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OPTIMIZING COMPLIANCE COST FOR COAL-FIRED ELECTRIC GENERATING FACILITIES IN A MULTIPOLLUTANT CONTROL ENVIRONMENT

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ABSTRACT

Higher natural gas prices have increased the importance of coal-fired generation at a time when environmental uncertainty is raising the risks of operating coal-fired units. The likely need for increased investment in environmental control technologies comes at a time when many electricity generators are under great financial stress. This combination of forces makes a structured and comprehensive approach to assessing compliance strategies essential to managing generating assets. The approach needs to incorporate the high degree of uncertainty that can be otherwise buried in key assumptions, such as regulatory requirements, market pricing of allowances, plant capacity factor, wholesale electric prices, etc. The approach should also facilitate testing of assumptions under a range of scenarios to allow for flexibility in possible compliance strategies.

In this paper an approach for evaluating compliance risks and quantifying the potential costs under various scenarios will be described. The approach integrates market-based compliance mechanisms with capital improvements in control technology while providing methods to address the uncertainty of key assumptions. The approach facilitates optimizing the balance between market-based and technology–based compliance approaches so that the environmental compliance risk profile can be tailored to the specific situation. A unique feature of this approach is that it incorporates the effects of the market risk associated with emissions markets along with market derivative instruments designed to manage risk, while also incorporating comprehensive technology analysis so that costs and risks can be well quantified under any regulatory scenario. The approach lends itself to active scenario review to facilitate flexibility in decision making while avoiding premature commitments.

INTRODUCTION

Coal-fired generating plants have been, and will continue to be, subject to increasingly strict environmental regulations. This comes at a time of financial stress for the industry, making cost control and risk control more critical. These plants will have to control multiple air pollutants at the same time, making the analysis complex. The technology analysis is complicated by the fact that pollution control technologies have demonstrated varying degrees of influence on one another - so that controlling one pollutant may make it more or less difficult to control others. An alternative to reducing emissions of a pollutant is to pay for others to reduce their emissions of the pollutant by purchasing allowances. However, this introduces significant market risk. As a result, determining the lowest cost compliance approach with an acceptable amount of risk requires careful analysis of a range of complex, and sometimes interrelated, issues.

Air pollution control technology cost and performance modules have been developed and allowance market modules are under development for a new multipollutant compliance analysis method that integrates market-based compliance mechanisms with capital improvements in control technology while providing methods to address the uncertainty of key assumptions. The approach facilitates optimizing the balance between market-based and technology–based compliance approaches so that the environmental compliance risk profile can be tailored to the specific needs of the facility owner.

COMPLIANCE-AT-RISK^{SM} [1]

Value at Risk (VAR) is a process that is used by financial institutions to assess the organization's exposure to unfavorable events and to manage the associated risk. The outcome of a VAR analysis for a bank, insurance company or hedge fund may show, for example, that a company has less than a 1% chance of experiencing a loss of one billion dollars over the next year. These are drawn from a probability distribution of possible outcomes for the period evaluated. There are three parts of the output – probability, quantity (of the outcome), and time. There are a number of approaches that are used to estimate VAR, but they all involve statistical modeling of some sort. When there is only one major parameter of uncertainty, it is possible to perform a simple spreadsheet analysis. But, when there are multiple, independent sources of uncertainty, more sophisticated methods of analysis are necessary. One approach that lends itself to complex statistical modeling is Monte-Carlo simulation, where variables that are deemed to have uncertainty to them are characterized by a probability distribution (rather than a single value) and a computer performs many calculations to estimate the range of the various outcomes that are possible given the range of inputs that are possible. This approach lends itself well to complex systems where there are multiple relationships, such as technology calculations, market calculations, etc. Monte Carlo simulation used to be considered a major technical challenge. Fortunately, advances in computer technology have made Monte Carlo simulation much easier to perform today than it was only a few years ago.

The Compliance at Risk^{SM} method is an analysis methodology that is under development. Figure 1 shows how the Compliance at Risk^{SM} method works. A Monte-Carlo simulation package is used to model uncertainty in variables that exist in economic parameters, in technology parameters and in market prices. The economic parameters will affect calculations in the technology parameters. For example, the cost of capital will impact the annualized cost of technology. The technology modules include modules to calculate cost and performance of various control technologies.

The Technology Performance and Cost Modules provide very comprehensive cost and performance estimation capability for the technologies addressed. Capital costs are estimated (or can be input), and all major consumables, by-products and disposal costs are estimated along with parasitic power losses.

