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GE Power Systems

Intelligent Optimization of Coal Burning to Meet Demanding Power Loads, Emission Requirements, and Cost Objectives

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Abstract

Coal is the most important fuel in the generation of electricity, accounting for between 55% and 60% of the power produced in the United States and Canada. Available in great abundance from indigenous sources, there are no foreseen issues associated with the long-term supply of the fuel resource of coal. In the past, because of the regulated business environment in which utilities operated, coal was viewed as a necessary evil and was always treated as a "pass through" cost. Although the quality of coal impacts boiler operations and subsequent power produced and emissions, utilities had no economic interest in monitoring or managing coal quality.

This perspective has started to change with initial legislative requirements for the control of SO_2 emissions. The legislative agenda has now advanced to include NO_x emissions and necessitates a clear understanding of the interactions between coal quality and the process of combustion. Further, the economic aspects of coal utilization are also changing. The main driving force behind this change is the increasing tendency in the United States to allow utilities to keep any savings they can achieve in the cost of their coal. Since coal usage accounts for nearly seventy percent of operation and maintenance (O&M) costs of electricity generation, coal provides a maj s utilities to use the most economic blend of coals under varying conditions of load, emissions, and operational requirements. This form of blending, wherein the blend of coals reaching the burners is changed to accommodate the changing conditions in the boiler, is defined as “dynamic blending.” This is a significant departure from the practice of using a fixed blend of coal under all conditions. The CBAS product was developed mainly with funding from the U.S. Department of Energy and TransAlta Utilities and is currently installed at 26 boilers at power plants around the world.

Please note that the terms “silo” and “bunker” are used interchangeably in this paper, and refer to the coal storage devices used at power plants. Silos and bunkers have been modeled successfully in CBAS product installations.

Introduction

Fuels cost reductions are achieved by delivering coal of a predetermined quality to the burners at all times. If a power plant adopts a dynamic approach to coal blending (i.e., the as-fired blends change continuously to adjust to changing conditions such as load, emissions, opacity, coal availability, and expected coal deliveries), the power plant can reduce fuel-related costs significantly.

Dynamic blending of coals can improve efficiency and decrease costs in a number of ways. Plants blending their boiler feed from a number of coals can maximize the use of the least expensive coal whenever conditions permit; utilities can rationalize the use of coals to avoid over-using premium coals and under-using problem coals; and utilities can deliberately increase purchases of better spot-market coals knowing that they can mitigate the attendant problems by controlled dynamic blending. The economic benefits of this approach are considerable, as plants are able to reduce operating costs significantly by optimizing the coal blend burned.

Figure 1 shows a typical utility coal yard where coal is received from a number of sources and stored in semi-segregated piles. The coal is removed from these piles and loaded into the mill silos. Each silo feeds a pulverizer, and usually has a storage capacity of about eight hours.

The main goal for a power plant is make sure that the most economic coal of precisely the

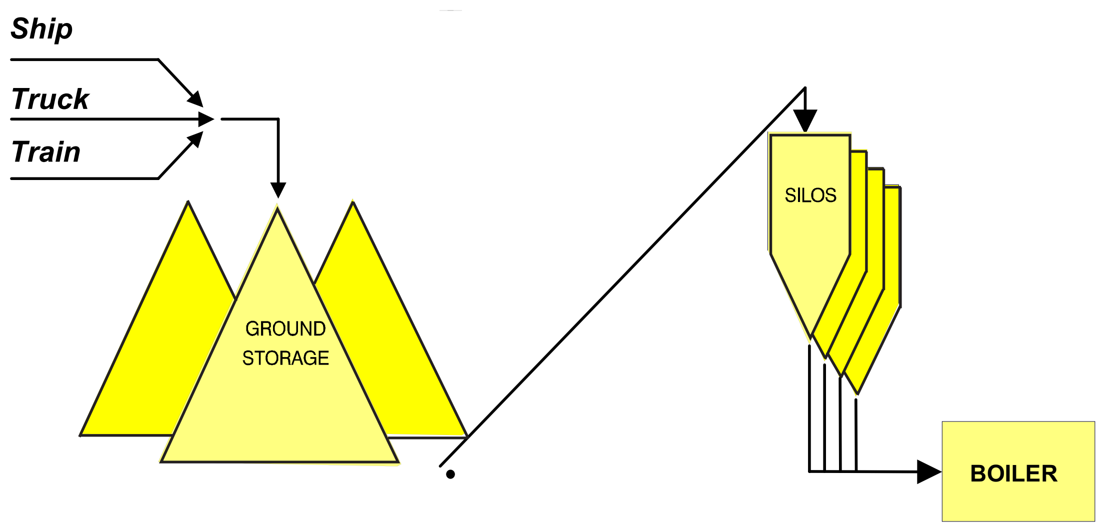

Figure 1. Schematic showing typical power plant coal yard

right quality gets to the burners to meet the boiler requirements. For example, a boiler can be fed coals of lower quality at low-loads and only needs high-quality coals at full-load operations. The ability to deliver the right coals to the burners consistently can reduce fuel costs for the plant significantly.

