National Energy Technology Laboratory

DOE/NETL-2008/1338

Demonstration of Integrated Optimization Software at the Baldwin Energy Complex

A DOE Assessment

September 2008

U.S. Department of Energy
Office of Fossil Energy
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DISCLAIMER

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TABLE OF CONTENTS

List of Figures

List of Tables

EXECUTIVE SUMMARY

In the mid 1980s, Congress created and funded the Clean Coal Technology (CCT) programs—a series of programs intended to bring new coal-based technologies into the commercial market. The CCT programs, managed by the Department of Energy at the National Energy Technology Laboratory, consist of three programs: the Clean Coal Technology Demonstration Program that comprised five solicitations, the Power Plant Improvement Initiative that consisted of a single solicitation, and the current Clean Coal Power Initiative (CCPI) in which two solicitations have been completed to date. The goal of these programs is to demonstrate a new generation of innovative coal-utilization technologies in a series of projects carried out across the country. These demonstrations are conducted on a commercial scale to prove the technical feasibility of the technologies and to provide technical and financial information for future applications. The primary objective of Round 1 of the CCPI (CCPI-1) was to reduce emissions and improve efficiency and maintainability while extending asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources.

One of the projects selected in CCPI-1 was "Demonstration of Integrated Optimization Software at the Baldwin Energy Complex," proposed by NeuCo, Inc., of Boston, MA. NeuCo designed and demonstrated an integrated online optimization system at the Dynegy Midwest Generation power plant located in Baldwin, IL. The Baldwin Energy Complex consists of two 600 MW cyclone-fired boilers with selective catalytic reduction (SCR) systems for the control of nitrogen oxides (NO_x) and a 600 MW tangentially fired boiler equipped with low-NO_x burners. Sulfur dioxide emissions are limited by firing the boilers with low-sulfur western coal.

The following optimization systems were developed, refined, and demonstrated:

- CombustionOpt®
- SCR-Opt®
- SootOpt®
- PerformanceOpt®
- MaintenanceOpt®

All five optimizers were installed on Unit 2 (cyclone-fired) and different combinations (but not all five) were installed on Unit 1 (cyclone-fired) and Unit 3 (tangentially fired).

The goals of the project, in addition to development of the optimization systems, were as follows:

- Reduce boiler NO_x emissions by 5 percent.
- Reduce heat rate by 1.5 percent.
- Increase annual available MWh by 1.5 percent.
- Show commensurate reductions in greenhouse gases, mercury, and particulates.
- Show commensurate increases in profitability from lower costs, improved reliability, and higher availability.

With the exception of reducing heat rate by 1.5 percent, all goals were met or exceeded. The heat rate goal could have been met, however cyclone stability (availability) and continuous emissions monitoring system and SCR inlet NO_x were prioritized over heat rate in the event stability, and NO_x needed to be traded-off with heat rate. This resulted in a doubling of the target NO_x reduction but less than targeted heat rate improvement.

I. INTRODUCTION

The Clean Coal Technology Demonstration Program (CCTDP) and the two subsequent programs—the Power Plant Improvement Initiative (PPII) and the Clean Coal Power Initiative (CCPI)—are government and industry co-funded programs. The goal of these programs is to demonstrate a new generation of innovative coal-utilization technologies in a series of projects carried out across the country. These demonstrations are conducted on a commercial scale to prove the technical feasibility of the technologies and to provide technical and financial information for future applications.

A goal of these programs is to furnish the marketplace with a number of advanced, more efficient coal-based technologies that meet increasingly strict environmental standards. These technologies will help mitigate the economic and environmental barriers that limit the full utilization of coal. The primary objective of Round 1 of the CCPI (CCPI-1) was to reduce emissions and improve efficiency and maintainability while extending asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources.

The solicitation and project selections for CCPI-1 were completed in January 2003 with the naming of eight projects selected for negotiation. Two projects withdrew before negotiations could be completed, two projects were discontinued during the project development phase, and one project has been completed. Three projects are currently active with two in the operation phase and one in the negotiation phase. Of the six projects that entered the negotiation phase, the U.S. Department of Energy's (DOE) funding commitments represent approximately 27 percent ($254 million) of the total estimated costs ($931 million), while participant commitments are over $680 million.

One of the projects selected for negotiation was "Demonstration of Integrated Optimization Software at the Baldwin Energy Complex (BEC)," proposed by NeuCo, Inc., (NeuCo) of Boston, MA. The Cooperative Agreement was awarded on February 18, 2004, and the project was completed November 17, 2007. This project was intended to demonstrate the application of sophisticated computational techniques to a coal-fired power plant to increase power plant efficiency and reduce air emissions. NeuCo designed and demonstrated an integrated online optimization system at the Dynegy Midwest Generation power plant located in Baldwin, IL. The Baldwin Energy Complex (BEC) consists of two 600 MW cyclone-fired boilers with selective catalytic reduction (SCR) systems for the control of nitrogen oxides (NO_x) and a 600 MW tangentially-fired boiler equipped with low-NO_x burners. Sulfur dioxide (SO_2) emissions are limited by firing the boilers with low-sulfur western coal.

In conducting this project, NeuCo built on its proprietary ProcessLink® technology platform with the development, optimization, and testing of five system-optimization modules: cyclone combustion, sootblowing, SCR operation, overall unit thermal performance, and maintenance optimization. Dynegy Midwest Generation contributed the host site, human resources, and engineering support to ensure the project's success. Numerous factors affect overall power plant performance and these factors are often interrelated. Attempts to optimize one aspect of operation will sometimes negatively impact other aspects. For example, minimizing heat rate might cause an increase in NO_x. The goal of this project was to develop and test a set of intelligent computer modules that will achieve overall plant optimization while allowing plant personnel to decide on the relative importance of the different possible outcomes. This was exemplified during the course of the project when BEC personnel decided to accept a lesser heat rate improvement to fully minimize NO_x emissions. The total cost of this 45-month project was approximately $19.1 million. DOE provided approximately $8.1 million (45 percent) while NeuCo provided the balance of approximately $10.5 million (55 percent).

This document is a DOE post-project assessment of the "Demonstration of Integrated Optimization Software at the Baldwin Energy Complex" project.

II. PROJECT PROCESS DESCRIPTION

A. Project Site

The BEC, located in Randolph County, IL, is owned by Dynegy Midwest Generation. It consists of three coal-fired units. Units 1 and 2 are cyclone boilers that were designed to fire high-sulfur bituminous coal. These two units came online in the early 1970s. Both are rated at a nominal 600 MW (net). Units 1 and 2 are each equipped with a cold-side electrostatic precipitator (ESP) for particulate control. These cyclone boilers were equipped with SCR systems starting in 2002. Unit 3, which came online in 1975, was also designed to use high-sulfur coal. NO_x is controlled with low-NO_x burners that were installed in 2000. Unit 3, a tangentially fired dry-bottom boiler, is rated at 600 MW (net) and particulate matter is controlled with a cold-side ESP. All three units are base-load units with high capacity factors.

