

Management

Evaluating the Economics of Energy-Saving Projects

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Uncertainty in fuel prices
makes it difficult to assess the
potential financial return on such investments.

For most plants in the chemical process industries (CPI), energy is the second-largest operating cost component after the cost of raw materials. The rising cost of energy has increased interest in strategic process investments that are intended to reduce energy use. However, evaluation of the potential financial return on such investments is often complicated by the inherent volatility of energy prices (Figure 1) (1), which makes it difficult for engineers to determine what prices should be used as the basis for the financial analysis.

When faced with volatility in energy or fuel pricing, it is attractive to consider investments that will enable the use of multiple primary energy sources, so that the fuel source can be switched periodically from a more-expensive to a less-expensive one. Figure 1 shows that since 2000, increased volatility in U.S. natural gas and fuel oil pricing (on an equivalent Btu basis) has been the norm rather than the exception. Furthermore, the volatility is nonsymmetric, with frequent spikes. Similar price behavior occurs in other countries, although the absolute values are different.

This article offers recommendations on analyzing energy investments when there is significant uncertainty related to fuel prices, as well as for projects that involve potential fuel switching.

Financial analysis basics

Most organizations have more potential investments than available capital, so it is necessary to rank the possible investments based on their attractiveness, typically in terms of financial return. The financial analysis requires valuation models that compare the time-based income stream generated by the investment with the costs associated with the project. Various metrics are available to carry out such a comparison,

including payback period and internal rate of return (IRR).

From a rigorous financial point of view, the preferred approach is to use the net present value (NPV) of the future series of after-tax cash flows (ATCF) generated, discounted back to the present time. The NPV of the financial benefits is compared with the NPV of the investment to determine whether the investment has a positive return (2). The discount factor is the sum of the corporate weighted-average after-tax cost of capital (r_c) plus a factor (r_r) that reflects the risk of the investment.

If the ATCF sequence over time is known exactly, its net present value can be expressed as:

$$NPV_{ATCF} = \sum_{i=1}^{i=n} \frac{ATCF_i}{(1+r_c+r_r)^i} + \frac{CoV_{n+1}}{(1+r_c+r_r)^{n+1}} \quad (1)$$

The NPV of the cash flows calculated by Eq. 1 is then compared with the NPV of the investment sequence, which is determined by:

$$NPV_{IC} = \sum_{i=0}^{i=n} \frac{IC_i}{(1+r_c)^i} \quad (2)$$

If NPV_{ATCF} is greater than NPV_{IC} , the investment provides a positive return. Profitability index, which is defined as the ratio of the financial return to the investment — *i.e.*, $(NPV_{ATCF} - NPV_{IC})/NPV_{IC}$ — can be used to rank different investments.

However, this ranking is applicable only when the projected cash flows are known with very high probability — for instance, if the investment is essentially equivalent to a high-quality bond (Ref. 3 provides the full mathematical explanation). In the past, some energy investments were made based on guaranteed fuel prices and guaranteed demands; Eqs. 1 and 2 are suitable for the analysis of such situations.

Accounting for uncertainty and risk (7)

For most investments made today throughout the CPI (particularly those for energy-saving projects), there are no cost or demand guarantees. Energy-based projects have many risk factors that lead to uncertainty in the calculation of the expected return. These risk factors may be either internal (related to the technical performance of the equipment, project execution efficiency, and user acceptance), or external (related to demand, material and labor costs, financing costs, and energy prices). Of these, the largest risk factor is typically associated with primary fuel prices.

Before performing an analysis, it is necessary to quantify the risks. Risk associated with fuel pricing (and many other variables) is represented by the assumed statistical distribution of the variable over the life of the investment. At the same projected future mean value of the variable, a projection with higher variance is considered to be a riskier or more-uncertain investment than one with a lower variance.

In project investment analysis, management is interested not only in the most likely value for the expected return, but also in its potential variability — that is, even if the mean is positive, what is the probability of a negative return? For a single fuel, if the price distribution is normal (Gaussian), there is an analytic solution for the mean and the variance of the NPV; if the price distribution is not normal, there is no analytic solution. Fuel switching introduces additional complexity into the analysis.

The most common investment risk assessment techniques are sensitivity analysis and Monte Carlo simulation. In sensitivity analysis, the high and low endpoints of the ranges of possible outcomes are used as the basis for financial evaluations of each case. If the worst case has an adequate return, then the investment can be approved. However, for many situations, this is not the result, and it is necessary to evaluate the probability distribution of the expected return on investment.

