How to Estimate Utility Costs

Utility estimates are often complicated because they depend on both inflation and energy costs. This simplified approach offers a two-factor utility-cost equation and the relevant coefficients for a number of utilities.

Gael D. Ulrich and Palligarnai T. Vasudevan
University of New Hampshire

Typical process utilities include electricity, process steam, refrigerants, compressed air, cooling water, heated water, hot oil, process water, demineralized water, municipal water, and river, lake, or ocean water. For preliminary cost estimates, waste disposal cost can also be treated like a utility expense.

Unlike capital, labor, and other expenses, utility prices do not correlate simply with conventional inflationary indexes, because basic energy costs vary erratically, independent of capital and labor. In essence, utility price is linked to two separate variables — inflation and energy cost. Elements of manufacturing expense that depend on labor and capital follow inflationary metrics like the CE Plant Cost Index (CE PCI). Energy cost, such as that for fuel in an electrical or steam generating plant, is like a raw material whose price can vary widely and erratically. To reflect this dual dependence, we need a two-factor utility cost equation such as the following:

$$C_{S,u} = a \cdot (CE\ PCI) + b \cdot (CS_f)$$

where $C_{S,u}$ is the price of the utility, $a$ and $b$ are utility cost coefficients, $CS_f$ is the price of fuel in $/GJ$, and CE PCI is an inflation parameter for projects in the U.S.\(^1\)

**Deriving the coefficients**

To derive Coefficients $a$ and $b$, a manufacturing cost analysis must be prepared for a given utility. Electric power price, for instance, includes raw material costs, labor, supervision, maintenance, overhead, and a number of other items that determine total manufacturing expense and, ultimately, selling price. In such a list, individual cost items can be divided into two categories, those dependent on normal inflation and those dependent on energy cost.

1. Evaluated monthly by the staff of Chemical Engineering and printed along with historical values of this and other indexes on the last page of each issue.

### TABLE 1. UTILITY COST COEFFICIENTS

<table>
<thead>
<tr>
<th>Process Model</th>
<th>Cost coefficients $$/m³</th>
<th>Cost coefficients $$/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Electricity, $/kWh</td>
<td>1.3 x 10⁻⁴</td>
<td>0.010</td>
</tr>
<tr>
<td>Process module</td>
<td>1.4 x 10⁻⁴</td>
<td>0.011</td>
</tr>
<tr>
<td>Grass-roots plant</td>
<td>1.1 x 10⁻⁴</td>
<td>0.011</td>
</tr>
<tr>
<td>Compressed and Dried Air, $/Nm³</td>
<td>5.0 x 10⁻⁴ e⁻³⁰ ln p</td>
<td>9.0 x 10⁻⁴ e⁻³⁰ ln p</td>
</tr>
<tr>
<td>Process module</td>
<td>4.5 x 10⁻⁴ e⁻³⁰ ln p</td>
<td>9.0 x 10⁻⁴ e⁻³⁰ ln p</td>
</tr>
<tr>
<td>Instrument Air, $/m³</td>
<td>1.25 x 10⁻⁴</td>
<td>1.25 x 10⁻⁴</td>
</tr>
<tr>
<td>Process module</td>
<td>1.15 x 10⁻⁴</td>
<td>1.25 x 10⁻⁴</td>
</tr>
<tr>
<td>Demineralized (boiler feed) Water, $/m³</td>
<td>0.001 x 3.0 x 10⁻⁴ e⁻¹</td>
<td>0.003</td>
</tr>
<tr>
<td>Process module</td>
<td>0.00072 x 2.5 x 10⁻⁴ e⁻¹</td>
<td>0.003</td>
</tr>
<tr>
<td>Natural Water, Pumped and Screened, $/m³</td>
<td>7.0 x 10⁻⁴ + 3.0 x 10⁻⁴ e⁻⁰</td>
<td>0.003</td>
</tr>
<tr>
<td>Process module</td>
<td>5.0 x 10⁻⁴ + 2.5 x 10⁻⁴ e⁻⁰</td>
<td>0.003</td>
</tr>
<tr>
<td>Water Desalination</td>
<td>1.0 x 10⁻⁴ + 7.0 x 10⁻⁴ e⁻⁰</td>
<td>0.003</td>
</tr>
<tr>
<td>Process module</td>
<td>7.0 x 10⁻⁴ + 2.0 x 10⁻⁴ e⁻⁰</td>
<td>0.003</td>
</tr>
<tr>
<td>Refrigerant, $/kJ cooling capacity a</td>
<td>0.6 Qₜ₂ (°F⁻¹)</td>
<td>1.1 x 10⁶ T⁻⁵</td>
</tr>
<tr>
<td>Grass-roots plant</td>
<td>0.5 Qₜ₂ (°F⁻¹)</td>
<td>1.1 x 10⁶ T⁻⁵</td>
</tr>
<tr>
<td>Hot Water, Hot Oil, or Molten-Salt Heat Transfer Media, $/kJ heating capacity b</td>
<td>7.0 x 10⁻⁴ Qₜ₂ (°F⁻ⁱ)</td>
<td>6.0 x 10⁻⁴ Qₜ₂ (°F⁻¹)</td>
</tr>
<tr>
<td>Grass-roots plant</td>
<td>6.0 x 10⁻⁴ Qₜ₂ (°F⁻¹)</td>
<td>6.0 x 10⁻⁴ Qₜ₂ (°F⁻¹)</td>
</tr>
</tbody>
</table>

