EXECUTIVE SUMMARY – Investors and plant operators have been switching in large numbers from coal plants to natural gas plants over the last few years due to increasing greenhouse gas and pollutants emissions standards and regulations along with the shale gas boom. This report is an aid to both power plant operators and financial investors with an interest in power plant projects. Financial models were used to evaluate the expected returns on both a typical coal-fired power plant and a typical natural gas-fired power plant that would be found in the United States. Binomial lattice analysis was used to determine the expected probability weighted future commodity prices for both plants, and how these changing commodity prices would affect the expected net present value of the project over a time period. Two sensitivity analyses were also used to observe how the expected net present value changes with both changing electricity prices and with changing capital costs. The financial models revealed that the natural gas power plant is the favorable financial investment and will have higher returns compared to the coal power plant. At the assumed electricity price of $40/MWh, the coal power plant did not even break into the positive net present value, while the natural gas power plant did. The sensitivity analysis showed that the coal plant only becomes financially sound (i.e. positive returns) at high electricity prices. Sensitivity analysis also illustrated that for any electricity price and for any reasonable amount of changing capital costs (±30%), the natural gas power plant always returns a higher value than the coal power plant. For these reasons, it is recommended that natural gas-fired power plants are favored over coal-fired power plants. It is not recommended to even construct a coal-fired power plant in these typical U.S. market conditions analyzed in this report, because they will most likely not break even over the analyzed time period. Natural gas is clearly the favorable and recommended power plant to construct.
Background
The surge in popularity of natural gas in the last few years that is attributed to shale gas has prompted many power plant operators to build or switch to natural gas plants over coal-fired plants. In addition, the increasing greenhouse gas and pollutants regulations are hurting the coal industry more and more as time goes on. Thus, the question has been raised, concerning the recent growth in natural gas power plant adoption, about which type of power plant project – coal or natural gas – currently yields the highest expected financial return. This report, written for a potential power plant investor/operator and decision maker, will aid in the choice between coal and natural gas power plants with the use of financial models. The sources used to construct these models will give the most aid to the typical decision maker in the United States. Decision makers in specialty markets or markets in which the commodity price, electricity price, or fixed or variable costs are an outlier to the typical data presented by the U.S. Energy Information Agency or PJM Interconnect should consult additional sources before making the decision to choose coal or natural gas.

As stated, the two alternatives analyzed in this report are coal and natural gas power plants. These alternatives were crafted to represent typical coal and natural gas power plants found in the United States. The coal power plant was assumed to be a 500 MW single unit advanced pulverized coal power plant that consumes bituminous coal. The natural gas power plant was assumed to be a 500 MW conventional combined cycle power plant that consumes standard grade natural gas.

Two general financial models were used in the analyses of both the potential coal and natural gas power plants: binomial lattice analysis and sensitivity analysis. Binomial lattice analysis was used to take into account the likely commodity prices that would affect the overall expected net present value of the power plant project. Sensitivity analysis was then used to observe the expected net present value of each plant in response to changing electricity prices. Sensitivity analysis was also used to observe the expected net present value of each plant in response to varied capital costs. These analyses were both used to evaluate the expected performance of each plant and to observe the plant with the higher expected return.

One major engineering constraint that is assumed in this report is the constant output of each power plant. To simplify calculations and maintain applicability to the widest range of power plant operators/decision makers, it was assumed that the power plant would remain on for the total duration of the analysis. It is often costly to shut off and turn back on a power plant, especially coal and less so, natural gas. Therefore, flexibility options to shut down the power plant were not considered.

Methods
The binomial lattice analysis method was used for analyzing both the coal and natural gas plants. The method for each plant was the same but with different inputs; therefore the word “commodity” hereby refers to coal or natural gas. Historical pricing data for each commodity was obtained for the purposes of setting a starting price and determining up (u), down (d), probability up (p), and probability down (pd) values. Equations 1 – 4 illustrate how these values were determined, where \( v \) is the average of the percentage growth of the respective commodity, \( \sigma \) is the standard deviation of the percentage growth of the respective commodity, \( \Delta t \) is the time period.
Financial Analysis of Coal vs. Natural Gas Power Plants

\[ u = e^{(\sigma \sqrt{\Delta t})} \]  \hspace{1cm} (1)

\[ d = e^{-\sigma \sqrt{\Delta t}} \]  \hspace{1cm} (2)

\[ p = 0.5 + 0.5 \left( \frac{V}{\sigma} \right) \sqrt{\Delta t} \]  \hspace{1cm} (3)

\[ pd = 1 - p \]  \hspace{1cm} (4)

These values for each determined for each commodity are shown in Table 1. The values in Table 1 were used to create a price outcome lattice and a probability lattice for each commodity. The price outcome lattice and probability lattice for each commodity were used to construct a probability density function for each commodity to better illustrate the pricing trends to expect in the future.

<table>
<thead>
<tr>
<th>Table 1: Input Values for Binomial Lattice Analysis</th>
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<tbody>
<tr>
<td><strong>Coal</strong></td>
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<tr>
<td>Starting Value</td>
</tr>
<tr>
<td>$u$</td>
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<tr>
<td>$d$</td>
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<td>$p$</td>
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<td>$pd$</td>
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A cash flow lattice was then created using the price outcome lattice along with values for commodity use (short ton/year or thousand ft$^3$/year), fixed cost ($/yr), electricity price ($/MWh), and electricity production (MWh/yr). These values were determined using information concerning typical U.S. electricity plant commodity uses, costs, production,\(^3\) and PJM electricity rates.\(^4\) Table 2 shows these values. A discount rate of 10% was also assumed.

