EPA/452/B-02-001

Section 1

Introduction

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Chapter 2

Cost Estimation: Concepts and Methodology

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2.1 Introduction

This chapter presents a methodology that will enable the user, having knowledge of the source being controlled, to produce study-level cost estimates for a control system applied to that source. The methodology, which applies to each of the control systems included in this Manual, is general enough to be used with other "add-on" systems as well. Further, the methodology can apply to estimating the costs of fugitive emission controls and for other non-stack abatement methods.

2.2 Types of Cost Estimates

As mentioned in Chapter 1.1, the costs and estimating methodology in this Manual are directed toward the "study" estimate with a nominal accuracy of ± 30% percent. According to Perry's Chemical Engineer's Handbook, a study estimate is "… used to estimate the economic feasibility of a project before expending significant funds for piloting, marketing, land surveys, and acquisition … [However] it can be prepared at relatively low cost with minimum data."[1] Specifically, to develop a study estimate, the following must be known:

- Location of the source within the plant;
- Rough sketch of the process flow sheet (i.e., the relative locations of the equipment in the system);
- Preliminary sizes of, and material specifications for, the system equipment items;
- Approximate sizes and types of construction of any buildings required to house the control system;
- Rough estimates of utility requirements (e.g., electricity);
- Preliminary flow sheet and specifications for ducts and piping;
- Approximate sizes of motors required.[1]

In addition, the user will need an estimate of the labor hours required for engineering and drafting activities because the accuracy of an estimate (study or otherwise) depends on the amount of engineering work expended on the project. There are four other types of estimates, three of which are more accurate than the study estimate. Figure 2.1 below, displays the relative accuracy of each type of cost estimation process. The other processes are:[1]

- Order-of-magnitude. This estimate provides "a rule-of-thumb procedure applied only to repetitive types of plant installations for which there exists good cost history". Its error bounds are greater than ± 30%. (However, according to Perry's, "… no limits of accuracy can safely be applied to it.") The sole input required for making this level of estimate is the control system's capacity (often measured by the maximum volumetric flow rate of the gas passing through the system).

- Scope, Budget Authorization, or Preliminary. This estimate, nominally of ± 20% accuracy, requires more detailed knowledge than the study estimate regarding the site, flow sheet, equipment, buildings, etc. In addition, rough specifications for the insulation and instrumentation are also needed.

- Project Control or Definitive. These estimates, accurate to within ± 10%, require yet more information than the scope estimates, especially concerning the site, equipment, and electrical requirements.

- Firm or Contractor's or Detailed. This is the most accurate (± 5%) of the estimate types, requiring complete drawings, specifications, and site surveys. Consequently, detailed cost estimates are typically not available until right before construction, since "time seldom permits the preparation of such estimates prior to an approval to proceed with the project."[1]

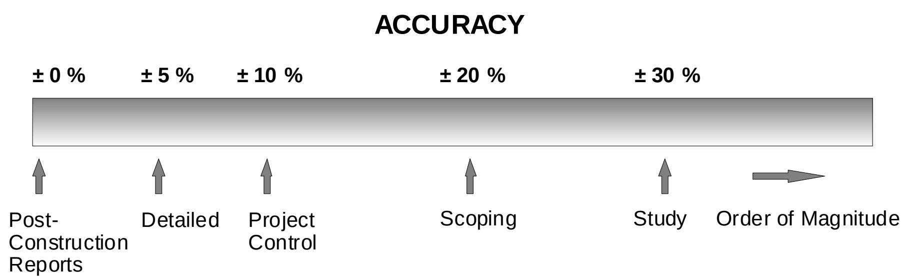


Figure 2.1: The Continuum of Accuracy for Cost Analyses

Study-level estimates are acceptable for regulatory development because they represent a compromise between the less accurate order-of-magnitude and the more accurate estimate types. The former is too imprecise to be of much value, while the latter are not only very expensive to make, but require detailed site and process-specific knowledge that most Manual users will not have. Over time, this Manual has become the standard for air pollution control costing methodologies for many regulatory agencies. For example, Virginia requires that the Manual to be used in making cost estimates for BACT and other permit applications, unless the permit applicant can provide convincing proof that another cost reference should be used.[1]

When used by industry to plan for the installation of a pollution control device, this Manual offers the user an opportunity for greater accuracy than that used by regulators. Since the industrial user will necessarily have much more detailed information than the generic cost and sizing information used in a study estimate, the methodology employed by this Manual can provide cost estimates

[1] Correspondence with William Vatavuk, former editor and author of the Manual, 12/24/01.

that approach those of a scoping study. However, the EPA does not claim cost estimates for industry at a greater than study level accuracy for industrial users, even though the anecdotal evidence from most testimonials volunteered by industrial users indicate a much greater than ±30 percent accuracy can be attained.

2.3 Cost Categories Defined

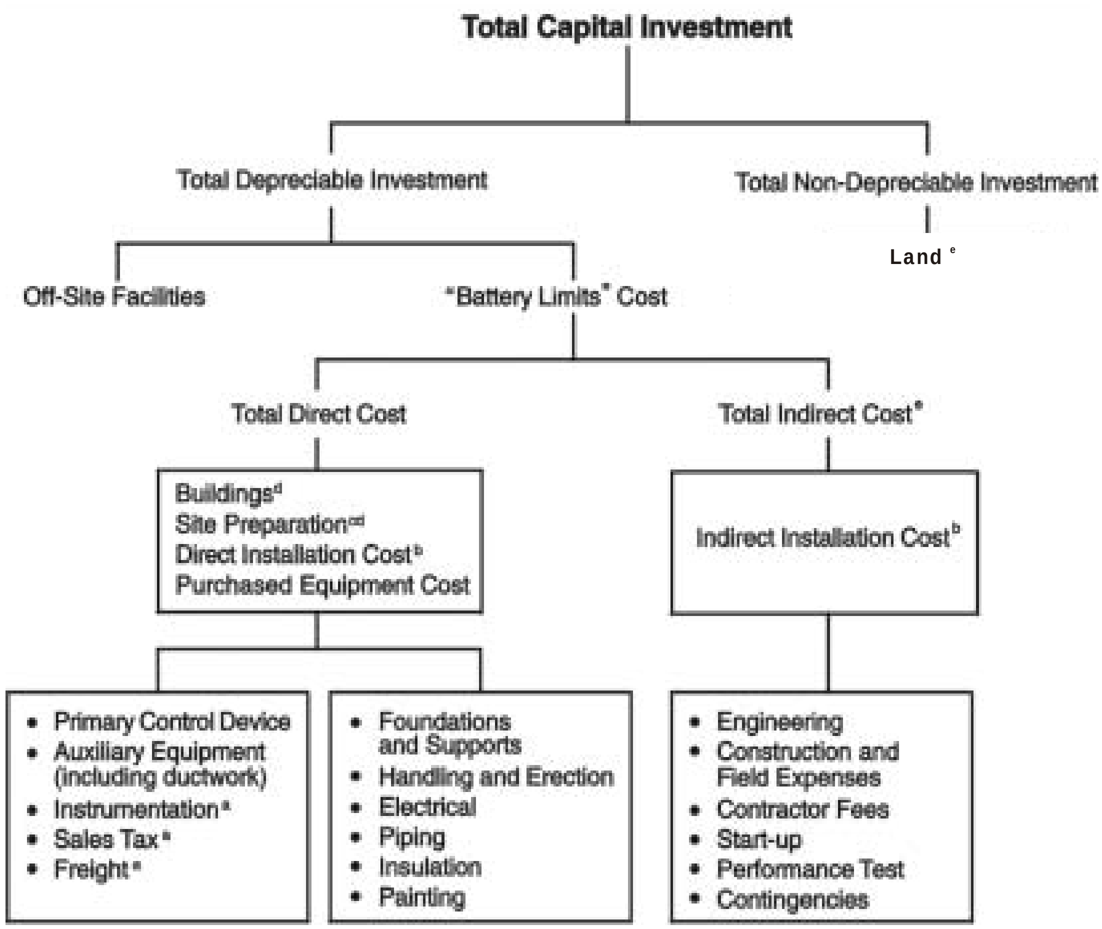
The terminology used in the earlier editions of this Manual were adapted from the American Association of Cost Engineers.[2]. However, different disciplines give different names to the same cost components and the objective of this edition is to reach out to a broader scientific audience. For example, engineers determine a series of equal payments over a long period of time that fully funds a capital project (and its operations and maintenance) by multiplying the present value of those costs by a capital recovery factor, which produces an Equivalent Uniform Annual Cash Flow (EUAC) value. This is identical to the process used by accountants and financial analysts, who adjust the present value of the project's cash flows to derive an annualized cost number.

2.3.1 Elements of Total Capital Investment

Total capital investment (TCI) includes all costs required to purchase equipment needed for the control system (purchased equipment costs), the costs of labor and materials for installing that equipment (direct installation costs), costs for site preparation and buildings, and certain other costs (indirect installation costs). TCI also includes costs for land, working capital, and off-site facilities.

Direct installation costs include costs for foundations and supports, erecting and handling the equipment, electrical work, piping, insulation, and painting. Indirect installation costs include such costs as engineering costs; construction and field expenses (i.e., costs for construction supervisory personnel, office personnel, rental of temporary offices, etc.); contractor fees (for construction and engineering firms involved in the project); start-up and performance test costs (to get the control system running and to verify that it meets performance guarantees); and contingencies. Contingencies is a catch-all category that covers unforeseen costs that may arise, such as "… possible redesign and modification of equipment, escalation increases in cost of equipment, increases in field labor costs, and delays encountered in start-up."[2] Contingencies are not the same thing as uncertainty and retrofit factor costs, which are treated separately in this chapter.

