FINAL TECHNICAL REPORT

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Project Title: "A Marketing Survey and Assessment of the Potential for Desulfurized Illinois Coal"

ICCI Project Number: 86-87/3.1B-3
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ABSTRACT

The overall objective of the reported research has been to measure the market for desulfurized coal. How much of a price premium will consumers pay for reduced-sulfur coal?

Focusing on char and ultrafine products, we have been concerned with ~~preferences regarding sulfur and volatile matter. To address the value~~ of sulfur, we statistically analyzed actual utility coal transactions. Preliminary results indicate a sulfur premium for Illinois consumers in the range $17-24 per ton for a reduction of sulfur of 1 lb./MMBtu.

To measure preferences regarding low volatile product, we conducted a survey of over seventy power plants in the Illinois market area. The results of this analysis suggest that the penalty for low volatility is on the order of $3-4/ton for each 5 percentage point reduction in volatile matter.

All results are preliminary and await further analysis. However, some R & D conclusions are forthcoming. Volatile matter is very important to existing consumers. Furthermore, a significant premium will be paid for lower sulfur coal.

EXECUTIVE SUMMARY

Air pollution regulations of the past two decades have had a big impact on coal markets. Most coal is used for industrial and electric utility combustion, and coal combustion accounts for major shares of the particulates, sulfur and nitrogen oxides, and certain other pollutants released into the atmosphere. Pollution regulations have induced many industries and utilities to use cleaner coals or shift to other fuels.

Illinois contains more coal reserves than any other state. Illinois coal can be shipped cheaply to midwestern industries and utilities and its combustion qualities generally are good. But, most of the coal in Illinois contains too much sulfur to be burned alone under federal air pollution standards. Utilities and industries have turned increasingly to lower sulfur alternatives, from the East or West, to fuel their furnaces. The market for coal from Illinois has stagnated while the overall market for coal has grown. Renewal of Illinois' coal industry depends on overcoming the sulfur problem.

Many scientists are studying and testing methods for removing sulfur from coal. Generally, these go beyond conventional physical "cleaning" processes, which are already used at many mines. More sophisticated methods are likely to be more costly, and it is not clear that the resulting products will fetch prices sufficient to cover the additional processing costs as well as the regular mining and transportation costs. To guide research in this area, fundamental information is needed about the market value of reducing the sulfur content of Illinois coal. That is the focus of the research reported here.

The research reported herein attempts to estimate the market value of treatments that can reduce the sulfur content of coal. The research begins with an examination of the forces shaping the market for Illinois coal and technologies for reducing sulfur levels. It is clear, from this review, that there are definite bounds on the value of reducing sulfur levels; bounds resulting from the availability of naturally low sulfur coals, the capacity to mix coals, and from the regulatory environment. Moreover, sulfur contributes in positive ways to some aspects of boiler operation, so many users do not want sulfur to be far below permissable levels. These considerations, as well as experience with the operating characteristics of particular boilers, are the basis of fuel purchasing decisions made by electric utilities.

Two issues are confronted in attempting to measure the potential value of desulfurized coal. One concerns abstracting from the myriad of different characteristics of desulfurized cost, the few key characteristics which are most important to potential consumers. The other issue concerns valuing those key characteristics.

From the technology review and discussions with knowledgeable scientists, it was clear that desulfurization would change many attributes of coal: its size distribution, moisture, ash content, volatility, heat content, and others. It was impossible to focus on all of these. After extensive discussion with the CRSC, it was decided to focus on sulfur content and volatility. These were determined to be particularly critical parameters and were selected for investigation. Because electric utilities consume most coal, and constitute the largest potential market for Illinois coal, we concentrate on the demand of the utility industry.

Having identified sulfur and volatility as the two characteristics of desulfurized coal on which to focus, the next issue is how utilities view and value these characteristics. Measuring the value of reduced sulfur is facilitated by observing actual coal transaction and measuring the actual premia utilities attach to low sulfur.