To achieve this goal, a power plant must address three main issues. The first and the easiest to address is to know the quality of all the coals purchased and stockpiled at the site. In general, the quality data provided by the coal supplier is considered sufficient for use in the CBAS product. The second key issue, operational in nature, is for the power plant to keep track of all coals as they arrive and to stockpile them in segregated or semi-segregated piles. This can be done through electronic data acquisition in most cases, and no manual data entry is required. The third key issue is the ability to know what coals are being loaded into the mill silo when and in what quantity. From this information, the CBAS product can calculate the quality of the coal being discharged to the boiler from each of the silos in real time. Since the coals in the silos rarely come out in the same sequence as they were loaded in, this aspect of the CBAS product is extremely complex and requires the modeling of coal flows through the silos. This is handled by a special component of the CBAS product called the Silo Flow™ Model, which models the coal flow in three dimensions and is able to accurately correlate the input quality sequence with the output quality sequence. The model can also be used for similar purposes in modeling flow through various types of stockpiles.

Once the flow of coal in silos and stockpiles can be accurately modeled, the tracking of all coals in a yard, from receipt to combustion, becomes relatively easy. In addition, the same capability can also be used to perform controlled loading sequences into the silos to assure that coal of a prescribed quality is discharged at prescribed times. The CBAS product uses this capability to deliver the "right coal to the burners at the right time," saving users significant fuel costs.

The Silo Flow Model is described below in greater detail.

Silo Flow™ Model

The approach adopted by Praxis Engineers to calculate the flow patterns in the silos combines coal quality with silo geometries. The three-dimensional Silo Flow Model uses the sequence of input quality to predict the sequence of output quality, thus making it possible to know fuel quality at the burners in real time for many hours in the future. A typical silo is shown in *Figure 2* and its active and dead zones are identified. Four different coals have been loaded into the silo in sequence and the problem is to predict the quality of the output stream. The Silo Flow Model is able to do this for all silo designs.

The silo represented in this instance has one cylindrical section and two sloping conical sections. This silo design was used as the prototype to develop the first Praxis Silo Flow Model in 1987. Note that this design is somewhat more complex than many silos normally used to feed utility boilers, which have a single conical section below the cylindrical one.

Please note that regardless of the silo geometry, the CBAS product is individually configured for each power plant. A team of engineers visits the site and records the flow properties (e.g. angles of friction, moisture contents, size distribution, bulk density) that are required to customize the model for the silos at each site. Currently, all silo and bunker types generally found at power plants have been modeled.

The sequence of input and output coal qualities for the silo in *Figure 2* is shown in *Figure 3*. For illustrative purposes, it is assumed that the four coals loaded into the silo had different ash contents of 10, 12, 14, and 16% respectively. As the diagram shows, the outflow coal quality (in terms of ash content) follows neither a first-in-first-out (FIFO) pattern, nor an average value, as might be assumed. The actual pattern is considerably more complex and difficult to predict without intensive computation and accurate modeling. In this particular case, it can be demonstrated that a considerable quantity of the second coal (12% ash) came out at the very end, in blends with Coal 3 and possibly Coal 4 as well.

Once the ability to predict and control coal quality at a plant has been codified, most users employ the CBAS product to get blend or coal loading recommendations in order to achieve

