OPTIMIZING THE FUEL SUPPLY CHAIN
IN COAL-FIRED POWER PLANTS

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ABSTRACT
The current power generation market in Asia creates enormous challenges for power producers to operate assets at a profitable level because of issues with available coal supply, poor coal quality and increased imported coal prices.

Power producers can effectively manage these issues by optimizing the fuel supply chain through properly implemented data handling processes and plant fuel-related performance models and optimizers combined with expert fuel management techniques. An optimized fuel supply chain reduces the total cost of power by ensuring the most effective use of available resources and options.

Too often, coal purchase decisions are based on inadequate data and poor models, which mask the true cost of production. Understanding the total cost of fuel choices is critical to maintaining the viability of power generation assets, and this has led to the development of techniques in optimizing the fuel supply chain as a rapid and reliable way to reduce costs.
Optimization requires collecting the right data and turning that data into actionable intelligence through advanced modeling and planning tools. Properly executed fuel supply optimization strategies improve fuel purchasing decisions at one end of the supply chain while also improving operational decisions at the other.

Understanding how plant reliability and performance issues are affected by changing coal quality is the basis for optimization. The typical method of looking at only fuel price, quality and availability inevitably leads to higher total cost of production, sometimes in obvious ways and sometimes in subtle ways. Individual coal constituents, including ash constituents, affect total plant costs in ways that are sometimes difficult to understand. Knowing all coal-related costs is necessary in making optimal fuel purchasing and blending decisions, and incorporating that knowledge into plant operations and maintenance (O&M) decisions is required to achieve truly optimized production.

This paper describes the steps required to help power producers reduce the total cost of production by optimizing the fuel supply chain.

UNDERSTANDING COAL QUALITY IMPACTS

Fuel is the largest factor in determining the total cost of production, which makes optimizing the fuel supply chain a high priority for power producers. Significant attention is paid to the price of fuel and cost of transportation, but equally important are the impacts coal has on the availability, reliability, efficiency and capacity of a unit. Analytical models are a fast and cost-effective way to determine the impact various fuels and fuel blends will have on a unit.

Without a detailed model of the boiler and other plant equipment to calculate the effects of coal constituents on plant performance, gross approximations must be made to estimate the cost; however, these approximations fail to consider the true complex nature of burning coal and can result in the power producer making costly mistakes in managing fuel decisions.

Fuel purchase specifications are often based on the design specification of the unit; however, design specifications are typically developed to provide a certain performance guarantee. Depending on the design margin of the unit and unit demand (which may change over time), the unit may be able to tolerate a wider range of quality. In addition, when coal options are limited or only lower quality coal is available, the best operating and blending approach to
minimize costs and optimize operations must be determined while identifying risks and capacity restrictions and meeting emissions limits and other operating constraints.

The large number and ranging quality of coal choices available in the market require a unique solution beyond the consideration of only calorific value and delivered price. In order to achieve a competitive advantage, power generating companies must consider the total cost of burning each fuel as it relates to efficiency, equipment limitations and forced outages. The typical view of fuel only considers delivered price within certain coal quality specifications. This limited view cannot effectively explain the total fuel effects including the following:

- Generating capacity reductions due to equipment limitations.
- Unit efficiency changes.
- Soot blowing requirements due to slagging and fouling requirements.
- Emissions changes.
- Pollution equipment loading.
- Ash byproduct constituents.
- Ash byproduct quantity.
- Equipment loading and increased equipment wear.

The way to account for these impacts is through either a strong analytical approach or lengthy test burns. Test burns have limitations because they are expensive to perform and must be of sufficient duration to provide an accurate representation of a fuel’s impact performance on the equipment. In addition, a plant can only test a few fuels or blend combinations before the process becomes untenable. Fuel blending is, however, beneficial in that it may allow a plant to burn a wider selection of fuels, but at the same time, it can add significantly to the complexity of the problem plants are already trying to solve.