The U.S. Department of Energy (DOE)) collects data on all coal purchases by domestic electric utilities, including prices paid and the heat, sulfur, and ash content of the coal. These data were used in this study to estimate the worth of changes in sulfur levels using a technique known as hedonic analysis. Our preliminary results are that this worth varies with the original sulfur level of the coal which is desulfurized; a 1 pound sulfur per million Btu (lb./MMBtu) reduction is worth more for 2 lb./MMBtu parent coal than for 3 lb./MMBtu parent coal. We have found the marginal value of sulfur reduction ranges from about \$0.70/MMBtu/lb.-/MMBtu to slightly more than \$1.00/MMBtu/lb./MMBtu. This is the unit "discount" or penalty applied to coal containing sulfur. The total discount per ton of coal is the product of the unit penalty and the sulfur content. Thus the total penalty would be reduced by reducing the level of sulfur.

Notably absent from the DOE data is information on volatility, nor is transaction information with respect to this parameter available elsewhere. In order to investigate the value of volatility, we had to generate new data. This was done through a survey of all electric utilities that purchased Illinois coal in 1985. A thorough investigation of survey methodology provided background for our construction of a survey which we then used in a survey of over seventy power plants in the Illinois market area (a response rate of about 80% was achieved). Reduced-sulfur coals were specified in the survey as containing from 15.1% to 35.3% volatile matter. This range extends well below levels to which most utilities are accustomed. Preliminary results indicate that volatility is highly valued; an increase from 25.0% volatile matter (by weight) to 27.5% volatile matter was valued by the respondents at about 8¢/MMBtu.

The reported results of both sets of analyses (the hedonic and the survey) should be regarded as preliminary. Additional efforts are underway to improve each. In the case of the actual market data, improvements are expected from expanding the data set to include non-Illinois transactions. Doing so awaits better procedures for dealing with spatial relationships of coal suppliers and users. The survey results will be better understood after the qualitative responses (to survey question 9) are analyzed. As indicated above, further efforts are needed to rationalize the different results for the sulfur variable in the two analyses.

This study reenforces the need for close attention to economic considerations as research into sulfur reducing technologies is planned and implemented. At least for the steam electric utility market, attaining rock bottom levels of sulfur is not desirable. Most of the price advantages appear to accrue as compliance levels are approached. Dropping below compliance levels earns little return; in fact, it can be a disadvantage due to losses of operating efficiencies in emission control equipment. Furthermore, changes in attributes other than sulfur (such as volatility) can be critically important. If the product cannot be handled easily or burned efficiently, it may be viewed as an inferior fuel irrespective of its sulfur level.

I. OBJECTIVES

Air pollution regulations of the past two decades have had a big impact on coal markets. Most coal is used for industrial and electric utility combustion, and coal combustion accounts for major shares of the particulates, sulfur and nitrogen oxides, and certain other pollutants released into the atmosphere. Pollution regulations have induced many industries and utilities to use cleaner coals or shift to other fuels.

Illinois contains more coal reserves than any other state. Illinois coal can be shipped cheaply to midwestern industries and utilities and its combustion qualities generally are good. But, most of the coal in Illinois contains too much sulfur to be burned alone under federal air pollution standards. Utilities and industries have turned increasingly to lower sulfur alternatives, from the East or West, to fuel their furnaces. The market for coal from Illinois has stagnated while the overall market for coal has grown. Renewal of Illinois' coal industry depends on overcoming the sulfur problem.

Many scientists are studying and testing methods for removing sulfur from coal. Generally, these go beyond conventional physical "cleaning" processes, which are already used at many mines. More sophisticated methods are likely to be more costly, and it is not clear that the resulting products will fetch prices sufficient to cover the additional processing costs as well as the regular mining and transportation costs. To guide research in this area, fundamental information is needed about the market value of reducing the sulfur content of Illinois coal. That is the focus of the research reported here.

The research reported herein attempts to estimate the market value of treatments that can reduce the sulfur content of coal. The research begins with an examination of the forces shaping the market for Illinois coal and technologies for reducing sulfur levels. It is clear, from this review, that there are definite bounds on the value of reducing sulfur levels; bounds resulting from the availability of naturally low sulfur coals, the capacity to mix coals, and from the regulatory environment. Moreover, sulfur contributes in positive ways to some aspects of boiler operation, so many users do not want sulfur to be far below permissable levels. These considerations, as well as experience with the operating characteristics of particular boilers, are the basis of fuel purchasing decisions made by electric utilities.