The allowance market module that is under development includes trading of market derivative instruments, such as forward contracts, options, swaptions, etc. These market trading modules and the integration of derivatives trading are important to the Compliance at Risk^{SM} approach because it is the use of the market derivative instruments in combination with technology that enables the facility owner to tailor their risk to suit their specific needs. As will be shown, market instruments can be combined to achieve a similar cost and risk profile as if control equipment were installed. We will show how market derivative instruments can be combined with the use of control equipment to achieve a specific risk profile.

CONTROL TECHNOLOGY PERFORMANCE AND COST MODULES

The control technology modules perform the necessary calculations to estimate the capital and operating costs associated with the technologies under consideration. Table 1 lists the technologies addressed in the Technology Performance and Cost Modules at this time. Modules for control technologies not listed in Table 1, but of interest to the industry, will be developed over time.

The NOx control technology modules include modules for Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction and combustion controls. This approach may be integrated with other software, such as, CAT MANAGER™[2], a proprietary software tool that enables SCR

[1] Compliance at Risk^{SM} is a service mark of Andover Technology Partners

[2] CAT MANAGER™ is a trade mark of Andover Technology Partners

operators to evaluate catalyst management strategies and predict catalyst performance and cash flows over the life of a facility. CAT MANAGER™ output for projected SCR costs may be input to the SCR module (but, CAT MANAGER™ is not necessary for using the SCR module). CAT MANAGER™ is described in more detail in References 1 and 2.

FIGURE 1. THE COMPLIANCE AT RISK[SM] APPROACH

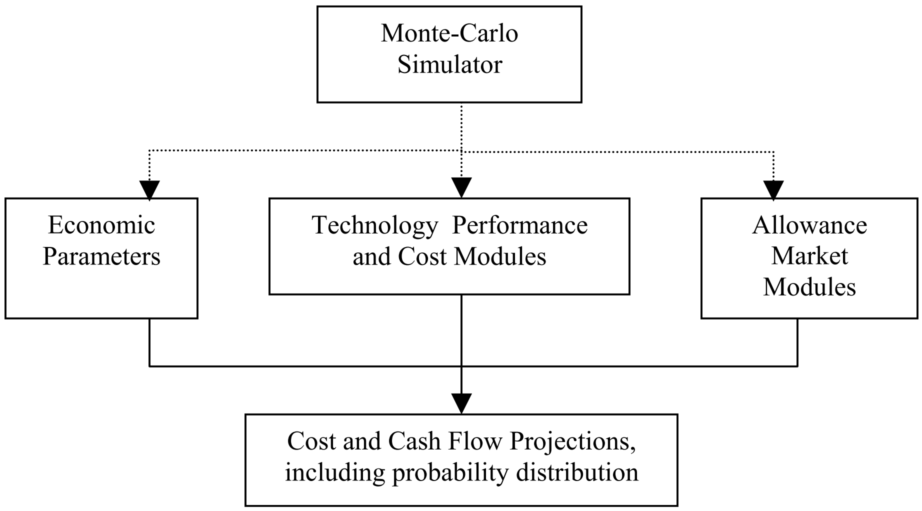


TABLE 1. CONTROL TECHNOLOGY PERFORMANCE AND COST MODULES

Pollutant	Control Technologies (and technology nomenclature)
NOx	• Combustion Controls • Selective Non Catalytic Reduction (SNCR) • Selective Catalytic Reduction (SCR)
SO_2	• Limestone Forced Oxidation Wet FGD (LSFO) • Spray Dryer Absorber (SDA) • Advanced Dry FGD (Adv Dry FGE, or CFB Scrubber)
Mercury	• Powdered Activated Carbon (PAC) Injection with and without downstream Pulse Jet Fabric Filter (PJFF) • Multipollutant control technologies • Cobenefit approaches with other control technologies
Particulate	• Dry Electrostatic Precipitator (ESP) • Reverse Gas Fabric Filter (RGFF or FF) • Pulse Jet Fabric Filter (PJFF) • Wet Electrostatic Precipitator (WESP)
Multipollutant	• Electro-Catalytic Absorption (ECO)

Mercury and multipollutant control modules were developed in work performed for ARCADIS and the U.S. Environmental Protection Agency. Technologies addressed include Injection of Powdered Activated Carbon (including combinations with existing equipment and downstream pulse-jet fabric filters and COHPAC), Electro-Catalytic Oxidation, Advanced Dry FGD, and Wet ESPs. In estimating the mercury removal, the effects of existing equipment are taken into account, and the mercury removal by add-on technologies, such as PAC injection, is in addition to the removal by existing equipment. These models are the most comprehensive mercury control models we are aware of, and have been used in combination with EPA's Coal Utility Environmental Cost (CUECOST) modeling tool to estimate the cost of controlling mercury in Reference 3.