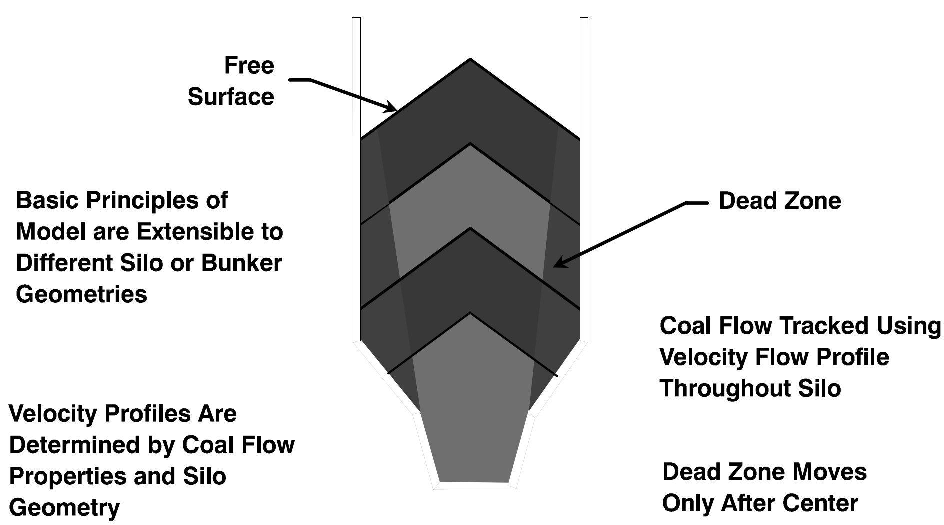

Figure 2. Schematic of typical expanded flow silo

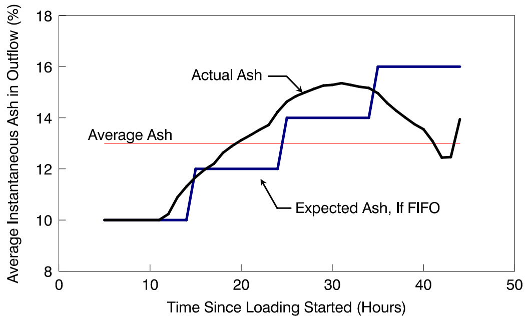

Figure 3. Silo model prediction of silo output composite quality vs. time

their particular goals. The CBAS product examines all available coals and provides one to five ranked coal loading recommendations to achieve all of the plant's goals. These goals may include matching coal to load, SO_2 compliance, NO_x emissions, opacity control, or others. Please note that a user can specify a main criterion, such as ash, and any number of secondary constraints such as sulfur, moisture, and BTU value.

A typical manner in which recommendations are presented to the user is shown in *Figure 4*. The plant wants to match the ash content of the coal to the expected load demand over the next period of hours, such as 24. The operational constraint in this case is that the plant only loads coal into each silo twice a day. Its goals are to use high-ash, low-price coal blends when the load is low, and low-ash coals when the load is high. If done successfully, the implementation of this strategy leads to the use of the lowest-price coal consistent with all load conditions.

Three graded recommendations, characterized by a "Fitness Function," are presented to the users for each of the two loadings. Their respective value to the plant is indicated by the fitness function (the lower the better), and the yard operators can select any one of the suggested approaches, with each able to meet its objectives, though at somewhat different costs. This feature allows the plant operators to take into consideration any unforeseen events or equipment breakdowns that the CBAS product may not be collecting data for and thus cannot consider in making the recommendations.

Three Key Applications of the CBAS Product

Application 1: Matching Coal Quality to Load Profile

Figure 5 shows the ability of the CBAS product to match coal quality to the load requirements. The expected load demand curve is either entered into the CBAS product by the plant operators (or obtained on-line from a plant data source). Next the CBAS product makes recommendations for coal loading and blending to assure that the right coal is available at the burners to meet the load requirements.

The example shown in *Figure 5* is a sample of test data from a utility that measured the accuracy of the model. The model's predictions were always within 0.5% of the actual coal blend exiting the mills. The load profile is shown at the top of the graph. As the load increased, the percent ash in the coal decreased, demonstrating the load matching capability of the CBAS product.