In 2002, all three units switched fuels to comply with a U.S. Environmental Protection Agency Consent Decree. A consent decree is issued by a judge based on a voluntary agreement between parties to make that agreement legally binding. As a result, all three units now burn low-sulfur subbituminous coal from the Powder River Basin (PRB). Burning an off-design coal can be problematic with any boiler, and is especially so for wet-bottom boilers, including cyclones. The PRB coal used at the BEC has a substantially lower heating value than the design coal, which requires that the mills and coal feed systems handle a greater quantity of coal to maintain the total heat input to the boiler. In addition, the different ash composition of the PRB coal makes it more difficult to maintain the proper slag viscosity in wet-bottom boilers. The different ash analysis can also lead to increased slagging and fouling on the boiler tubes. These factors often require a significant derate or substantial modifications to the boiler and coal feed systems if the operator wants to maintain generation capacity. Another issue is that the heating value of the coal received at the BEC exhibited a downward trend in recent years, as shown in Figure 1. Despite these potential problems, the BEC has not had to accept a derate with the PRB coal.

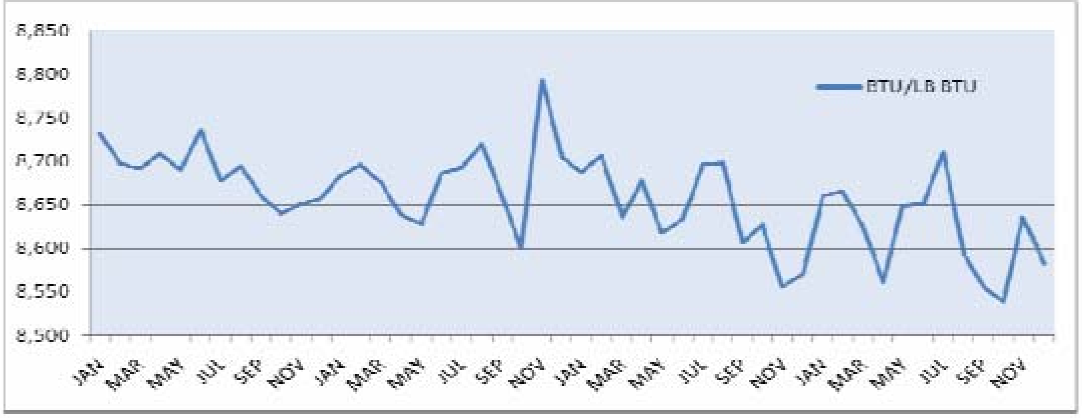


Figure 1. BEC Coal Analysis Btu/lb (Jan. 2004- Dec. 2007)

B. Project Description

The NeuCo project comprised the design, installation, and development of five integrated artificial intelligence-based optimization systems at the BEC. These systems are designed to optimize the performance of the combustion, soot blowing, and SCR operations as well as to optimize the plant's process and equipment health and overall plant performance. These individual optimization systems are linked together and coordinated by NeuCo's proprietary ProcessLink® technology. The five optimization systems are:

- CombustionOpt®
- SCR-Opt®
- SootOpt®
- PerformanceOpt®
- MaintenanceOpt®

The project was divided into two budget periods. During the first budget period, the optimization modules were developed, installed, and integrated, and the prototype modules were tested. Also during the first budget period, NeuCo identified and resolved issues associated with integrating the modules with plant operations and collected input from plant personnel. The second budget period comprised improving products and analyzing operating data to quantify the benefits of the integrated system. During both budget periods, NeuCo issued a series of updated models based on its experience and input from BEC personnel.

Different combinations of the models were installed on each of the three BEC units:

Unit 1 (cyclone-fired)

- CombustionOpt
- SCR-Opt
- PerformanceOpt
- MaintenanceOpt

Unit 2 (cyclone-fired)

- CombustionOpt
- SCR-Opt
- SootOpt
- PerformanceOpt
- MaintenanceOpt

Unit 3 (tangentially fired)

- CombustionOpt
- SootOpt
- MaintenanceOpt

C. Project Goals

In addition to developing, deploying, and refining the optimization modules as previously described, there were specific goals for improving BEC operational performance:

- Reduce boiler NO_x emissions by 5 percent.
- Reduce heat rate by 1.5 percent.
- Increase annual available MWh output by 1.5 percent.
- Show commensurate reductions in greenhouse gases, mercury, SO_2, and particulates.

- Show commensurate increases in profitability from lower costs, improved reliability, and higher availability.

D. Technology Description

A power plant is a large complex system consisting of a number of subsystems. If one is optimized without regard to the others, it may produce negative results. For example, if heat rate is minimized without regard to other processes, NO_x formation might increase. This project demonstrated five separate optimization models that communicate through NeuCo's ProcessLink technology. This technology uses neural networks, first principles, expert systems, direct search optimization, and fuzzy logic in addition to enterprise software and a robust calculation engine to link the individual optimization modules and achieve the optimum overall result. The models used in this project do not use theoretical or empirical relationships to model plant operation but "learn" the relationships from actual plant operation.

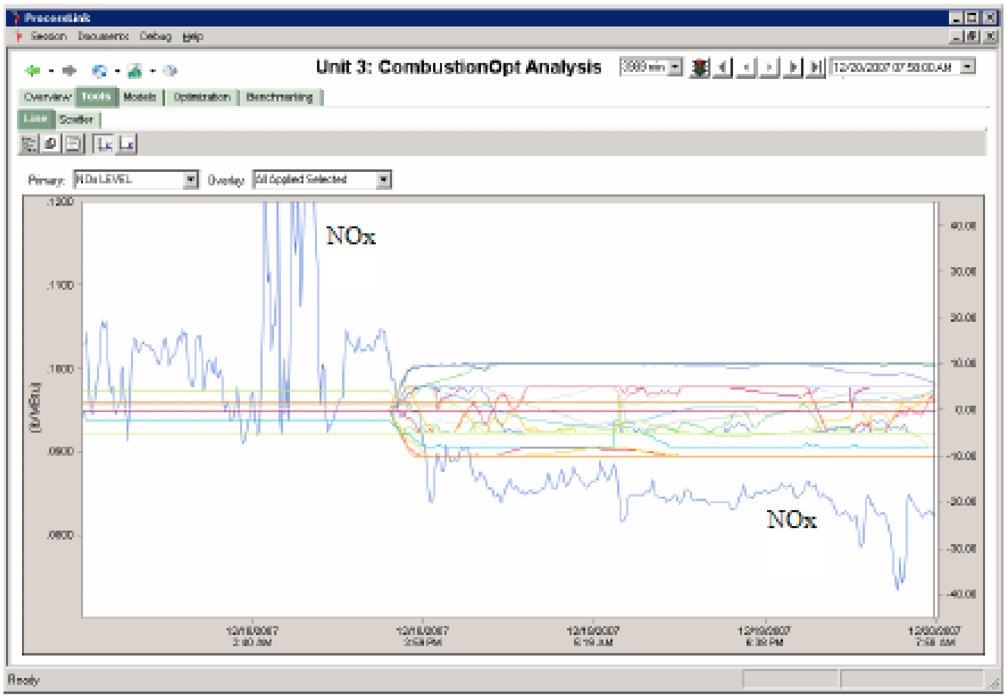
1. CombustionOpt and SCR-Opt

Because CombustionOpt and SCR-Opt are tightly integrated, they will be described together. CombustionOpt and SCR-Opt both use neural networks to develop relationships that enable them to understand how to change input variables to achieve the performance objectives determined by the plant operators. These relationships are based on real-time and recent data to relate input variables to the desired objectives set by the plant. Important relationships for these two models include ammonia (NH_3) consumption, heat rate, and NO_x formation.

