

WASTE-TO-ENERGY FACILITY CAPITAL COSTS

H. GREGOR RIGO AND A. DALE CONLEY

Rigo & Rigo Associates, Inc.
Berea, Ohio

ABSTRACT

The prices of waste-to-energy facilities are predictable once existing data has been adjusted to account for differences in the year of construction, special site conditions and costs, location, facility size, design philosophy, energy product, procurement method, and the type of air pollution control equipment. This paper presents a facility pricing equation that is useful for estimating waste-to-energy facility capital costs during the early project planning stages when study-level estimates ($\pm 25\%$) are sufficiently accurate.

INTRODUCTION

With the number of techniques available for managing municipal solid waste, public officials have a wide variety of options which must be evaluated before the best can be selected for a community. When beginning a study of alternatives, the cost data found in articles and Official Statements not only seem to make no sense but actually indicate that a detailed facility cost must be developed to avoid simply picking a price at random. This perception is understandable given scattergrams like Fig. 1 which show unit prices for waste-to-energy facilities built in the United States.

This paper presents the results of studying and rationalizing the available cost data for waste-to-energy facilities. The final results are a formula and graph

that can be used to develop study-level estimates of the construction price to be paid to a contractor for a specific waste-to-energy facility.

In order to estimate the total capital cost of a project, land purchase and infrastructure improvement costs, development, and owner's administration expenses must be added to the facility price in order to develop a subtotal for the amount of money that must be available to support construction. If a construction loan or bonds are to be used to finance construction, the cost of borrowing money during construction, placing the loan or selling the bonds, and purchasing insurance must be added to arrive at the total debt burden to be carried by the project. Readers are cautioned to account for these additional project and site specific costs. Failure to do so can easily result in an underestimate of annual debt service (carrying cost) of up to 50%.

ANALYTIC APPROACH TO THE PRICE EQUATION

The data for the 61 waste-to-energy facilities used in this analysis was randomly selected. It was obtained principally from Official Statements. The open literature and private sources were also employed.

Facility price is defined in this paper to include the vendor quote for construction plus contingency, utility interconnection expenses and any identified allowances