As previously mentioned, a coal quality specification does not examine the broad spectrum of potential operating problems that could occur at a unit. For example, the purchase of a high sodium coal could cause problems such as upper furnace tube fouling, even though this has never been a problem for the plant. While the specification for the ash-softening temperature may mitigate some of this risk, an analytical model is required to fully understand the complexity of the full potential risk.
Furthermore, an analytical-based model can be used to determine the sensitivity each individual unit has to certain coal and ash parameters. Knowing the important parameters and acceptable ranges in negotiating coal contracts provides the coal purchaser more leverage and a higher degree of confidence. Systems without an underlying detailed analytical model rely on performance proxies, which can have a high degree of uncertainty for fuel effects across the fleet and can also lead to operating with a higher level of margin since all impacts or unknowns with blending cannot be adequately evaluated.

ANALYTICAL MODEL FOUNDATION

A strong analytical approach incorporated into a fuel management system allows the plant to experiment with various coal sources and blends quickly and cost-effectively without the problems associated with test burns. Analytical models can quickly identify the optimal fuel plan and the cost of deviating from that plan. The knowledge and transparency provided by analytical models are vital to developing short-, medium- and long-term fuel strategies that consider the entire cost of production including efficiency, emissions, outages and maintenance costs. This is why analytical models are the foundation upon which coal supply chain optimization is based.

In the context of this paper, analytical models are considered for use within a comprehensive fuel management platform to enable fleetwide fuel supply chain optimization. Analytical models can also be used in a stand-alone manner as shown on Figure 1.

To fully evaluate the fuel impacts presented in this paper, the analytical model should include detailed equipment performance models tailored to each specific equipment system affected by fuel quality including the following:

- Fuel handling.
- Primary air, forced draft, induced draft and scrubber booster fans.
- Feeders, pulverizers and cyclones.
- Air heaters.
- Steam generator.
- Hot-side precipitator, cold-side precipitator and fabric filter.
- Sorbent injection systems, including powered activated carbon, trona, hydrated lime, etc.
Figure 1. Stand-Alone Analytical Fuel Impact Model

- Selective catalytic reduction and selective noncatalytic reduction.
- Wet and dry/semidry flue gas desulfurization (FGD).
- Bottom ash handling.
- Fly ash handling.
- FGD waste disposal.

The steam generator warrants special attention. A detailed heat transfer model can evaluate steam generator performance, including boiler efficiency, gas and steam temperatures, attemperation, slagging potential, fouling potential and soot blowing requirements. As with other equipment, the model of the steam generator should be based on the actual configuration of the steam generator, the steam temperature control methods, design operating parameters and target turbine cycle parameters.

Proper characterization of each equipment system should incorporate configuration, design and current performance as follows:

- System configuration – number and type of components.
- Design parameters – capacity, efficiency and horsepower.
• Performance data – throughput, efficiency and horsepower associated with the calibration fuel.

Consideration should also be given to maintenance and availability impacts. A robust model should include the effects of fuel quality on individual component capacities, sparing, duty cycle and failure rates. Failure rates can be developed for each component modeled and can be combined with other data to develop overall unit maintenance and availability predictions. For some components, changes in failure rates are a direct result of changes in fuel quality. For other components, failure rates are not directly impacted by fuel quality but are indirectly affected because changes in fuel quality affect component capacity and, therefore, sparing and duty cycle.

The functionality of such an analytical model can be leveraged by plant personnel to make tactical fuel decisions to help align unit operation with the overall fleetwide strategy. The following factors should be considered in developing optimum fleetwide long-term fuel and transportation strategies:

- Contract options.
- Existing obligations.
- Existing and future fuel markets.
- Unit/fuel generation costs.
- Transportation contracts.
- Emissions constraints.
- Inventory targets/constraints.
- System load and power sales.

Once fuel burn plans are finalized, the fuel management system can be used to identify spot market opportunities and immediately know the break-even point for any number of fuels in order to maintain profitability while identifying the risk associated with the fuel. The fuel management system can also determine the size of penalties to be assessed because of bad quality coal. The detailed plant model allows the fuel purchaser to understand how fuel choices will affect each unit’s total cost of production. Inconsistencies in fuel quality and associated plant performance data can result in non-optimal fuel purchases with errors totaling millions of dollars in magnitude; therefore, the fuel purchase evaluation is critical in realizing lower fuel and generation costs.
The push for green energy has led many power producers to consider blending biofuels with existing coals. Biofuels present a number of challenges in terms of how they interact with various coals and how they impact boiler performance. In addition to efficiency changes, slagging and fouling will be affected by the presence of biofuels in the combustion process as will ash handling and emissions. The flexibility of a fuel management system should extend to cover biofuels to remain relevant in the current power generation market.