The elements of total capital investment are displayed in Figure 2.2. Note that the sum of the purchased equipment cost, direct and indirect installation costs, site preparation, and buildings costs comprises the battery limits estimate. By definition, this is the total estimate "… for a specific job without regard to required supporting facilities which are assumed to already exist…"[2] at the plant. This would mainly apply to control systems installed in existing plants, though it could also apply to those systems installed in new plants when no special facilities for supporting the control system (i.e., off-site facilities) would be required. Off-site facilities include units to produce steam, electricity, and treated water; laboratory buildings; and railroad spurs, roads, and other transportation infrastructure items. Pollution control systems do not generally have off-site capital units dedicated to them since pollution control devices rarely consume energy at that level. However, it may be necessary—especially in the case of control systems installed in new or "grass roots" plants—for extra capacity to be built into the site generating plant to service the system. (A venturi scrubber, which often requires large amounts of electricity, is a good example of this.) Note, however, that the capital cost of a device does not include utility costs, even if the device were to require an off-site facility. Utility costs are charged to the project as operating costs at a rate which covers both the investment and operating and maintenance costs for the utility. Operating costs are discussed in greater detail below.



[a]Typically factored from the sum of the primary control device and auxiliary equipment costs.
[b]Typically factored from the purchases equipment cost.
[c]Usually required only at "grass roots" installations.
[d]Unlike the other direct and indirect costs, costs for these items usually are not factored from the purchased equipment cost. Rather, they are sized and costed separately.
[e]Normally not required with add-on control systems.

Figure 2.2: Elements of Total Capital Investment

As Figure 2.2 shows, the installation of pollution control equipment may also require land, but since most add-on control systems take up very little space (a quarter-acre or less) this cost would be relatively small. Certain control systems, such as those used for flue gas desulfurization (FGD) or selective catalytic reduction (SCR), require larger quantities of land for the equipment, chemicals storage, and waste disposal. In these cases, especially when performing a retrofit installation, space constraints can significantly influence the cost of installation and the purchase of additional land may be a significant factor in the development of the project's capital costs. However, land is not treated the same as other capital investments, since it retains its value over time. The purchase price of new land needed for siting a pollution control device can be added to the TCI, but it must not be depreciated, since it retains its value forever. Instead, if the firm plans on dismantling the device at some future time, then the land should be either excluded from the analysis, or the value of the land should be included at the disposal point as an "income" to the project to net it out of the cash flow analysis (more on cash flow analyses later, in section 2.4.4.1).

One might expect initial operational costs (the initial costs of fuel, chemicals, and other materials, as well as labor and maintenance related to start-up) should be included in the operating cost section of the cost analysis instead of in the capital component, but such an allocation would be inappropriate. Routine operation of the control does not begin until the system has been tested, balanced, and adjusted to work within its design parameters. Until then, all utilities consumed, all labor expended, and all maintenance and repairs performed are a part of the construction phase of the project and are included in the TCI in the "Start-Up" component of the Indirect Installation Costs.

2.3.2 Elements of Total Annual Cost

Total Annual Cost (TAC) has three elements: direct costs (DC), indirect costs (IC), and recovery credits (RC), which are related by the following equation:

$$TAC = DC + IC - RC \tag{2.1}$$

Clearly, the basis of these costs is one year, as this period allows for seasonal variations in production (and emissions generation) and is directly usable in financial analyses. (See Section 2.3.) The various annual costs and their interrelationships are displayed in Figure 2.3.

Direct costs are those that tend to be directly proportional (variable costs) or partially proportional (semi-variable costs) to some measure of productivity - generally the company's productive output, but for our purposes, the proper metric may be the quantity of exhaust gas processed by the control system per unit time. Conceptually, a variable cost can be graphed in cost / output space as a positive sloped straight line that passes through the origin. The slope of the line is the factor by which output is multiplied to derive the total variable cost of the system. Semi-variable costs can be graphed as a positive sloped straight line that passes through the cost axis at a value greater than zero - that value being the "fixed" portion of the semi-variable cost and the slope of the line being analogous to that of the variable cost line discussed above.

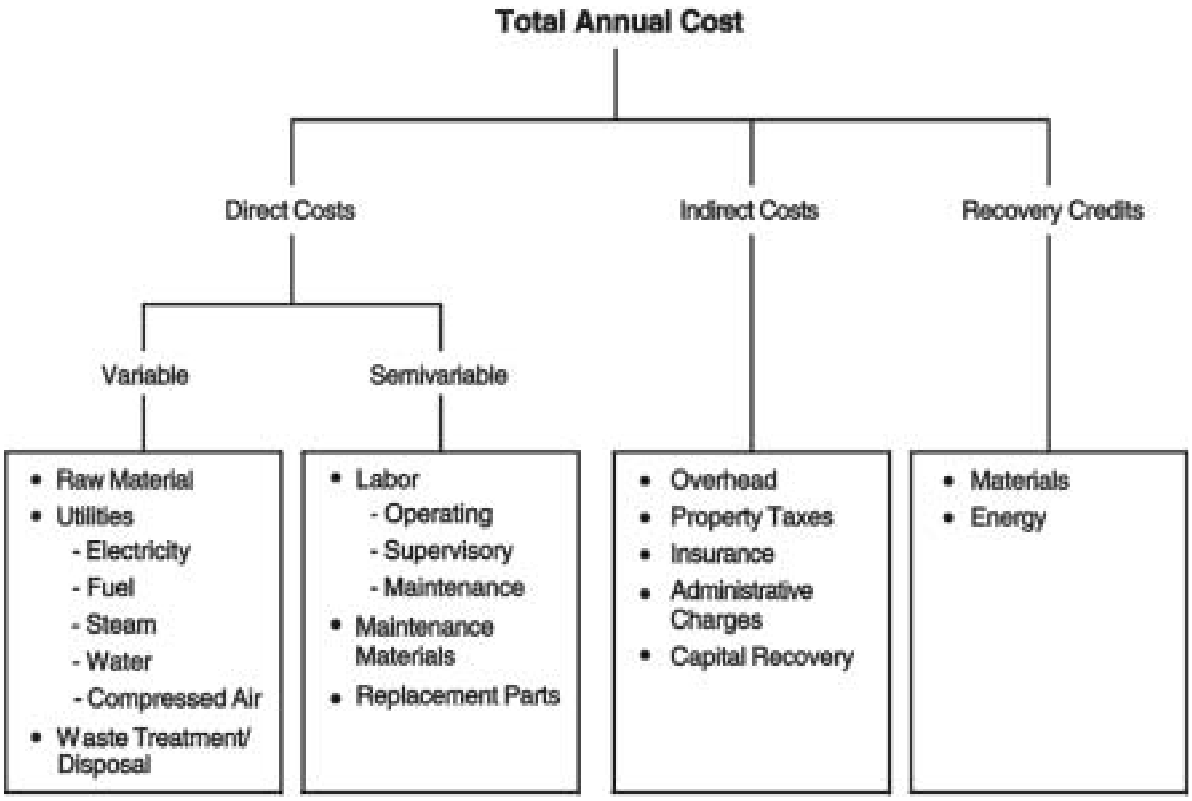


Figure 2.3: Elements of Total Annual Cost

In the graphical representation of variable and semi-variable costs in Figure 2.4, the blue line (lower line) indicates a variable cost function, with all of its value directly related to the level of output on the X-axis. At zero output, the variable cost function returns a variable cost of zero, as well. Alternatively, the upper, red line in Figure 2.4 shows a semi-variable cost, where even at an output level of zero, the system will still incur a cost of $50. The key difference between the two types of variable cost is that at an output level of zero, a semi-variable cost will still exist. An example would be a boiler producing process steam for only sixteen hours a day. During the time the boiler is idle, it costs less to keep the boiler running at some idle level than to re-heat it at the beginning of the next shift. Consequently, that idle level operation cannot be attributed to production and should be considered the fixed component of the semi-variable fuel cost of the boiler. Direct costs include costs for raw materials (reagents or adsorbers), utilities (steam, electricity, process and cooling water), waste treatment and disposal, maintenance materials (greases and other lubricants, gaskets, and seals), replacement parts, and operating, supervisory, and maintenance labor. Generally, raw materials, utilities, and waste treatment and disposal are variable costs, but there is no hard and fast rule concerning any of the direct cost components. Each situation requires a certain level of insight and expertise on the part of the analyst to separate out the cost components accurately.

Capital is depreciable, indicating that, as the capital is used, it wears out and that lost value cannot be recovered. Depreciation costs are a variable or semi-variable cost that is also included in the calculation of tax credits (if any) and depreciation allowances, whenever taxes are considered in a cost analysis. (However, taxes are not uniformly applied, and subsidies, tax moratoriums, and deferred tax opportunities distort how the direct application of a tax works.

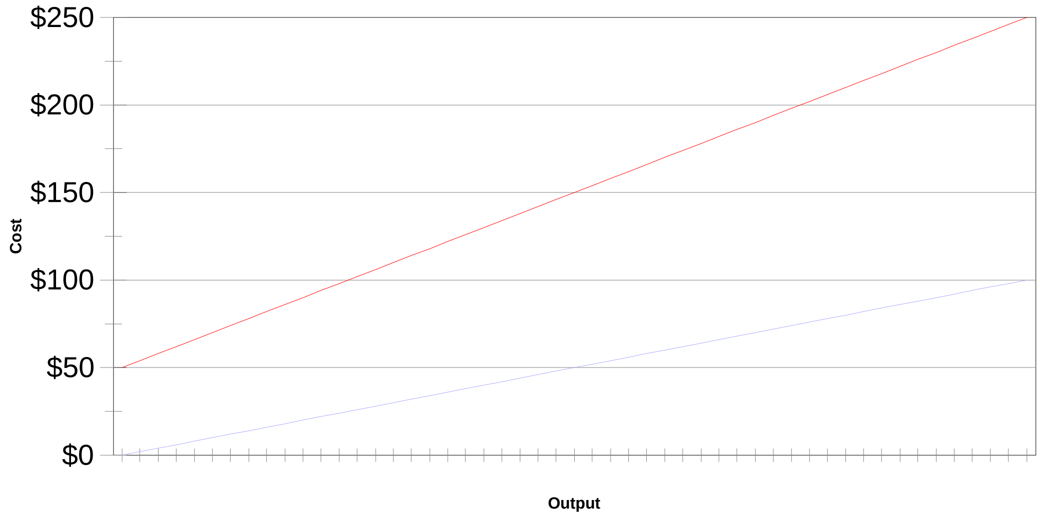


Figure 2.4: Graphical Comparison of Variable and Semi-variable Costs

Therefore, this Manual methodology does not consider income taxes.) Notice that when 100% of the system costs are depreciated, no salvage value can be taken for the system equipment at the conclusion of its useful life. This is a reasonable assumption for add-on control systems, as most of the equipment, which is designed for a specific source, cannot be used elsewhere without modifications. Even if it were reusable, the cost of disassembling the system into its components (i.e., "decommissioning cost") could be as high (or higher) than the salvage value. If a salvage value exists and will be recouped at the end of the useful life of the control, then that value must be included in the analysis. The exercise discussed later in this chapter employs a salvage value to illustrate its proper use.