In normal operation, operators usually make only occasional adjustments to the various controls based on their understanding of how specific changes to a controller will affect unit performance. These adjustments are usually made when an operating condition is at or approaching an unacceptable level. While this method has worked well for keeping the overall operation within acceptable limits, it does not provide optimal operation.

CombustionOpt calculates in real-time the control settings that improve the mixing of the fuel and air in the furnace, leading to reduced furnace NO_x production.

While operators generally make few changes, CombustionOpt makes numerous changes based on current boiler conditions. These changes are based on the model's understanding of the changes required to meet established performance objectives. Figure 2 demonstrates the ability of CombustionOpt to lower NO_x emissions by plotting NO_x levels before and after CombustionOpt is activated.



Primary: NOx LEVEL
Overlay: All Applied Selected

Figure 2. NO_x, Pre- and Post-Optimization On Unit 3

If a unit is equipped with an SCR, CombustionOpt and SCR-Opt are integrated to improve the mixing of the fuel and air in the furnace to reduce furnace NO_x production and maintain critical combustion parameters, such as combustion efficiency, while increasing SCR efficiency. The integrated goals of these models are to maintain Cyclone Main Flame Scanner Quality and reduce SCR inlet NO_x, which results in lower NH_3 flow to the SCR system. As with all of the NeuCo optimizers, ProcessLink uses advanced modeling to provide several benefits. One of these is monetized tradeoffs in which the cost to implement an action and its benefits is compared for two or more alternative actions. Each optimizer prioritizes the objectives and manages tradeoffs between them based on their value. When considerations other than dollar values describe the real priority, the priority is based on engineering considerations. ProcessLink also contains sets of objective definitions, constraints, response times, and step sizes to accommodate different operating environments and uses these optimization profiles to obtain the best unit performance. Each optimizer can address a variety of operating situations and can anticipate as far ahead as necessary for dynamic situations; thus, each neural optimizer can rapidly accommodate changing conditions, inputs, controls, and objectives. The optimizers can be easily modified or expanded to incorporate new controls and objectives, or to address additional optimization goals.

The user interface for CombustionOpt and SCR-Opt is a shared home page that provides information that enables users to obtain the maximum benefit from the technology. This includes optimization advice, a display that shows the operator what is taking place and why it is taking place, and charts that show how well the unit is being optimized. The upper left section of the home page shows advice on how to further optimize the unit, along with information to help the operator prioritize specific actions. This advice typically consists of repair or maintenance actions that need to be performed to obtain full optimization. The demonstration technology can only optimize the operation to the maximum extent possible without plant personnel performing these actions. The lower left section of the page provides information that enables the operator to understand the purpose of the optimizer’s actions. The section on the right of the home page shows how the optimizer achieved its optimization objectives and how it might have improved over a four-week period if all advice were followed. An example of the home page is shown in Figure 3.