The combustion, ESP, Fabric Filter, wet FGD, and Spray Dryer Absorber modules were adopted from the EPA's Coal Utility Environmental Cost (CUECOST) modeling tool, which is described in Reference 4.

EMISSIONS MARKET MODULES

Air pollution allowance markets for NOx and SO_2 have been operating for several years and have proven to be an important tool in overall emissions compliance. Under the proposed Clear Skies Act mercury emissions may also be traded. The cost of purchasing or the revenue from selling air pollution control allowances needs to be incorporated into the cost analysis. However, limited liquidity and changing market conditions, especially in the OTR NOx control market, have contributed to high volatility at times. Most participants in this market will recall that in 1999 costs of NOx allowances ranged from a high of about $7,600/ton to a few hundred dollars per ton within a period of a few months. Figure 2 shows the frequency histogram of OTR vintage 1999 NOx allowance prices estimated by comparing trades EPA deemed "Economically Significant" (between independent parties) and market prices at the time of the reported trades. Figure 3 shows the results of a similar analysis for vintage 2000 trades during 2000. As shown in Figure 2, in some years it may be very difficult to anticipate the price that will be paid for allowances, as prices may range between extremes depending upon the balance between supply and demand at the particular time. In such years "average" or "expected" allowance prices may have little relation to the actual market prices, making allowance pricing models of little use in predicting the price that will be paid at the time of a trade. However, in other years, such as in 2000, pricing may be better behaved and more predictable over the period. Nevertheless, even in years of relatively low volatility, the price of NOx allowances have doubled or halved over the period of a few months. So, the market risk may be high even under periods of little market strain. 2003 Vintage NOx allowances exhibited another year of extremes in pricing, as shown in Figure 4. In this case it would have been difficult to accurately predict the market pricing using an economic model.

The SO_2 allowance market allows banking without the flow control feature of the NOx market. It is also a nationwide, rather than a regional, market that has been in existence for several more years than the NOx market. These characteristics make it less volatile (and, therefore, somewhat more predictable) than the OTR NOx market.

Although facility owners attempt to predict the value of allowances, market volatility has caused actual prices to deviate significantly from the predictions. This makes planning compliance strategy far more difficult if participation in the allowance market is to be part of the plan.

FIGURE 2. FREQUENCY HISTOGRAM OF OTR NOx ALLOWANCE PRICES (1999 Vintage)
for "Economically Significant" trades through Dec 1999

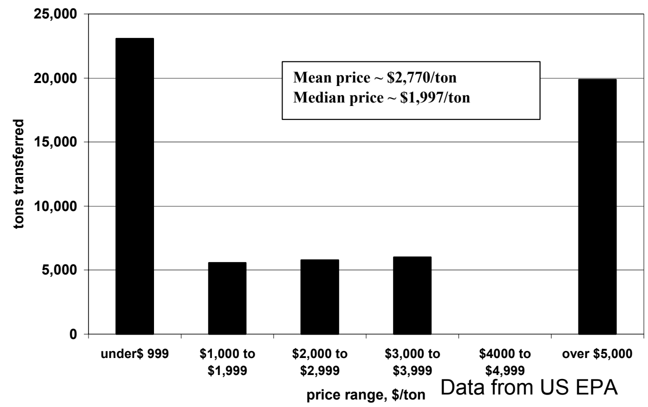


FIGURE 3. FREQUENCY HISTOGRAM OF OTR NOx ALLOWANCE PRICES (2000 Vintage)
for "Economically Significant" trades through Dec 2000