II. BACKGROUND

A. TRENDS AND MARKET FORCES IN THE US COAL INDUSTRY

The public perception of the coal industry, prior to the sharp increase in oil prices, was that the industry was in decline. That perception was revised considerably following the 1973 oil price increase. A close examination of the industry over the past few decades shows that these perceptions were off the mark. Coal production has grown steadily since about 1960 despite oil being at its all-time cheapest in the 60's. And is true that after the OPEC oil price action of 1973, coal production boomed, although output growth has slowed in the 1980's. However, hidden beneath the overall growth is a major shift in the regional structure of coal markets, a shift due large to the Clean

Air Act of 1970 and its 1977 amendments. High-sulfur coal markets have stagnated or declined as a result of tightened environmental regulations. Low-sulfur markets have grown rapidly, as a result of increased overall demand for coal and particularly as a result of demand shifting away from high-sulfur producers.

Clearly sulfur emission laws were responsible for the decline in high-sulfur coal markets. But why has the overall coal market been booming since the early 1960's, not just since the oil price rises? The answer can be seen by examining the patterns of consumption. In fact, the coal industry has undergone a dramatic change in the last thirty to forty years. Residential, commercial and transportation use has dropped dramatically in the post-war era. Industrial and coke use have remained relatively stable throughout the 1950's and 1960's, but has declined significantly in the 1970's and 1980's. In contrast, use of coal for electricity generation has grown steadily at a rate of nearly 6% per year in the 1949-85 period. Non-electric power uses have essentially vanished while electric power use has grown dramatically from 17% of the coal market in 1949 to 85% in 1985. Thus the downturn in the 1950's followed by an upturn in the 1960's and 1970's was the result of a rapid decline in other uses, eventually overcome by steady growth in electric power.

B. COAL QUALITY, POWER GENERATION AND COAL PROCUREMENT PRACTICE

Coal quality is an important factor in coal procurement decisions. The modest decision rule of minimizing delivered cents per million Btu has given way to analysis of coal quality characteristics in engineering models of operating systems to assess a prospective coal's impact on the heat rate, capacity, availability, maintenance and emissions of a coal-fired electric generating station. Procurement practices typically specify the levels of a number of key coal quality characteristics with known correlations to the operating performance of the plant. Adjustments for deviations from design characteristics are made by coal blending, capacity derating and equipment retrofit.

This section serves two purposes. First, we review the impact of coal quality on coal procurement practice in general. Second we report on a survey of coal procurement requirements, conducted for this project, at a number of coal fired power plants in the east and midwest. As part of our survey, we requested information on the coal procurement specifications of our respondent generating stations. Most stations issue specifications for a long list of coal quality characteristics.

Changes in the technological, regulatory and economic environment of coal-fired power generation during the last quarter century have transformed the focus of coal procurement from delivered price to explicit consideration of the total busbar cost of electricity generation. The total busbar cost is determined by the coal quality and the delivered price given the embedded plant technology. For example, a lower quality coal may have a cheaper delivered price per million Btu but may degrade plant performance to the point that the busbar cost increases over a higher delivered price alternative. Fuel procurement procedures at most utilities now require analysis of coal quality characteristics and their impact on the total busbar cost of power generation. Utilities no longer purchase fuel solely on the basis of least delivered price.

III. EXPERIMENTAL PROCEDURES

Two issues are confronted in attempting to measure the potential value of desulfurized coal. One concerns abstracting from the myriad of different characteristics of desulfurized cost, the few key characteristics which are most important to potential consumers. The other issue concerns valuing those key characteristics.

From the technology review and discussions with knowledgeable scientists, it was clear that desulfurization would change many attributes of coal: its size distribution, moisture, ash content, volatility, heat content, and others. It was impossible to focus on all of these. After extensive discussion with the CRSC, it was decided to focus on sulfur content and volatility. These were determined to be particularly critical parameters and were selected for investigation. Because electric utilities consume most coal, and constitute the largest potential market for Illinois coal, we concentrate on the demand of the utility industry.

Having identified sulfur and volatility as the two characteristics of desulfurized coal on which to focus, the next issue is how utilities view and value these characteristics. Measuring the value of reduced sulfur is facilitated by observing actual coal transaction and measuring the actual premia utilities attach to low sulfur.