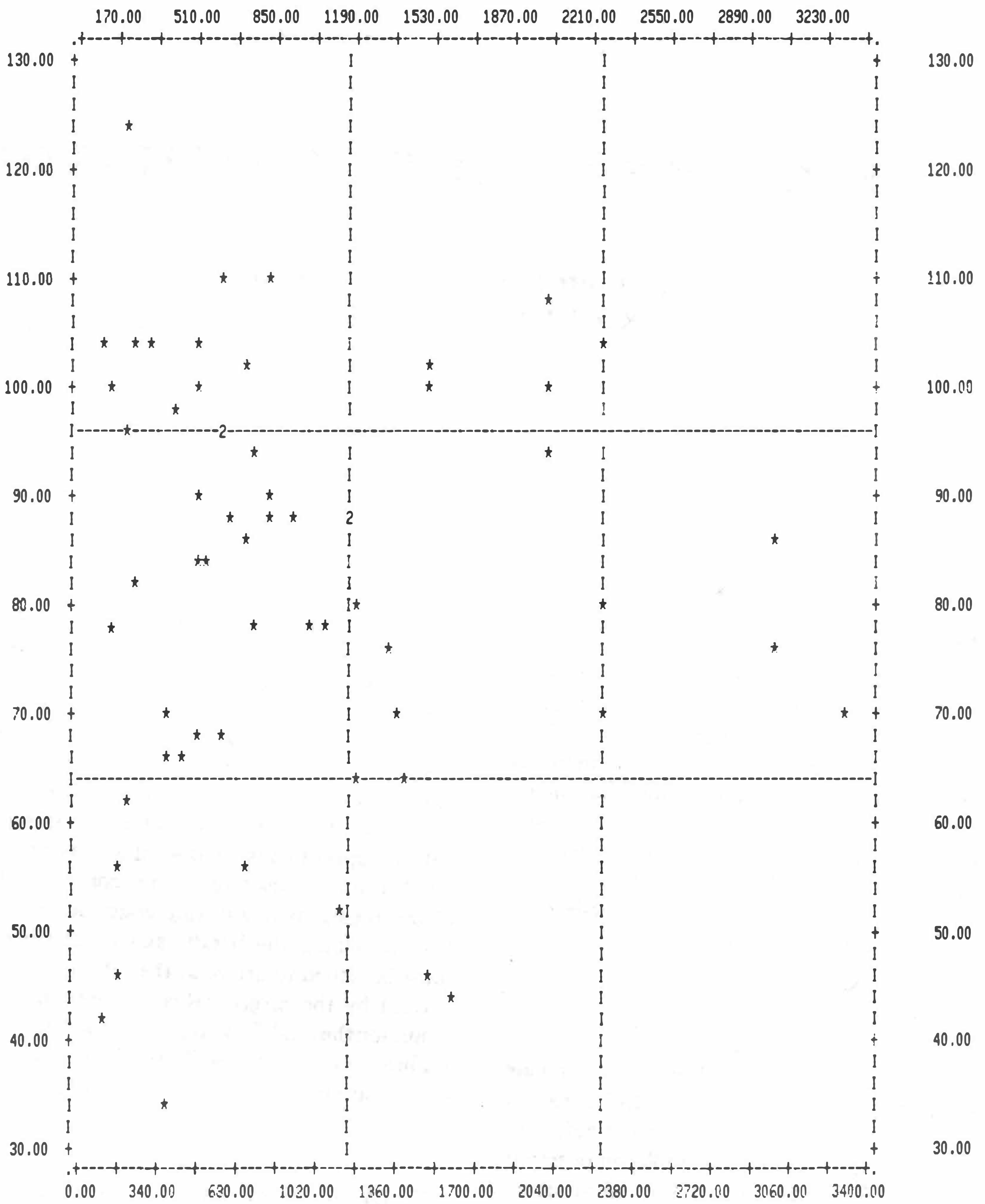


FIG. 1 SCATTERGRAM OF NORMALIZED FACILITY PRICES SHOWING ITS APPARENTLY RANDOM NATURE

clearly associated with the construction price. All other costs, such as land, interest during construction, development costs, management fees, etc. were eliminated due to their highly projected specific nature.

The plant capacity, number of furnaces, type of construction, year priced, location, type of pollution control and procurement method (architect/engineer, turn-key, full service or military) were established. Unique features such as retiring old debt within the contractor's price, refurbishing and reusing portions of existing plants, and any evidence of inordinately long or expensive vendor development costs were noted.

These data were used to calculate the unit capacity price in thousands of dollars per ton of daily installed capacity by dividing facility price by installed capacity. The unit prices were brought to a common reference point of mid-1987 by escalating the unit prices with The Chemical Engineering Plant Index (mid-year 1987 Index value 321) and brought to an average American datum by dividing by the appropriate Weighted Average City Cost Index reported in Means *Building Construction Cost Data 1987*. Different indexes could have been used to time and location normalize the data. The general availability of the chosen indexes and the fact that the unit price data reflects business deals, corporate risk posture, and differing profit margins in addition to cost, makes different index choices of little utility.

The normalized data was analyzed to determine which aspects significantly affected the price per ton. The analysis was carried out with SPSS-PRO computer software on a DEC PRO 380 minicomputer. The software was validated by comparing the results for a test multiple linear regression problem¹ developed at the Bureau of Labor Statistics and found to be accurate to five decimal places, the limit of presentation provided by the software.

Multiple linear regression techniques were used to relate the price per ton of the installed daily name plate's capacity to: capacity, procurement method, type of air pollution control equipment, type of energy product, and predominant type of incinerator and power-block construction (e.g., shop fabrication, modular erection and field fabrication) and special conditions. Each of the classification systems were represented by properly selected "dummy variables" which take on a value of one when the feature is relevant and zero otherwise.²

Waste-to-energy facilities can be classified by a num-

ber of schemes which can be used to define categories for use in data analysis. Since such facilities are complex, they usually have many distinct attributes so that they must either reside in many categories simultaneously or the classification scheme must be very fine.