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<tr>
<td><strong>Coal</strong></td>
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<td>Commodity Use</td>
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<td>Fixed Cost ($/yr)</td>
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<tr>
<td>Electricity Price ($/MWh)</td>
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<tr>
<td>Electricity Production (MWh/yr)</td>
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The expected net present value (ENPV) for each plant was calculated using an ENPV lattice. This last period of this lattice uses the values of the last period of the cash flow lattice. Then, for prior periods, a discounted probability weighted cash flow from the period after it is calculated using $p$ and $pd$, the added to the cash flow value of that prior period. This results in the value in the 0 time period being the ENPV. The capital cost (determined via EIA information\(^3\)) for each plant was then subtracted from the ENPV to determine the ENPV with capital for each plant.
Following the binomial lattice analysis for both the coal and natural gas power plant, a sensitivity analysis to evaluate the effect that varying electricity costs have on the ENPV with capital was conducted. The electricity price was varied in a range from $18/MWh to $70/MWh. These values were chosen because they were reasonably likely to occur as the maximum or minimum value when observing typical PJM electricity prices.  

Lastly, another sensitivity analysis was conducted; this analysis observed the effect that a varying capital cost had on the ENPV with capital. The respective capital costs for the coal and natural gas plants were varied in a range of ±30%. The effect that a higher or lower capital cost had on the ENPV with capital was noted.

**Results**

The probability density functions for both coal and natural gas are shown in Figure 1 and 2. The PDFs were constructed using the price outcome lattice and the probability lattice.

![Figure 1: Coal Price PDF](image1)

![Figure 2: Natural Gas Price PDF](image2)
The probability density functions for both coal and natural gas is shown in Figure 1 and 2. The PDFs were constructed using the price outcome lattice and the probability lattice. The resulting cash flow lattices were constructed for both coal and natural gas, and used to calculate the ENPV after discounting. For an assumed cost of electricity of $40/MWh, the ENPV for coal was $732,201,088.72, and the ENPV for natural gas was $602,577,699.86. After considering the cost of capital for the coal and natural gas models, the ENPV with capital for coal was -$890,798,911.3, and the ENPV with capital for natural gas was $144,077,699.9. With this electricity cost assumption based on the PJM electricity price data, it is clear that the more financially sound choice is the natural gas plant.

The electricity price sensitivity analysis that was conducted adjusts the price of electricity from the assumed $40/MWh to a range of electricity prices from $18/MWh to $70/MWh. These values were chosen based on the minimum and maximum electricity prices reported in the PJM electricity price data (while the maximum electricity price was reported to be $544/MWh, this analysis considers this to be an outlier, and a value of $70/MWh to be a more appropriate maximum electricity price value). Figure 3 shows the results of the electricity price sensitivity analysis, i.e., how the ENPV with capital changes as the electricity price changes. The sensitivity analysis shows that as the electricity price increases, the ENPV with capital increases for both the coal plant and natural gas plant. For all electricity prices, the natural gas plant returns a higher ENPV with capital. It is shown that the ENPV for the coal plant only returns a positive value at the highest electricity price analyzed.

The capital cost sensitivity analysis that was conducted adjusts the capital costs upwards and downwards up to ±30% for both the coal plant analysis and natural gas plant analysis. The capital costs for each analysis was assumed using the EIA information on electricity plant capital costs. For coal the starting capital cost was assumed to be $1,623,000,000, and for natural gas the starting capital cost was assumed to be $458,500,000. The ENPV with capital for both coal and natural
gas when adjusting the capital costs ±30% is shown below in Figure 4. The price of electricity is fixed at an assumed value of $40/MWh. The sensitivity analysis shows that for both plants, as the capital cost increases, the ENPV with capital decreases; however, this effect is more pronounced with the coal plant. It is also shown that for in the range of ±30% capital costs, the natural gas will always return a higher ENPV with capital. It is shown that the coal plant does not return a positive ENPV even when the capital cost is reduced by 30%, and that the natural gas plant returns a positive ENPV for the entire ±30% range.

![Figure 4: Sensitivity Analysis of ENPV with Changing Capital Costs](image)

**Recommendation**

The binomial lattice analyses of the coal and natural gas plants took into account the upward or downward movement of the price of coal and natural gas, respectively. With the assumptions described above concerning the electricity price and capital costs, the binomial lattice analysis determined that the ENPV of the natural gas plant was higher than the ENPV of the coal plant. Under these assumptions, the natural gas plant is a better financial investment.

These assumptions were adjusted using two sensitivity analyses; one analysis examined different electricity prices, and the other analysis examined higher and lower capital costs. The two sensitivity analyses confirmed that even with changing electricity prices and capital costs, the natural gas plant always returned a higher value than the coal plant.

Based on the binomial lattice analyses and the sensitivity analyses, the natural gas plant is a better financial investment than the coal plant. Under the normal assumptions assumed in the binomial lattice analysis, the coal plant failed to return a positive ENPV with capital value, while the natural gas plant did. Even in conditions in which the coal plant had positive returns, the natural gas plant had higher returns. Current energy market trends and national and international politics suggest that the natural gas price will continue to be in the price range shown in Figure 2, which greatly
influenced the results of this report. It is possible that the price of coal will drop and the price of natural gas will rise (due to the future possibility of U.S. natural gas exportation) resulting in the coal plant being a better investment, but this report asserts that the chances of that are slim.

References