Indirect, or "fixed", annual costs are independent of the level of production (or whatever unit of measure serves as the analytical metric) and, in fact, would be incurred even if the control system were shut down. Indirect costs include such categories as administrative charges, property taxes, insurance, and capital recovery. A fixed cost function added to Figure 2.4 would be a horizontal line appearing at the level of the fixed cost.

Finally, direct and indirect annual costs can be offset by recovery credits, taken for materials or energy recovered by the control system, which may be sold, recycled to the process, or reused elsewhere at the site. An example of such credits is the by-product of controlling sulfur with an FGD. As the lime or limestone reagent reacts with the sulfur in the exhaust gas stream, it becomes transformed into $CaSO4$ - gypsum - which can be landfilled inexpensively (a direct cost) or collected and sold to wallboard manufacturers (a recovery credit). These credits, must be calculated as net of any associated processing, storage, transportation, and any other costs required to make the recovered materials or energy reusable or resalable. Great care and judgement must be exercised in assigning values to recovery credits, since materials recovered may be of small quantity or of doubtful purity, resulting in their having less value than virgin material. Like direct annual costs, recovery credits are variable, in that their magnitude is directly proportional to level of production. A more thorough description of these costs and how they may be estimated is given in Section 2.4.

2.4 Financial Concepts

Engineers use a relatively small set of financial tools to assess alternative capital investments and to justify their selections to upper management. Most often, the engineer's purpose is to show how the recommended investment will improve the company's profitability. To a great extent, this sort of decision is voluntary. Adding a new assembly line or changing from one type of gasket material to another can be postponed or even rejected. This is not the case with pollution control devices, which are necessary for compliance with State and Federal pollution standards and generally have a deadline attached to their installation. Consequently, a decision to install device X may not originate with the engineer. Instead, the process may actually work backward, relative to the profitability motivated assessment of the engineer: the company's environmental manager could identify the need for pollution control equipment and then pass that decision on down to the engineer.

When air quality regulations limit the source's choice to only one control type, (e.g., when the regulation specifies the technology to be used), this Manual serves two functions. First, it ensures as complete a cost profile as possible has been taken for planning purposes. Second, identification of the appropriate control technology does not include site-specific requirements that need to be identified and costed out. This Manual provides engineering data for the proper sizing and design specification of the control. When the environmental manager can choose between alternative control technologies to achieve the same pollution abatement requirement, this Manual performs a third function by "normalizing" the financial data from each alternative so that a well reasoned selection can be made.

To fully assess the cost of a pollution control device, the reader must understand several financial analysis concepts. This section of the Manual discusses how these concepts fit together to provide the analyst with insight into the cost and selection of alternative pollution control equipment. Earlier editions of the Manual focused on the assessment of financial information from an engineering perspective. However, EPA has learned the audience that uses the Manual extends well beyond the engineering discipline. Consequently, one of the key changes in this edition of the Manual involves adjusting the financial and economic data to reach that broader audience. Wherever earlier editions included engineering-specific names for financial terms, the engineering name remains, but the technical term from a financial perspective has been included, as well.

Section 2.4.1 discusses how the value of money changes over time and how that led to the derivation of interest and discount rates. Section 2.4.2 discusses the three kinds of interest rates that are important to this Manual, and how to select the right interest rate for your analysis. Section 2.4.3 describes how persistent increases in the general level of prices (inflation) are handled in this edition of the Manual and how to select and use a price index to translate the prices in this edition (2001 dollars) to your future analyses.

2.4.1 Time Value of Money

The costs and benefits of an investment occur over an extended period of time rather than at the moment of purchase. Consequently, financial analyses and benefit-cost studies must accommodate the future effects of current decisions. If individuals placed the same value on a dollar in the future that they placed on a dollar in the present, financial analysis could be simplified to the summation of all future costs and incomes derived from the investment. However, as the old saying goes: "A bird in the hand is worth two in the bush". Not only could the promise of a future dollar go unfulfilled, but the purchasing power of that dollar could decline. Furthermore, spending the dollar in the present offers immediate rewards that have to be postponed if the dollar is withheld until some future date. Therefore, individuals demand compensation to offset these concerns, thereby increasing the value of a future payment to more than a dollar. Conversely, to take payment today on a dollar promised for some time in the future, that same person will accept less than a full dollar because they could enjoy its benefits immediately without the risks of inflation or non-payment. This adjustment process is called the principle of the time value of money.

Adding more time to the delay of payment has a cumulative effect. For example, if an investment required an adjustment of ten percent for each year the decision maker has to postpone collection, a dollar would have to return \$1.10 at the end of the first year (\$1.00 times 110%), and \$1.21 for the decision maker to wait two years (\$1.00 times 110% times 110%). The formula for calculating the future value of a dollar invested today is:

$$FV = \$1 \times (1+i)^n \tag{2.2}$$

where FV is the future value of the dollar invested, i is the interest rate, and n is the number of interest rate periods (typically years) before the investment has matured. Analogously, discounting future payments to the present has the same "accumulative" effect. For example, if a person wanted to be paid immediately, rather than wait one year for payment of a dollar, (at the same ten percent interest rate used above), they would be willing to accept \$0.92 (\$1 divided by 110%). To be paid immediately for a dollar promised in two years, they would be willing to accept $0.83 ($1 divided by [110% times 110%]). The present value (*PV*) of a future dollar realized in year n can be calculated by the following formula:

$$PV = \frac{\$1}{(1+i)^n} \tag{2.3}$$

2.4.2 Interest Rates

Analysts use the interest rate to estimate the time value of money. It can be thought of as a return on investment or the cost of borrowing. A discount rate is an interest rate used to estimate the value of current payments in lieu of waiting until some time in the future. There are three types if interest rates that are important for this Manual: real, nominal, and social. The interest rate stated by lending institutions is a nominal interest rate. It is the cost of borrowing and the lender will have included in it a factor to account for anticipated changes in the general level of prices (inflation). Removing the inflation adjustment from the nominal interest rate yields the real rate of interest - the actual cost of borrowing. For example, say an investor borrows $100 at 10% from a bank for one year. At the end of the year, the investor must pay back $110 dollars. However, if during that year the inflation rate was six percent, the bank may receive $10 in interest, but it takes $106 to equal the purchasing power of the $100 loaned out the previous year. Consequently, it only made $4 in real interest. In equation form, the nominal interest rate (i) equals the real interest rate (i_r) plus the expected rate of inflation (p^e):

$$i = i_r + p^e \tag{2.4}$$

The interest rate employed in this Manual differs from that used in non-governmental financial analyses. It represents a social interest rate established by the Office of Management and Budget (OMB) for the comparison of public policy issues. Like a nominal or real interest rate, a social rate of interest compensates for the foregone benefits associated with spending a dollar today; but for slightly different reasons. Society as a whole has a collective rate of time preference that equates the value of future benefits with an equivalent level of benefits enjoyed now. This rate of preference (interest) would be the same as that which the market would assign to a completely riskless investment. In practice, that riskless investment is represented by the long-term interest rate on government bonds and securities. When determined in this manner, the social rate of discounting should be appropriate for the evaluation of social projects. However, the process is not that simple. Private funds bankroll public projects, and tax effects distort the true cost of borrowing. Furthermore, government securities play a macroeconomic role in the maintenance of

[1]This assumption introduces very little error.

the overall economy, fluctuating with the supply of money to stimulate and impede spending as conditions warrant. (For example, at this writing, the 30-year Treasury Bill rate of interest has fluctuated between 4.5 and 5.5 percent within the last 30 days.) Therefore, the interest rate of government securities may be a starting point, but they are not the same as the social discount rate.

In social terms, spending a dollar today on pollution control equipment means not making investments that could have provided immediate improvements to social welfare. For instance, the installation of a fabric filter baghouse on a coal-fired boiler will reduce the amount of particulate matter (*PM*) emitted into the atmosphere, but the steel used to build the baghouse could have been used to expand the factory or make ambulances or fire trucks. The social discount rate (a real interest rate) measures these kinds of foregone alternative uses. Unlike the return on investment for industry, which varies across industries (and even across firms within an industry), the foregone social benefits associated with an investment remain the same across industries. Also, since a change in the general level of prices affects everyone simultaneously, social rates of interest do not account for inflation. OMB sets the social interest rate for governmental analyses, and it is currently set at seven percent.[1]

When State, local, Tribal and other governmental authorities assess pollution control costs, the seven percent interest rate employed in this Manual should produce estimations comparable to those established by the Agency when it performs its own evaluations. However, the social rate of interest is probably not appropriate for industry. When choosing between alternative air pollution control devices, the industrial planner must not only take into consideration the costs of each device, they must also understand how the cost of each device fits into the financial structure of their business. Furthermore, a number of air regulations allow sources of pollution to petition for extensions on deadlines, variances from the regulation, or exemption from installing control devices, based upon the economic impact that equipment would have upon the source. In these cases, the source may find it useful to apply their own interest rate to the calculation of control costs. Common interest rates used by industry and accepted by the EPA for source petitions include the business' current borrowing rate, the current prime rate, and other acceptable industrial rates of return. Because industry may use an interest rate different from the EPA's seven percent social rate for its calculations, EPA facilitates the application of a customized interest rate in each chapter of the Manual by providing detailed explanations of all formulas and by allowing users of the CO$T-AIR spreadsheets and the Air Compliance Advisor program with the ability to change their interest rates to suit their specific situation.