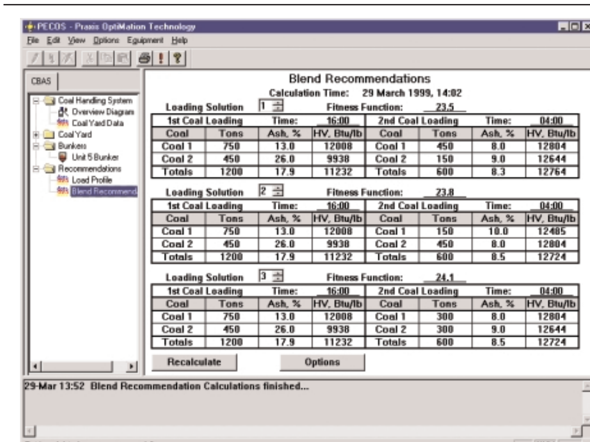

Figure 4. The CBAS product blend recommendation table

CBAS Predictions Are Accurate

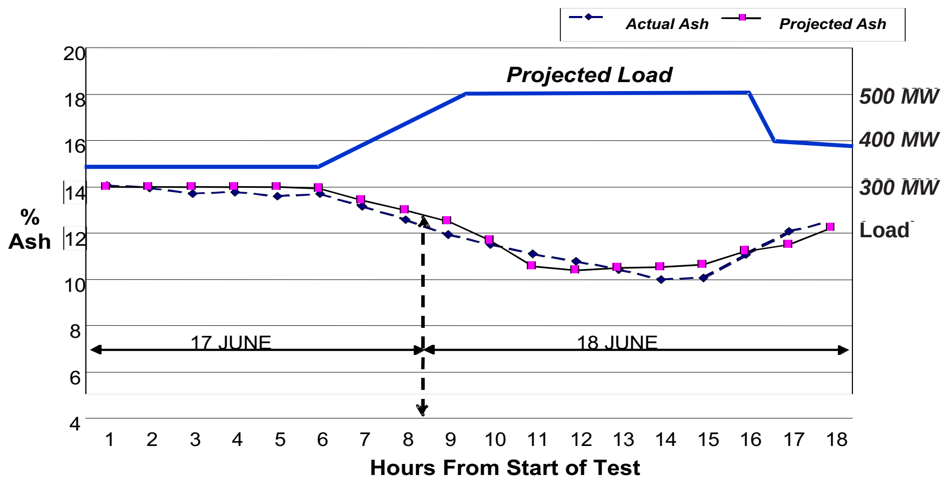

Figure 5. Least expensive coal to meet power load

Application 2: Using the CBAS Product to Manage Emission Requirements

Figure 6 shows the ability of the CBAS product to blend coals to avoid generation losses that a plant was incurring due to uncontrolled blending/usage of its coals. The plant obtains all of its coals from four or five seams in a captive mine. Each of these coals has a different "opacity potential" and if the opacity at the stacks exceeds a certain value, the plant has to shed load in order to remain in compliance. The CBAS product, by managing all coal receipts and blending the coals appropriately, was able to avoid nearly all instances of exceeding these opacity values. As a result, the plant produced an additional 70,000 MW-hr in one year, with a subsequent increase in its revenues.

Remarkably, the CBAS product required no change in the mining practice and only a minimal change in the yard operations. No new equipment was added, and the plant continued to use all the same coals. The CBAS product simply rationalized the use of available coals. However, this made a difference of approximately $2 million (USD) in added revenues.

CBAS Reduces Derates

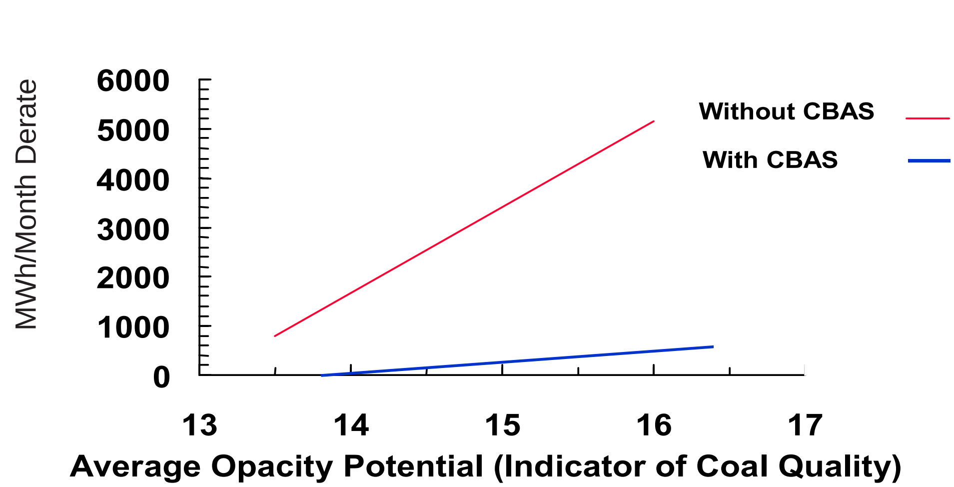

Figure 6. Opacity derate history with and without the CBAS product vs. varying coal quality

Application 3: Using the CBAS Product to Deliver Premium Coals when Rates Are High

Figure 7 illustrates the use of the CBAS product to deliver a coal of extra-high quality to the burners during the hours of expected peak demand when the price of power is at its highest. By using the best coal only when needed, and using less expensive coals at other times, the CBAS product assists the plant in two ways: lower fuel costs and increased revenues.