### a. Costs are plotted in Figure 1.

### b. Coefficients apply to ranges of q and p indicated, where q is total auxiliary air (Nm/s) and p is delivered pressure of air (bara). Use price of fuel burned in the boiler for $C_{SF}$; $m_o$ is total auxiliary boiler steam capacity (kg/s).

d. $q$ is total water capacity (m³/s).

### c. $C_{SE}$, the price of fuel that partners with Coefficient b, is based on the higher or gross heating value. For electrical power, compressed air, refrigerant, cooling water, and other auxiliary facilities where electricity is used to drive pumps and compressors, it is the price of fuel at the electric power station. For steam, it is the price of boiler fuel at the plant. Historic values for $C_{SF}$ are plotted in Figure 4.

e. Use price of fuel burned in the boiler for $C_{SF}$; $m_o$ is total auxiliary boiler steam capacity (kg/s).

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**Note:**
- Process module
- Grass-roots plant
- Tertiary (filtration, activated sludge, and chemical processing)
- Membrane Processes (see water desalination costs above)
- Liquid/Solid Waste Disposal
- Conventional solid or liquid wastes
- Toxic and hazardous solids and liquids
- Combustion as Supplementary Fuel
- Endothermic Flaring
- Thermal or Catalytic Incineration
- Thermal or Catalytic Incineration (with flue gas cleaning)
- Combustion as Supplementary Fuel (with flue gas cleaning)
- Combustion as Supplementary Fuel (with flue gas cleaning)
TABLE 2.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Higher (Gross) Heating Value</th>
<th>Density</th>
</tr>
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<tr>
<td>Wood</td>
<td>27-33 MJ/kg</td>
<td>640-860 kg/m³ (bulk)</td>
</tr>
<tr>
<td>Lignite</td>
<td>15-19 MJ/kg</td>
<td>640-860 kg/m³ (bulk)</td>
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on fuel price. This allows one to calculate values for a and b. We have done that for a host of utilities. Results are presented in Table 1. Meanwhile, the higher heating values for a number of typical fuels are given in Table 2.

