An Analysis of Power Plant Investment Opportunities using a Compound Exchange Option

Term Project

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Content

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1. Executive Summary

Our company is a major player in the international energy sector and we are interested in furthering our operations to serve the market's energy needs. In order to achieve this goal, it is in the company's best interest that we should examine all available investment opportunities the firm can embark on with the most cost effective measure. We gathered data on potential power plant dispatch locations and evaluated every possible decision paths the firm would face and measure its outcome. This paper presents our findings, comparisons and the optimal decision the company should undertake.

2. Introduction

To analyze investment opportunities into a power plant, we perform a real option analysis that is akin to a compound exchange option (CEO). A compound exchange option is an option for which the underlying is another option, also known as a simple exchange option (SEO). The SEO is the value of the decision whether the firm dispatches the power plant, running either on natural gas or coal as fuel. The CEO is the value of the decision whether the firm invests in physical assets such as land, permits or electricity generator, or does nothing at all.

In this paper we attempt to evaluate CEO premias for 15 different geographical locations that are likely favorable for building a power plant, each exhibiting a number of unique factors under different economic conditions. Unique factors of concern here are the current wholesale price volatilities of electricity, natural gas and coal, as well as the correlation of prices between them. These factors in turn affect electricity generation costs and carbon dioxide (CO_2) output. For economic factors, we attempt to evaluate the economics dictated by the government's policy on clean energy, specifically a power plant's CO_2 emission costs. We include a “no emission cost” and "high emission cost" case, as well as a "base case", in our study. We also include a case of "high capital costs" in our study.

3. Methodology

3.1 **Simple exchange option.** We attempt to derive the values of SEO for every power plant investment opportunity using the closed-form solution for a spread option:

$$\text{spread option price} = V_0 N(d_1) - U_0 N(d_2)$$

Where V_0 is the wholesale price of electricity at time 0, U_0 is the price of the fuel at time 0, N(.) is the standard normal cumulative distribution, $d_1 = \frac{\ln\left(\frac{V_0}{U_0}\right) + 0.5\sigma^2 T}{\sigma\sqrt{T}}$, $d_2 = d_1 - \sigma\sqrt{T}$, and σ is the portfolio volatility.

3.2 **Compound exchange option.** Using the Monte Carlo simulation method, we simulate the price paths of electricity prices and fuel prices for coal and natural gas. These simulated values gives us the electricity prices of the proposed power plant. The value of the CEO is calculated as a spread option with strike price K. This is similar to the closed-form analytical solution for compound spread option:

$$CEO = VN_2(d_1\,(P/P^*, T_1), d_1(P, T_2)) - DN_2(d_2\,(P/P^*, T_1), d_2(P, T_2)) - qDN_1(d_2\,(P/P^*, T_1))$$

Where $N_2(a, b)$ is the standard bivariate normal cumulative distribution, $P=V/D$, T_1 and T_2 are the option evaluation times where $T_1<T_2$, V is the wholesale electricity price, D is the fuel price, q = (capital cost)/(heat rate x (fuel price + emission rate x emission cost)), and P^* is determined by $P^*N_1(d_1\,(P^*))-N_1\,(d_2(P^*))=q$.

3.3 **At-the-money CEO Option.** We assumed the strike price, or the capital cost of building the power plant, to be the mean of our simulated SEO values and give us an estimate of at-the-money (ATM) CEO option value.

3.4 **Absolute error control.** Using the conditional Monte Carlo simulation method with control variates, we can reduce the simulation time and improve variance reduction to control the absolute error within plus/minus 1 cent with a 95% confidence.

3.5 **Case scenarios.** For "base case", we assumed the CO_2 emission cost as $35 per ton and capital cost of $36.06/MWh. For the "high emission cost" case, we set the CO_2 emission cost as $70 per ton. In the "high capital cost" case, we set the CO_2 emission cost same as the "base case" at $35 per ton, but with a capital cost of $72.12/MWh.

3.6 **Exercise frequency.** We take into account the probability of the CEO option being exercised. In other words, the exercise frequency indicates how likely an investment decision is to be accepted to build a power plant.

4. Numerical results

4.1 CEO premias by Base Case

Table 1. Top 5 CEO premias by Base Case with $35 per ton CO_2 emission cost and $36.06/MWh capital cost.