The graph in *Figure 7* shows how the CBAS product can be used to deliver the highest-grade coals (highest Btu/lb) to the burners only during peak periods, allowing the plant to generate extra MW only during the peak periods. Lower-grade coals were delivered before and after the peak periods, minimizing the usage of expensive coals.

Additional CBAS Product Applications

The system can also be used to optimize Flue Gas Desulfurization systems. The CBAS product can track each type of coal and the associated sulfur content. The CBAS product recommends blends to meet regulatory requirements, and also recommends a bypass operation when conditions permit this. This type of operation can save millions of dollars per year in energy and reagent costs, and optimize the usage or generation of SO_x credits.

The CBAS product can also be used to manage any other emission issues that are related to coal. For instance, fuel NO_x (the NO_x related to the nitrogen content in the fuel) produces approximately 70% of the total NO_x generated in the boiler. As such, fuel NO_x is a very important variable in the control of NO_x. The CBAS product can track the nitrogen content in the coal, and notify the boiler/NO_x system of upcoming changes in fuel nitrogen content. This allows the boiler optimization system to make much better decisions in the management of NO_x. In addition, the CBAS product could even be used to blend coals based on their nitrogen content, significantly improving a plant's ability to manage NO_x emissions over a daily or weekly period.

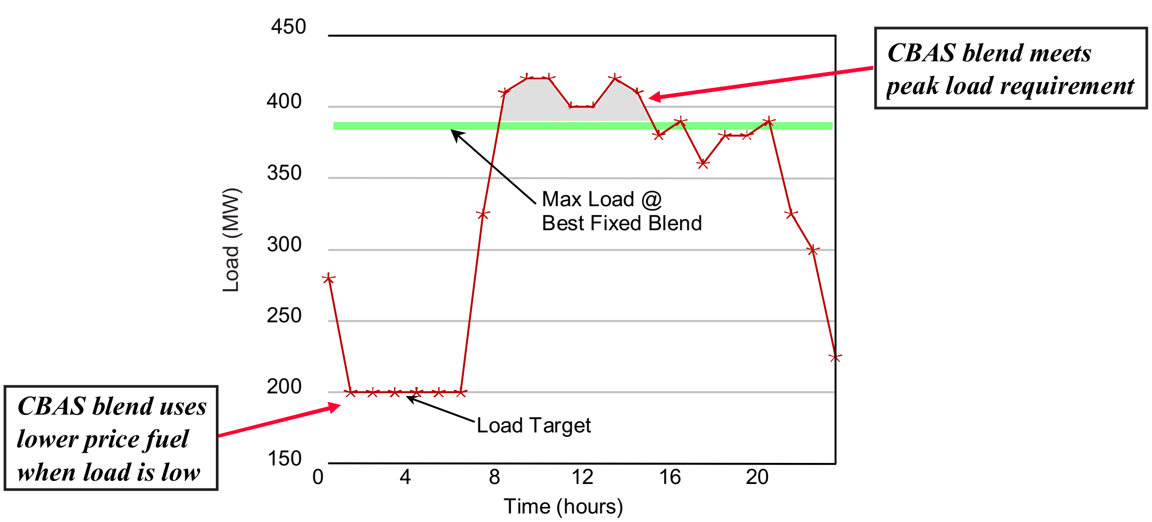

Figure 7. The CBAS product matching of coal blend to load curve

CBAS Product Architecture and Installation

The CBAS architecture is shown in *Figure 8*. The architecture consists of a number of modules such as the CBAS Client (the graphical user interface), DASMod, EventMan (Event Manager), CoalTrack, and OptiMix. The module functions are outlined below.

The CBAS Client is the module for the human/user interface. The CBAS Client module displays the current status of the coal yard, including the coal properties in the piles, bunkers and silos, and the coal entering the boiler. The CBAS Client also displays the results of the OptiMix calculations. It is the vehicle used to set any manually entered data, such as equipment status and OptiMix targets and options.

DASMod is the data acquisition module which connects the CBAS product to the plant data sources. A number of modules for the commonly used DCSs are available and others can be developed as and when needed. The EventMan module manages all the information traffic flow between the other modules of the CBAS product.