While fuel management processes can improve the ability to select the correct fuel for each unit, market forces may nevertheless dictate purchases that result in non-optimal unit performance or operation that is outside of comfortable operating margins. Negative results of this non-optimal operation can be mitigated through the use of remote monitoring and diagnostics (M&D).

**REMOTE MONITORING AND DIAGNOSTICS**

Software tools and data management infrastructure are vital parts of a remote M&D center; however, power plants generally have much of the required infrastructure in place. The concept of remote M&D has its roots in online performance monitoring, and the two share some of the same infrastructure requirements. When a gap in tools or infrastructure exists, the need can often be filled with off-the-shelf software and hardware. The infrastructure design can be modified to fit the needs and capabilities of the plant; however, the basic remote M&D infrastructure consists of the components shown on Figure 2.

The infrastructure starts with the Data Layer, where data are bundled for transmission to the M&D center. The Data Layer includes plant instruments, process historians, performance calculations and other data sources. This layer enables the remote M&D center to gather information from various plant data sources through API (Application Programming Interface), OPC (Open Process Control) and other proprietary communication protocols. Data sources can also include manually recorded data such as fuel information, outage schedules and operational logs. This additional information helps the M&D center place the plant measurements into the proper context and improves the analysis process. Many plants have an incomplete Data Layer; however, a properly designed remote M&D program is flexible enough to make the best use of the available data and provide room to grow as the available data increase.
The Communications Layer securely transmits data to the remote M&D center. Because of the remote collaboration capabilities of the M&D center, maintaining data security and integrity is an important part of a remote M&D program. On-site data buffering and automatic data backfill functionality guard against data loss from communication interruptions and help maintain a continuous archive. A dedicated server at each plant site will typically handle data collection and data buffering. Several data communications options are available, but the most secure and reliable data transmission occurs over the Internet using 128-bit encryption with certificate authentication. The plant local area network (LAN) as well as the remote M&D center LAN remain safely behind firewalls to protect against outside threats. A few popular data historians on the market support secure encrypted communications; however, custom solutions are also available. An example of a typical M&D network configuration using the Internet for data transmission is shown on Figure 3.
The M&D Layer is typically located away from the plants being monitored, although hosting a center on-site is also possible. The key infrastructure components of the M&D Layer (refer to Figure 2) include Supplemental Analytics, an Anomaly Detector, a Data Historian and an Issues Database.

Supplemental Analytics improve the value of the raw data prior to evaluation by providing important data transformation capabilities such as averaging, totaling, data validation and engineering units. Performance calculation packages can be attached to the Supplemental Analytics to fill gaps in plant performance data and to ensure uniform performance calculations across a fleet of plants for benchmarking purposes.

Anomaly Detection software scrutinizes incoming data using predictive analytics in real time and issues alerts on suspicious data. The most common type of Anomaly Detection
software uses Advanced Pattern Recognition algorithms with historical data-based reference datasets. Historical data are preferred over design data for anomaly detection because power plants change over time as equipment degrades and fuels change. Historical data help filter out noise and reduce false alarms. The very latest anomaly detection software employs adaptive techniques to ensure the reference dataset remains up-to-date with little or no human interaction. This improves the usefulness of the software and helps to reduce false alarms seen with static reference datasets.

The collected data gain additional value as they pass through the Supplemental Analytics and Anomaly Detection tools. For this reason, it has become necessary to install a Data Historian in the M&D center. The Data Historian provides monitoring personnel quick access to long-term data that improves the investigative process by placing emerging issues in proper historical context.

The Issues Database stores a history of all identified and diagnosed issues and prioritizes and categorizes them based on a predefined set of criteria. The methodology used for detection and diagnosis is stored along with measurements and calculation results. Capturing the issue life cycle – detection, investigation and resolution – is a powerful tool that can be referenced by M&D personnel and plant personnel when similar issues arise.