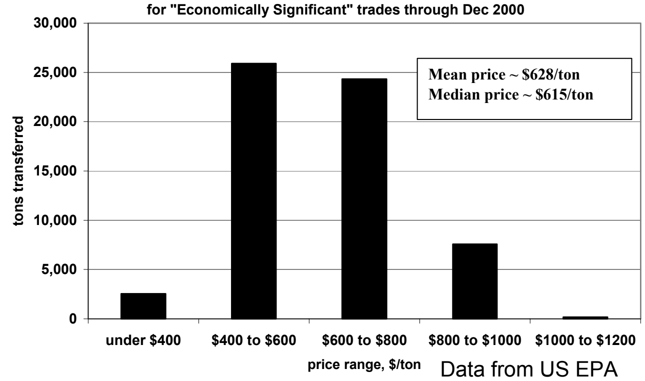
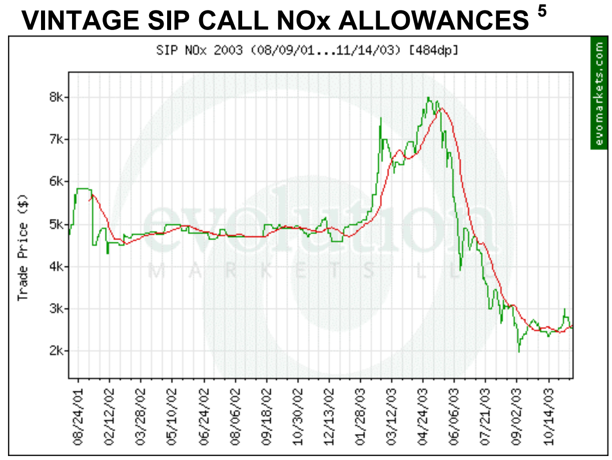


FIGURE 4. MARKET PRICE OF 2003 VINTAGE SIP CALL NOx ALLOWANCES [5]



If mercury emissions ultimately are traded, as proposed in the Clear Skies Initiative, then it is likely that there will be significant volatility in the early years as industry gains experience with mercury reduction methods and with mercury measuring and reporting. A cap ("safety valve" cap) of $35,000/lb has been proposed under Clear Skies, which will reduce the market risk for buyers of allowances. Other variable-rate caps have been proposed as well.[6] In any event, below the prevailing cap there is likely to be significant pricing volatility in the early years of the mercury-trading program.

In order to address the volatility concerns discussed earlier, the emissions market has become sophisticated, providing market derivative instruments for managing risk. Forward contracts (also called futures when exchange traded), Swaps, Options, and Swaptions (an instrument with the characteristics of a Swap and an Option) are instruments that can be used alone or in combination to manage risk. In a forward contract, one party agrees to deliver something to the other party at an agreed price at some agreed point in the future. Sometimes they can be settled with a cash payment equal to the difference between the agreed contract price and the market price at expiration. In other cases the actual item is physically delivered (more commonly done in the allowance market). Swaps are where one party trades one market risk for another with a counterparty over a period of time. They can be similar to a series of forward contracts. Options are contracts where one party (the option buyer) has the right but not the obligation to execute a trade at some agreed future time at a strike price that is set at the time the agreement is made. The purchaser of a call (put) option has the right, but not the obligation, to purchase (sell) the underlying item. The option buyer pays a premium to have this right and the seller of the option receives the premium payment. The seller of the option is obligated to execute the trade at the agreed strike price if the option buyer decides to exercise their right. Of course, the option buyer will only exercise that right if it is in their best interest to do so. So, they will execute the call (put) option only if the then prevailing market price is higher (lower) than the strike price (the option is "in the money"). Swaptions are similar to a series of options. For parties interested in hedging risks, Options and Swaptions are very useful in establishing caps and minimums on prices, interest rates, or whatever is the basis of the swap or option. Forward contracts and Swaps are very useful for locking in specific prices, interest rates, etc.

So far, allowance market trades have mostly had to be settled through delivery of the physical item - the allowances. This has tended to limit market participants to companies that can produce or can use the allowances. If trades could instead be settled in a cash transaction based on publicly available pricing, then financial institutions and traditional risk-management companies could enter the market and provide greater liquidity. The Emissions Marketing Association (EMA) has developed a suggested market index procedure that should facilitate the equivalent of a "futures" market in pollutant emissions. These may not be true futures contracts in the sense of being traded on an exchange. But, they will have many of the same features - such as standardized terms and publicly available pricing - that would facilitate liquidity. Air Daily has decided to publish the allowance prices according to EMA's recommendations, which may help provide liquidity for these new derivative instruments based on allowance prices.[7, 8]

The Emissions Market Modules under development incorporate methods to address the allowance market risk for NOx, SO_2 and mercury emissions along with derivative market instruments - such as forward contracts (or futures), options, and swaptions – to manage market risk. Acknowledging the uncertainty that experience has shown characterizes the emissions allowance markets, the Compliance At Risk[SM] incorporates the ability to model the uncertainty of allowance prices (as well as other important parameters) with statistical distributions. The impacts of market uncertainty on the total compliance risk can thereby be quantified, understood, and strategies for risk control can be planned.