The CoalTrack module contains the Praxis simulation modules for coal handling equipment, silos, bunkers and coal piles. This module uses the real-time operations data for weigh scales, conveyor status, flop gate positions and the like along with the Silo Flow Model which models bulk materials flow in piles and silos to track the flow of coal from receipt, through piles, conveyors, and silos all the way to the burners.

The OptiMix module implements the Model Predictive Control (MPC) strategy. The OptiMix module uses several types of models, either alone or in conjunction with one another, such as mathematical models, fuzzy-neural models, and the Silo Flow Model, and con-

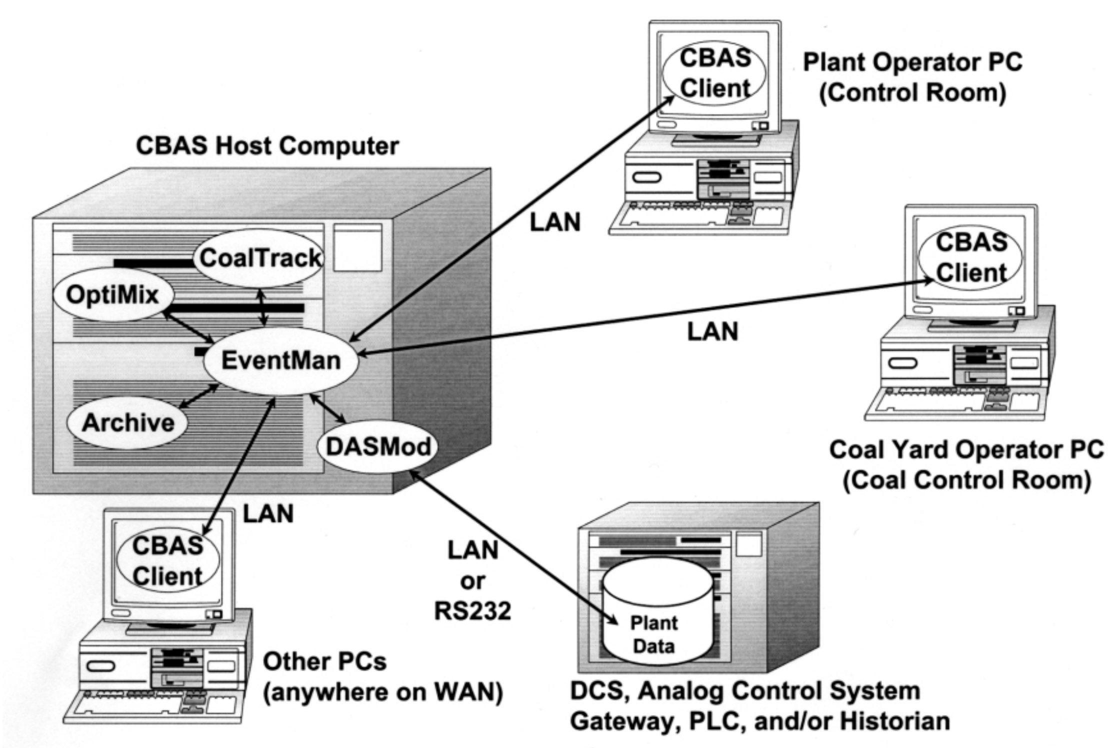

Figure 8. The CBAS product architecture

verges at an optimum solution for a case-specific prediction horizon. The strength of this module lies in its accuracy and flexibility, both in modeling and in optimization. The optimization techniques in the CBAS product use conventional methods, fuzzy logic-based algorithms, and Genetic Algorithms (GA). Based on adjustable constraints and requirements, OptiMix computes the best pile management, coal blending, and bunker feed actions for the coal yard and boiler operators.

All other CBAS product computations and functions are performed on the CBAS Host Computer, a dual-processor Pentium® (or better) PC running Windows NT®. Please note that installation of the CBAS product at a plant is generally simple, as the host computer only needs to be connected to the plant data system. In general, the implementation of the CBAS product is completed within twenty weeks.

Summary

The CBAS product is a powerful tool that can improve the economics of power plant operations significantly. Based on the economic benefits that may be achieved, the payback of a CBAS product can be achieved in months and results in millions of dollars in coal savings for the power plant. Some ways the CBAS product can improve plant profitability include:

- Using the least expensive coal to meet power load demands
- Minimizing derates through control of coal quality burned
- Limiting the burn of expensive high-quality coal to only peak generation times
- Managing boiler emissions through appropriate coal blending at the burners
- Minimizing double handling.

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