The U.S. Department of Energy (DOE)) collects data on all coal purchases by domestic electric utilities, including prices paid and the heat, sulfur, and ash content of the coal. These data were used in this study to estimate the worth of changes in sulfur levels using a technique known as hedonic analysis. Our preliminary results are that this worth varies with the original sulfur level of the coal which is desulfurized; a 1 pound sulfur per million Btu (lb./MMBtu) reduction is worth more for 2 lb./MMBtu parent coal than for 3 lb./MMBtu parent coal. We have found the marginal value of sulfur reduction ranges from about $0.70/MMBtu/lb.-/MMBtu to slightly more than $1.00/MMBtu/lb./MMBtu. This is the unit "discount" or penalty applied to coal containing sulfur. The total discount per ton of coal is the product of the unit penalty and the sulfur content. Thus the total penalty would be reduced by reducing the level of sulfur.

Notably absent from the DOE data is information on volatility, nor is transaction information with respect to this parameter available elsewhere. In order to investigate the value of volatility, we had to generate new data. This was done through a survey of all electric utilities that purchased Illinois coal in 1985. A thorough investigation of survey methodology provided background for our construction of a survey which we then used in a survey of over seventy power plants in the Illinois market area (a response rate of about 80% was achieved). Reduced-sulfur coals were specified in the survey as containing from 15.1% to 35.3% volatile matter. This range extends well below levels to which most utilities are accustomed. Preliminary results indicate that volatility is highly valued; an increase from 25.0% volatile matter (by weight) to 27.5% volatile matter was valued by the respondents at about 8¢/MMBtu.

The survey was also designed to permit analysis of the value of sulfur content, for comparison with results of the hedonic analysis. The sulfur specifications ranged from 0.45 lb./MMBtu to 1.78 lb./MMBtu, all near or below allowable standards. Preliminary analysis of the results failed to reveal a significant value for changes in sulfur in this range. Further interpretation of this result, in light of the hedonic analysis, is needed.[1]

IV. RESULTS

As was discussed earlier, there are three primary outputs from our analysis. One concerns utility fuel buying specification; another concerns measuring the value of reduce-sulfur coal from market data; the third involves measuring the penalty associated with low volatility desulfurized coal. Each of these issues is discussed in turn below.

A. BUYING SPECIFICATIONS

As discussed in more detail below, a detailed questionnaire was sent to a sample of coal-fired electric generating stations in the east and midwest. Page 2 of the survey was designed to gather information on the procurement specifications applied by the coal-fired generating stations in the sample. In order to evaluate the probability of successfully marketing a reduced sulfur coal product, we must know the specifications used by the utilities as part of their procurement decision. In our survey, minimum BTU, volatility and grindability levels and maximum sulfur, moisture, raw ash content and size dispersion levels are

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[1]More detail on the results of our work may be found in Charles D. Kolstad, John B. Braden, Jose A. Machado and Rodger A. Woock, "A Marketing Survey and Assessment of Desulfurized Illinois Coal," University of Illinois Institute for Environmental Studies Report, Urbana, Illinois (August 1987).

specified by at least three-quarters (3/4) of our respondents. Over one-half (1/2) additionally specified a minimum ash fusion temperature. These were principally dry-bottom plants. The smaller group of wet-bottom plants specified maximum ash fusion temperatures. More than a third (1/3) of the respondents reported specifications on ash chemistry. The range of specifications indicated the sample utilities purchased coal from the Powder River Basin, from the midwest region including the Illinois Basin, and from the Appalachian Region. This indicates that Illinois Basin coal competes with the other major coal producing regions. The vast majority of volatility specifications are concentrated in the 30%-39% range. Only a handful of generating stations operate with coals with less than 30% volatility.

Clearly in our sample, coal quality characteristics are closely watched. In fact only one utility reported basing procurement decisions on delivered price alone. Coal quality specifications beyond BTU, ash and moisture have become the industry norm in procurement practice. The operators of coal-fired steam generating stations are concerned about how well a particular coal will perform in their furnace and how the fuel's performance will affect operating capacity of the station. To measure the expected performance, utilities rely on engineering correlations between coal quality characteristics and performance parameters for their particular generating station. Using the engineering models with the measured coal quality characteristics allows the utility to estimate the effect on heat rate, capacity, availability and maintenance of a procurement decision. When a coal product is sufficiently unknown, but appears to be satisfactory from the model, a test burn is usually required to confirm the engineering model's results. Thus procurement decisions are no longer made on the basis of delivered price per million BTU by most utilities. Coal quality characteristics have a fundamental impact on procurement decisions.