2.4.3 Prices and Inflation

The prices in the Manual were not standardized. Some chapters had prices developed in the late 1990s, and other chapters had prices developed from as far back as 1985. Because these differences were not explicitly discussed in these earlier additions, the Agency attempted to

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[1] www.epa.gov/ttn/catc/products.html#cccinfo

[2] U.S. Office of Management and Budget, Circular A-94: Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs. October 29, 1992. Prior to 1992, the OMB-determined social discount rate was 10%.

standardize all prices in this sixth edition of the Manual to reduce the chance for analytical error. Over the past two years, new values for equipment costs were developed by re-surveying affected industries and vendors. This effort updated all the costs to at least 1990.

To develop the costs used in each of the chapters of this Manual, we surveyed the largest possible group of vendors to determine an industry average price for each cost component. In many cases, this involved contact with hundreds of vendors and the assimilation of large amounts of data. In other cases, the pollution control equipment was supplied by only a few vendors, which limited the independence of our models. And, in still other cases, the number of existing manufacturers or the highly site-specific nature of their installation made it difficult for us to develop completely unbiased prices for some components.

Updating costs is an on-going effort at EPA with a goal of standardizing all costs to one base year. Each chapter of the Manual fully discloses the limitations of the costing information found in that chapter. This allows the analyst may make any adjustment they deem necessary.

Real and nominal prices act in the same way as real and nominal interest rates. Nominal prices are actual prices (i.e., the sticker price) and represent the value of a particular good at a particular point in time. Real prices remove the effect of inflation. Adjusting nominal prices to real prices involves establishing a base year for comparison purposes and then creating an adjustment factor for each year's prices relative to those in the base period. This adjustment factor is a price index (PI) that can then be used to adjust nominal prices to an equivalent base year value; derived through the following formula:

$$PI = \frac{price\ in\ given\ year}{price\ in\ base\ year} \tag{2.5}$$

The Federal government and industry develop a variety of indexes tailored to the analysis of specific price issues. The most recognizable of these indexes are the Consumer Price Index (CPI) and the Producer Price Index (PPI), which investigate the change in prices across the entire economy. However, these indexes are often too general for the specific needs of industry. For pollution control purposes, OAQPS has developed and maintained the Vatavuk Air Pollution Control Cost Indexes (VAPCCI) which provides an estimate of the change in prices for the purchase of pollution control devices. The VAPCCI can be found on the Internet, at the OAQPS web site and the Technology Transfer Network (TTN) web site. [1]   Other indexes are also available from industry and academic sources through the Internet, industry publications, trade journals, and financial institutions. When choosing the right price index for your analysis, employ the "ABC Principle" - that the index is Accepted by industry or financial institutions, it is Bias-free, and it is Conservative. Bias is a statistical sampling or testing error caused by systematically favoring some outcomes over others. It is a reflection of the judgement and opinion of the analyst but is not the same thing as "professional judgement." Bias most commonly appears as a "self-fulfilling prophesy" that incorrectly validates an incorrect assumption on the analyst's part. "Conservative" often gets interpreted as "careful" - an intentional over- or under-estimation of the actual value to avoid the negative effects of errors. Selection of an index employing these standards will most likely not cause estimation error or be challenged by persons or agencies overseeing your work.

2.4.4 Financial Analysis

Once you have amassed all of the necessary information on the design, installation, operation, and revenue of a possible capital investment, what does that tell you about how that investment will affect the overall financial health of your firm? When comparing two different investment opportunities, how do you distill all of these data into one comprehensive and coherent form so that an informed decision can be made? This section deals with a number of the concepts and operations that will help you answer these questions.

When alternative investment opportunities exist - or, for our purposes, when more than one pollution control device may be used - the selection of the most appropriate alternative depends on that alternative's effect on the firm's profitability. Consequently, financial analysts have created a set of tools that provide insight into the potential financial consequences associated with an investment. While no single tool works in all instances, applying several of these tools can provide the financial manager with sufficient insight for a meaningful decision to be made.

Survey evidence indicates most analysts use more than one tool to make financial decisions.[2] The remainder of this section discusses each of these tools and describes their relative strengths and weaknesses. The most fundamental analysis needed is that of cash flow, which formalizes the expected inflows of revenue and outflows of expenses associated with an investment alternative. Pollution control devices do not typically generate revenues, but environmental cost accountants still begin their evaluation of pollution control alternatives through cash flow analysis as a precursor to the application of other tools.[3] The next section discusses cash flow analysis and how it applies to pollution control equipment. Probably the most important tool in the analyst's arsenal is net present value (*NPV*) since it acts as the foundation for a number of related analyses, including benefits/cost analysis. The sections after cash flow analysis discuss these common financial analysis tools. At the end of this chapter is an exercise that applies these concepts.

2.4.4.1 Cash Flow

Incomes and expenditures take place over the life of an investment (its planning horizon), the amounts and timing of which constitute the cash flows of the project. Pollution control system costing always includes expenditures but may not necessarily have incomes. For a control to be income generating, it must reduce production cost (through fewer inputs or product reformulation), or it must capture and recover a pollutant with recyclable characteristics (e.g., solvent recovery).

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[2] c.f., R.S. Kaplan and A.A. Atkinson, Advanced Management Accounting, 2nd ed., Engelwood Cliffs, NJ: Prentice Hall, 1989.

[3] U.S.Environmental Protection Agency, Environmental Cost Accounting for Capital Budgeting: A Benchmark Survey of Management Accounting, #EPA742-R-95-005. Washington D.C., U.S. EPA Office of Pollution Prevention and Toxics, 1995.

For illustration purposes, consider a hypothetical series of cash flows for a project with an operational life of ten years. The data for this figure can be found in Table 2.1, below and will be used as the basis for further financial discussion to follow.

Table 2.1: Hypothetical Cash Flow

	Year										
	0	1	2	3	4	5	6	7	8	9	10
Expenses	-250	-33	-30	-30	-30	-30	-30	-30	-32	-34	-39
Revenues	0	50	65	65	65	65	65	65	62	58	50
Net Cash Flow	-250	17	35	35	35	35	35	35	30	24	11

Figure 2.5 is the cash flow information in graphical form. Expenses are solid red bars extending below the line and incomes are solid blue bars above it. Figure 2.5 displays net cash flow - the difference between incomes and expenses - as white bars on the graph. Typical of many equipment-related cash flows, the greatest cost occurs at time zero, when the control is purchased and installed. In the first years of operation, costs tend to be relatively high for operating and maintaining new equipment, due to balancing and breaking-in conditions. After that, costs tend to drop and remain fairly constant until the equipment approaches the end of its useful life, when operations and maintenance costs tend to rise again. In the hypothetical example, the control generates income that offsets the costs of operations and maintenance during the life of the equipment. This is not the typical situation for pollution control devices, but is used in this hypothetical example because it allows us to illustrate other financial concepts.

2.4.4.2 Payback

Probably the simplest form of financial analysis is the payback period analysis, which simply takes the capital cost of the investment and compares that value to the net annual revenues that investment would generate. If net annual revenues are the same every year, the revenue can simply be divided into the total capital investment to calculate the payback period. If the annual net revenues differ, then the values need to be summed sequentially until the revenue exceeds total capital investment. The payback decision rule is to select that investment with the shortest payback time. For instance, consider the hypothetical example above. It has a capital investment of $250, and costs between $30 and $39 per year to operate and maintain. The project also has an expected revenue generating capacity of between $50 and $65 per year, for annual net revenues of between $11 and $35 per year. If all revenues and expenses were equal, say to the steady state values of $65 and $30, respectively, the project would

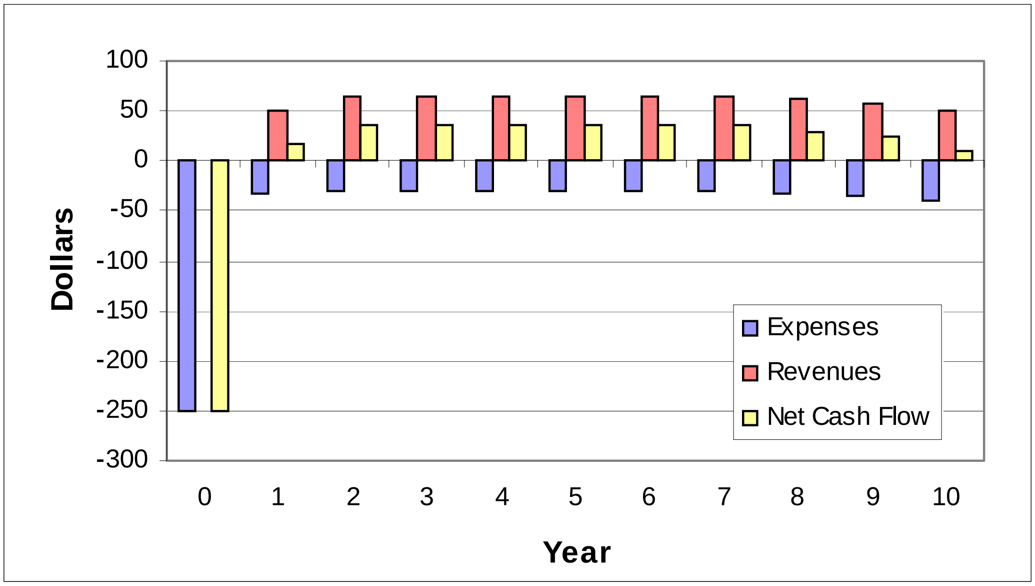

Figure 2.5: Hypothetical Cash Flow Diagram

have had a net annual revenue of $35 per year, suggesting the investment would "pay itself back" in a little more than seven years ($250 divided by $35/yr). However, with uneven revenues and costs, we have to sum the net revenues to determine when they exceed the initial capital cost - in year eight, for the hypothetical example.