Method of construction is one classification scheme: small facilities which are extensively shop fabricated; medium sized mass and refuse derived fuel fired steam generating facilities that utilize modular fabrication techniques with field assembly of large components; and large mass and refuse derived fuel fired steam-electric generating facilities that, due to their physical size, require extensive field fabrication. Additional classification can be performed on the basis of stoking technique: mass burning and refuse derived fuel or semisuspension firing. Furnace construction can be a basis for categorization: water wall or refractory wall systems. Facilities can also be classified on the basis of air pollution control devices: no air pollution control equipment; electrostatic precipitator and baghouse with or without dry scrubbers; and selective noncatalytic or catalytic reduction NO_x control techniques. Facilities can be classified on the basis of primary energy products: steam, electricity, steam and electricity; district heating and cooling; and potable water. Procurement method is another classification: architect/engineer, turn-key, full service, Department of Defense.

There are also a variety of special conditions that can serve as a basis of facility classification including: using the waste-to-energy facility to repower an existing turbine generator; the retirement of old bonds as part of the full service facility price; facilities priced after extended development periods; and facilities known to be priced under radically different international exchange rate structures.

RESULTS AND FINDINGS

The data indicate that at the study-level, the prices of refuse derived fuel and mass burning water wall installations are indistinguishable. This result is reasonable because the extra cost of an refuse derived fuel front end can be offset by the comparatively smaller furnace and emissions control system than is required for an mass burning water wall based system. Also, since the available price data are the result of competitive processes, any real cost difference could easily be obscured by a bidder's pricing practices. As a result, the same equation can predict the study-level price for both the refuse derived fuel and the mass burning water wall facilities. This means that the mass burning water

¹ Langley, J. W. *JASA* 62 (no. 319).

² Draper, N. R., and Smith, H. *Applied Regression Analysis*. New York: John Wiley & Sons, Inc., 1981, 241ff.

wall versus refuse derived fuel decision need not be made during the preliminary development stages of a project. Instead, the final decision can probably be made on the basis of noncost considerations.

Mass burning refractory wall facilities, including Modular Combustion Units, were less expensive than mass burning water wall or refuse derived fuel fired facilities in the range of capacities where they are generally used.

When the steam generating systems are small enough, they can be extensively shop fabricated and shipped to the field as large modules for assembly. When the equipment becomes larger, practical shipping restrictions limit the size of the pieces. Thus, extensive field work is required in order to erect the plant. As plants increase in size and pass through a threshold, somewhere between 35 and 50 MW, the physical characteristics of the backend equipment (e.g., turbines, cooling towers, chillers, etc.) change so that considerably more field work is required than is required for smaller plants. Modular construction techniques decreased the cost of large incinerators. However, while shop fabrication of small combustion units reduced the cost relative to similarly sized field erected mass burning water wall's, their unit price is greater than that experienced by modular mass burning refractory wall units. When the usual range of application of the techniques is considered, the trend lines are virtually continuations of each other. This finding is not unreasonable considering that shop assembled units and modularized mass burning refractory wall's fill different market niches.

These investigations showed that electric generating, cogenerating and district heating and cooling installations have the same study-level price. Steam plants are less expensive and potable water (desalination) installations are more expensive.

The available data logically indicates that facilities without air pollution control equipment are less expensive than facilities with high efficiency electrostatic precipitators. Combining a dry scrubber with a baghouse or an electrostatic precipitator is more expensive than simply equipping a facility with an electrostatic precipitator. However, recent bidding experience indicates that one dry scrubber/baghouse installation was priced by a vendor below an ultra-high efficiency electrostatic precipitator designed to meet an 0.01 gr/DSCF @ 12% CO₂ standard. Further, the EPA report to Congress³ provides guidelines which require dry

scrubbers and either baghouses or electrostatic precipitators so that considering any other pollution control option, while necessary for data understanding, is probably only of academic interest. As a result, coefficients are not provided for the recommended study level pricing equation.

While two of the plants in the data base employ SNCR technology, no significant facility price impact could be discerned. Most procurement methods (architect/engineer, full service or turn-key) did not explain a statistically significant portion of the data variance except for facilities bought using Department of Defense procurement methods. Since the Department of Defense facilities included in the data base were mostly built 10–20 years ago, this finding might be happenstance rather than real. As a result, a coefficient is not provided in the recommended study-level pricing equation.