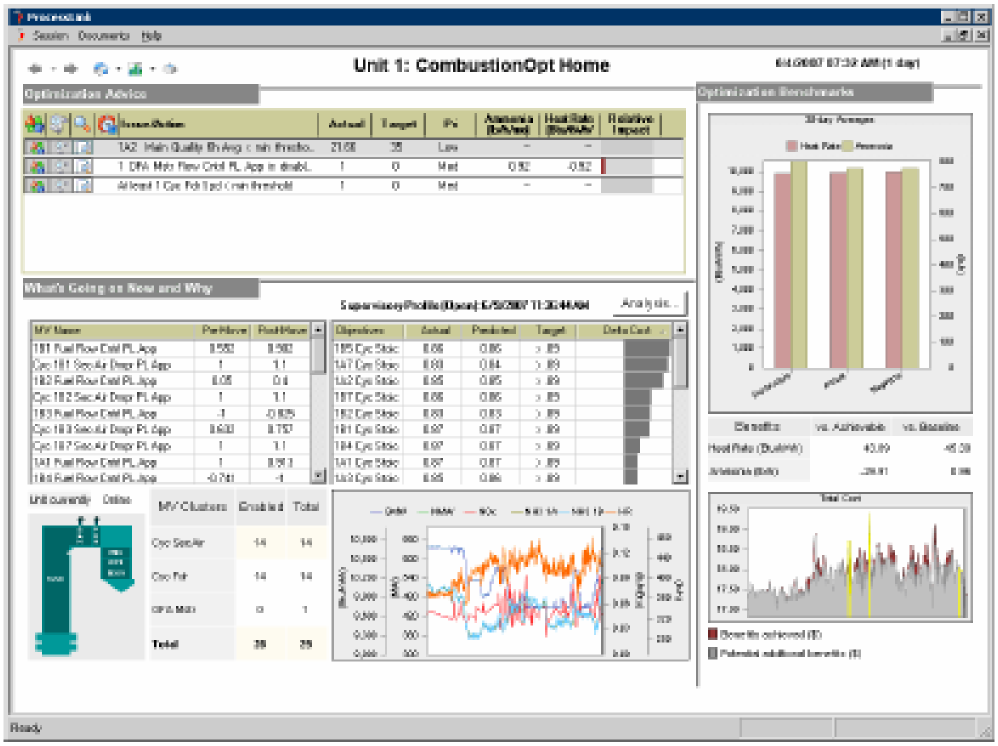


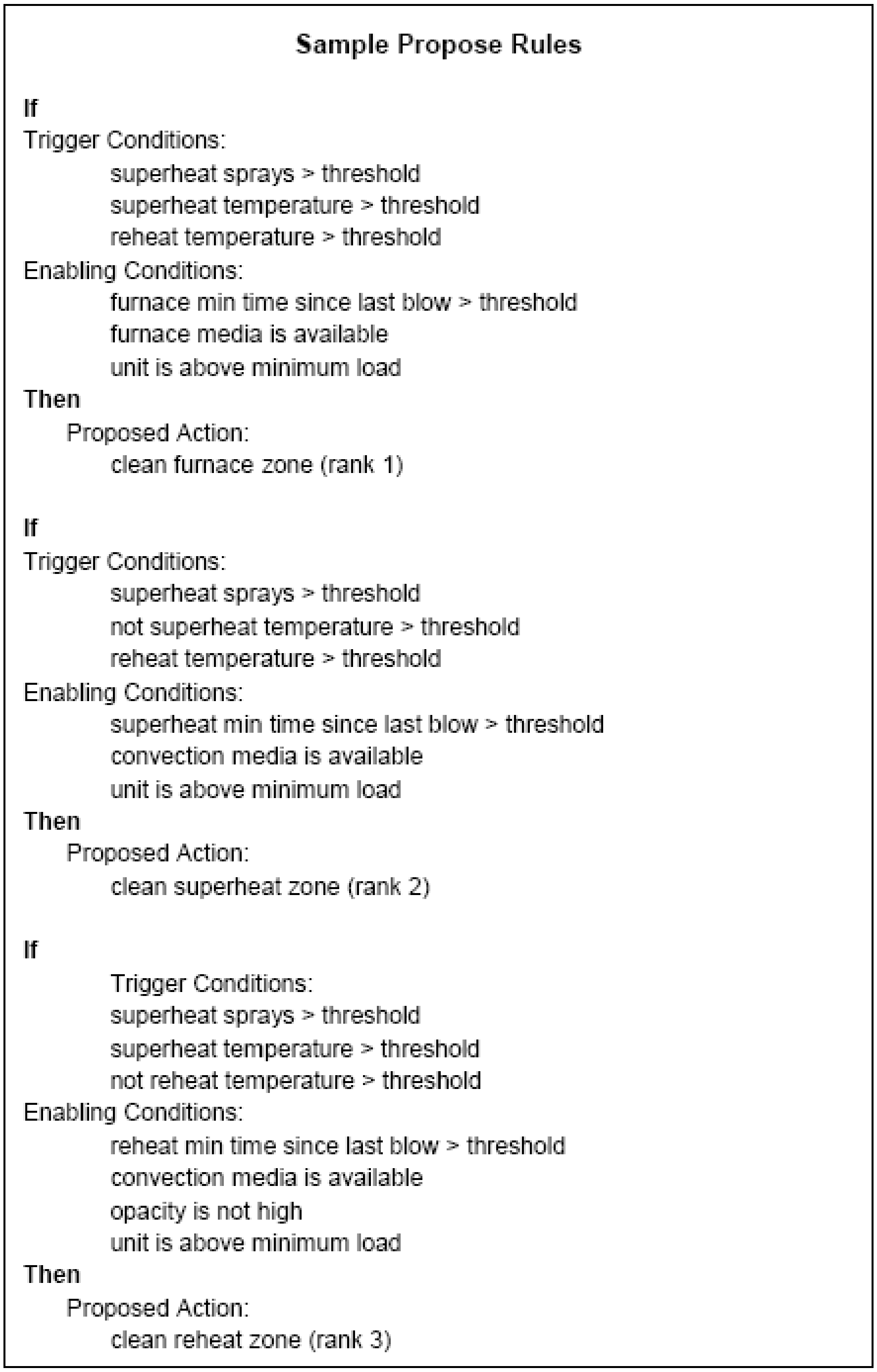
Figure 3. CombustionOpt/SCR-Opt Home Page

2. SootOpt

SootOpt is a closed-loop optimization system that aligns soot blowing actions with unit goals. It factors in heat rate, reliability, emissions, and operational constraints. SootOpt models the effect of soot blowing on heat transfer throughout the furnace and determines cleaning actions to best achieve improved boiler operation while minimizing the number of cleaning operations.

Traditionally, soot blowing has been operator-controlled based on a set schedule. This method is basically a hit-or-miss approach that has several disadvantages. If the operation is triggered when not needed, the steam (or other media) is wasted and efficiency suffers. In addition, sootblowing increases wear on the boiler parts being cleaned. When slagging and fouling occur, delays in sootblowing can result in lower furnace efficiency, increased NO_x production, and excessive flue gas exit temperatures.

SootOpt combines neural network and expert system optimization methods with direct measurements and local controls to optimize the soot blowing operation. It can be installed on top of existing control technologies and can use existing equipment. In addition to adaptive modeling techniques, SootOpt leverages customized operational constraints and control considerations, in the form of “propose rules” or heuristics, to identify the correct response to different operating conditions. Some of these conditions include when soot blowing is required or should be suspended due to suboptimal steam temperatures or high sprays, or when soot-cleaning media limitations dictate coordination of activity. An example is shown in Figure 4. SootOpt also takes into account information received from CombustionOpt in determining optimal soot blowing in a total unit context.



Sample Propose Rules

If
Trigger Conditions:
superheat sprays > threshold
superheat temperature > threshold
reheat temperature > threshold
Enabling Conditions:
furnace min time since last blow > threshold
furnace media is available
unit is above minimum load
Then
Proposed Action:
clean furnace zone (rank 1)

If
Trigger Conditions:
superheat sprays > threshold
not superheat temperature > threshold
reheat temperature > threshold
Enabling Conditions:
superheat min time since last blow > threshold
convection media is available
unit is above minimum load
Then
Proposed Action:
clean superheat zone (rank 2)

If
Trigger Conditions:
superheat sprays > threshold
superheat temperature > threshold
not reheat temperature > threshold
Enabling Conditions:
reheat min time since last blow > threshold
convection media is available
opacity is not high
unit is above minimum load
Then
Proposed Action:
clean reheat zone (rank 3)

Figure 4. Sample Propose Rules

The SootOpt home page (Figure 5) provides several types of information that allow users to obtain the maximum value from the technology. The upper left section shows SootOpt's advice for how to further optimize the unit, and in those cases where it can be determined, SootOpt displays the impact of its advice over the next 30 days. The lower left section provides information that enables the operator to understand what SootOpt has done, and the right-hand section of the page shows the baseline, actual, and optimum performance.

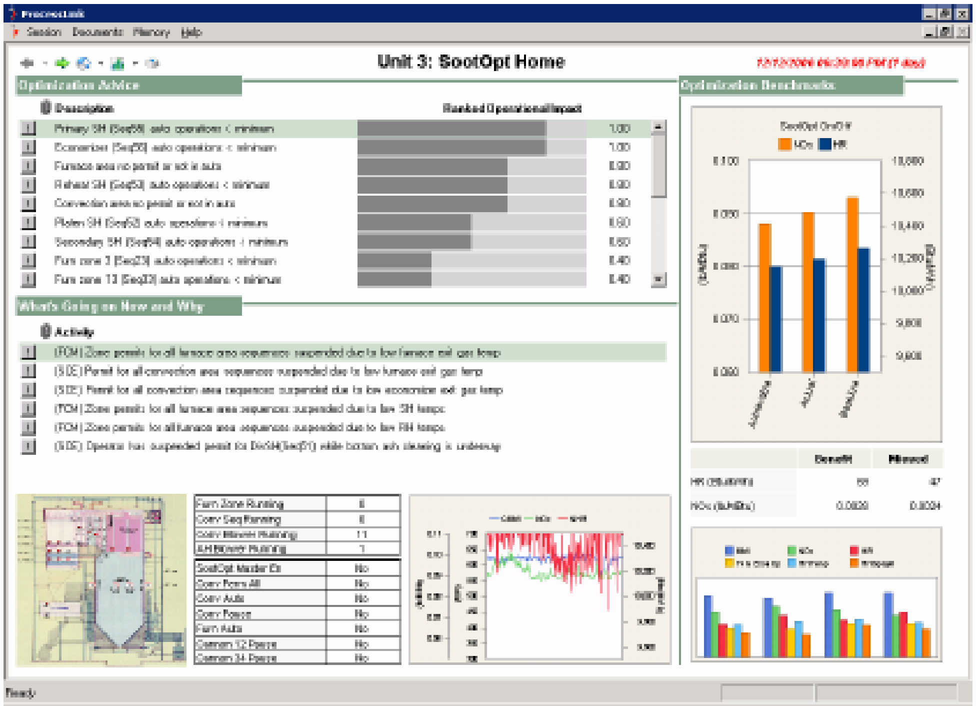


Figure 5. SootOpt Home Page

3.   PerformanceOpt

PerformanceOpt is a predictive performance management system that identifies efficiency and capacity losses so that operators can take actions to reduce losses and operating costs. PerformanceOpt performs mass and energy balances on a minute-by-minute basis and determines the results for thousands of variables. These variables include process flow rates and conditions, heat transfer rates, and subsystem and unit performance results. It uses these results to identify problems that are causing non-optimum performance and determines their efficiency and capacity impacts.