B. MEASURING THE SULFUR PENALTY FROM MARKET DATA

As was discussed earlier, since the passage of the 1970 Clean Air Act there has been a considerable shift in demand away from high-sulfur coal toward low-sulfur coal. Coal consumers have frequently been willing to pay a premium for low-sulfur coal over high-sulfur coal. The premium is bounded, of course, since the undesirability of sulfur varies from consumer to consumer, due to differences in applicable environmental regulations and because of technologies are available for reducing the sulfur content of coal or reducing emissions from the combustion of coal. Estimating the magnitude of the sulfur premium is the main purpose of this study. This premium can be interpreted as the increased price desulfurized coal could bring in the marketplace. In this study we take several approaches to measuring this premium.

In this portion of the research we have attempted to infer the sulfur premium based on observed purchases of coal by utilities. By examining individual fuel purchases and statistically comparing low-sulfur and high-sulfur purchases, accounting for everything but sulfur content, we can infer the sulfur premium.

More specifically, using a hedonic price technique, a price function is statistically estimated for coal as a function of coal quality (sulfur, ash and thermal content) and location in Illinois. The marginal valuation placed on sulfur is inferred from the results. The statistical analysis is based on transactions-level data on Illinois utility purchases of coal in 1985. Thus we focus on all purchases within Illinois, including purchases of Illinois coal and coal from other states.

1. The Sample

The Federal Energy Regulatory Commission (FERC) collects monthly data (on FERC form 423) from utilities on coal purchases by each generating station. Each purchase is detailed, giving quantity purchased, certain quality characteristics (sulfur, ash, thermal content), delivered price and the identity of the power plant receiving the fuel. Latitude and longitude data for each of these consumers was extracted from Energy Information Administration form 767 and merged with the form 423 data. Based on these data, we have developed a data base of all coal purchases by utilities in the United States from 1970--1986. From this data set, we extracted information on 1985 purchases in Illinois. The resulting data set contains 644 observations, consisting of prices paid, the indicated coal characteristics, and the location of the purchaser.

It is clear from the data that at low ash and sulfur levels (for example, zero values), the price of coal tends to be slightly higher the further north in the state one goes, a reasonable result because most mines are in central and southern Illinois. In addition, coal prices from the price function are lower in eastern Illinois. It can also be seen from the results that the price of sulfur is negative, as it should be, and decreases in absolute value as sulfur content increases.

The response of coal price to sulfur level can be seen more clearly in Figure 5-2. In the figure, the price of coal is plotted, as a function of sulfur level, for the mean ash value (8.8 pounds per million Btu) for coal purchased in central Illinois (latitude, 40°, longitude, 88°).

The slope of a line at a particular point represents the price of sulfur, the permit "bribe" referred to earlier, necessary to induce consumers to take the sulfur along with the thermal value. For instance, central Illinois coal with no sulfur would sell for $3.90 per million Btu (MMBtu). Coal with 1 lb. of sulfur per million Btu would sell for $2.73 per NNBtu with a sulfur penalty of $1.04 per MMBtu. This implies that the price of the thermal content of the 1 lb. sulfur coal is $3.77/MMBtu. When the consumer buys the 1 lb. sulfur coal, he pays $3.77 but gets a discount of $1.04 for the sulfur he takes as well. Coal with 2 lbs. sulfur per million Btu goes for $1.82 per million Btu, with a sulfur price of -$0.78MMBut/lbs/MMBtu per pound of sulfur per million Btu, resulting in a fuel price of $3.38 per million Btu. Ash has been neglected in this discussion (but not in the figure or estimated equation), so these numbers are not quite accurate.[2]

In terms of the sulfur penalty, the price of sulfur can be interpreted as the marginal payoff to the producer from reducing sulfur; alternately, it can be interpreted as the incentive to the consumer to take higher sulfur. Thus a sulfur price of -$0.78/MMBtu/lb.S/MMBtu implies that for a reduction in the sulfur content by 1 pound per million Btu., the price can be raised by 78¢, and still be competitive. For a 12,000 Btu per pound coal, this translates to roughly $19 per ton. As is

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[2]Another inaccuracy is that the unit sulfur penalty changes with sulfur level so that total sulfur penalty can only accurately be obtained by integration.

shown in the figure, the higher the sulfur level, the lower is the sulfur price in absolute terms. This is a result of the convexity assumption.