The Presentation Layer, as shown on Figure 2, consists of a Performance Dashboard and an Issues Tracking Portal. Both the Dashboard and Portal are typically hosted in the remote M&D center and are configured to provide a common access point for key personnel at any location in the organization. The Performance Dashboard combines results from the online Performance Calculations and the Supplemental Analytics to give a transparent view of the M&D process and performance improvement process across the entire fleet. Another feature of the Performance Dashboard is that it provides a common platform to display contextual data from a multitude of sources in a single location.

The Issues Tracking Portal is a collaborative environment where users can track and comment on emerging issues uncovered by the M&D team. The Portal also serves as the interface for navigating resolved issues. This tool helps build the team link where key team members can contribute and view the problem workflow process.
REMOTE MONITORING AND DIAGNOSTICS PROCESS

A successful performance improvement program using a remote M&D center must go beyond tools and data. The quality of the workflow process ultimately determines the success or failure of a program. An effective process helps build a performance improvement culture across an organization and establishes accountability among the team members by focusing on root cause analysis and corrective action plans. The right process will allow for collaboration with experts during the diagnostic process and will integrate experts into the performance and maintenance decisions. The steps required to transition from reactive to proactive are shown on Figure 4 and summarized as follows:

- Anomaly or Deficiency Detection – The first step in the process is to detect anomalies or changes in plant or equipment performance. Software tools are used to generate an alert when further action is required.

![Remote M&D Process Diagram](image.png)

Figure 4. Remote M&D Process
- **Rule Out False Indication** – Once an alert is triggered, an M&D expert steps in to review the supporting information related to the alert. Instrumentation issues, changes in fuel and changes in ambient conditions can all contribute to false alarms and must be ruled out as possible causes. The M&D expert determines the validity of the alert before continuing.

- **Impact & Risk Quantification** – After an alert has been deemed to be real, the cost of the deviation is determined though engineering analysis and estimation. Assigning a cost to the alert is an important step because it enables the plant to make better informed maintenance decisions.

- **Diagnosis Validation** – The diagnosis of the problem is then validated to ensure that the plant is acting on accurate information. This usually involves reviewing historical data, but sometimes targeted equipment testing is required.

- **Issue Recommendation** – After a problem has been verified and a cost assigned, the M&D center is in a position to recommend a course of corrective action.

- **Documentation & Prioritization** – Prioritizing issues is important to understanding how to best allocate maintenance resources and managing the time available for repairs. Finally, documenting issue life cycles is an important step to preserving the knowledge acquired during the M&D process.

Effectively communicating potential problems with the plant is a vital function of a remote M&D program. Key plant personnel and experts must be engaged in the M&D process; they need the process to make the best use of their time and help allocate resources appropriately. Core plant teams need to be identified and clear communication guidelines defined and implemented. The M&D tools such as the Performance Dashboard and Issues Portal help improve the interaction between the plant and the M&D center and within the plant itself. The process is geared toward integrating experts in managing and recording the complete life cycle of each problem from identification, to criticality assessment, to diagnosis, through corrective action planning, and finally to fixing the problem and documenting the avoided cost.

Remote M&D centers provide power producers a key advantage over stand-alone performance monitoring software by enabling a proactive rather than reactive approach to performance improvement and analysis. The inclusion of equipment health parameters with performance parameters helps improve reliability and availability of the unit as well.
Implementing the right process with a remote M&D center creates a critical team link between Operations, Maintenance and Engineering by using a collaborative process that puts information in the hands of those who need it and can take action. The tools enable the fleet to engage specialists and experts relatively easily. The Issues Portal captures information about each issue that speeds the process the next time a similar issue occurs and helps inexperienced personnel learn and be effective more quickly. Remote M&D centers are a cost-effective way to improve efficiency, especially considering that many power plants already have much of the necessary infrastructure.

**CASE STUDIES**

Some of the noteworthy gains realized through fuel management system and M&D capabilities are shown in the following case studies.