DETERMINING TOTAL COMPLIANCE COST FOR MULTIPLE POLLUTANTS

The goal of the Compliance at Risk[SM] approach is to manage the risk, or uncertainty, associated with the cost of compliance. We will define the total annual cost of emissions control to be equal to:

- The amortized capital cost of the equipment installed to control emissions (including cost of capital), plus
- The operating cost of the equipment installed to control emissions, plus
- The net cash flow from allowance market transactions.

The first two items are determined by technology selection, the cost of materials, and a host of economic parameters such as project lifetime, cost of capital, inflation, depreciation, etc. The two remaining items are determined by the amount of allowances that must be purchased or are available for sale, and the pricing of those allowances. Other important items that affect the analysis, but can be highly uncertain, are the capacity factor and the wholesale price of electricity.

Because coal power plants must control several pollutants and are subject to market risk for each of the tradable pollutants, a complete analysis requires more sophisticated tools than a spreadsheet alone. The following example - that will analyze for NOx, SO_2 and mercury control using several technologies - will use the Monte Carlo simulator that was discussed earlier in combination with several linked spreadsheets. But, the example will still be simple in the sense that we will only include allowance market risk for single years. Other risks - such as wholesale power price, capacity factor, fuel or reagent costs, and even allowance price distributions that vary by year, etc. – can all be included as well if the effects of these risks are significant and of interest. But, to keep things simple for the time being, we will only consider allowance market price risk.

In the following example, numerous assumptions will be made. It is recommended that the reader not dwell on the exact assumptions made for this example or the precise outcome, but rather on the methodology and the risk management methods that are illustrated. One reason is because this example is simplified to help make a point. But, more importantly, in a real modeling exercise it is important to test many different assumptions to try to identify circumstances where catastrophic events might occur so that the risk of such events can be managed. Possibly the greatest benefit of these modeling exercises is not the answer produced by the simulation, but the thought process management is forced to go through when testing various cases and assumptions.

In the following example, we will consider a 500 MW coal-fired plant that fires a low-sulfur eastern bituminous coal. Its existing controls include an ESP and Low NOx burners. The unit will be subject to annual emission limitations of 2000 tons for NOx, 1500 tons of SO_2, and 50 lbs of mercury, as listed in Table 2. It is assumed that all of these pollutants may be traded. Probability distributions are assumed for the allowance prices as shown in Table 2. The probability distributions for the allowance prices are not projections and were not chosen for any particular reason. It is also important to note that for the simulation shown here it was assumed that each pollutant price distribution is assumed to be independent. Therefore, it is assumed that no correlation exists between the prices of various allowances. We will discuss the implications of that assumption later. Five cases are modeled, each with a different control strategy.

- Case 1 is no additional controls and purchase of allowances at market prices
- Case 2 is addition of PAC injection and a downstream PJFF for mercury control and purchase of NOx and SO_2 allowances at market prices (77% mercury removal to exactly meet the 50 lb/yr limit).
- Case 3 is addition of an ECO system for NOx, SO_2 and mercury control (90% NOx removal, 98% SO_2 removal and 85% Hg removal). In this case allowances can be sold at market prices for all pollutants.
- Case 4 is addition of an SCR (90% NOx removal) and Advanced Dry FGD with Fabric Filter (95% SO_2 control) after the ESP. In this case allowances can be sold at market prices for all pollutants.
- Case 5 is addition of an SCR (90% NOx removal) and a Spray Dryer Absorber and Fabric Filter (95% SO_2 removal) downstream of the ESP. In this case allowances can be sold at market prices for all pollutants.

It is acknowledged that other technologies and combinations of technologies may be provide attractive alternatives. In a real situation, you would want to model several other technologies as well.