PerformanceOpt ensures model accuracy and reliability by making use of sophisticated sensor validation techniques. PerformanceOpt continuously monitors key equipment- and unit-level performance factors and detects (in real-time) when performance deviates from optimum operating conditions. The optimum operating conditions are determined through "what-if" scenarios that are run with the full-scale model of the unit. PerformanceOpt uses its predictive simulations to determine the potential improvement in efficiency and capacity that would result from resolving each problem. Problem identification workflow is shown in Figure 6.

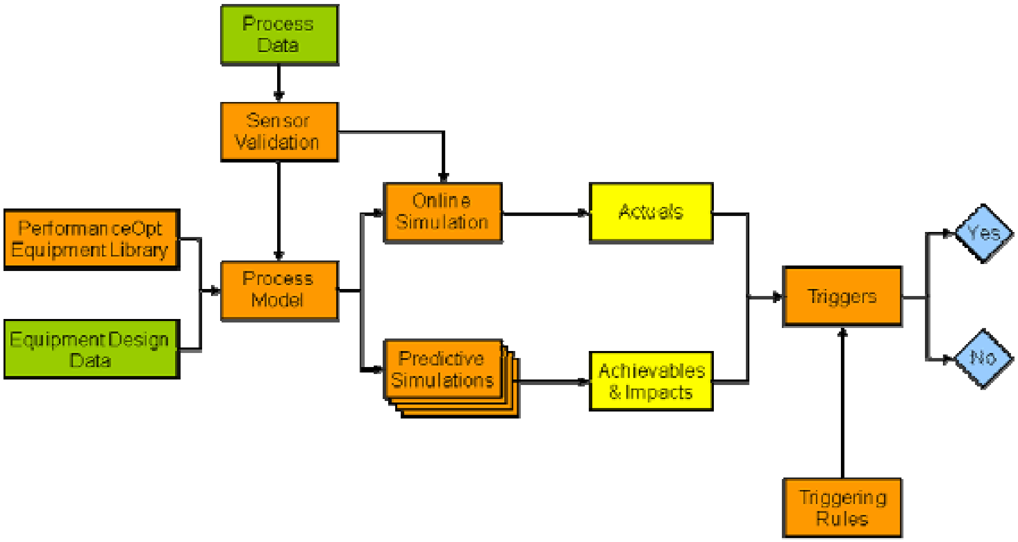


Figure 6. PerformanceOpt Components in Problem Identification

The PerformanceOpt model of the integrated plant processes typically comprises several interconnected flow sheets that represent all of the plant equipment, their interconnecting streams, instrumentation, source streams, and products. This model is used for both monitoring and predicting performance. It calculates both the actual and achievable plant performance as well as the efficiency and capacity impacts associated with the deviations between actual and achievable performance.

Once problems are identified, PerformanceOpt prioritizes them based on calculating their impacts. PerformanceOpt then facilitates the analysis needed to determine the root cause of the problem and to identify appropriate action by providing the user with grouped, detailed information. The operator can review this information as well as other data that he may gather, diagnose the problem, and take corrective action.

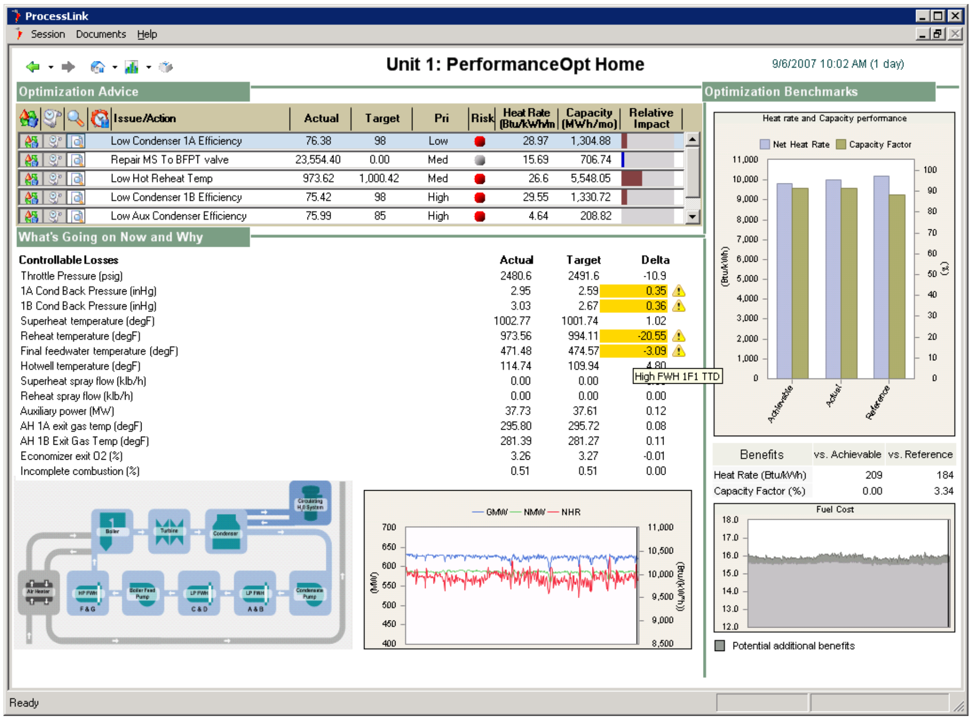
All data received from the PerformanceOpt data acquisition system is processed through a sophisticated set of data validation and substitution algorithms to ensure the integrity of the data being fed into the PerformanceOpt model.

PerformanceOpt uses an engineering library that consists of heat and mass balance models of all individual equipment and subsystems comprising a power generation unit. The library also includes various stream types that connect the equipment blocks in a flow sheet representation of the process. The model supports the major equipment and systems as well as all important process conditions. In addition, PerformanceOpt contains a library of engineering and physical property functions that include:

- American Society of Mechanical Engineers (ASME) 1967 and 1997 Steam Tables
- Psychrometric functions
- *The Health Effects Institute, 8th edition*
- The National Institute of Standards and Technology gas property tables

Calculation modules in PerformanceOpt include those for boiler efficiency, boiler cleanliness, ASME turbine performance, and heat rate. Equipment-level performance results are also generated during the model simulation and made available to the user. These results include boiler efficiency and performance parameters for the high-, intermediate-, and low-pressure turbine sections. Performance parameters are also available for the deaerator, condenser, any other closed or open heat exchanger, pumps, fans, and the cooling tower.