For most pollution control devices, payback analysis is not possible because the device does not produce revenue. However, for a limited number of devices (FGD units, VOC recovery devices, etc.), the device may produce a saleable product that produces a revenue stream. In these cases, payback is a very limited tool and offers only the grossest of estimates with regard to relative profitability, for the following reasons. First, payback ignores the magnitude and direction of cash flows in all of the years in the planning horizon beyond the payback period. A project that paid for itself in five years and produced revenues in all years after payback would have the same payback value as one that paid back in the same time yet incurred huge losses in all subsequent years!

Second, payback does not take into account the time value of money. Consider the example above. Applying the social discount rate of seven percent, the capital investment will never pay for itself. The net revenues for the ten years of the payback period in real "year zero" dollars are $15.89, $30.57, $28.57, $26.70, $24.95, $23.32, $21.80, $17.46, $13.05, $5.59, respectively, leaving the payback of investment short in real terms by more than 20 percent! [1]

Next, even if the payback analysis is performed in real terms rather than in nominal terms,

[1] Apply the discounting factors found in Appendix A at the end of this chapter to derive these values.
[2] The author invites the reader to construct the appropriate cash flow analyese spreadsheets as an exercise.

the process still fails when comparing dissimilar projects. Payback considers all projects with equal payback periods to be equally feasible, regardless of other characteristics. Referring again to our hypothetical example, assume the equipment has a useful life of ten years and a payback value of seven. Furthermore, consider a second alternative investment, again with a payback period of seven years, but now the equipment has a useful life of only seven years. For simplicity sake, assume all years for both investments have a net revenue of $35.[2] While payback considers both projects to be equal, the second project would actually cost more over the ten year period because it would have to be replaced at the end of its useful life. Therefore, when using the payback method, the analyst must be sure to standardize all of the alternatives to the length of the longest planning horizon among the choices.

2.4.4.3 Net Present Value

To evaluate alternative pollution control devices, the analyst must be able to compare them in a meaningful manner. Since different controls have different expected useful lives and will result in different cash flows, the first step in comparing alternatives is to normalize their returns using the principle of the time value of money discussed in section 2.4.1. The process through which future cash flows are translated into current dollars is called present value analysis. When the cash flows involve income and expenses, it is also commonly referred to as net present value analysis. In either case, the calculation is the same: adjust the value of future money to values based on the same (generally year zero of the project) , employing an appropriate interest (discount) rate and then add them together. The decision rule for NPV analysis is that projects with negative NPVs should not be undertaken; and for projects with positive NPVs, the larger the net present value, the more attractive the project.

Derivation of a cash flow's net present value involves the following steps:

- Identification of alternatives - for example, the choice between a fabric filter bag house and an electrostatic precipitator (ESP) for removing particulate matter (PM) from a flue gas stream.

- Determination of costs and cash flows over the life of each alternative - each of the subsequent chapters of this Manual offer detailed costing information on specific air pollution control devices and equipment, and the supplemental programs that support the Manual, the Air Compliance Advisor (ACA) program, and the CO$T-Air spreadsheets provide the same costing information electronically.

- Determination of an appropriate interest (discount) rate - for States, local, Tribal, and other environmental management organizations, the EPA's seven percent social discount rate will probably be the most appropriate. Industrial users of this Manual should consult with their financial officers and / or trade association for input. Section 2.3.2 in this chapter, discusses some of the issues that govern industry's choice of an appropriate interest rate. If no private defendable discount rate can be identified, then the industry analyst should fprobably use the Agency's social rate for its own analyses.

- For each alternative: Calculate a discounting factor for each year over the life of the equipment - For example, the EPA's seven percent discount rate produces discount factors of: 0.9346, 0.8734, 0.8163, 0.7629, and 0.7130 for the 1st, 2nd, 3rd, 4th, and 5th years of a piece of equipment's life, respectively. Table A.1 in Appendix A displays discount factors for interest rates from 5.5 to 15 percent, in half-percent increments for 25 years.

- For each year's cash flows, sum all incomes and expenses to determine the net cash flow for that year in nominal terms (see section 2.4.4.1).

- Multiply each years' net cash flow by the appropriate discount factor.

- Sum the discounted net cash flows to derive the net present value.

- Compare the net present values from each alternative. Higher net present values indicate better investment opportunities, relative to the other alternatives in the decision set.

The net present value of a stream of cash flows over the life of an investment can be calculated using equation 2.6:

$$NPV = \sum_{t=0}^{n} NCF_t \left(\frac{i}{1 - (1+i)^{-t}} \right) \qquad (2.6)$$

where NCF_t represents the net cash flow for year *t*, and *i* is the interest rate.

However, net present value analysis has limitations. Consider a hypothetical firm investigating the installation of two alternative air pollution controls. One alternative would be to retrofit existing equipment that has only five years of useful life remaining. The other strategy would be to salvage existing equipment and replace it with new state-of-the-art components that pollute less. This strategy would have a useful life of 20 years. If the retrofitting process has a higher net present value, does that mean it is the better choice? Not necessarily, because the new equipment would have to be purchased in five years, anyway, resulting in two sets of investments. If the new equipment strategy had a higher NPV, would it be a better choice? Not necessarily, since the firm would have to scrap existing equipment to install the new system. Furthermore, timing the installation of the state-of-the-art controls with the replacement of the fully depreciated equipment postpones the investment for five years (allowing it to decline in value in real terms) and avoids scrapping equipment that is still useful.

One solution to the timing problem described above would be to extend the retrofit alternative by adding 15 years' worth of equipment replacement at the end of the retrofit period. This would provide a more meaningful comparison, since it would be for similar time periods and would also include the two expenditures for equipment necessary for the retrofit to occur. Another solution would be to augment the information received from net present value analysis by employing other financial analysis tools.

Calculating NPV is not difficult, but it does require some subjective decision-making by the analyst to establish the appropriate discount rate or rates to apply. Since market forces typically incorporate inflation adjustments into investment returns and borrowing costs, often the discount rate is keyed to a standard reference rate. As with choosing a cost index, when choosing the appropriate rate for a present value analysis, apply the "ABC Principle" - that the rate is Accepted, Bias-free, and Conservative. As a general rule of thumb, the higher the discount rate, the less expensive (more discounted) the present value will be. Therefore, the ideal discount rate would be one that which matches the highest rate of return the firm can obtain by investing, or the lowest rate at which it can borrow money, whichever is higher. If the analyst chooses a discount rate lower than this "ideal" rate, then the net present value of the investment will appear high, relative to other investment opportunities and the firm will run the risk of taking on an investment decision that has been artificially inflated to make it more attractive. Conversely, if the discount rate chosen is too high, then the net present value of the investment will appear unfavorable, relative to other investment opportunities and the firm risks rejecting a potentially favorable investment. The same arguments hold for pollution control decisions. When applying for a permit to build or operate a source of pollution, the application of an inappropriate discount rate can lead to erroneous petitions for waivers or variances. Therefore, the EPA pays particular attention to the interest / discount rates used in operating and new source review permits.

2.4.4.4 Equivalent Uniform Annual Cash Flow and Annualization

When you purchase a new home, you do not immediately pay for the cost of construction, maintenance, upkeep, and all of the other expenses you will incur over the next thirty years. Instead, you probably borrowed the money from a lender to make the initial purchase and will pay annual expenses as the occur. Net present value analysis allows us to evaluate between investments by summing the present value of al future incomes and expenses, but that does not give us an insight into the expected cash flows that will actually occur. So, instead of paying up front for all the future costs of installation, maintenance, and operation of a pollution control device (NPV analysis), what if the payments could be equalized (in constant net present value dollars) over the life of the control? A common engineering tool for this sort of evaluation is called the equivalent uniform annual cash flow (EUAC) method.[3] EUAC works best when the is only one capital investment to incorporate and annual cash flows are constant or normalized to one year, typically year zero. When comparing EUACs for competing systems, analysts should avoid comparing systems with widely differing useful lives. Comparing EUACs for systems with lives differing by two or three years may be reasonable, but beyond that range, comparisons become problematic. This Manual does not recommend the use of EUAC by itself and only when the useful lives of alternative controls are very similar.

Annualization is a process similar to EUAC but is not limited to constant cash flows. It involves determining the net present value of each alternative equipment investment and then determining the equal (in nominal terms) payment that would have to be made at the end of each year to attain the same level of expenditure. In essence, annualization involves establishing an annual "payment" sufficient to finance the investment for its entire life, using the formula:

$$PMT = NPV\left(\frac{i}{1-(1+i)^{-n}}\right) \tag{2.7}$$

where *PMT* is the equivalent uniform payment amount over the life of the control, *n*, at an interest rate, *i*. *NPV* indicates the present value of the investment as defined above in equation 2.6.

Engineering texts call this payment the capital recovery cost (*CRC*), which they calculate by multiplying the *NPV* of the investment by the capital recovery factor (*CRF*):

$$CRC = NPV \times CRF \tag{2.8}$$

where *CRF* is defined according to the formula:

$$\mathrm{CRF} = \left(\frac{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{n}}}{(1+\mathrm{i})^{\mathrm{n}}-1}\right) \tag{2.8a}$$

The *CRF* equation is a transformation of the *PMT* form in equation 2.7 and returns the same information. Table A.2 in Appendix A lists the *CRF* for discount rates between 5.5 percent and 15 percent for annualization periods from one to 25 years.

2.4.4.5 Other Financial Analysis Tools

Many firms make investment decisions based upon the return on investment (*ROI*) of the proposed capital purchase, rather than the magnitude of its net present value. In and of itself, the ROI of an investment opportunity is of little use. For most pollution control investments, *ROI* analysis does not provide much in the way of useful information because, like a payback analysis, it must have positive cash flows to work properly. Calculated by dividing annual net income by the investment's capital cost, results in a percentage of the investment that is returned each year. The decision rule one should apply for *ROI* analysis is if the resulting percentage is at least as large as some established minimum rate of return, then the investment would be worth while. However, different industries require different rates of return on investments, and even within an industry, many different rates can be found. Analysts should consult with their firm's financial officers or an industrial association to determine what percentage would apply.