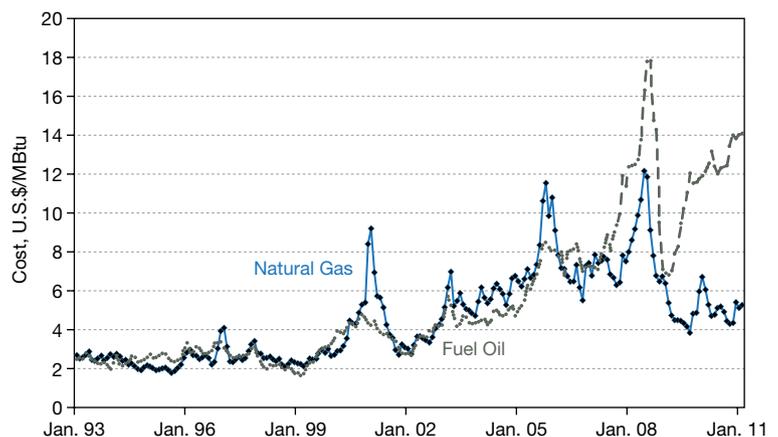
The Monte Carlo approach simulates a large number of cases in which the variables of interest — in this case, the expected fuel prices — are assigned random values that are consistent with the assumed probability distribution. This produces results in the form of a distribution, which is then used to evaluate the potential investment.

References 4–8 discuss investment risk assessment in more detail. Hertz (4) provides an early reference on the use of Monte Carlo simulation to evaluate competing project investment opportunities. Dixit and Pindyck (5) review investment analysis when the timing of the investment is one of the primary uncertainties. Mills *et al.* (6) discuss how to evaluate perfor-

Nomenclature	
$ATCF_i$	= incremental after-tax cash flow in period (year) i generated by the investment
CoV_{n+1}	= continuing value of the investment in period $n+1$
i	= investment period index
IC_i	= capital investment in year i
IC_{ci}	= cumulative capital investment through year i
M_i	= maintenance costs in year i
n	= number of financial evaluation periods for the investment
NPV	= net present value
OD	= days of operation per year
OE_i	= change in operating earnings in year i
P_j	= price of fuel j , \$/MBtu
Q	= energy demand, MBtu/h
r_c	= corporate weighted-average after-tax cost of capital, %/100
r_d	= depreciation rate for the investment, %/100
r_r	= risk premium to be applied to the expected returns from a particular investment, %/100
r_t	= incremental tax rate for earnings, %/100
Greek Letters	
η_N	= new heater efficiency, %
η_O	= old heater efficiency, %

mance risk for energy projects and quantitatively set the appropriate project discount rate. Van Groenendaal (7) presents an assessment of risk in energy projects using sensitivity analysis. Kulatilaka (8) describes a technique known as real options analysis for the evaluation of investments that use multiple fuels when there is uncertainty in the timing of the investment.

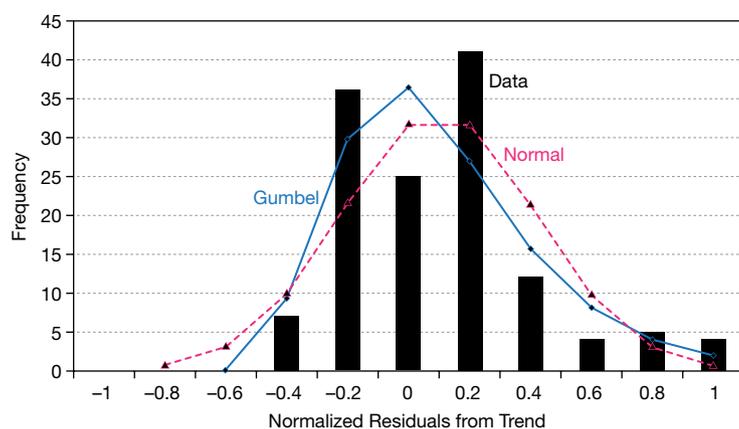
The first step in an investment analysis is to develop price projections for both the trend of the mean and the variance about the mean. This is a very important step,



▲ **Figure 1.** In recent years, there have been periods when natural gas was cheaper than fuel oil, and other periods when fuel oil was cheaper.



▲ **Figure 2.** U.S. natural gas prices have trended upward, but with much variability.



▲ **Figure 3.** The volatility in the price of natural gas is significantly nonsymmetric.

and there are many different approaches to preparing such estimates. For this article, the historical U.S. time-series data for natural gas prices (I) is split into two regions — before and after Jan. 1, 2000 — which is consistent with the price-modeling assumptions presented in Brown and Yucel (9).