These results reflect the power of using hedonic techniques to measure the sulfur premium in coal. The results are qualitatively in agreement with intuition about how the coal market operates in Illinois. However, this approach has only been explored in a rudimentary way here. Unresolved questions concern the treatment of coal contracts, the proper treatment of space, including the possibility of arbitrage between locations, and the spatial autocorrelation of errors. These issues are being explored in current research.

The implications of this work for desulfurization R & D are significant. The preliminary results show that a premium of as much as \$1.30/MMBtu per pound of sulfur per million Btu may be supported by the market. Further research is needed to refine these results as well as to develop results for other coal characteristics.

C. THE VALUE OF VOLATILITY BASED ON SURVEY INFORMATION

There are two major ways by which that information can be elicited. One, explored above, is based on actual market transactions. Here we will develop an alternative approach based on directly asking utilities how much are they willing to buy, at a given price, of a fuel with a given set of attributes. By varying attributes and prices over the sample, we generate a data set directly relating fuel quality, its price, and utilities' purchases. These data are then used to estimate the functional relationship among those variables.

The major difference between the two approaches is thus the data set on which they are based: actual price/quantity observations in the hedonic price framework (Chapter V); and hypothetical price/quantity/attributes observations in the direct survey approach (this chapter). The relative strengths and weaknesses of the two methods stem from that difference. On the one hand, because it is based on actual rather than intended actions, the hedonic price model may provide more accurate information. On the other hand the range of attributes and hence fuels that can be investigated with hedonic methods is narrower. Indeed, as it is based on actual data, an hedonic study is limited to the fuel characteristics for which such data exists and its predictions are valid for that range of fuels. With a survey instrument, on the contrary, one can create and therefore investigate entirely new fuels.

From our review of the survey literature, particularly the contingent valuation literature, we come to two conclusions regarding our survey instruments:

- Utilities should be asked for "quantity bids" rather than for "price bids";
- The offered clean fuels should be characterized as thoroughly as possible, in a way which is familiar to respondents.

The specification of the fuels being offered accounts for pages 5 and 6 of the survey. This specification obeyed two major concerns: a) if the study was to provide useful information about how utilities value coal's sulfur content and volatility, a "significant" number of fuels with different contributions of these attributes had to be offered; b) at the very least, any useful specification had to include the proximate and ultimate analysis of the fuels. As it was clearly unfeasible to get a sufficient number of "real" clean fuels, the strategy adopted was to take as references the laboratory analyses of two such fuels (one char and one froth-flotation product) and then to generate the remaining by perturbing some of the parameters in those analyses, staying within the range of quality levels indicated by the laboratory analyses as well as expert advice received from Illinois Geological Survey personnel. Specifically, three sulfur content levels (0.45%, 0.95% and 1.78%), three volatility levels (15.12%, 25.14% and 35.26%), and two ash fusion temperatures were considered.

The formulation of a "payment card" type of question to elicit the "quantity bid" (p. 7 of the survey) faced two major problems: the determination of a "reasonable" price for the fuel being offered -- i.e., a price at which the question "how much are you willing to buy" could be asked--and the set-up of a relevant quantities choice set -- i.e., what would be the appropriate scale of an array of quantity responses. The solution found for the latter problem was to ask utilities to choose the percentage of their 1986 coal usage that they would be willing to replace with the offered product.

The purpose of an econometric analysis of the survey answers is to determine if and how the proportion of the current burn utilities are willing to buy (Q) is related to the survey design variables (X), namely to the attributes and price of the fuels being offered.

A casual inspection of the "quantity answers" (questions 7 and 8) reveals that part of them (about 50%) are zero, i.e., about half of the plants in the sample were not willing to buy the fuel they were offered at any (nonnegative) price.

The set of potential explanatory variables (X) includes the "Reference Coal" characteristics (Reference Ash (RA) and Reference Sulfur (RS)), the treatment variables (Sulfur (S), Volatility (V) and Ash (A) content of the offered fuel), price variables (average price of current burn (RP) and offer price of the alternate fuel (P)) and technological variables such as the existence of cold side electrostatic precipitators (ESP = 1 if the plant has these precipitators, 0 otherwise) and a variable reflecting whether the plant is dry or wet bottom (T = 1 if "dry", 0 otherwise).