Using the Compliance at Risk^{SM} method with a Monte-Carlo simulation, we estimate the cost of compliance using a specific strategy along with probability for that cost. Modeling the total control cost and probability for each of these cases results in Figure 5. Figure 5 is shows the cumulative probability of each outcome. The median outcome for any case is at the 50% cumulative probability point (50% of the outcomes are below that value and 50% are above). For example, the median for Case 4 is about 4.25 mills/KWhr. The 90% confidence interval would be the range of outcomes between a cumulative probability of 5% and a cumulative probability of

95%, and so on. The most certain, or least risky, cases would have the narrowest confidence intervals, as shown by steep lines on Figure 5. Wider confidence intervals are the most uncertain, and therefore are the most risky.

As shown in Figure 5, Case 1 is potentially the lowest cost strategy, but it also has a significant risk of being a very high cost strategy. The cost of Case 1 covers a wide range (95% confidence interval between about 2.2 and 6.8 mills/KWhr) and, therefore, is highly uncertain with significant risk that the cost could be quite high. The wide range of costs for Case 1 is a result of the need to rely on the emissions allowance market for compliance – and the uncertainty in allowance prices. Case 2 is even higher in cost with similar uncertainty. Case 4 appears (in this simulation with these assumptions) to be the lowest cost across the widest range of probabilities. So, this Case is worth exploring further under other scenarios. At this point, it would be useful to perform additional simulations, testing other allowance price distributions, other technology combinations, etc., to see their effect.

Another simulation was run to see the effect of using options to manage the market risk associated with the allowance market. The five cases for this second simulation are as follows:

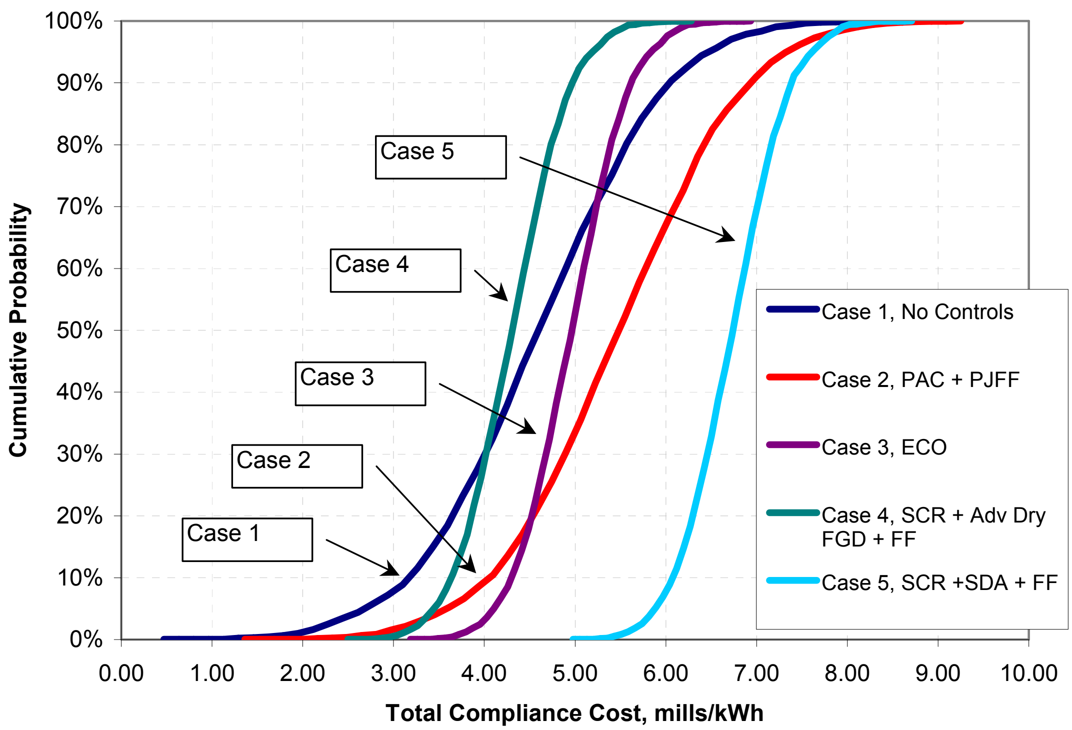
- Case 1 is no additional controls and purchase of allowances at market prices (the same as in the previous simulation)
- There is no Case 2
- Case 3 is the same as Case 1 plus purchase of call options to address risk of high allowance market prices
- Case 4 is addition of an SCR (90% NOx removal) and Advanced Dry FGD with Fabric Filter (95% SO_2 control) after the ESP (the same as Case 4 in the previous simulation)
- Case 5 is the same as Case 1 plus purchase of Call options to address risk of high market prices and selling of lower priced put options to help pay for the call options.

