

EXHIBIT F

Opportunities to Improve the Efficiency of Existing Coal-fired Power Plants

WORKSHOP REPORT

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Opportunities to Improve the Efficiency of Existing Coal-fired Power Plants

Executive Summary

Reducing the carbon footprint of energy production activities has emerged as one of the defining environmental issues of the 21st century. The U.S. energy infrastructure encompasses an enormous investment in capital assets and systems to produce fuels and electric power for businesses, transportation, and homes. While the long-term opportunity to reshape this infrastructure to have a low-carbon profile is promising, near-term opportunities to reduce carbon emissions are very limited. Because coal-fired power plants account for over 80 percent of carbon emissions from the power sector, improving the efficiency of the existing coal-fired power plant fleet presents one of the most promising, low-cost options for reducing near-term carbon emissions.

Increasing the thermal efficiency of the existing U.S. fleet of coal-fired power plants by 10 percent within five years would save 150 million metric tons of carbon equivalent emissions per year and reduce the amount of coal required to produce the current level of electric power generation from these plants. A 10 percent increase in the thermal efficiency would raise the overall efficiency of the coal-fired power plant fleet from 32.5% to 35.8% – about three percentage points of efficiency gain – and likely reduce other environmental emissions. Data analysis conducted by the National Energy Technology Laboratory (NETL) and the consensus of selected industry experts indicate that this opportunity is technically and economically achievable but will require leadership from power plant owners and operators and commitments from regulators, vendors, federal agencies, and the public. Although some technical issues exist, most barriers to improving thermal efficiency are based on regulatory uncertainty, lack of economic incentives, business practices, plant operating practices, and inadequate training and knowledge.

Technical Workshop for Improving Power Plant Efficiency

The U.S. Department of Energy National Energy Technology Laboratory hosted an industry workshop on July 15-16, 2009 in Chicago, IL to explore opportunities to improve the thermal efficiency of existing and future coal-fired power plants (CFPP). The workshop grew out of a study conducted by NETL that analyzed the efficiency of the CFPP fleet and suggested that improvements could be made, largely through better operating and maintenance practices. The workshop brought together 18 leading industry experts, representing utility owners and operators, equipment vendors, energy consultants, and power industry associations, to analyze technical and non-technical issues affecting plant efficiency and determine how they can be addressed.

Through facilitated discussions, workshop participants

- Recommended ways to enhance the NETL data analysis
- Identified barriers to achieving efficiency higher efficiencies in coal-fired power plants
- Identified solutions to overcome these barriers
- Outlined the respective roles of stakeholders in implementing the solutions
- Identified the most important technical improvements that could be implemented
- Framed an overall opportunity to improve the CFPP fleet

The full workshop results are presented in Exhibits 1 through 6.

Major Findings

- The analysis of U.S. fleet of coal-fired power plants shows a wide variation in efficiency levels but the basic message is that these levels have been largely stagnant for decades and that there is “headroom” for efficiency improvements among all plants including those that currently operate at below average, average, and above average efficiency levels. However, the analysis and supporting data can be improved to provide better information about the magnitude of the potential efficiency gains. For example:
 - If available, data from plant operators on design heat rates could enable analysis of actual heat rates versus design heat rates on a plant-by-plant basis to estimate the magnitude of potential efficiency improvements.
 - Data on which plants have done recent testing and the length of time since major turbine overhauls could be helpful in explaining the wide variation in plant efficiency levels.
 - Market segmentation analysis could also help explain variation, a.g., those plants greater than 200 MW, or those that have on-site performance engineers/heat rate monitors.
 - Additional in-depth case studies of specific plants could be helpful in replicating best practices from above average efficiency plants to average and below average efficiency plants.
- To boost efficiency levels, a number of technical, regulatory, and institutional barriers must overcome. For example:
 - Making changes in plants to improve efficiency is hampered by the New Source Review provisions of the Clean Air Act, which can trigger potentially lengthy and costly regulatory proceedings when capital improvements and other changes in the plant are made.
 - The lack of economic incentives to address efficiency improvements due to the presence of fuel adjustment clauses in approved electricity rates that enable power companies to “pass-through” changes in fuel costs directly to customers.
 - Concerns about regulatory proceedings, combined with the lack of economic incentives, make it difficult to get management commitment for power plant efficiency programs that must compete for scarce corporate capital and labor resources. At the same time, the primary aim for power plant operators is to optimize the profitability of the units and ensure they are available to serve load.