Pretesting has indicated poor explanatory performance of the reference attributes (RA, RS) and of the dummy ESP. The way the survey was designed precludes the simultaneous use of the Ash treatment (A) and of the dummy variable T (e.g., see the raw data table). The potential regressors are therefore, P, RP, S, V and T.

Having chosen the covariates, one must specify a functional form; i.e., determine the form those variables enter the regression equation (the demand function for the clean fuels). Ideally this function should be specified in such a way that there exists a (well behaved) technology from which that demand function could be derived. In our case following rigorously this requirement proved to be difficult because utilities' demand for coal is a demand for a given set of attributes whose price is not observed. We have thus followed a looser approach to the specification of the demand equation. This was set to meet a number of requirements which were felt to be desirable, namely: (i) the main characteristics of the fuels being offered, sulfur and volatility content, should be present not only because they are the object of the study but also to reflect the heterogeneity of fuels; (ii) the reference price (RP) and the offer price (P) should enter has a ratio (RP/P) to capture the idea that only relative prices matter, that is, demand should not change if, ceteris paribus, RP and P change in the same proportion; (iii) the variables should enter in a nonlinear form so that their impact on purchases depends on the level of those variables; (iv) engineering considerations suggest that the behavior of wet and dry bottom plants differ, so the influence of the dummy variable T should be measured.

These results clearly indicate that, for a given quantity bought, utilities are willing to pay more for higher volatile content. A rough estimate is that if the volatility were 1% higher than the average (27.5% instead of 25.01%) utilities would be willing to pay about 141¢/MMBtu instead of 132.7¢ (keeping the expected purchase and reference price constant at their average levels, 6.56% and 163.47c/MMBtu respectively).

The results in this section indicate that the sulfur content did not influence the quantity answers in a statistically significant way. The data appears to indicate that the dropping out of sulfur effect is not due to different and offsetting tastes for sulfur of wet and dry bottom plants. Indeed, as we have seen, the inclusion of T and $S^{-1/2} \cdot T$ is rejected. Furthermore, in initial testing, models which include $S^{-1/2} \cdot T$ instead of $S^{-1/2}$ or both $S^{-1/2} \cdot T$ and $S^{-1/2}$ were clearly rejected in favor of the specification adopted in this section.

The econometric analysis of the survey data seems to indicate four main conclusions:

- Wet and dry bottom plants stated buying intentions that were not significantly different.
- The intended purchases are sensitive to the prices of the reduced-sulfur fuels.
- Utilities have a taste for higher volatility.
- Utilities did not reveal a taste for low sulfur, in the sense that their buying intentions were not significantly affected by the sulfur content of the offered clean fuels.

This last conclusion should be regarded with some suspicion not only because it seems to be counterintuitive but also because it contradicts hedonic studies which show that utilities' <u>actual</u> purchases reflected a willingness to pay a premium for low sulfur coal. One possible explanation stems from the difference between <u>actual</u> and <u>intended actions</u>, the latter being those evaluated in a survey. These differences may have at least two origins. As utilities do not bear any cost for their stated buying intentions, the incentives for accuracy are thereby reduced. On the other hand in a survey set up it is very difficult to control the expectations and perceptions of the respondents. Thus, although the analyst thinks that respondents are reacting only to the design variables, their answers may in fact be conditioned by a multitude of factors external or internal to the survey, for which no control was exercised (i.e., factors to which does not correspond any design variable). For instance, in the hypothetical setting of the survey, the regulatory constraints on emissions may not be perceived to be as decisive as they are in the "real world." Also, it may be the case that the information provided about the offered fuel was insufficient for a knowledgeable decision to be made.

A different set of possible explanations emphasizes more "objective" causes. First, there are technical problems associated with the burning of low sulfur coal in facilities with electrostatic precipitators, which account for 73% of the plants in the sample. Second, it is conceivable that utilities do not have an "intrinsic" taste for low sulfur coal, i.e., in a unregulated environment they would not be willing to pay a premium for cleaner coal. So, if compliance with the emission standards is already ensured by the current burn and if the new fuel is to be blended with the coal currently used, the buying intentions may not reflect any strong dependence on the sulfur content of the offered fuel.