For this analysis, we made assumptions about the premium of put and call options. We also assumed that we could buy options in lots exactly equal to the amount we needed for the hedge. In reality, “odd” lots may not be available or may incur a higher premium than normal lots. The actual effect, though, would not materially impact our analysis.

TABLE 2. EMISSIONS PARAMETERS FOR 500 MW EXAMPLE PLANT

	NOx	**SO_2**	**PM**	**Hg**
Current Emissions	0.35 lb/MMBtu (LNBs)	0.85 lb/MMBtu (low S coal)	0.03 lbs/MMBtu (ESP)	0.10 mg/kg in coal
Annual Limit	2000 tons	1500 tons	Na	50 lbs
Expected Allowance Distribution	Normal	Normal	Na	Triangle
Mean or peak	$3000/ton	$200/ton	Na	$25,000/lb (peak)
Std Dev or Max/Min	$1000/ton	$25/ton	Na	$35,000/lb max $2,000/lb min
	NOx Control	**SO2 Control**	**PM**	**Hg Control**
Case 1 (Fig 11)	LNBs	none	ESP	
Case 2 (Fig 11)	LNB’s	none	ESP	PAC + PJFF
Case 3 (Fig 11)	LNBs + ECO	ECO	ESP	ECO
Case 4 (Fig 11)	LNBs + SCR	Adv. Dry FGD (CFB)	ESP + FF added after dry scubber	Cobenefit from other controls
Case 5 (Fig 11)	LNBs + SCR	SDA	FF added after SDA	Cobenefit from other controls

Figure 5. Multipollutant Simulation



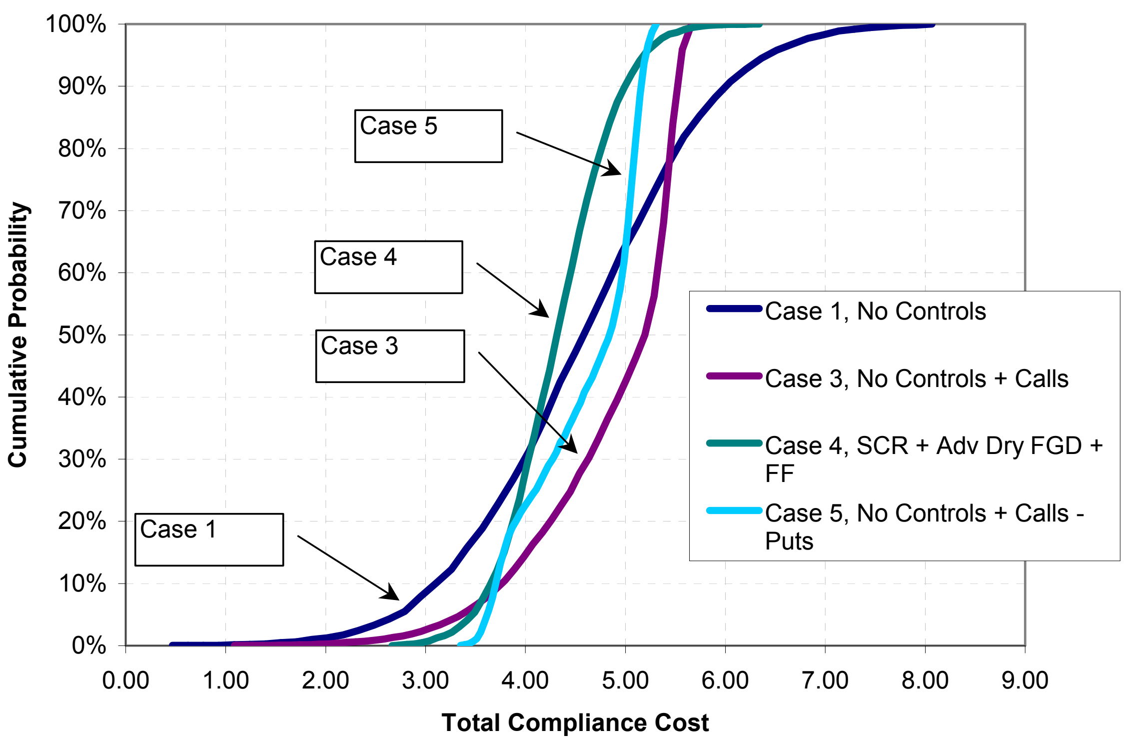
As shown in Figure 6, Case 1 continues to be the case with the most uncertain cost outcome. Case 3 is shifted to the right (higher cost) of Case 1, except at the upper end (higher cost end) of the Case 3 curve. The shift is due to the increased cost of the option premium that must be paid for purchasing call options. The bend of the upper part of the Case 3 curve to make it more vertical is the effect of the call options in reducing the risk of high allowance market prices. This has the effect of producing a 95% confidence level of cost being between about 3.0 and 5.6 mills/KWhr as compared to between 2.2 and 6.8 mills/KWhr for Case 1.