While heat rates and efficiency are important, fuel cost savings represent only a small portion of total costs and are typically of secondary concern when compared to needs for maintaining system reliability.

- In order to control and improve efficiency levels, power plant operators need to know about power plant performance across a variety of systems and subsystems including turbines, boilers, fuel handling, and air management. Unfortunately, there is a widespread lack of measurement and instrumentation systems in power plants across the fleet and operators lack the real time data they need to make operational adjustments even if they had the mandate for doing so.
 - Even if power plant operators were getting the data they need to improve efficiency levels, there is a widespread lack of on-site performance engineers who are dedicated to heat rate improvement.
- Addressing these and other barriers is essential for power plant efficiency improvements to be made across the entire fleet. Some plants operators have the data, personnel, and management support they need to address efficiency improvements and are addressing the issue. In these cases the magnitude of the “headroom” for efficiency gains will be limited. One of the key challenges will be implementing these best practices with those operators who for a variety of reasons are not currently able to mount efficiency program efforts. This will require regulatory agencies and power industry executives to approve a renewed focus and efficiency and the changes in practices, new equipment and systems, new personnel, and capital investments that will be needed.
 - There are a number of specific improvements in power plants that can be investigated relatively quickly. These include, for example:
 - Cleaning tubes and boilers
 - maintaining instrumentation
 - restoring seals
 - removing deposits on turbine blades
 - condenser maintenance programs
 - decreasing excess oxygen to the boiler
 - Installing variable speed drives for motors
 - Pursuing opportunities for waste heat utilization for coal drying and using solar energy for feed water heating
 - While the precise magnitude of the opportunity for power plant efficiency improvements in the existing fleet is unknown, the need for such improvements to address global climate change and reductions in the emission of greenhouse gases is an important national priority.

Next Steps

- The NETL data analysis of the CFPP fleet to estimate the potential efficiency improvement can be strengthened by obtaining additional data and conducting additional studies to fine tune the estimates of the potential magnitude of carbon savings and the costs of achieving those savings.
- The results of that analysis needs to be shared with a wider group of plant owners and operators to help determine how NETL can assist in addressing the barriers to efficiency gains and in building a public-private partnership to leverage the resources of federal and state government agencies, power plant owners and operators, and vendors and suppliers.
- A plan should be developed for public outreach and stakeholder engagement to educate key audiences about the magnitude of the opportunity for reductions in greenhouse gas emissions to facilitate inclusion of power plant efficiency efforts in national programs to address carbon emissions and global climate change.

Exhibit 1. Ways to Enhance the NETL Analysis

CONSTRUCT AN ANALYSIS FRAMEWORK FOR INVESTMENT DECISIONS

- Study year-to-year variation in the heat rate achieved at each plant
- Obtain more robust data about equipment at each plant
- Estimate improvements above the performance above the current top 10% of power plants
- Construct an analysis framework for investment decisions
- Analysis of the unexplained efficiency data variation
- Case studies of specific units
- Normalized dollars spend for O&M
- Focus on plants that have done recent testing
- Years since last major turbine overhaul
- Estimate best potential for each segment
- Analysis the turbine cycle
- Existence of a performance engineer/heat rate monitor
- Examine data quality
- Analysis of CFPPs above 200MW
- Corporate focus on efficiency
- Operating and maintenance practices
- No dedicated performance engineer