V. CONCLUSIONS AND RESEARCH IMPLICATIONS

The results of the analyses are generally consistent with expectations. Using hedonic techniques on data for actual market transactions by Illinois utilities, reducing sulfur content was shown to be worth from about $0.70 to $1.00 per million Btu for each pound of sulfur per million Btu of heat content. On a per ton basis, assuming 12,000 Btu/ton, this works out to $17 to $24 per ton. The actual value varies across individual consumers and with other attributes of the coal, such as ash and heat content. There is a great deal of statistical uncertainty associated with this low-sulfur premium, uncertainty which we are currently seeking to reduce. Furthermore, these results only apply to Illinois consumers.

Due to the absence of actual market data that specifies volatility levels, a survey was used to elicit the value of volatility (and sulfur) among current purchasers of Illinois coal. Preliminary analyses of the survey responses clearly indicate that utilities are willing to pay more for higher volatile content. Given coal with 25% volatile matter, an increase of 10% (to 27.5%) would warrant a price premium of about 8¢/MMBtu or roughly $2/ton. Considered in the context of sulfur reducing technologies that also reduce volatility, this translates into a reduction in willingness to pay. This suggests that it is worth exploring methods for restoring volatile matter to chars and similar products. The price effect of changed volatility could vary with other coal attributes, and should decline as the base volatility rises. Most coal burned by utilities contains 30% to 40% volatile matter. In this range, small changes in volatility probably make little difference in willingness to pay.

Several limitations are apparent in this study, and must be kept in mind as the results are considered. First, we considered only two characteristics that are particularly critical in current experimental technologies: sulfur and volatility. Insofar as other important characteristics of coal are degraded by sulfur-reducing technologies, the price benefits from removing sulfur could be at least partly offset.

Second, available data on market transactions specify a very small list of the relevant attributes: sulfur, ash, and heat content and source of the coal. These data provide an adequate (although not complete) basis for analyzing the value of sulfur, but do not help at all with respect to volatility. For that attribute, we had to generate and use data from a contingent valuation survey. The survey focused mainly on volatility levels well below those to which most utilities are accustomed. Hence, the responses were probably somewhat speculative, and the price effects inferred from them should be interpreted with caution.

Third, the value of a change in any single attribute can be influenced by other characteristics of the coal; e.g., the value of a marginal change in sulfur could be influenced by the heat content of the coal. These cross effects must be kept in mind as the results are interpreted. Moreover, it is entirely possible that our results could be changed by the inclusion of additional characteristics in our models.

Fourth, the results presented here are preliminary and subject to a signficiant error. We will be undertaking more definitive analysis of these data for the CRSC and should obtain more reliable results at the conclusion of that project.

Fifth, we have only investigated existing power plants subject to existing environmental regulations. While these are important users of untreated and desulfurizsed Illinois coal, we are excluding new power plants from our analysis. And new power plants may prove to be major users of Illinois coal due to the required use of scrubbers.

Sixth, and finally, measuring the sulfur/volatility penalty does not indicate the demand for desulfurized coal. If the price is right, will one ton be sold or 100 million tons? Even if desulfurized coal betters the price targets, that does not mean significant quantities of desulfurized coal can be sold. Measuring demand is one issue which will be investigated in the upcoming CRSC project.

The reported results of both sets of analyses (the hedonic and the survey) should be regarded as preliminary. Additional efforts are underway to improve each. In the case of the actual market data, improvements are expected from expanding the data set to include non-Illinois transactions. Doing so awaits better procedures for dealing with spatial relationships of coal suppliers and users. The survey results will be better understood after the qualitative responses (to survey question 9) are analyzed. As indicated above, further efforts are needed to rationalize the different results for the sulfur variable in the two analyses.

This study reenforces the need for close attention to economic considerations as research into sulfur reducing technologies is planned and implemented. At least for the steam electric utility market, attaining rock bottom levels of sulfur is not desirable. Most of the price advantages appear to accrue as compliance levels are approached. Dropping below compliance levels earns little return; in fact, it can be a disadvantage due to losses of operating efficiencies in emission control equipment. Furthermore, changes in attributes other than sulfur (such as volatility) can be critically important. If the product cannot be handled easily or burned efficiently, it may be viewed as an inferior fuel irrespective of its sulfur level.