<table>
<thead>
<tr>
<th>Case No. 1</th>
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</thead>
<tbody>
<tr>
<td>Optimized Fuel Purchase Plan</td>
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<tr>
<td><strong>Goal:</strong></td>
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<tr>
<td>• Determine the least-cost fuel selection strategy for coal-fired power plants.</td>
</tr>
<tr>
<td><strong>Challenges:</strong></td>
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<tr>
<td>• Existing coal purchase obligations.</td>
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<tr>
<td>• Emissions, unloading, maximum inventory and other constraints.</td>
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<tr>
<td>• Changing market.</td>
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<tr>
<td>• Complexity of coal and transportation contracts and escalation clauses.</td>
</tr>
<tr>
<td><strong>Benefits:</strong></td>
</tr>
<tr>
<td>• Optimize supply of fuel while satisfying quantity and quality components.</td>
</tr>
<tr>
<td>• Quickly determine the cost of making non-optimal operational decisions.</td>
</tr>
<tr>
<td>• Potential for US$3 million fuel savings for 2,500 megawatt (MW) system of four plants.</td>
</tr>
</tbody>
</table>
### Case No. 2
Failing High-Pressure Feedwater Heater Partition Plate – Offline Repairs Made

<table>
<thead>
<tr>
<th>Early Detection: What was found?</th>
<th>• Slowly increasing terminal temperature difference.</th>
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</table>
| Quantify the Loss: What was the cost and risk? | • US$12,000 per month heat rate.  
• 0.4 MW capacity loss. |
| Action: What should be done? | • Noncritical issue was repaired during scheduled maintenance outage. |

### Case No. 3
Failing Reheat Stop Valve – Offline Repair of Valve

| Early Detection: What was found? | • Drop in intermediate-pressure turbine efficiency along with reheat bowl and exhaust pressure.  
• Valve issue suggested. |
|-----------------------------------|---------------------------------------------------|
| Quantify the Loss: What was the cost and risk? | • US$65,000 per month heat rate.  
• 3 to 5 MW lost capacity. |
| Action: What was done? | • Valve test confirmed which valve was the problem.  
• Outage scheduled and offline repair was made. |
## Case No. 4
Failing Internal Low-Pressure Feedwater Heater Extraction Line – Offline Replacement of All Similar Expansion Joints

| Early Detection: What was found? | • Subtle deviation in feedwater heater extraction line pressure.  
• Extraction line failure suggested. |
|----------------------------------|-------------------------------------------------------------------|
| Quantify the loss: What was the cost and risk? | • US$15,000 per month heat rate.  
• Risk of forced outage. |
| Action: What was done? | • Repair scheduled, parts ordered.  
• Replacements made during outage. |

## Case No. 5
Understanding Fuel Costs

| Goal: | • Understand how different fuels will affect the plant. |
| Challenges: | • Identify fuel-related impacts to existing plant equipment – without test burn.  
• Identify potential fuel-related capital modifications to improve availability with new coals.  
• Prioritize modifications and suggest operating and performance changes to minimize detrimental fuel impacts. |
| Benefits: | • Detrimental maintenance and availability impacts with potential future fuel supplies were quantified.  
• Cost of unavailability justified plant upgrades to minimize these impacts. |
Case No. 6
Forced Draft Fan Discharge Damper Linkage Problem – Linkage Adjustments Made

| Early Detection:                  | • Bias between A and B fan motor amperage.  
| What was found?                   | • Unit load limitation.                     |
| Quantify the Loss:                | • 7.5 MW capacity loss.                    |
| What was the cost and risk?       |                                               |
| Action:                          | • Fan damper and linkage adjusted at next outage opportunity. |
| What was done?                    |                                               |

CONCLUSION

It is not enough to make optimum fuel purchase plans or detect emerging issues. Power producers must also be able to act on available information in a way that improves the performance of the fleet. The solutions presented in this paper, when integrated, combine past and current data with predictive simulations to make better forward-looking decisions that span both operational and business requirements, therefore putting current operations and forward-planning decisions in the same context (refer to Figure 5).

![Image](image-url)

**Figure 5. Combined Historical and Plan View**
When issues management and fuel planning are integrated into a common platform, strategic and operational alignment are improved; operational actions can be taken with a view of the future; and informed planning decisions can be made with an understanding of current operations.

Current coal and power markets create an increasingly challenging environment for power producers. Making the most of the resources and opportunities that are available requires both powerful analytics tools and a flexible response.