EXHIBIT 2. FACTORS AFFECTING CFPP EFFICIENCY

ANALYSIS VARIABLES	ADDITIONAL FACTORS
<ul style="list-style-type: none">• Nameplate capacity• SCR SO₂ control equipment• Coal Btu content• Investor owned utility• Steam pressure• Load factor• Number of starts• Recirculated cooling	<ul style="list-style-type: none">• Current fuel vs. design fuel• Reheat temperature• Design heat rate (Δ from design)• Excess air - data available• Corporate culture• Whether plant has been given its “death sentence” or not• Fuel cost pass through• IPP [ownership] vs. regulated utility• Are co-ops and munis different• AGC and LGC are these installed• Regulatory policies affect utility actions and interest in O&M• SO₂ control equipment retrofits not optimal• SCR control equipment• Plant footprint is a constraining factor• If you don’t measure it you can’t control it• Type of air heater

**EXHIBIT 3. BARRIERS TO ACHIEVING HIGHER EFFICIENCIES IN CFPPs
(IN ORDER OF IMPORTANCE)**

CFPP FLEET DIVERSITY	QUANTIFYING AND ANALYZING ISSUES AND BENEFITS	TECHNICAL ISSUES	PUBLIC PERCEPTION
<ul style="list-style-type: none"> • Variation in power plant design • Wide fuel range • “No one size fits all solution” - different steam turbine • models and configurations that require R&D 	<ul style="list-style-type: none"> • Identify and quantify issues in plant <ul style="list-style-type: none"> – Measuring small incremental improvements is problematic • Difficulty in monetizing benefits • No accepted optimization equation <ul style="list-style-type: none"> – Cost-value trade-off analysis, CO₂ dollars, efficiency, fuels, etc. – New metrics for evaluating PP performance • Obtaining “valid” process data needed for efficiency calculations • Ability to identify cost-effective improvements we have not already made • Making use of models and analysis to make improvements • Better instrumentation for measuring changes 	<ul style="list-style-type: none"> • Knowledge of fuel chemistry and HHV in real-time • Tail end fouling acid dewpoint • Technical: global excess O₂ kept higher than “optimum” to avoid fouling, corrosion • Need low temperature heat sink/utilization and or reduce infiltration XR • Condenser performance monitoring (largest heat sink) • Waste heat utilization • Improvement longevity - turbine seals, tower repairs • Best available technology does not meet to the ideal requirement of objective • Coal pricing based on HHV not LHV • Difficulty of testing/developing new technologies at scale 	<ul style="list-style-type: none"> • Public perception not favorable • Environmentalism coal is a four letter word • Resources diverted to renewables

EXHIBIT 3. BARRIERS TO ACHIEVING HIGHER EFFICIENCIES IN CFPPs (CONT'D)
(IN ORDER OF IMPORTANCE)

BUSINESS PRACTICES	COST AND BUDGETING	REGULATORY STRUCTURE
<ul style="list-style-type: none"> • Management support for performance improvements • Dedicated resources for action • Lack of experienced performance engineers dedicated to heat rate improvement • Plant focus on heat rate vs. availability • Its cost effectiveness not efficiency effectiveness • Justification - competition for funds <ul style="list-style-type: none"> – Management decision making processes • Lack of experienced plant managers • “Utility” culture - “been doing it this way for years”, “already optimized” • Less sharing of information among utilities and vendors • Ownership - some plants no Btu gain, no maintenance 	<ul style="list-style-type: none"> • Payback uncertainty - investing in dying plants • Budget limits - efficiency vs. availability, outage cycles • Payback period cost of fix vs. recovery time cost/benefit ratio • Decrease in frequency of planned outages • ROI/PB - small units continue to justify full turbine upgrade • Ability to borrow money at a reasonable rate - getting better • Overall utility budget - fight for share of tight budget 	<ul style="list-style-type: none"> • No economic incentive - fuel pass through, low fuel cost • Contradictory EPA air emission requirements • Ability to pass through cost of fixes • Cannot measure and justify a 100 Btu change • Uncertain CO₂ price - opportunity threat • Pass through of CO₂ costs