In its simplest terms, internal rate of return (IRR) is a special case of net present value analysis used to separate "good" investment opportunities from "bad". In fact, many trade organizations publish standard IRR rates for their particular industry. Projects with an IRR less than the industry standard should be rejected as not providing sufficient income to make them worth while; and projects with IRRs greater than the industry standard should be considered good investment opportunities. NPV analysis is actually a series of current values, each one associated with a different interest rate. For each interest rate chosen, the NPV of the same investment will differ, increasing from a negative NPV at very low interest rates to a positive NPV at higher rates. For each investment analyzed, the interest rate that results in a net present value of exactly zero is the investment's IRR. However, the application of IRR depends on having positive cash flows, which again limits their use in analyzing pollution control alternatives; but, when there are positive cash flows, IRR can provide useful information.

Twenty years ago, IRR was not easily used because there is no direct method for deriving it. Instead, a project's IRR had to be determined manually by an iterative process that could take many hours to perform. Today, although the mathematical processes behind determining an IRR have not changed, the convenience of computers have made it much easier to perform. Most spreadsheet programs available today offer an IRR calculator within their financial tools. One of the biggest problems with applying the internal rate of return methodology happens when the relevant cash flow switches between positive and negative. When this occurs it is possible to derive two or more different IRRs for the same project. When that happens, IRR is not applicable for determining the acceptance of independent projects or for identifying the best investment risk out of a group of potential projects.

The benefit-cost ratio of an investment is defined as the ratio of the discounted benefits to the discounted cost, each evaluated at the same constant dollar rate - generally in year zero dollars. With benefits in the numerator of the ratio, the criterion for accepting a project on the basis of the benefit-cost ratio is whether or not the benefit-cost ratio is greater than or equal to one (i.e., benefits are greater than costs). However, as with the payback analysis and financial tools that rely on incomes, benefit cost ratios can be problematic when applied to pollution control devices and evaluated from a strict financial standpoint.

2.4.4.6 Economic versus Accounting Costs and Benefits

From a strict financial standpoint, many of the tools discussed above do not have an application to industry when evaluating pollution control devices. This is not the case when the analysis is being performed at the regulatory level. In these cases, all of the above tools can prove beneficial - provided the analyst includes the appropriate set of costs and benefits (incomes). Clearly, benefit cost analysis is a powerful regulatory tool for evaluating pollution control equipment when assessed from an economic perspective, where the external costs and benefits of the device

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[2] Retrofit factors for specific applications (coal-fired boiler controls) have been developed. See references [14] and [15].

can be more easily quantified. That is because economic costs are not the same as accounting costs and economic benefits are not the same as accounting benefits.

Accounting costs are those costs included in a financial statement, ledger, or other accounting record. They “account for” the transfer of funds between one entity and another. However, economic costs are a much broader cost category. While they include accounting costs, other typical economic costs a regulator may encounter when assessing pollution control issues would include external costs - the cost incurred by others and not part of the accounting system of the firm. For example, a boiler may produce large particles of unburned or partially burned fuels (soot). While the owner of the boiler pays for the cost of that fuel through higher fuel costs, it does not include the cost of cleaning that soot off of buildings and houses upwind of the plant. The owner also does not have to pay for the asthma medicine for affected people who suffer respiratory problems because of that soot, nor does it compensate them for the discomfort of that asthma attack. The first of these economic costs is fairly straight forward and the economic literature has many examples of how to approximate it. The second is a health issue that can also be approximated, although only after a great deal of study and analysis. The third cost, compensation for discomfort, is a psychic cost and is extremely difficult to quantify. However these and many other similar costs should be considered by the regulatory analyst when assessing the usefulness of a pollution control alternative.

Similar to economic and accounting costs, accounting benefits (revenues, avoided production costs) are a subset of economic benefits. Pollution control devices reduce pollution and their installation reduces the occurrence of these economic costs, so the regulatory analyst would include among the benefits of the device the avoided economic costs derived from the pollutant. In other words, a soot free building does not have to pay for cleaning - and that avoided cost is considered a benefit of the device. Similarly, not having an asthma attack is also considered a benefit of the device. When we perform an economic assessment of a pollution control device, we such as a bag house for capturing soot before it enters the atmosphere, we look at the benefit of avoiding these economic costs.

When performing an economic assessment of a pollution control alternative, the analyst can apply economic costs and benefits to payback (to establish a “social payback” period), net present value analysis (for benefit cost analyses or to compare to the social discount rate through ROI or IRR). Without going into detail on the science of economic assessment, the analyst should be able to go back to each of the discussions above and readily see how to apply these simple accounting tools to an economic study.

2.5 Estimating Procedure

The estimating procedure used in the Manual consists of five steps: (1) obtaining the facility parameters and regulatory options for a given facility; (2) roughing out the control system design; (3) sizing the control system components; (4) estimating the costs of these individual components; and (5) estimating the costs (capital and annual) of the entire system.

2.5.1 Facility Parameters and Regulatory Options

Obtaining the facility parameters and regulatory options involves not only assembling the parameters of the air pollution source (i.e., the quantity, temperature, and composition of the emission stream(s)), but also compiling data for the facility's operation. (Table 2.2 lists examples of these.) We identify two facility parameters: intensive (with values independent of quantity or dimensions) and extensive (size-dependent variables, such as the gas volumetric flow rate).

Regulatory options are usually specified by others (generally a regulatory authority) and are often technology driven, typically defining allowable ways to achieve a predetermined emission limit. These options range from "no control" to a requirement for the system to reach the maximum control technically achievable. The options allowed will depend, firstly, on whether the emission source is a point source (a stack or other identifiable primary source of pollution), a fugitive source (a process leak or other source of pollution that could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening) or an area fugitive source (an unenclosed or partly enclosed area, such as a storage pile or a construction site). Stacks are normally controlled by "add-on" devices - the primary focus of this Manual. (However, some of these devices can be used to control process fugitive emissions in certain cases, such as a fabric filter used in conjunction with a building evacuation system.) Add-on pollution controls are normally used to meet a specified emission limit, although in the case of particulate emissions, they may also be required to meet an opacity level.

Table 2.2: Facility Parameters and Regulatory Options

Facility Parameters	Regulatory Options
Intensive	**No control**
Facility status (new or existing, location)	
Gas Characteristics (temperature, pressure, moisture control)	**ìAdd-onî devices**
	Emission limits
Pollutant concentration(s) and/or particle size distribution	Opacity limits
Extensive	**Process modification**
Facility capacity	Raw material changes
Facility life	Fuel substitution
Exhaust gas flow rate	
Pollutant emission rate(s)	**Source/Feedstock pretreatment**
	Coal desulfurization
	Wet dust suppression

2.5.2 Control System Design

Roughing out the control system design involves deciding what kinds of systems will be priced (a decision that will depend on the pollutants to be controlled, exhaust gas stream conditions, and other factors), and what auxiliary equipment will be needed. When specifying the auxiliary equipment, several questions need to be answered:

- What type of hood (if any) will be needed to capture the emissions at the source?
- Will a fan be needed to convey the exhaust through the system? Does the system require any other auxiliary equipment, such as a pump to inject liquids into the exhaust gas stream?
- Does the exhaust stream pose any hazard to the materials of the hoods, ducts, fans, and other auxiliary equipment? Is the exhaust caustic or acidic? Is it abrasive? Does the treatment of the exhaust render it caustic or acidic?
- Does the exhaust stream require any pre-treatment (e.g., cyclone or another pre-cleaner) before it enters the control device?
- Will the captured pollutants be disposed of or recycled? How will this be done?
- Can the on-site capacity (e.g., utilities, stockpiling space) accommodate the added requirements of the control system?

The kinds of auxiliary equipment selected will depend on the answers to these and other site-specific questions. However, regardless of the source being controlled, each system will likely contain, along with the control device itself, the following auxiliaries:

- Hood, or other means for capturing the exhaust;
- Ductwork, to convey the exhaust from the source to, through, and from the control system;
- Fan system (fan, motor, starter, inlet/outlet dampers, etc.), to move the exhaust through the system and to prevent pressure drop within the system due to the pollution control system;
- Stack, for dispersing the cleaned gas into the atmosphere.

2.5.3 Sizing the Control System

Once the system components have been selected, they must be sized. Sizing is probably the most critical step because the assumptions made in this step will more heavily influence capital investment than any other. Table 2.3 lists examples of these parameters. Also listed in Table 2.3 are general parameters which must be specified before the purchased cost of the system equipment can be estimated. Note that, unlike the control device parameters, these parameters may apply to any kind of control system. They include materials of construction (which may range from carbon steel to various stainless steels to fiberglass- reinforced plastic), presence or absence of insulation, and the economic or useful life of the system. As indicated in Section 2.4.2, this last parameter is required for estimating the annual capital recovery costs. The lifetime not only varies according to the type of the control system, but with the severity of the environment in which it is installed. Each of the control-specific chapters of this Manual and the Air Compliance Advisor (ACA) program include a comprehensive list of the specific parameters that must be considered for each device.

Table 2.3: Examples of Typical Control Device Parameters [11]

General	Device-Specific
Material of construction: carbon steel	Gas-to-cloth ratio (ìcritical parameterî): 3.0 to 1
Insulated? Yes	Pressure drop: 6.0 in w.c. (inches water column)
Economic life: 20 years	Construction: standard (vs. custom)
Redundancy[a]: none	Duty: continuous (vs. intermittent)
	Filter type: shaker
	Bag material: polyester, 16-oz.

[a] Refers to whether there are any extra equipment items installed (e.g., fans) to function in case the basic items become inoperative, so as to avoid shutting down the entire system.