Location	Type of Plant	CEO	Confidence Interval	Exercise Frequency	Number of Trials
Alaska	Coal Plant	17.6591	0.010025	0.9707	27,305,768
Colorado	Coal Plant	15.0410	0.010024	0.9691	19,883,238
Alaska	NG Plant	12.8875	0.010045	0.8962	17,665,995
Oregon	Coal Plant	12.7799	0.010022	0.9656	14,464,705
Pennsylvania	Coal Plant	12.5611	0.010023	0.9644	14,010,268

The results suggest that Alaska and Colorado make the best locations to build a power plant, according to a base case scenario of $35 per ton CO_2 emission cost and $36.06/MWh capital cost.

4.2 CEO premias by Case of No Emission Cost

Table 2. Top 5 CEO premias with $36.06/MWh capital cost and no emission costs.

Location	Type of Plant	CEO	Confidence Interval	Exercise Frequency	Number of Trials
Alaska	Coal Plant	19.3224	0.010028	0.9924	31,273,516
Colorado	Coal Plant	16.7010	0.010028	0.9945	23,278,959
Oregon	Coal Plant	14.3725	0.010025	0.9936	17,272,062
Pennsylvania	Coal Plant	14.1211	0.010025	0.9920	16,721,628
Georgia	Coal Plant	13.7113	0.010026	0.9931	15,731,718

The result suggests that in the absence of emission costs, Alaska is the ideal location to dispatch a power plant, followed by Colorado and Oregon.

4.3 Best CEO premias by Case of High Emission Costs

Table 3. Top 5 CEO premias with $70 per ton carbon emission cost and $35/MWh capital cost.

Location	Type of Plant	CEO	Confidence Interval	Exercise Frequency	Number of Trials
Alaska	Coal Plant	16.4490	0.010023	0.9556	24,502,565
Colorado	Coal Plant	13.8859	0.010019	0.9526	17,594,661
Alaska	NG Plant	12.4378	0.010043	0.8925	16,550,334
Oregon	Coal Plant	11.7066	0.010020	0.9478	12,645,960
Pennsylvania	Coal Plant	11.5084	0.010019	0.9468	12,249,959

The results suggest that Alaska is the ideal plant dispatch location when the carbon emission cost is high at $70 per ton.

4.4 **Best CEO premias by Case of High Capital Costs**

Table 4. Top 5 CEO premias with \$35 per ton CO2 emission cost and \$72.12/MWh capital cost.

Location	Type of Plant	CEO	Confidence Interval	Exercise Frequency	Number of Trials
Alaska	Coal Plant	17.6591	0.010025	0.9707	27,305,768
Colorado	Coal Plant	15.0410	0.010024	0.9691	19,883,238
Alaska	NG Plant	12.8875	0.010045	0.8962	17,665,995
Oregon	Coal Plant	12.7799	0.010022	0.9656	14,464,705
Pennsylvania	Coal Plant	12.5611	0.010023	0.9644	14,010,268

Again, Alaska proved to be the most economic location with high capital costs of \$72.12/MWh capital cost.

5. Discussion

5.1 **Market data agree with simulation results.** Simulation results agree with the intuition that the value of building a power plant is greatest in locations where the wholesale electricity price is the highest, which in this case is Alaska. This is because it makes more economic sense for the company to generate electricity from cheaper fuel prices than to purchase at higher market wholesale prices.

5.2 **Risk on uncertain future carbon emission policy.** Should the firm decide to go ahead and build a power plant in a year's time, government policy uncertainty is the risk that the company has to take into consideration, as this will affect the balance sheet negatively.

Suppose the firm dispatched a coal power plant in Alaska based on the highest CEO premia when the carbon emission cost is zero. Now, suppose that a few years later a government policy came into effect and introduced a case of high carbon emission cost. We can then calculate the loss inflicted on the company.

Table 5. Calculation of potential loss when there is a switch of government policy from zero emission cost to high emission cost for a coal power plant in Alaska.

Location	Type of Plant	Case	CEO
Alaska	Coal Plant	High Emission Cost Case	16.448957
Alaska	Coal Plant	No Emission Cost Case	19.322366
		Potential Maximum Loss	2.8734089
		Percentile Loss	14.87%

From Table 5, the company faces a potential loss of 14.87% during a period of government policy uncertainty after a coal power plant is dispatched in Alaska.

Now let us consider the case where the firm decides to build a natural gas plant instead. Suppose the natural gas power plant is built in Alaska based on the highest CEO premia value during a period of zero CO_2 emission costs. Now suppose that a few years later, the government introduces a policy of high CO_2 emission costs. We then calculate the value affecting this decision.