To cover all types of common CPI projects, two additional factors must be considered. First, since capital and labor expenses are not linear functions of capacity, it is necessary to make Coefficient a dependent on plant size. This reflects the simple fact that relative capital and labor costs per unit of capacity decline as plant size increases. We see this, for instance, in the entry for cooling water in Table 1. In a cooling system designed to handle 1 m³/s, water will be more expensive per cubic meter than from a plant designed to handle 10 m³/s, and the expression for Coefficient a reflects that.

Use of Equation (1) calls for judgment. If your module includes a heat exchanger that consumes 0.1 m³/s and there are no other uses of cooling water on site, you will simply use 0.1 m³/s for q in the equation for Coefficient a. If, on the other hand, the exchanger is part of a larger plant where total cooling-water needs are 6 m³/s, 6 is the appropriate value for q in the equation (Table 1) for Coefficient a.

Wisdom also tells us there is a limit on practical plant size. In a larger complex where total cooling-water demand is greater than 10 m³/s, that or a lesser value should be used for q, because standard cooling systems are limited to 10 m³/s. Greater needs are met with multiple units.

A second consideration hinges on whether your module is a part of a grass-roots facility or an existing plant. For example, water is cooled in what is described as an "offsite facility."3 If the heat exchanger in question is part of a new project being built from scratch, offsite capital is included in total project capital. If, on the other hand, the exchanger is being added to a plant where adequate offsite facilities are already in place, the costs of the offsite facility have already been paid. To be fair and accurate in assigning costs, an addition should be treated like a purchase, because the operating or on-line cost of utilities can be considered.

One might ask why equations for utilities like cooling water and compressed air are co-generated with electric power. Because large, free-standing electric power plants tend to be more efficient than onsite generating facilities, this supports a rule of thumb that self-generation of electricity is not attractive unless cheap fuel is available or electricity can be co-generated with process steam.

PUTTING THE METHOD TO USE

To illustrate the use of Equation (1), consider the cost of electricity generated using Number 6 (residual) fuel oil. In mid-2000, the CEPCI was 392, the equivalent price of energy from residual oil was $4/GJ ($27/barrel), and the cost of purchased electricity (estimated from Equation [1] with coefficients taken from Table 1) is calculated to be:

\[
C_{SEA, 2000} = 1.3 \times 10^{-4}(392) + 0.010(4.0) = 0.0891\text{$/kWh}
\]

This agrees closely with the price of electricity charged to large industrial customers in the northeastern U.S., where residual fuel oil was a prominent utility fuel in 2000.

Coal is an important resource in the U.S. because it is abundant and relatively inexpensive. Its use is limited, however, to large power plants where combustion is efficient and clean. With coal at $1.20/GJ, the price of electricity generated from this source in 2000 would have been 6.4 cents per kWh, about two-thirds the price of electricity generated from No. 6 fuel oil that year. Historical price data for coal, oil, and other important fuels are plotted in Figure 1.

ESCALATING PRICES FOR THE FUTURE

Continuing with the No. 6 fuel-oil example, what will the price of electricity be in 2010? Inflation, estimated at

4. Even though owned by the same company.
5. In these instances, \(C_{SE, i}^{\text{MM}}\) in Equation [1] is the price paid for fuel by the electric power plant.

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3 to 3.5% per year, foreshadows a CE PCI of 550. Fuel prices, on the other hand, are capricious. Assume that pressure from coal and nuclear energy moderate the recent escapades in oil prices. Extrapolating from the relatively stable 1990s at an annual rate of 4 to 5%, we arrive at a price of about $6/GJ for No. 6 fuel oil. Accordingly, the 2010 price of electricity from this source is projected to be:

\[
C_{E,2010} = 1.3 \times 10^{-4}(550) + 0.01(6.0) = $0.132/kWh
\]

Any projection so many years in the future is highly speculative. Based on historical data for capital costs, the projected CE PCI is reasonable, but there is little evidence to support the projected fuel price. One could easily argue for an energy price that is double or triple that calculated above. This would mean electricity prices of 19 to 25 cents per kWh.

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References

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