To characterize the sample variance, least-squares analysis is used to reduce the post-2000 price trend to a straight line (Figure 2), and the residuals (*i.e.*, the differences between the actual price data points and the straight line) provide a measure of the variability in the data (Figure 3). A plot of the residuals normalized as a fraction of the mean at the time of the reading (the bars in Figure 3) has a positive skew (*i.e.*, the tail on the right is longer than the tail on the left, and the bulk of the values lie to the left of the mean), so a nonsymmetric (rather than a Gaussian) distribution is called for. Several nonsymmetric distributions, including log-normal, inverse normal, and Gumbel, were compared based on the weighted least-squares error. The Gumbel distribution (9) produced the lowest mean-square error (approximately 40% of the equivalent measure for the normal distribution) and was used for subsequent calculations.

Table 1. Assumptions for the base-case investment.

Process Demand	150.0 MBtu/h
Old Equipment Efficiency	75%
New Equipment Efficiency	90%
New Heater Investment Cost	\$13 million
Initial Gas Price	\$7/MBtu
Annual Gas Price Increase	\$0.29/MBtu
Fixed Costs	\$15,000/yr
Annual Maintenance Costs	2% of initial investment
Annual Operation	355 days/yr
Equipment Life	15 yr
Depreciation	\$867,000/yr
Cost of Capital	10%
Tax Rate	33%

Single fuel analysis

Consider an investment in a new process heater that would burn a single fuel, in this case natural gas, and would deliver a higher efficiency (90%) than that of the heater it would replace (75%). Table 1 provides the parameters used for the analysis. The new heater delivers 150 MBtu/h and has an investment cost of \$13 million in the initial year. Yearly maintenance costs are assumed to be 2% of the initial investment, with additional fixed costs of \$15,000 per year. A 15-yr equipment life is assumed, with straight-line depreciation, a cost of capital of 10%, and a tax rate of 33%.

Base case analysis with no price volatility. As a base case, the potential investment is evaluated using traditional financial analysis techniques, which ignore price volatility.

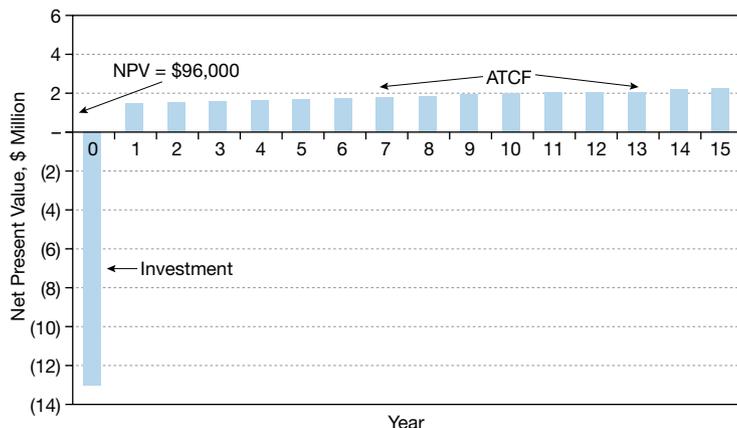
To carry out the investment analysis, engineers must estimate energy prices over the life of the investment. For this example, the gas cost is assumed to be \$7/MBtu in the first year and increase linearly in subsequent years. (Note that this is not a projection of pricing in any particular country, but rather the basis that is assumed for this analysis. Other pricing assumptions can be similarly evaluated.)

First, the change in operating earnings (OE_i) in each year i that accrue from the reduction in energy costs due to the new heater's higher efficiency is calculated:

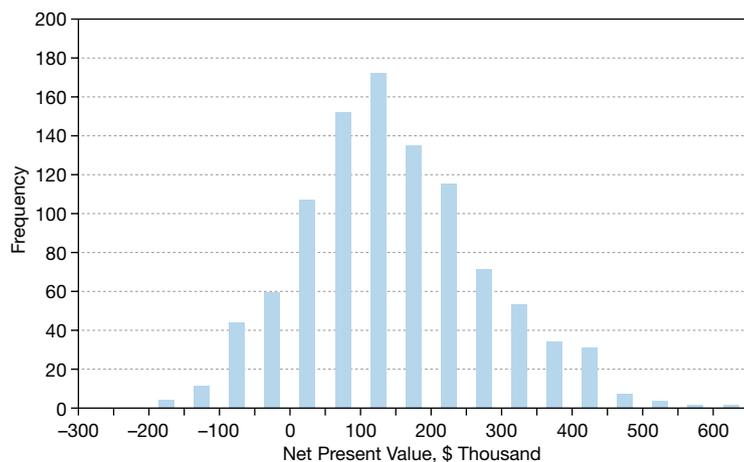
$$OE_i = (Q \times 24 \times OD \times p_i) \left(\frac{100}{\eta_o} - \frac{100}{\eta_N} \right) \quad (3)$$