Like the other home pages, the PerformanceOpt home page (Figure 7), provides information that enables users to obtain maximum results. The upper left section shows current advice for how to further optimize the unit base, and the lower left section provides access to information that describes both how the unit is currently operating and facilitates understanding PerformanceOpt's advice. The right-hand section shows how the unit has performed in the recent past, comparing actual heat rate and capacity factor to a baseline and an achievable performance determined from what-if simulations of the rigorous PerformanceOpt model.



Unit 1: PerformanceOpt Home

9/6/2007 10:02 AM (1 day)

Optimization Advice

Issue/Action	Actual	Target	Pri	Risk	Heat Rate (Btu/kWh/m	Capacity (MWh/mo)	Relative Impact
Low Condenser 1A Efficiency	76.38	98	Low	●	28.97	1,304.88	
Repair MS To BFPT valve	23,554.40	0.00	Med	●	15.69	706.74	
Low Hot Reheat Temp	973.62	1,000.42	Med	●	26.6	5,548.05	
Low Condenser 1B Efficiency	75.42	98	High	●	29.55	1,330.72	
Low Aux Condenser Efficiency	75.99	85	High	●	4.64	208.82	

What's Going on Now and Why

Controllable Losses	Actual	Target	Delta
Throttle Pressure (psig)	2480.6	2491.6	-10.9
1A Cond Back Pressure (inHg)	2.95	2.59	0.35 ⚠
1B Cond Back Pressure (inHg)	3.03	2.67	0.36 ⚠
Superheat temperature (degF)	1002.77	1001.74	1.02
Reheat temperature (degF)	973.56	994.11	-20.55 ⚠
Final feedwater temperature (degF)	471.48	474.57	-3.09 ⚠
Hotwell temperature (degF)	114.74	109.94	4.80
Superheat spray flow (klb/h)	0.00	0.00	0.00
Reheat spray flow (klb/h)	0.00	0.00	0.00
Auxiliary power (MW)	37.73	37.61	0.12
AH 1A exit gas temp (degF)	295.80	295.72	0.08
AH 1B Exit Gas Temp (degF)	281.39	281.27	0.11
Economizer exit O2 (%)	3.26	3.27	-0.01
Incomplete combustion (%)	0.51	0.51	0.00

High FWH 1F1 TTD

Optimization Benchmarks

Benefits	vs. Achievable	vs. Reference
Heat Rate (Btu/kWh)	209	184
Capacity Factor (%)	0.00	3.34

Figure 7. PerformanceOpt Home Page

4. MaintenanceOpt

MaintenanceOpt continuously monitors process and equipment data to identify anomalies that might indicate reliability, capacity, or efficiency problems. When anomalies are detected, MaintenanceOpt identifies the most likely causes and estimates the impacts on efficiency, reliability, and capacity. Based on these estimates, it prioritizes the order in which problems should be addressed.

MaintenanceOpt presents the maintenance problems, their diagnoses, required actions, and impacts and risks, which help engineers manage the process of correcting a problem more effectively. MaintenanceOpt displays all the information required to determine whether the detected anomaly points to a real problem or is the result of sensor problems.

If engineers decide the problem is real, they use MaintenanceOpt's diagnostics database to identify possible causes for the problem. Based on the projected impacts, plant engineers assign a priority to the problem and put it on their action list. The workflow supported by MaintenanceOpt is shown in Figure 8 below.

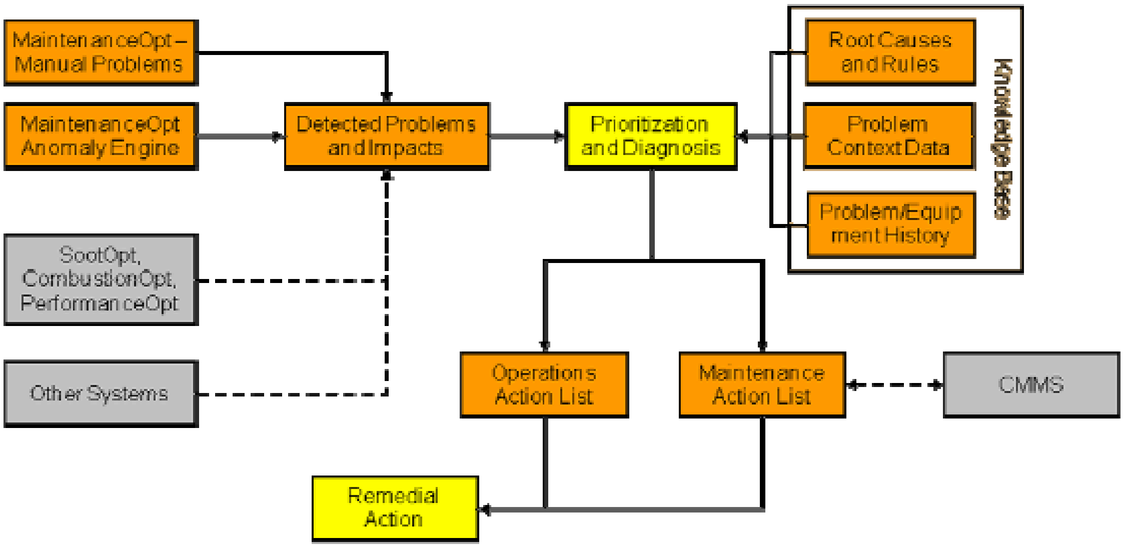
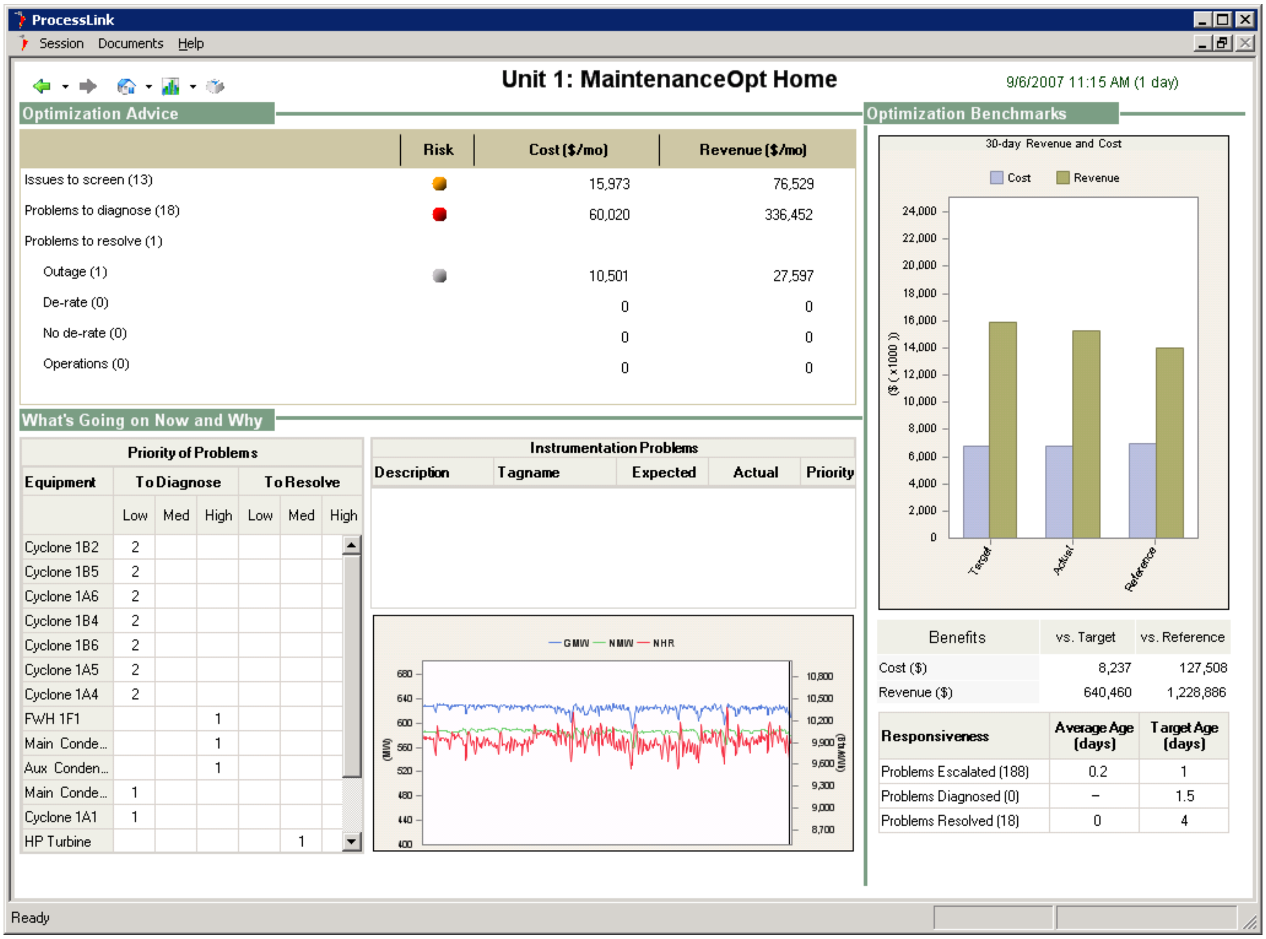