Case 5 is shifted to the left (lower cost) of Case 3, except at the lower end (low cost end) of the Case 5 curve. The shifting to the left is the effect of option premiums received for selling put options. The bend of the lower part of the Case 5 curve to make it more vertical is the effect of the put options in reducing the uncertainty of low market prices. As shown, Case 5 limits compliance cost to a range of about 3.6 mills/KWhr to about 5.2 mills/KWhr with a 95% confidence level with an "average" cost of about 4.6 mills/KWhr. Case 4 maintains total compliance cost within a range of about 3.3 to 5.3 mills/KWhr with a 95% confidence interval and an average cost of 4.3 mills/KWhr. The maximum cost estimated for Case 5 is 5.30 mills/KWh versus 6.34 mills/KWhr for Case 4. Therefore, it may be possible to achieve environmental compliance with lower capital commitment than required for Case 4 and with lower risk through a combination of lower cost technologies and market derivatives. At a time when electric utilities are under financial stress, this is an important result.

Normally, it would be desirable to test a range of other parameters as well. For one, the expected probability distribution for allowance prices may change from one year to the next. So, to evaluate a decision over a specific period would require either estimating an expected "average" price distribution over that period and testing different assumed distributions. Or, another solution is to estimate price distributions for each year or for groups of future years and let the computer do the number crunching to estimate probability distributions of future cash flows. Additionally, we've only focused on uncertainty in allowance prices. Fuel prices, capacity factors and other effects will be uncertain to some degree as well. Addressing the uncertainty in all of these parameters adds complications. But, these complications can all be incorporated into the Monte Carlo simulation as needed.

As noted earlier, in these analyses we assumed that allowance prices for NOx, SO_2 and mercury were completely independent of one another. There may be reason to believe that at times they could exhibit some positive correlation. At times of positive correlation, the actual risks would be higher than predicted by a simulation that treated the prices independently. Therefore, independent treatment of the allowance prices may underpredict the risks somewhat, and testing of situations where prices are correlated would be valuable.

Figure 6. Multipollutant Simulation with Options



SUMMARY

Coal generation is a critical part of the US power generation asset base. However, it is subject to significant environmental compliance risk that must be carefully assessed. The risks result from uncertainties that can underlie many of the key assumptions necessary to perform analysis. In this paper a methodology for addressing some of the uncertainties was presented. The approach can be used to lead management to the approach that provides the highest probability of being the lowest cost. It can also be used to test risk management strategies. While the discussion in this paper focused on the risk associated with price volatility in the emission allowance market, the approach is very flexible and can be used to address other uncertainties as well.

The Compliance at Risk[SM] approach performs comprehensive analysis of control technologies and emission allowance markets, with uncertainties in these addressed through Monte Carlo simulation. The Compliance at Risk[SM] approach addresses the complexities associated with estimating the cost of controlling multiple pollutants with technologies that may offer cobenefits, where pollutant allowances may be traded and where risk may be managed through market derivative instruments. Control of the pollutants NOx, SO_2 and mercury are all addressed with comprehensive Technology Performance and

Cost Modules. An Emissions Market Module enables incorporation of market risk and the use of market derivative instruments for managing the market risk of each of these pollutants. The paper showed examples of how the Compliance at Risk^{SM} approach performs a comprehensive estimate of total multipollutant compliance cost, developing probability distributions for each case analyzed. The paper also showed how the Compliance at Risk^{SM} approach provides management insight to possible risk-control management strategies that may be used. Because the Compliance at Risk^{SM} approach facilitates interactive computer analysis, he approach lends itself well to active scenario review to facilitate flexibility in decision making.

Possibly the most important finding of the analysis performed in this paper is that the approach shown here may uncover compliance strategies that offer low cost and low risk through combination of low-cost technology and market instruments.

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