2.5.4 Estimating Total Capital Investment

2.5.4.1 General Considerations

The fourth step is estimating the purchased equipment cost of the control system equipment. As discussed in Section 2.2, total direct cost includes purchased equipment cost, which in turn, is the sum of the base equipment cost (control device plus auxiliaries), freight, instrumentation, and sales tax. The values of these installation factors depend on the type of the control system installed and are, therefore, listed in the individual Manual chapters dedicated to them. These costs are available from this Manual for the most commonly used add-on control devices and auxiliary equipment, with each type of equipment covered in a separate chapter (see Table of Contents and the discussion in Chapter 1). Total Direct Cost also includes Direct Installation Cost, which contains many of the cost categories included in Section 2 of this Manual, Generic Equipment and Devices.

Most of the costs in each of the subsequent sections of this Manual were derived from data obtained from control equipment vendors. For many control devices there are many vendors, which allowed us to offer highly representative costs, based upon the average cost of components submitted by those vendors in response to Agency survey efforts. [7] For items that are mass produced or "off-the-shelf" equipment, vendors provided a written quotation listing their costs, model designations, date of quotation, estimated shipment date, and other information. For other equipment there are not many vendors or we did not receive many responses to our inquiries. In these cases, we offer costs that are as representative as possible and the cost discussion in that control's particular chapter offers an appropriate caveat to the analyst.

For some controls, no amount of vendor data would have made our cost numbers more accurate because the control in question is either so large or so site-specific in design that suppliers design, fabricate, and construct each control according to the specific needs of the facility. For these devices (specifically, SCR reactors and FGD units), the Manual deviates from its standard approach of providing study level costs and, instead, provides a detailed description of the factors that influence the TCI for the analyst to consider when dealing with a vendor quotation. For these kinds of controls, the vendor may still give quotations, but will likely take much longer to do so and may even charge for this service, to recoup the labor and overhead expenses of his estimating department. When performing a cost analysis, the cost of the quotation is a part of the TCI.

Generally, vendor quotes are "F.O.B." (free-on-board) the vendor, meaning that no taxes, freight, or other charges are included. For these equipment, the analyst must take care to identify and include the cost of transportation, taxes, and other necessary charges in the TCI (see Figure 2.1). The costs of freight, instrumentation, and sales tax are calculated differently from the direct and indirect installation costs. These items are developed by multiplying the base equipment cost (F.O.B. the vendor) by an industry-accepted factor. Unlike other estimating factors that differ from system to system, installation factors are essentially equal for all control systems. Table 2.4, below, displays values for these factors.

Table 2.4: Cost Ranges for Freight, Sales Tax, and Instrumentation

	% of Total Equipment Cost, FOB	
Cost	Range	Typical
Freight	0.01 ñ 0.10	0.05
Sales Tax	0 ñ 0.08	0.03
Instrumentation	0.05 ñ 0.30	0.10

To some extent, the application of an appropriate factor requires the subjective application of the analyst's best judgement. For example, the range in freight costs is, in part, a function of the distance between the vendor and the site. The lower end of the factor range represents shorter distance deliveries, while the upper end of the range would reflect freight charges to remote locations such as Alaska and Hawaii.[6] The sales tax factors simply reflect the range of local and state tax rates currently in effect in the United States.[8] In some locations, and for many institutional and governmental purchases, sales taxes do not apply; (hence the zero value at the low end of the sales tax factor range). The range of instrumentation factors is also quite large. For systems requiring only simple continuous or manual control, the lower factor would apply. However, if the control is intermittent and/or requires safety backup instrumentation, the higher end of the range would be applicable.[6] Finally, some "package" control systems (e.g., incinerators covered in Chapter 3) have built-in controls, with instrumentation costs included in the base equipment cost. In those cases, the instrumentation factor to use would, of course, be zero.

2.5.4.2 Retrofit Cost Considerations

Probably the most subjective part of a cost estimate occurs when the control system is to be installed on an existing facility. Unless the original designers had the foresight to include additional floor space and room between components for new equipment, the installation of retrofitted pollution control devices can impose an additional expense to "shoe-horn" the equipment into the right locations. For example, an SCR reactor can occupy tens of thousands of square feet and must be installed directly behind a boiler's combustion chamber to offer the best environment for NOx removal. Many of the utility boilers currently considering an SCR reactor to meet the new federal NOx limits are over thirty years old - designed and constructed before SCR was a proven technology in the United States. For these boilers, there is generally little room for the reactor to fit in the existing space and additional ductwork, fans, and flue gas heaters may be needed to make the system work properly.

To quantify the unanticipated additional costs of installation not directly related to the capital cost of the controls themselves, engineers and cost analysts typically multiply the cost of the system by a retrofit factor. The proper application of a retrofit factor is as much an art as it is a science, in that it requires a good deal of insight, experience, and intuition on the part of the analyst. The key behind a good cost estimate using a retrofit factor is to make the factor no larger than is necessary to cover the occurrence of unexpected (but reasonable) costs for demolition and installation. Such unexpected costs include - but are certainly not limited to - the unexpected magnitude of anticipated cost elements; the costs of unexpected delays; the cost of re-engineering and re-fabrication; and the cost of correcting design errors.

The magnitude of the retrofit factor varies across the kinds of estimates made as well as across the spectrum of control devices. At the study level, analysts do not have sufficient information to fully assess the potential hidden costs of an installation. At this level, a retrofit factor of as much as 50 percent can be justified. Even at detailed cost level (± 5 percent accuracy), vendors will not be able to fully assess the uncertainty associated with a retrofit situation and will include a retrofit factor in their assessments. For systems installed at the end of the stack, such as flares, retrofit uncertainty is seldom a factor. In these cases, an appropriate retrofit factor may be one or two percent of the TCI. In complicated systems requiring many pieces of auxiliary equipment, it is not uncommon to see retrofit factors of much greater magnitude can be used.

Since each retrofit installation is unique, no general factors can be developed. A general rule of thumb as a starting point for developing an appropriate retrofit factor is: The larger the system, the more complex (more auxiliary equipment needed), and the lower the cost level (eg. study level, rather than detailed), the greater the magnitude of the retrofit factor. Nonetheless, some general information can be given concerning the kinds of system modifications one might expect in a retrofit:

1. Auxiliary equipment. The most common source of retrofit-related costs among auxiliary equipment types comes from the ductwork related costs. In addition, to requiring very long duct runs, some retrofits require extra tees, elbows, dampers, and other fittings. Furthermore, longer ducts and additional bends in the duct cause greater pressure drop, which necessitates the upgrading or addition of fans and blowers.

2. Handling and erection. Because of a “tight fit,” special care may need to be taken when unloading, transporting, and placing the equipment. This cost could increase significantly if special means (e.g., helicopters) are needed to get the equipment on roofs or to other inaccessible places.

3. Piping, Insulation, and Painting. Like ductwork, large amounts of piping may be needed to tie in the control device to sources of process and cooling water, steam, etc. Of course, the more piping and ductwork required, the more insulation and painting will be needed.

4. Site Preparation. Site preparation includes the surveying, clearing, leveling, grading, and other civil engineering tasks involved in preparing the site for construction. Unlike the other categories, this cost may be very low or zero, since most of this work would have been done when the original facility was built. However, if the site is crowded and the control device is large, the size of the site may need to be increased and then site preparation may prove to be a major source of retrofit-related costs.

5. Off-Site Facilities. Off-site facilities should not be a major source of retrofit costs, since they are typically used for well-planned activities, such as the delivery of utilities, transportation, or storage.

6. <u>Engineering. Designing a control system to fit</u> into an existing plant normally requires extra engineering, especially when the system is exceptionally large, heavy, or utility-consumptive. For the same reasons, extra supervision may be needed when the installation work is being done.

7. <u>Lost Production.</u> The shut-down for installation of a control device into the system should be a well-planned event. As such, its cost should be considered a part of the indirect installation cost (start-up). However, unanticipated problems with the installation due to retrofit-related conditions can impose significant costs on the system. (For example, consider a pollution control device to be installed in the middle of a stack. After shutting down the plant, removing a section of the stack reveals it has been worn too thin to weld the device to it, necessitating the fabrication and replacement of a major portion of the stack.) The net revenue (i.e., gross revenue minus the direct costs of generating it) lost during this unanticipated shutdown period is a bonafide retrofit expense.

Due to the uncertain nature of many estimates, analysts may want to add an additional contingency (i.e., uncertainty) factor to their estimate. However, the retrofit factor is a kind of contingency factor and the cost analyst must be careful to not impose a double penalty on the system for the same unforseen conditions. Retrofit factors should be reserved for those items directly related to the demolition, fabrication, and installation of the control system. A contingency factor should be reserved (and applied to) only those items that could incur a reasonable but unanticipated increase but are not directly related to the demolition, fabrication, and installation of the system. For example, a hundred year flood may postpone delivery of materials, but their arrival at the job site is not a problem unique to a retrofit situation.

2.5.5 Estimating Annual Costs

Determining the total annual cost is the last step in the estimating procedure. As mentioned in Section 2.3 the TAC is comprised of three components—direct and indirect annual costs and recovery credits. Unlike the installation costs, which are factored from the purchased equipment cost, annual cost items are usually computed from known data on the system size and operating mode, as well as from the facility and control device parameters.

Following is a more detailed discussion of the items comprising the total annual cost. (Values/factors for these costs are also given in the chapters for the individual devices.)

2.5.5.1 Raw Materials

Raw materials are generally not required with control systems. Exceptions would be chemicals used in gas absorbers or venturi scrubbers as absorbents or to neutralize acidic exhaust gases (e.g., hydrochloric acid). Chemicals may also be required to treat wastewater discharged by scrubbers or absorbers before releasing it to surface waters. If the source uses the same raw materials for production, the analyst must be careful to include only are only those costs that are attributable to the raw materials needed by the control device. Quantities of chemicals required are calculated via material balances, with an extra 10 to 20% added for miscellaneous losses. Costs for chemicals are available from the Chemical Marketing Reporter and similar publications.