Special circumstances, such as repowering an existing plant or buying an abandoned plant as part of the facility price, were found to be significant. Due to their infrequent occurrence, the coefficients are highly statistically significant but not intuitively meaningful for purpose of estimating study-level facility prices. We note that such facilities exhibit unit prices that are within the 90% upper confidence limit discussed later in this paper.

Only a slight improvement was found when the pricing model coefficients were estimated for data "plotted" on log-log paper (as is conventionally done to "linearize" the cost of different size equipment) compared to a curve fit using usual engineering units. The linear form of the equation is provided due to ease of use.

The data analysis indicates that the following equation is a good study-level predictor of facility price:

$$\begin{aligned}
 k\$/\text{TPD} = & 112.6 - 0.0129 (\text{TPD}) + 7.41 (\text{FAB1}) \\
 & \quad [5.82] \quad [1.12] \\
 & - 10.40 (\text{FAB2}) - 26.10 (\text{FTYPE}) \\
 & \quad [3.36] \quad [5.42] \\
 & - 23.40 (\text{ETYPE}) \\
 & \quad [6.38] \\
 & \quad \quad \quad N = 61 \\
 & \quad \quad \quad \text{Multiple } R = 0.914 \\
 & \quad \quad \quad F_{12,48} = 20.33 \\
 & \quad \quad \quad \text{Std. Error} = 9.65
 \end{aligned}$$

where

(a) $k\$/\text{TPD}$ is the price in thousands of dollars per ton of daily installed capacity.

³ Greene, Stephen. *Municipal Waste Combustion Study: Report to Congress*. National Technical Information Service, PB87-206074AS, June 1987.

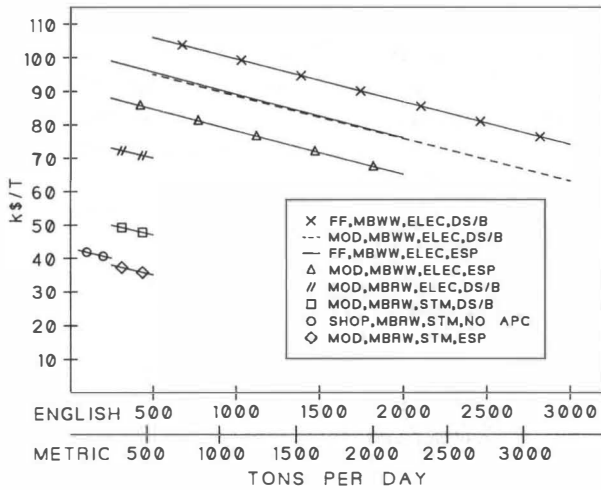


FIG. 2 FACILITY PRICES PER TON OF DAILY INSTALLED CAPACITY PREDICTED USING THE FORECASTING EQUATION

(b) TPD is the installed name plate capacity of the facility in tons per day.

(c) FAB1 has a value of 1 for shop fabricated modular combustion furnaces and 0 for all other types.

(d) FAB2 has value of 1 for units that make extensive use of modular construction techniques and 0 for all other types. This usually applies in the 75–450 TPD individual furnace capacity range.

(e) FTYPE has a value for 1 for a refractory wall unit and 0 for all others.

(f) ETYPE has a value of 1 if process or heating steam is the energy product and a value of 0 for all other products.

The *t*-statistic for each regression coefficient is shown in brackets under the coefficients. All the coefficients are intuitively meaningful. With the exception of the adjustment for a shop assembled unit, all the coefficients are highly statistically significant.

Please note that the default reference plant is a field erected, mass burning water wall or refuse derived fuel fired steam electric plant equipped with a dry scrubber and baghouse (or dry scrubber and electrostatic precipitator) procured using a full service or turn-key approach. To determine the price for such a plant, set all the dummy variables to zero and the equation reduces to the leading constant and the TPD term.

