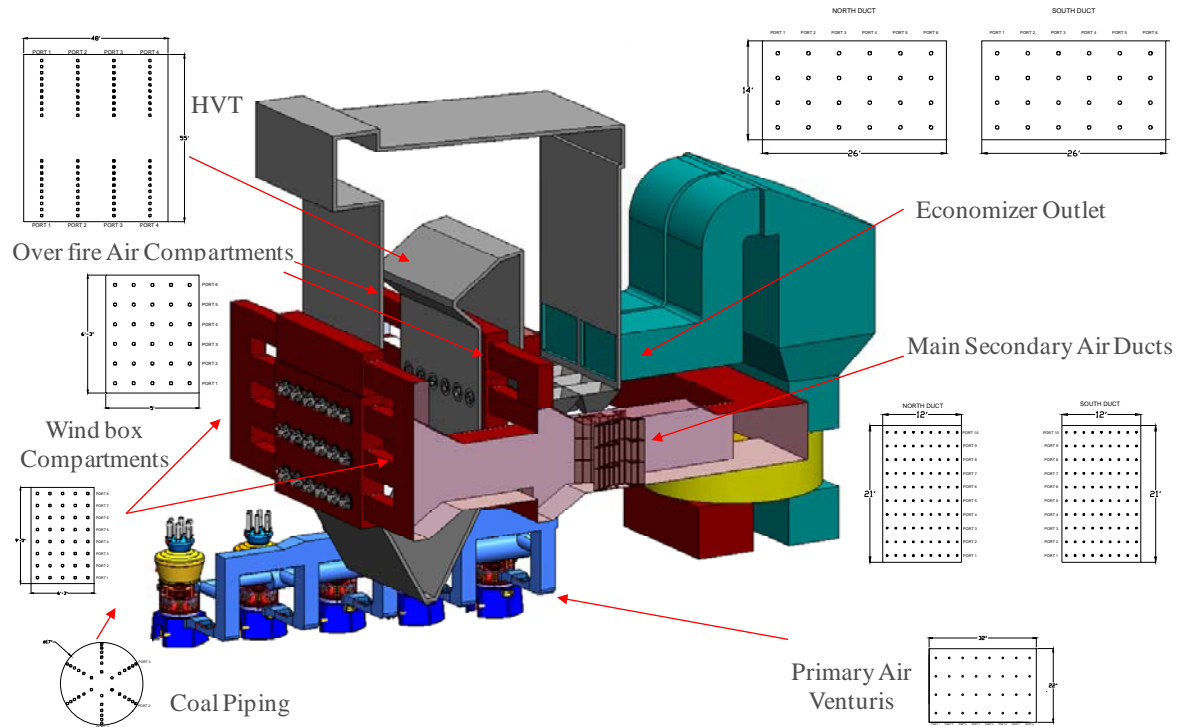
Figure 7B Illustrations of Typical Boiler Performance Test Locations

What are the rewards for Applying the Fundamentals? Well, if a 500 MW pulverized coal plant is operating at a heat rate of say 10,700 Btu/kWh and the heat rate can be reduced to 10,200 Btu/kWh the financial incentive is millions of dollars in fuel savings, plus the reduction in carbon dioxide.

Typical opportunities are outlined on the table below. [2, 3, 4, 5, 7, 8, 21, 23]

	Controllable Variable Qualities
Air In-Leakage	**200 Btu/kWh**
Primary Airflow Optimization	**50 Btu/kWh**
Pulverizer Optimization and Improved Fuel Line Balance	100 Btu/kWh
Reducing Air Heater Leakage	**80 Btu/kWh**
Reduced Coal "Pyrites" Rejects	40 Btu/kWh
Reduced Carbon in Ash	50 Btu/kWh
Reduction of de-superheating spray water flows	50 Btu/kWh
Total:	**570 Btu/kWh**

Figure 8

6.0 <u>Summary</u>

There are two observations that I have made over my 40+ years in this business. 1) During the 60's there was much attention to pulverizer coal fineness testing, air in-leakage testing, airheater tests and periodic unit heat rate tests. Plant Results Engineering staff focused on these tests and results. Back then, the boilers were often relatively new compared to the aging coal fleet we now depend upon. It has been my observation that there are less results engineering and test and results technicians employed in the plant staffs now, than there was 40 years ago. This would seem to be a missed opportunity for heat rate improvement, reduction of fuel costs and reduction of carbon emissions.

2) The second point is that the boiler furnace duty has been increased since the 60's and 70's. There have been extreme measures to reduce NO_X with the installation of low NO_X burner systems. Fuels have been changed, many boilers designed for eastern bituminous fuels, now fire lower grade western fuels such as PRB. Exacerbating the challenge is the fact that often major plant overhauls have been changed from 6 months between boiler scheduled outages to sometimes more than 2 years. The overall reliability, considering the NO_X changes, extended time between overhauls and fuel changes, are remarkable and noteworthy accomplishments. However, these accomplishments could, in the author's opinion be made even better with more attention to applying the fundamentals to the furnace performance.