Figure 8. MaintenanceOpt Workflow for Problem Detection, Diagnosis, and Resolution

MaintenanceOpt can detect both slowly developing problems that have an increasingly negative impact on capacity and efficiency as well as problems that could have a critical near-term reliability impact. In addition to supporting the diagnosis and resolution of problems it detects, MaintenanceOpt also supports the diagnosis and resolution of problems found by other optimizers such as PerformanceOpt, CombustionOpt, and SootOpt; thus serving as a clearing house for all problems that are impacting plant performance to be addressed by the appropriate plant personnel. Maintenance tasks are also categorized into activities that require no derate, require a derate, or require an outage.

The MaintenanceOpt home page, shown in Figure 9, also provides several types of information that enable users to obtain the maximum benefit from the technology. The top left section displays a summary of all issues currently managed in MaintenanceOpt and provides an overview of the reliability risks and impacts associated with the current problem lifecycle. The bottom left section shows a summary view into current problems managed in MaintenanceOpt, based on affected equipment and priority. In addition, the user is also presented with a consolidated list of instrumentation-related problems. The section on the right shows recent unit performance compared to baseline and target performance standards. This section also benchmarks the efficiency of problem lifecycle management over that period, based on the average time problems remained in various states (e.g., not yet screened, undiagnosed).



Unit 1: MaintenanceOpt Home

9/6/2007 11:15 AM (1 day)

Optimization Advice

	Risk	Cost ($/mo)	Revenue ($/mo)
Issues to screen (13)	●	15,973	76,529
Problems to diagnose (18)	●	60,020	336,452
Problems to resolve (1)			
Outage (1)	●	10,501	27,597
De-rate (0)		0	0
No de-rate (0)		0	0
Operations (0)		0	0

What's Going on Now and Why

Priority of Problems

Equipment	To Diagnose			To Resolve		
	Low	Med	High	Low	Med	High
Cyclone 1B2	2					
Cyclone 1B5	2					
Cyclone 1A6	2					
Cyclone 1B4	2					
Cyclone 1B6	2					
Cyclone 1A5	2					
Cyclone 1A4	2					
FWH 1F1			1			
Main Conde...			1			
Aux Conden...			1			
Main Conde...	1					
Cyclone 1A1	1					
HP Turbine					1	

Instrumentation Problems

Description	Tagname	Expected	Actual	Priority

Optimization Benchmarks

Benefits	vs. Target	vs. Reference
Cost ($)	8,237	127,508
Revenue ($)	640,460	1,228,886

Responsiveness	Average Age (days)	Target Age (days)
Problems Escalated (188)	0.2	1
Problems Diagnosed (0)	–	1.5
Problems Resolved (18)	0	4

Figure 9. MaintenanceOpt Home Page

III. REVIEW OF TECHNICAL AND ENVIRONMENTAL PERFORMANCE

Development and refinement goals of the optimizer modules were all fully met. The following summary will deal only with the results that pertain to the impact that the modules had on plant operation and emissions. The demonstration technology can operate in two modes: “closed loop” in which the plant is controlled in real-time by the optimization modules and an “advisory mode” in which the optimizers are used to advise the user who then decides whether or not to follow the advice. The following discussion describes how well these goals were met when operating in the closed-loop mode, where applicable.

The goal of reducing NO_x emissions by 5 percent was exceeded. The average reduction was reported to be between 12 and 14 percent. This reduction is basically due to the combined impact of CombustionOpt, SootOpt, and SCR-Opt. Operational data also show a drop in NH_3 consumption.

The combined impact of CombustionOpt, SCR-Opt, SootOpt, PerformanceOpt, and MaintenanceOpt resulted in an overall improvement in heat rate of 0.7 percent compared to the goal of 1.5 percent. As pointed out earlier, switching to PRB coal in a boiler designed for high-sulfur bituminous coal can be problematic. The inability of the optimization systems to achieve this goal is attributed to two priorities set by plant personnel. The first was to place a high priority on cyclone stability/availability, while the second was to place a higher priority on minimizing NO_x production. If not for these choices, the goal of a 1.5 percent improvement in heat rate would likely have been achieved. Another factor that may have contributed to the lower improvement in heat rate is that the deteriorating fuel quality described earlier may have increased the baseline heat rate had MaintenanceOpt not been used.

Although it is difficult to precisely measure available MWh, NeuCo reports that the goal of increasing available MWh by 1.5 percent was met. It was achieved by providing prioritized alerts and knowledge-based diagnostics for a wide array of plant equipment and process anomalies. This helped the plant to avoid additional derates often associated with moving from high-sulfur, high Btu Illinois coal to PRB. The demonstration technology also helped improve the management of cyclone flame quality through increased vigilance with respect to cyclone conditions. The improved management of flame quality likely avoided some degree of temporary derate due to cyclone slag build up.