Table 6. Calculation of potential loss when there is switch of government policy from zero emission costs to high CO2 emission costs for a natural gas power plant in Alaska.

Location	Type of Plant	Case	CEO
Alaska	NG Plant	High Emission Cost Case	12.43783
Alaska	NG Plant	No Emission Cost Case	13.333072
		Potential Maximum Loss	0.895242
		Percentile Loss	6.71%

From table 6, the company faces a potential loss of 6.71% should there be a change in government policy on CO_2 emission costs.

5.2 **Exercise frequency.** On examining the exercise frequencies, we find that the probability of an exercise on coal plants is higher than of natural gas plants. For example, a coal power plant in Alaska has an exercise frequency of 0.9707, compared to 0.8962 for a natural gas plant. Since the exercise frequency is close to 1, this suggests a power plant should be built than to take no action.

6. Conclusion

Our simulations show that Alaska is the ideal location for building a power plant. When the firm is uncertain about the government's green policy, building a natural gas plant possess less risk than building a coal power plant. From exercise frequency values, the decision to build a coal plant is the most valuable.

Besides Alaska, other sites of consideration are Colorado, Oregon and Pennsylvania, in order.

7. Appendix

Part A: Compare CEO in different method.

1. Calculate CEO in analytic solution:

   Before calculate CEO in analytic solution, we need to calculate P* first,

$$P^* N_1\big(d_1(P^*)\big) - N_1\big(d_2(P^*)\big) = q$$

   In typo version $d_1(y,t) = \frac{\ln(y)+\sigma^2 t}{\sigma\sqrt{t}}$, in correct version $d_1(y,t) = \frac{\ln(y)+0.5\sigma^2 t}{\sigma\sqrt{t}}$

   Then calculate CEO in Carr eq27,

$$C(S(V,D,\tau_s),qD,\tau_c) = VN_2\left(d_1\left(\frac{P}{P^*},\tau_c\right),d_1(P,\tau_s)\right) - DN_2\left(d_2\left(\frac{P}{P^*},\tau_c\right),d_2(P,\tau_s)\right) - qDN_1\left(d_2\left(\frac{P}{P^*},\tau_c\right)\right)$$

2. Calculate CEO in Monte Carlo simulation:

   First of all, simulate many Vc and Dc at time tau_c. Then calculate simple exchange option by using following formula,

$$Simple\ exchange\ option = V_c N_1(d_1) - D_c N_1(d_2)$$

Finally get the discounted value of CEO in Monte Carlo simulation,

$$CEO = e^{-r\tau_c} MAX(SEO - qD_c, 0)$$

3. Results:

   CEO premium using analytic solution with typo:

   13.4026

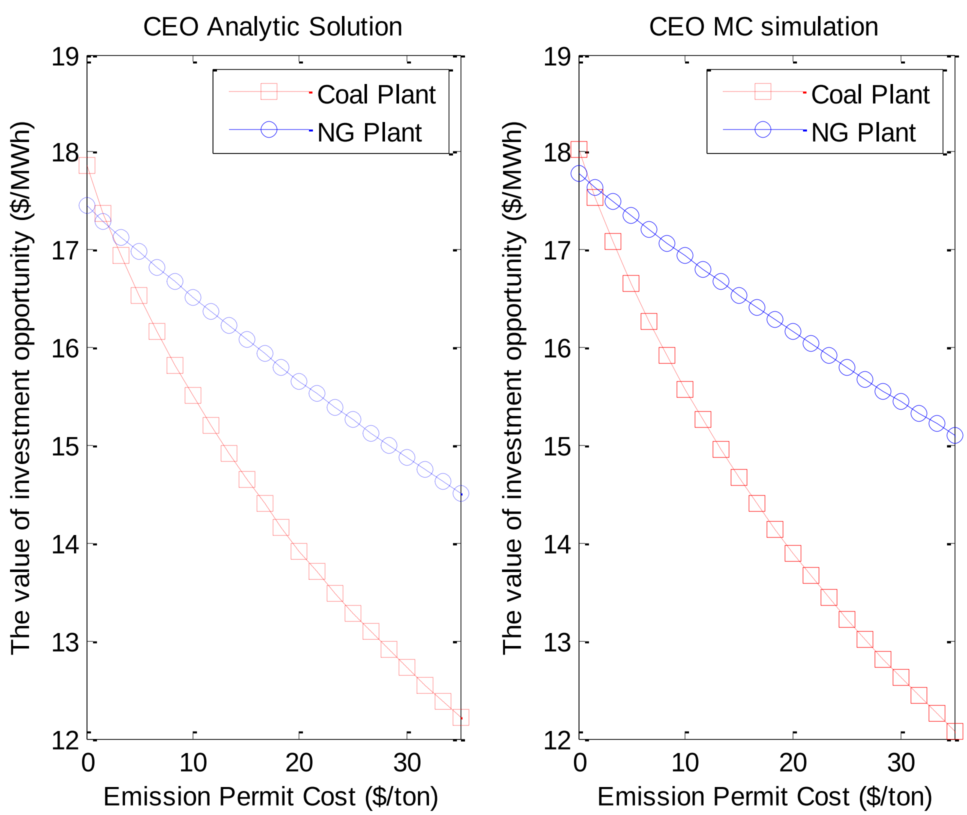
   CEO premium using analytic solution with typo corrected:

   17.4594

   CEO premium using Monte Carlo simulation:

   17.4741

Part B: **Replication of figure 2 in CEO Analytic solution and CEO MC simulation.**



Part C: **Consolidated simulation output (8 parts based on plant type and case type).**

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	Coal Plant	Base Case	17.65909	0.010025	0.970678576	27305768
Colorado	Coal Plant	Base Case	15.04104	0.010024	0.969078527	19883238
Oregon	Coal Plant	Base Case	12.77993	0.010022	0.965629302	14464705
Pennsylvania	Coal Plant	Base Case	12.56107	0.010023	0.964385264	14010268
Georgia	Coal Plant	Base Case	12.14088	0.010022	0.964414949	13089120
New York	Coal Plant	Base Case	11.99638	0.010023	0.964954643	12764230
New Mexico	Coal Plant	Base Case	10.90338	0.010024	0.961621339	10622283
California	Coal Plant	Base Case	10.16955	0.010025	0.960789232	9257457
Nevada	Coal Plant	Base Case	9.999466	0.010025	0.957968091	9008180
Washington	Coal Plant	Base Case	9.998848	0.010025	0.959815873	8969686
Virginia	Coal Plant	Base Case	9.813781	0.010023	0.959221015	8652545
Lousiana	Coal Plant	Base Case	9.65736	0.010023	0.959839297	8368753
Illinois	Coal Plant	Base Case	8.664116	0.010025	0.957172088	6777099
Idaho	Coal Plant	Base Case	7.947973	0.010025	0.95399342	5746265
Texas	Coal Plant	Base Case	7.79023	0.010025	0.954876333	5508484

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	NG Plant	Base Case	12.88747	0.010045	0.896208337	17665995
Colorado	NG Plant	Base Case	11.86697	0.010038	0.912488865	14274252
Pennsylvania	NG Plant	Base Case	10.51344	0.010034	0.921788872	10912130
Oregon	NG Plant	Base Case	10.37056	0.010038	0.915793248	10793410
Georgia	NG Plant	Base Case	10.17536	0.010034	0.922076924	10209928
New York	NG Plant	Base Case	9.669979	0.01004	0.913705609	9430891
New Mexico	NG Plant	Base Case	8.764464	0.010038	0.910515141	7814674
Washington	NG Plant	Base Case	8.533063	0.010031	0.922453229	7164631
California	NG Plant	Base Case	8.432069	0.010035	0.916992943	7101336
Lousiana	NG Plant	Base Case	8.254254	0.010033	0.922740112	6696981
Nevada	NG Plant	Base Case	8.143984	0.01004	0.909873422	6755743
Virginia	NG Plant	Base Case	7.987096	0.010038	0.911173706	6472678
Illinois	NG Plant	Base Case	7.119778	0.010036	0.911735381	5132215
Idaho	NG Plant	Base Case	6.608264	0.010033	0.91090681	4429407
Texas	NG Plant	Base Case	6.474896	0.010032	0.912024411	4239426