As a third party observer experienced in the art of coal power generation, a fair question occurs to me: Is it now time to apply the fundamentals of getting the furnace inputs optimized and driving maintenance work orders from actual diagnostic tests?

REFERENCES

[1] *"Getting the most from Boilers"* Stephen K. Storm, Industrial Fuels & Power Magazine, December 2008

[2] "The Fundamentals of Combustion & "The Apples Approach to Optimization". Stephen Storm, Power Plant Summit, 2008 CII, Sponsored by the U.S. DOE, NETL and U.S. AID, New Delhi, India

[3] "*Large Electric Utility and Combustion Performance Improvements Short Course*" – Storm Technologies, Inc., 2008

[4] "*The Extreme Importance of Total Air & Fuel Flow Measurement on a 450MW B&W Wall Fired Unit firing high sulfur fuels*". Electric Power Conference 2008 May 7th, 2008, Baltimore, MD.

[5] **"Maximizing Plant Performance" -** Stephen Storm. **Presentation at** Clyde Bergmann's Boiler Cleaning Symposium, 2008

[6] *"Quality Counts – A look at different ways to measure coal quality"* Stephen Storm, WORLD COAL MAGAZINE, March 2008

[7] *"A Review of the Importance of Measuring and Controlling the Furnace Inputs on a Typical PC Fired 500MW boiler*" R.F. Storm, Stephen Storm, POWER MAGAZINE, October 2007

[8] *"To Optimize Performance, Begin at the Pulverizer*" R.F. Storm, POWER MAGAZINE, February 2007

[9] *"Apply the Fundamentals to Improve Emissions Performance*" R.F. Storm, POWER MAGAZINE, October 2006

[10] *"Achieving Simultaneous NO_X & Combustion Improvements on a 90 MW CE Unit by applying the fundamentals*" Stephen Storm; Storm Technologies, Inc.; PWR2006-88157, Electric Power 2006

[11] "*Vertical Spindle Pulverizer Optimization*" Stephen Storm; Storm Technologies, Inc.; PWR2006-88156, Electric Power 2006

[12] "*NO_X Reduction without Low NO_X Burners*" Stephen Storm; Maureen Moss (Southern Company). (Electric Power 2005)

[13]"*Testing Improves Results*," Stephen K.Storm, Daniel S. Storm, Sammy Tuzenew, Adam McClellan; Storm Technologies, U.S. Review of how testing can be utilized to optimize old PC fired boilers; World Coal Magazine, September 2004

[14]"*Testing Improves Results*," Stephen K. Storm, Daniel S. Storm, Sammy Tuzenew, Adam McClellan; Storm Technologies, U.S. Review of how testing can be utilized to optimize old PC fired boilers; World Coal Magazine, September 2004

[15] *"Practical Diagnostic Tests to Identify Opportunities to improve heat rate, reliability and capacity on large pulverized coal fired boilers,"* R.F. Storm, Danny Storm, Adam McClellan, NTPC Thermal Power Generation Conference, 2003 New Delhi, India.

[16] Opportunities for Improvement of Controllable Heat Rate Variables at the Boiler. Are these Really "Stealth" Losses or Simply Correctable by Applying the Fundamentals? R.F. Storm, EPRI Conference, 2005

[17] "*Conducting a Comprehensive Diagnostic Test on a Pulverized Coal Fueled Boiler*; Richard F. Storm, Stephen K. Storm, Sammy Tuzenew; World Coal Magazine, September 2003.

[18] "*Three Years Operating Experience at a Low NOX Limit of .33lbs/MMBTU with Flyash Carbon Content Less than 5%,",*" Richard F. Storm, Glenn Burney, Ervin Carden, 3rd Annual Conference on Unburned Carbon on Utility Flyash - Sponsored by the U.S. Department of Energy. May 1997. Pittsburgh, PA.

[19] "*Performance Combustion and Reliability Optimization of a 360MW Unit, Firing 90% Pulverized Coal and 10% MSW,*" Richard F. Storm, William Furman, Jay Chesser, T.J. Reilly, POWER-GEN, 1996.

[20] "*A Comprehensive Common Sense Approach to Low NOX Combustion in Pulverized Coal Fired Boilers,*" Richard F. Storm, IJPGC, ASME technical Paper, 1996.

[21] "*Performance Optimization of a Boiler Equipped with Low NOX Burners,*" Richard F. Storm, Glen Burney, Mike Gallagher, Mark Lanseidel, POWER-GEN, 1995.

[22] "*Optimizing Combustion in Boiler with Low NOX Burners,*" Richard F. Storm, POWER Magazine, October 1993

[23] *"Optimizing Boiler Air & Fuel on a 450 MW Coal Fired Boiler,"* Patrick McGowan, Barry Pulskamp, Richard Storm University of Kentucky Coal Conference, April 1991

[24] *"Reducing CO2 Emissions by improving the efficiency of the existing Coal-Fired Power Plant Fleet,"* DOE-NETL, July 23, 2008.