To use the price equations, specify the installed name plate capacity for a facility, include other coefficients as appropriate, and then calculate the price per ton of installed capacity algebraically. For example, a 2500

TABLE 1 DATA PARAMETERS FOR THE WASTE-TO-ENERGY SCREENING LEVEL COST EQUATION

Parameter	Parameter Mean	Parameter Std. Deviation
TPD	943	772
FAB1	0.482	0.2766
FAB2	0.426	0.4986
FTYPE	0.131	0.3404
ETYPE	0.230	0.4240

TPD facility to be built with a dry scrubber and baghouse, using a turn-key procurement method and co-generating steam and electricity would, using the equation, has an estimated unit price of: \$80,350/T and the study-level estimate for the price paid to a vendor would be:

$$2500 \text{ TPD } [(80.35 \text{ k\$/TPD})(1000\$/\text{k\$})] = \$200,875,000$$

The Confidence Interval for the study-level estimate can be estimated using the following formula⁴ for estimating the confidence interval for the price given the average value (mean) and standard deviation of the parameters investigated and provided in Table 1.

$$CL = \pm (\text{Std. Error}) (t_{v,\alpha}) \left[1 + \frac{1}{N} + \frac{1}{N-1} \sum \left(\frac{\text{Parameter-Mean}}{\text{SDEV}_{\text{parameter}}} \right)^2 \right]$$

where: *CL* stands for confidence limit and the summation is over all the estimators in the equation.

We note that including the dropped terms into the confidence limit involves adding 1.4×10^{-3} to the equation inside the parenthesis (before taking the square root). The change is negligible.

For the preceding example, at the 90% confidence level, $t_{48,0.90} = 1.68$ and the Confidence Interval is $\pm 16.89 \text{ k\$/TPD}$ or $\pm 21\%$ of the estimate. This confidence interval provides estimated bounds. The likelihood that the price will be within a range (90% in this case) or below the upper bound (95% in this case) can be stated. Prices outside these limits are possible and depend on vendor pricing policy (vendor's marketing approach and risk posture) and market forces. We believe the 90% Upper Confidence Limit is a reasonably prudent estimate of facility price to use in planning.

Our analysis of the data demonstrates that the predicted price for the largest facility and the upper 90%

⁴Norusis, J. J. *SPSS* Introductory Statistics Guide*. New York: McGraw-Hill, 145, 1983, 145.

confidence limit for the smallest facility in each category described below are for:

(a) A small modular combustion unit based steam facility of less than 250 TPD are respectively \$40,000 and \$68,000 per ton of daily municipal solid waste processing capability.

(b) A small refractory wall steam facility (equipped with dry scrubbers) of between 200 and 500 TPD are respectively \$70,000 and \$90,000 per ton of daily municipal solid waste capability.

(c) A small field erected electric or cogeneration facility equipped with dry scrubbers of between 500 and 1500 TPD are respectively \$85,000 and \$112,000 per ton of daily municipal solid waste processing capability.

(d) A large field erected electric or cogeneration facility equipped with a dry scrubber of between 2000 and 3000 TPD, which is as large of a facility as we had information and data, are respectively \$112,000 and \$129,000 per ton of daily municipal solid waste processing capacity.

These facility prices must, of course, be recognized as only part of the total facility cost as previously discussed.

SUMMARY

The information presented here provides a framework and basis for study-level construction price estimates of waste-to-energy facilities. A statistically

significant, intuitively satisfying pricing model was calibrated. The models can be used to provide study-level construction price estimates during the early planning stages of a project. Project development, insurance, financing and interest expenses need to be added to estimate project costs.

Based upon the information collected and the general trends observed:

(a) Capital construction price decreases with increasing size within size ranges and increases with a higher value energy product.

(b) Price is also affected by the construction, procurement and air pollution control methods employed.

(c) Refuse derived fuel and mass burning water wall facilities are competitively priced.

Although this paper only addresses systems that recover energy from solid waste, it is important to remember that other resource recovery and conservation strategies should be considered and can be integrated with the use of these plants to create a comprehensive waste management strategy. Fortunately, waste-to-energy plants and waste reduction strategies are usually compatible. This combination allows public benefits to be maximized while an area's disposal costs are minimized.

ACKNOWLEDGEMENT

Amy B. Markiewicz's efforts in reducing the data was invaluable and is acknowledged.