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	Coal Plant	High Capital Cost Case	17.65909	0.010025	0.970679	27305768
Colorado	Coal Plant	High Capital Cost Case	15.04104	0.010024	0.969079	19883238
Oregon	Coal Plant	High Capital Cost Case	12.77993	0.010022	0.965629	14464705
Pennsylvania	Coal Plant	High Capital Cost Case	12.56107	0.010023	0.964385	14010268
Georgia	Coal Plant	High Capital Cost Case	12.14088	0.010022	0.964415	13089120
New York	Coal Plant	High Capital Cost Case	11.99638	0.010023	0.964955	12764230
New Mexico	Coal Plant	High Capital Cost Case	10.90338	0.010024	0.961621	10622283
California	Coal Plant	High Capital Cost Case	10.16955	0.010025	0.960789	9257457
Nevada	Coal Plant	High Capital Cost Case	9.999466	0.010025	0.957968	9008180
Washington	Coal Plant	High Capital Cost Case	9.998848	0.010025	0.959816	8969686
Virginia	Coal Plant	High Capital Cost Case	9.813781	0.010023	0.959221	8652545
Lousiana	Coal Plant	High Capital Cost Case	9.65736	0.010023	0.959839	8368753
Illinois	Coal Plant	High Capital Cost Case	8.664116	0.010025	0.957172	6777099
Idaho	Coal Plant	High Capital Cost Case	7.947973	0.010025	0.953993	5746265
Texas	Coal Plant	High Capital Cost Case	7.79023	0.010025	0.954876	5508484

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	NG Plant	High Capital Cost Case	12.88747	0.010045	0.896208	17665995
Colorado	NG Plant	High Capital Cost Case	11.86697	0.010038	0.912489	14274252
Pennsylvania	NG Plant	High Capital Cost Case	10.51344	0.010034	0.921789	10912130
Oregon	NG Plant	High Capital Cost Case	10.37056	0.010038	0.915793	10793410
Georgia	NG Plant	High Capital Cost Case	10.17536	0.010034	0.922077	10209928
New York	NG Plant	High Capital Cost Case	9.669979	0.01004	0.913706	9430891
New Mexico	NG Plant	High Capital Cost Case	8.764464	0.010038	0.910515	7814674
Washington	NG Plant	High Capital Cost Case	8.533063	0.010031	0.922453	7164631
California	NG Plant	High Capital Cost Case	8.432069	0.010035	0.916993	7101336
Lousiana	NG Plant	High Capital Cost Case	8.254254	0.010033	0.92274	6696981
Nevada	NG Plant	High Capital Cost Case	8.143984	0.01004	0.909873	6755743
Virginia	NG Plant	High Capital Cost Case	7.987096	0.010038	0.911174	6472678
Illinois	NG Plant	High Capital Cost Case	7.119778	0.010036	0.911735	5132215
Idaho	NG Plant	High Capital Cost Case	6.608264	0.010033	0.910907	4429407
Texas	NG Plant	High Capital Cost Case	6.474896	0.010032	0.912024	4239426

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	Coal Plant	High Emission Cost Case	16.4490	0.0100	0.9556	24502565
Colorado	Coal Plant	High Emission Cost Case	13.8859	0.0100	0.9526	17594661
Oregon	Coal Plant	High Emission Cost Case	11.7066	0.0100	0.9478	12645960
Pennsylvania	Coal Plant	High Emission Cost Case	11.5084	0.0100	0.9468	12249959
Georgia	Coal Plant	High Emission Cost Case	11.0935	0.0100	0.9463	11398373
New York	Coal Plant	High Emission Cost Case	10.9421	0.0100	0.9464	11085681
New Mexico	Coal Plant	High Emission Cost Case	9.9104	0.0100	0.9427	9172473
California	Coal Plant	High Emission Cost Case	9.2021	0.0100	0.9415	7932987
Nevada	Coal Plant	High Emission Cost Case	9.0737	0.0100	0.9395	7750669
Washington	Coal Plant	High Emission Cost Case	9.0475	0.0100	0.9406	7686100
Virginia	Coal Plant	High Emission Cost Case	8.8736	0.0100	0.9398	7407867
Lousiana	Coal Plant	High Emission Cost Case	8.7125	0.0100	0.9399	7140277
Illinois	Coal Plant	High Emission Cost Case	7.7730	0.0100	0.9366	5728727
Idaho	Coal Plant	High Emission Cost Case	7.1092	0.0100	0.9330	4836389
Texas	Coal Plant	High Emission Cost Case	6.9458	0.0100	0.9332	4612780