Another goal was to show commensurate reductions in greenhouse gases, mercury, $SO_{2,}$ and particulates. This goal was achieved since these pollutants' emission rates were lowered with the reduced coal consumption that resulted from the improved heat rate.

The final goal identified in Section II is to achieve commensurate increases in profitability from lower costs, improved reliability, and greater commercial availability. This goal was achieved as the direct result of all other goals being achieved, at least to some degree.

IV. DISCUSSION OF RESULTS

The project carried out by NeuCo was intended to develop and demonstrate a set of artificial intelligence-based optimization systems on two different types of utility boilers. Overall, the project goals were met or exceeded. As previously discussed, the one goal that was not strictly met was the goal of reducing the heat rate by 1.5 percent. The actual result was that heat rate was reduced by 0.7 percent. A number of factors contributed to this shortfall.

The likely cause is that plant personnel opted to place greater emphasis on cyclone stability and NO_x than on improving heat rate. While this defeated one major goal, it also demonstrates the product's flexibility. Another difficulty was the decline in the heat content of the coal during the course of the project. Without the optimization packages, the plant may have experienced some increase in heat rate.

The effectiveness of the combined modules in lowering NO_x formation was clearly established by the ability of the system to lower NO_x by more than twice the target amount.

In addition to fuel savings, the improved heat rate lowered the emission rates of several pollutants due to a decrease in the amount of coal fired. These emissions include mercury, SO_2, greenhouse gases, particulate matter, and numerous trace elements that are included in the particulate matter.

Improved reliability, lower maintenance costs, and higher output were also achieved, but these benefits are hard to precisely quantify. Changes in environmental conditions, various coal properties, wear on equipment, and numerous other factors can mask some portion of the optimization systems' benefits.

V. MARKET ANALYSIS

A. Potential Market

The demonstration technology enjoys a very large potential market for several reasons. One is that the individual optimization modules can be applied individually or in any combination depending on customer needs. The second reason is that the technology is applicable to coal-fired units and some modules are also applicable to other fossil fuel-fired utility boilers. Although the current focus is on utility boilers, the technology could also be applied to large industrial boilers.

A market analysis identified the potential market for each module:

- CombustionOpt for cyclones, 28 GW (100 boilers)
- SootOpt, 315 GW (1,066 boilers)
- SCR-Opt, 121 GW (234 boilers)
- PerformanceOpt, 485 GW (1,688 boilers)
- MaintenanceOpt, 485 GW (1,688 boilers)

B. Economic Impact

An engineering-economics benefits analysis was conducted by NeuCo to estimate the financial implications of the integrated optimizers at the BEC and to project the potential financial impact on the entire U.S. fleet of fossil-fired generating units. Two cases were developed. One places no value on reduced CO_2 discharge while the other projects a monetary value for the reduction in CO_2. The analysis was based on the data generated during the project and what are believed to be reasonable assumptions. It was necessary to estimate certain information such as the value of NO_x and CO_2 allowances. In addition, certain typical values were used when the actual data were considered proprietary by the BEC. Examples of proprietary data are heat rate and fuel cost.

This analysis estimated the total annual dollar value of the benefits associated with the products installed, refined, and commercialized at the BEC for each boiler and the total for the plant. Estimates for Unit 1 are \$3.2 and \$2.9 million with and without a CO_2

credit. The estimated values for Unit 2 are \$3.2 and \$2.7 million respectively, while the values for Unit 3 are \$1.9 and \$1.8 million respectively. The benefits are estimated to range from \$7.4 to \$8.3 million dollars per year plant-wide (depending on whether CO_2 benefits are included).

The results obtained at the BEC were extrapolated to all units that might benefit from the demonstration technology. The values used in the analysis come from a variety of sources: capacity and capacity factors from the 2005 Utility Data Institute North American Fossil Generation data base, baseline NO_x values and SCR and flue gas desulfurization installations from the McIlvaine Company, and baseline heat rate and fuel costs based on observations in the field.

NeuCo's analysis indicates that the benefits available to the industry, based on the results achieved at the BEC, are between \$2.3 and \$2.6 billion dollars per year in annual savings across the full combination of unit types, fuel sources, and post-combustion controls characterizing the current U.S. fossil generation fleet. These aggregate benefits are distributed across the categories of fuel efficiency, NO_x reduction, reagent costs, CO_2 emissions, and commercial availability.

C. Capital Costs and Operating and Maintenance Costs

In their final report, NeuCo indicated that the cost of the demonstration technology could be expected to yield well under a one-year payback for average-sized units across all unit types and fuel categories comprising the U.S. fossil power industry. Table 1 shows the payback in months for the combination of CombustionOpt, SootOpt, MaintenanceOpt, and PerformanceOpt as they pertain to the categories of unit types and fuel sources in the U.S. fleet. The product costs used include all software licenses, installation services, variable expenses (travel, living, computers, etc.) and one year of annual maintenance and support.

Simple Payback for Commercial Products	**PRB w/SCR**	**PRB No SCR**	**Bitum w/SCR**	**Bitum No SCR**	**ST + CCCT**
Commercial Payback Excluding CO_2 (Months)	4.38	8.51	4.01	7.02	9.45
Commercial Payback Including CO_2 (Months)	3.86	7.87	3.69	6.71	8.93

Table 1. Payback for Combined Units

VI. CONCLUSIONS

NeuCo successfully developed, refined, and integrated the optimization modules. The modules performed as expected. One goal pertaining to improved plant operation was not met, but this was due to priorities set by BEC personnel. The project is categorized as successful.

The products developed and demonstrated in the course of the project have the potential to improve the operation and cost in a variety of power plants while not requiring substantial downtime for installations. In addition, the optimization modules can be installed to operate with existing control equipment and sensors to help minimize costs. The data in Table 1 are derived from a broad range of facilities using typical values. The actual benefits and payback times may be more or less attractive at a specific power plant. Given its merits, the demonstration technology can be expected to generate considerable interest in the marketplace.

ACRONYMS AND ABBREVIATIONS

BEC	Baldwin Energy Complex
BTU	British thermal unit
CCE	Chicago Climate Exchange
CCPI	Clean Coal Power Initiative
CCPI-1	Clean Coal Power Initiative, Round 1
CCTDP	Clean Coal Technology Demonstration Program
CO_2	carbon dioxide
DOE	Department of Energy
ESP	electrostatic precipitator
FGD	flue gas desulfurization
GW	gigawatt
mmBtu	millions of BTUs
MW	megawatt
MWh	megawatt hour
NETL	National Energy Technology Laboratory
NH_3	ammonia
NO_x	nitrogen oxides
PPII	Power Plant Improvement Initiative
ppm	parts-per-million
PRB	Powder River Basin
RGGI	Regional Greenhouse Gas Initiative
SCR	Selective Catalytic Reduction
SO_2	sulfur dioxide
ST+CCCT	steam turbine + combined cycle combustion turbine

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