EXHIBIT 4. SOLUTIONS FOR OVERCOMING BARRIERS

NEED TO IDENTIFY/QUANTIFY ISSUES IN PLANTS	LACK OF KNOWLEDGE OF FUEL CHEMISTRY AND HHV IN REAL-TIME	PAYBACK UNCERTAINTY - INVESTING IN DYING PLANTS	LACK OF ECONOMIC INCENTIVE DUE TO FUEL COST PASS THROUGH
<ul style="list-style-type: none"> • Testing analytics monitoring instrumentation • Develop/install advanced instrumentation <ul style="list-style-type: none"> – Heat rate monitor • More precise measuring protocol <ul style="list-style-type: none"> – Better practices – Good tools/scorecard • Mandate the instrumentation and measurements • Prioritization guidance 	<ul style="list-style-type: none"> • Install advanced instrumentation - nuclear scare • Need to focus on bigger issues before the real-time HH • Focus on whole system boiler and turbine 	<ul style="list-style-type: none"> • Reduce legislative uncertainty <ul style="list-style-type: none"> – Tied to NSR • Mandate efficiency ala renewables - drive dollars into older plants • Retire them and remove the uncertainty <ul style="list-style-type: none"> – Cash for clunkers (government cost support) – New license contingent on retirement 	<ul style="list-style-type: none"> • Approach PUC on concept of passing through efficiency cost • Convince PUC on CO₂ benefit of CFPP efficiency vs. renewable • Bypass PUC - 1% utility self taught for performance improvement, creates investment stream • Change the public will - reshape national policy • Thermal performance - based rate making

CONTRADICTIONARY EPA AIR EMISSION REQUIREMENTS	LACK OF EXPERIENCED PERFORMANCE ENGINEERS DEDICATED TO HEAT RATE IMPROVEMENTS AND SYSTEMS	LACK OF MANAGEMENT SUPPORT FOR HEAT RATE IMPROVEMENTS
<ul style="list-style-type: none"> • Take a proactive approach to articulate the contradictions 	<ul style="list-style-type: none"> • Mandate the existence of a performance engineer in plants above xMW <ul style="list-style-type: none"> – Need the proper infrastructure • Create a “heat rate champion” <ul style="list-style-type: none"> – Tie to incentive compensation • Ensure instrument and tools exist • Initiate training program on heat rate performance <ul style="list-style-type: none"> – Tie with academic institutions • Corporate sharing of lessons learned • Build performance engineering as a green job 	<ul style="list-style-type: none"> • Create incentives for plant managers and leaders • Make it a priority for corporate leaders - education needed • Leverage efficiency and CO₂ for good public image <ul style="list-style-type: none"> – Educate out of the sector • Federal tax incentive for CFPP efficiency improvement • Create a federal “prize” for CFPP efficiency • Its cost effectiveness not efficiency effectiveness Plant focus on heat rate vs. availability

EXHIBIT 5. STAKEHOLDER ROLES

OWNERS AND OPERATORS	STATES AND REGULATORS	FEDERAL AGENCIES	VENDORS AND SUPPLIERS	PUBLIC
<ul style="list-style-type: none"> • Manage risk • Develop innovative strategies • Commit to the solution • Educate public • Training • Advocacy 	<ul style="list-style-type: none"> • Solve fuel cost pass through • Create the incentives • Champion efficiency • Understand the issues and the trade-offs 	<ul style="list-style-type: none"> • Mandates • Financial incentives • Fund research • Integrated strategies • Tax incentives • Enable/facilitate industry learning - training, information exchange • Educate public 	<ul style="list-style-type: none"> • New technology development and commercialization • BU (with right framework) • Shoot straight • Search for best available technology • Training 	<ul style="list-style-type: none"> • Understand, support, listen • Invest • Sacrifice and lifestyle changes