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	NG Plant	High Emission Cost Case	12.4378	0.0100	0.89251	16550334
Colorado	NG Plant	High Emission Cost Case	11.3338	0.0100	0.90622	13183445
Pennsylvania	NG Plant	High Emission Cost Case	9.9257	0.0100	0.91248	9921290
Oregon	NG Plant	High Emission Cost Case	9.8191	0.0100	0.90765	9843854
Georgia	NG Plant	High Emission Cost Case	9.5856	0.0100	0.91229	9253310
New York	NG Plant	High Emission Cost Case	9.1326	0.0100	0.90558	8561662
New Mexico	NG Plant	High Emission Cost Case	8.2447	0.0100	0.90161	7052016
Washington	NG Plant	High Emission Cost Case	7.9480	0.0100	0.91048	6383200
California	NG Plant	High Emission Cost Case	7.8789	0.0100	0.90619	6350635
Lousiana	NG Plant	High Emission Cost Case	7.6692	0.0100	0.91043	5944177
Nevada	NG Plant	High Emission Cost Case	7.6324	0.0100	0.90058	6057546
Virginia	NG Plant	High Emission Cost Case	7.4661	0.0100	0.90110	5787058
Illinois	NG Plant	High Emission Cost Case	6.5995	0.0100	0.89984	4532388
Idaho	NG Plant	High Emission Cost Case	6.0978	0.0100	0.89863	3882297
Texas	NG Plant	High Emission Cost Case	5.9600	0.0100	0.89897	3703300

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	Coal Plant	No Emission Cost Case	19.3224	0.0100	0.99239	31273516
Colorado	Coal Plant	No Emission Cost Case	16.7010	0.0100	0.99451	23278959
Oregon	Coal Plant	No Emission Cost Case	14.3725	0.0100	0.99360	17272062
Pennsylvania	Coal Plant	No Emission Cost Case	14.1211	0.0100	0.99201	16721628
Georgia	Coal Plant	No Emission Cost Case	13.7113	0.0100	0.99310	15731718
New York	Coal Plant	No Emission Cost Case	13.5930	0.0100	0.99477	15414789
New Mexico	Coal Plant	No Emission Cost Case	12.4320	0.0100	0.99243	12948636
California	Coal Plant	No Emission Cost Case	11.7006	0.0100	0.99394	11440467
Washington	Coal Plant	No Emission Cost Case	11.4988	0.0100	0.99237	11080760
Nevada	Coal Plant	No Emission Cost Case	11.4310	0.0100	0.98840	11033544
Virginia	Coal Plant	No Emission Cost Case	11.2916	0.0100	0.99148	10702287
Lousiana	Coal Plant	No Emission Cost Case	11.1625	0.0100	0.99343	10421217
Illinois	Coal Plant	No Emission Cost Case	10.1231	0.0100	0.99287	8579457
Idaho	Coal Plant	No Emission Cost Case	9.3172	0.0100	0.98924	7318674
Texas	Coal Plant	No Emission Cost Case	9.1981	0.0100	0.99226	7092682

Location	Type of Plant	Case	CEO	CI	Exercise Frequency	number
Alaska	NG Plant	No Emission Cost Case	13.3331	0.0101	0.89801	18938905
Colorado	NG Plant	No Emission Cost Case	12.4022	0.0100	0.91649	15549848
Pennsylvania	NG Plant	No Emission Cost Case	11.1166	0.0100	0.92842	12099935
Oregon	NG Plant	No Emission Cost Case	10.9360	0.0100	0.92149	11928516
Georgia	NG Plant	No Emission Cost Case	10.7842	0.0100	0.92935	11362733
New York	NG Plant	No Emission Cost Case	10.2262	0.0100	0.91976	10479531
New Mexico	NG Plant	No Emission Cost Case	9.3000	0.0100	0.91637	8746789
Washington	NG Plant	No Emission Cost Case	9.1527	0.0100	0.93169	8134664
California	NG Plant	No Emission Cost Case	9.0135	0.0100	0.92492	8031244
Lousiana	NG Plant	No Emission Cost Case	8.8784	0.0100	0.93254	7637633
Nevada	NG Plant	No Emission Cost Case	8.6817	0.0100	0.91665	7619425
Virginia	NG Plant	No Emission Cost Case	8.5301	0.0100	0.91814	7324644
Illinois	NG Plant	No Emission Cost Case	7.6749	0.0100	0.92040	5894736
Idaho	NG Plant	No Emission Cost Case	7.1628	0.0100	0.92032	5134970
Texas	NG Plant	No Emission Cost Case	7.0359	0.0100	0.92189	4934843

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