After-tax cash flow is calculated by adjusting the operating earnings for maintenance costs, depreciation, and taxes:

$$ATCF_i = (OE_i - M_i - r_d IC_{ci}) (1 - r_i) + r_d IC_{ci} \quad (4)$$



▲ **Figure 4.** The base-case investment analysis of after-tax cash flow, with no price volatility, determines that the NPV of the investment is positive.



▲ **Figure 5.** In the face of natural gas price volatility, there can be significant variability in the expected investment return (*i.e.*, the NPV distribution).

Figure 4 depicts the time-series of the incremental net after-tax cash flow generated by the investment. The NPV of the cash flow is \$13,096,000 — with a net positive return of \$96,000 over the capital investment of \$13 million. This investment has a positive return.

Price volatility analysis. To account for price uncertainty, the statistical distribution of the natural gas price is modeled using the Gumbel distribution with a mean that increases linearly; the predicted future statistical variance is then set, and the resulting distribution of the expected NPV is examined.

In this case, the future price uncertainty is assumed to have the same normalized variance as the variance in U.S. gas prices over the period from 2000 to 2011, and 1,000 Monte Carlo simulations are run. The resulting NPV distribution is shown in Figure 5.

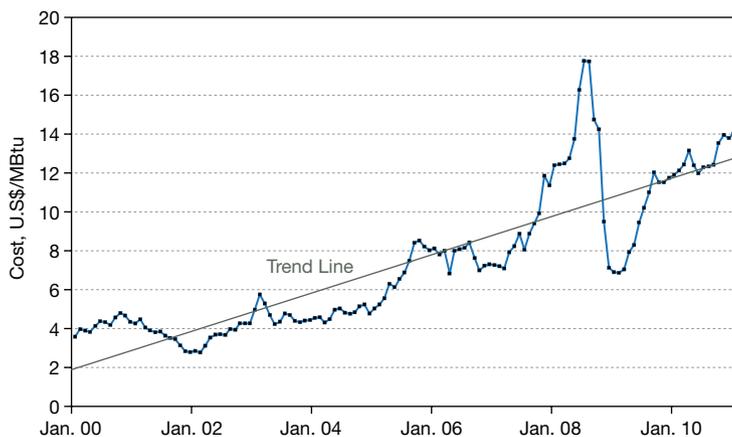
The simulation predicts an expected net NPV of approximately \$96,000 — the same as the base case with no volatility. However, this analysis provides additional information that is useful for risk-management. The probability of a negative return is approximately 22%, and the probability of a return greater than \$200,000 is 10%. These are important considerations when carrying out a comparative analysis of competing investment opportunities.

Fuel switching in the face of price volatility

Projects that have the flexibility to use multiple fuels enable equipment operators to switch to the least-expensive fuel as prices vary. Analyzing the investment potential of such projects is more complicated — ensuring flexibility requires investment now for an uncertain future payout; there are definite costs, but only potential benefits.

As was done for natural gas in the previous example, the price of fuel oil is plotted as a time-series, and least-squares regression is used to fit a straight line to the price data (Figure 6). The residuals from the trend line are best modeled by the Gumbel nonsymmetric distribution, with positive skewness (Figure 7).

The evaluation of a dual-fuel replacement heater assumes the same linear natural gas price relationship as in the previous section as the energy cost baseline. The variances in the natural gas price and the fuel oil price around this trend line are modeled using independent and uncorrelated Gumbel statistical distributions. (Only about 5% of the variances of the two series are related, which supports modeling them as independent and uncorrelated variables.) The mean value trend line vs. time is assumed to be the same for both fuels. The actual price assumed for



▲ **Figure 6.** The price of fuel oil experiences volatility with significant variability.

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either fuel in a period will depend on the specific variation from the mean generated by the Monte Carlo simulation. Adding the equipment for dual-firing capability adds approximately \$300,000 to the initial capital cost. All other assumptions are the same as those shown in Table 1.

Monte Carlo simulations with increasing variance in the price volatility are then run. In each period (in this case, one year), the cheaper fuel is chosen and the heater operates in the corresponding mode.