EXHIBIT 6. TECHNICAL OPPORTUNITIES TO IMPROVE EFFICIENCY IN FOR COAL-FIRED POWER PLANTS

SCOPE	TEAM 1	TEAM 2
<ul style="list-style-type: none"> • Within the power plant • Technical actions • Operations, maintenance • Capital projects 	<ol style="list-style-type: none"> 1. Perform equipment assessment <ul style="list-style-type: none"> – Generate heat balance, (design) as is – Perform cycle isolation alignment check – Determine deviations 2. Improve heat exchange at back end of boiler <ul style="list-style-type: none"> – Duplex seals, repair casing leak, intelligent soot blowing 3. Improve heat exchange at condenser and CT <ul style="list-style-type: none"> – Re-tube, clean tubes, maintain instruments, optimize condenser arrangement – Replace CT, fill adjust distribution of flow (L/g) – CFD tube bundle water box 4. Improve heat exchange in feed water heaters <ul style="list-style-type: none"> – Re-tube, optimize levels of heater drain pumps 5. Restore seals, remove deposits on turbine, improve turbine steam path <ul style="list-style-type: none"> – Install diffusers/vanes on turbine exhaust/hood 6. Improve control 7. Install sliding pressure control at low load 8. Install boiler optimization neural network control 9. Install equipment to measure and control PC flow to each burner 10. Variable speed drive for motors 	<ol style="list-style-type: none"> 1. Turbine seal replacement 2. Boiler leak seals 3. Turbine vale maintenance 4. Mill maintenance 5. Water chemistry - consistency and continued monitoring 6. Sliding pressure 7. Heat rate training 8. Optimization - transient ops 9. Add performance engineering 10. Real-time heat rate monitor 11. Boiler cleaning - optimization, sonic Horn 12. Upgrade air heater seals 13. Better air pre-heater cleaning
ASSUMPTIONS	Game Changer	Game Changer
<ul style="list-style-type: none"> • “Typical” CFPP • Expectation of reasonable funding • Management support • Regulatory support • Public support 	<ul style="list-style-type: none"> • Waste heat utilization coal drying • High temperature O₂ probe at the furnace exit • Coal pile umbrella • Some device to measure in situ flame temperature at each burner +/- 50°F • Condensing air heater, capture condensate and sulfur 	<ul style="list-style-type: none"> • Low grade waste heat recovery - Organic Rankine Cycle • Solar feed water heating • Biomass co-firing

EXHIBIT 6. TECHNICAL OPPORTUNITIES TO IMPROVE EFFICIENCY IN FOR COAL-FIRED POWER PLANTS (CONT'D)

COMMON THEMES	TEAM 3	TEAM 4
<ul style="list-style-type: none"> • Assess • Measure and monitor • Improve controls • Plug leaks • Clean and maintain • Replace/upgrade components • Increase expertise • Provide incentives 	<ol style="list-style-type: none"> 1. Operator training/performance engineers 2. Improve steam seals 3. Increased frequency of maintenance 4. Condenser maintenance program 5. Cooling tower performance 6. Dense pack steam turbines 7. Tramp air management 8. Decrease global excess O₂ 9. Improved heat transfer surface cleaning 10. Hardened variable drive fans 11. Mill air management/bypass 12. Extra Regenerative air-heater 13. Reduce air-heater fouling 14. Replace feedwater pump drive 	<ol style="list-style-type: none"> 1. Need a performance engineer 2. Incentive program 3. Assess and determine baseline testing 4. Gap analyses 5. Instrument and control 6. Educational training 7. Performance monitoring 8. Monitoring by skilled staff 9. Formal mechanic to get work done for efficiency 10. Cycle optimization
	Game Changer	Game Changer
	<ul style="list-style-type: none"> • Acid proof heat exchanger and ductwork 	<ul style="list-style-type: none"> • Cost benefit and analysis • Implement turbine upgrades, resurfacing, new instrument/control, water chemistry • Maintenance outage: prioritize efficiency activities and assure it gets done

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