Figure 8 summarizes the results. When there is little price volatility (*i.e.*, a low assumed price variance), the mean NPV of the investment is negative and the option of fuel switching is not justified. However, as the assumed price volatility (variance) increases, the expected mean NPV increases and the return becomes positive.

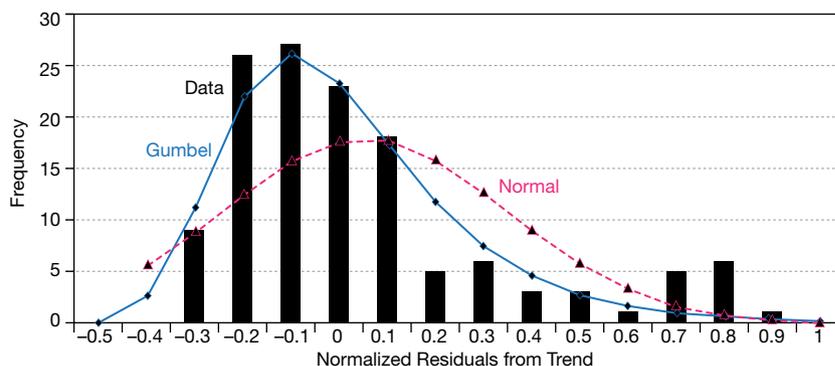
In this situation, increased price volatility for a given mean price increases the expected payback of the investment. Increased uncertainty is not normally considered a positive factor during investment analysis, and increased price volatility might be considered a negative factor for an investment. Yet, in the case of potential fuel switching, it actually increases the expected return.

Closing thoughts

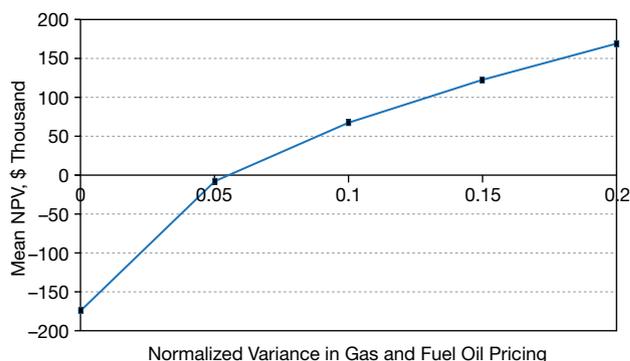
It may seem intuitive that adding equipment to increase operational flexibility in process plants has value. Yet it is often difficult to justify this incremental investment. The rigorous financial approach presented here can be used to analyze such investments based on projections of the expected uncertainty in the key variables affecting the return on investment — in this case energy prices. Increases in the uncertainty can actually increase the expected return from installation of the extra equipment.

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▲ Figure 7. The oil price residuals are distributed nonsymmetrically.



▲ Figure 8. In this case, increasing the assumed variance increases the expected investment return.

LITERATURE CITED

1. **U.S. Energy Information Administration**, "Short Term Energy Outlook," U.S. Dept. of Energy, www.eia.doe.gov/emeu/steo/pub/contents.html; Table 2. "U.S. Energy Prices — Henry Hub" (Dec. 11, 2010).
2. **Brealey, R. A., and S. C. Myers**, "Principles of Corporate Finance," 7th ed., McGraw-Hill Irwin, New York, NY (2003).
3. **Luenberger, D. G.**, "Investment Science," Oxford Univ. Press, New York, NY (1998).
4. **Hertz, D. B.**, "Investment Policies That Pay Off," *Harvard Business Review*, **46**, pp. 96–108 (Jan.–Feb. 1968).
5. **Dixit, A. K. and R. S. Pindyck**, "Investment Under Uncertainty," Princeton Univ. Press, Princeton, NJ (1994).
6. **Mills, E., et al.**, "From Volatility to Value: Analyzing and Managing Performance Risk in Energy-Saving Projects," *Energy Policy*, **34**, pp. 188–199 (2006).
7. **van Groenendaal, W. J. H.**, "Estimating NPV Variability for Deterministic Models," *European Journal of Operational Research*, **107**, pp. 202–213 (1998).
8. **Kulatilaka, N.**, "The Value of Flexibility: The Case of a Dual-Fired Industrial Steam Boiler," *Financial Management*, **22** (3), pp. 271–280 (1993).
9. **Brown, S. P. A., and M. K. Yucel**, "What Drives Natural Gas Prices," *Federal Reserve Bank of Dallas, Research Note* (Feb. 2005).