2.5.5.2 Labor

The amount of labor required to operate and maintain a pollution control system depends on its size, complexity, level of automation, and operating mode (i.e., batch or continuous). The labor is usually figured on an hours-per-shift basis. As a rule, though, data showing explicit correlations between the labor requirement and capacity are hard to obtain. One non-linear correlation found in the literature is shown below:[11]

$$\frac{L_2}{L_1} = \left(\frac{V_2}{V_1}\right)^y \qquad (2.9)$$

where

L_1, L_2 = labor requirements for systems 1 and 2
V_1, V_2 = capacities of systems 1 and 2 (as measured by the gas flow rate, for instance)
y = 0.2 to 0.25 (typically)

The exponent in Equation 2.9 can vary considerably. Conversely, in many cases, the amount of operator labor required for a system will be approximately the same regardless of its size.

Maintenance labor is calculated in the same way as operating labor and is influenced by the same variables. The maintenance labor rate, however, is normally higher than the operating labor rate, mainly because more skilled personnel are required. Many cost studies use a flat ten percent premium over the operations labor wage rate for maintenance labor costs.[12] A certain amount must also be added to operating labor to cover supervisory requirements. Generally, cost estimates include supervisory labor as a flat fifteen per cent of the operating labor requirement.[12] To obtain the annual labor cost, multiply the operating and supervisory labor requirements(labor-hr/operating-hr) by the respective wage rates (in $/labor-hr) and the system operating factor (number of hours per year the system is in operation). Wage rates also vary widely, depending upon the source category, geographical location, etc. These data are tabulated and periodically updated by the U.S. Department of Labor, Bureau of Labor Statistics, in its Monthly Labor Review and in other publications. This Manual uses labor rates that are representative of the industries at the national level. The supplemental CO$T-AIR spreadsheets and the Air Compliance Advisor (ACA) incorporate these rates as defaults. For regulatory cost assessments, these wages (adjusted for inflation through an appropriate cost index) should be adequate for study level purposes. For industry users of this manual, the CO$T-AIR spreadsheets and the ACA can be customized to include site-specific labor rates and improve the accuracy of the analysis.

Finally, note that the wage rates used by the Manual and its supplemental programs are base labor rates, which do not include payroll and plant overhead. Wages found in reports from the Bureau of Labor Statistics or some other reliable source may or may not include overhead. The analyst must be careful to apply overhead and other wage adjustment factors uniformly. (See the discussion on Overhead, below.)

2.5.5.3 Maintenance Materials

Maintenance also requires maintenance materials—oil, other lubricants, duct tape, etc., and a host of small tools. The costs for these items can be figured individually, but since they are normally so small, they are usually factored from the maintenance labor. Reference [11] suggests a factor of 100% of the maintenance labor to cover the maintenance materials cost.

2.5.5.4 Utilities

This cost category covers many different items, ranging from electricity to compressed air. Of these, only electricity is common to all control devices, where fuel oil and natural gas are generally used only by incinerators; water and water treatment, by venturi scrubbers, quenchers, and spray chambers; steam, by carbon adsorbers; and compressed air, by pulse-jet fabric filters. Techniques and factors for estimating utility costs for specific devices are presented in their respective sections. However, because nearly every system requires a fan to convey the exhaust gases to and through it, a general expression for computing the fan electricity cost (C_e) is given here:[6]

$$C_e = \frac{0.746\ Q\ \Delta P\ s\ \theta\ p_e}{6356\ \eta} \tag{2.10}$$

where

- Q = gas flow rate (actual ft^3/min, acfm)
- ΔP = pressure drop through system (inches of water, column) (Values for ΔP are given in the chapters covering the equipment items.)
- s = specific gravity of gas relative to air (1.000, for all practical purposes)
- θ = operating factor (hr/yr)
- η = combined fan and motor efficiency (usually 0.60 to 0.70)
- p_e = electricity cost ($/kwhr)

A similar expression can be developed for calculating pump motor electricity requirements.

2.5.5.5 Waste Treatment and Disposal

Though often overlooked, there can be a significant cost associated with treating and/or disposing of waste material captured by a control system that neither can be sold nor recycled to the process. Liquid waste streams, such as the effluent from a gas absorber, are usually processed before being released to surface waters. The type and extent of this processing will, of course, depend on the characteristics of the effluent. For example, the waste can first be sent to one (or more) clarifiers, for coagulation and removal of suspended solids. The precipitate from the clarifier is then conveyed to a rotary filter, where most of the liquid is removed. The resulting filter cake is then disposed of, via landfilling, for example.

The annual cost of this treatment can be relatively high—$1.00 to $2.00/thousand gallons of treated material or more.[13] The (non-hazardous) solid waste disposal costs (via landfilling, for example) typically would add another $20 to $30/ton of disposed material.[14] This, however, would not include transportation to the disposal site. Disposal of hazardous waste (which may not be landfilled) can be much more costly—$200 to $300/ton or more. More information on these technologies and their costs is found in References [13] and [14].

2.5.5.6 Replacement Materials

The cost or maintenance materials is a component of the operations and maintenance function of the system and is not the same thing as the system's replacement materials cost, which is the cost of such items as carbon (for carbon absorbers), bags (for fabric filters) and catalyst (for catalytic incinerators), along with the labor for their installation. Because replacement materials last for more than a year but are consumed by the system, they cannot be included in the general maintenance and operations costs, which are annual in nature. Instead, these costs must be annualized by first determining the life of the material, then applying the appropriate capital recovery factor to that cost to determine its annualized value (see section 2.4.5.3, above). The annual cost of the replacement materials is a function of the initial parts cost, the parts replacement labor cost, the life of the parts, and the interest rate, as follows:

$$CRC_p = \left(C_p + C_{pl}\right) CRF_p \quad (2.11)$$

where

CRC_p = capital recovery cost of replacement parts ($/yr)
C_p = initial cost of replacement parts, including sales taxes and freight ($)
C_{pl} = cost of parts-replacement labor ($)
CRF_p = capital recovery factor for replacement parts (defined in Section 2.3).

The useful life of replacement materials is generally less than the useful life of the rest of the control system - typically two to five years. Consequently, the annualization of the system's replacement materials must be done separately from the annualization of the control system itself. Furthermore, the annualized cost of the pollution control system should be performed net of the cost of the replacement materials needed at the beginning of operations to prevent double counting. Replacement materials labor will vary, depending upon the amount of the material, its workability, accessibility of the control device, and other factors. The cost of replacement materials labor should be included in the cost of the materials before annualization.

2.5.5.7 Overhead

This cost is easy to calculate, but often difficult to comprehend. Much of the confusion surrounding overhead is due to the many different ways it is computed and to the several costs it includes, some of which may appear to be duplicative.

There are, generally, two categories of overhead, payroll and plant. Payroll overhead includes expenses directly associated with operating, supervisory, and maintenance labor, such as: workmen's compensation, Social Security and pension fund contributions, vacations, group insurance, and other fringe benefits. Some of these are fixed costs (i.e., they must be paid regardless of how many hours per year an employee works). Payroll overhead is traditionally computed as a percentage of the total annual labor cost (operating, supervisory, and maintenance).

Conversely, plant (or "factory") overhead accounts for expenses not necessarily tied to the operation and maintenance of the control system, including: plant protection, control laboratories, employee amenities, plant lighting, parking areas, and landscaping. Some estimators compute plant overhead by taking a percentage of all labor plus maintenance materials [11], while others factor it from the total labor costs alone.[2]

For study estimates, it is sufficiently accurate to combine payroll and plant overhead into a single indirect cost. This is done in this Manual. Also, overhead is factored from the sum of all labor (operating, supervisory, and maintenance) plus maintenance materials, the approach recommended in reference [11]. The factors recommended therein range from 50 to 70% [11] An average value of 60% is used in this Manual. For more accurate assessments by industrial users of the Manual, the CO$T-AIR spreadsheets and the ACA allow for customization of these factors.

2.5.5.8 Property Taxes, Insurance, and Administrative Charges

These three indirect operating costs are factored from the system total capital investment, at 1, 1, and 2%, respectively. Property taxes and insurance are self-explanatory. Administrative charges covers sales, research and development, accounting, and other home office expenses. (It should not be confused with plant overhead, however.) For simplicity, the three items are usually combined into a single, 4% factor. This is standard approach used in in all OAQPS cost analyses and by this Manual.

2.6 Example

All-American Electrical (AAE) [1] operates a single 600 MWe tangentially fired high sulfur bituminous coal-fired boiler to produce steam to power it generators. It emits an uncontrolled 90,000 tons of sulfur per year, and because it is planning on a major renovation, it must install devices to reduce its sulfur emissions to less than 900 tons per year (99 percent removal efficiency). After careful study of the available technologies, AAE has determined that either a wet limestone flue gas desulfurization (FGD) unit or a wet buffered lime FGD would be the most logical choice to achieve such a high removal rate. For simplification purposes we will assume either device would have an operating life of five years, after which the scrubbers could be sold as scrap for a salvage value of about $500,000. Table 2.5, below, displays the capital and annual costs associated with each of the alternative devices.

Table 2.5: Capital, O&M, and Parasitic Energy Costs of Alternative FGD Controls

	Wet Limestone FGD	Wet Buffered Lime FGD
Capital Cost	$200,000,000	$180,000,000
Annual O&M Costs		
Fixed O&M Costs [a]	$2,000,000	$2,100,000
Reagent	$1,200,000	$3.750,000
Auxiliary Power	$1,300,000	$1,150,000
Annual Gypsum Sales	$1,200,000	$600,000
Parasitic Power [b]	$950,000	$375,000
Salvage Value (after 10 years)	$500,000	$500,000

[a] Estimated at 1% of capital cost
[b] In many systems, the insertion of a pollution control device causes the system to lose productive capacity. This can be caused by the device creating obstructions in the flue, temperature losses that create imbalances, or other physical changes that affect performance. these losses are collectively termed "parasitic power" losses.

From the information in Table 2.5, neither device can be shown to be superior to the other. It costs $20 million less to install a wet buffered lime scrubber, but a buffered lime FGD would cost over three times as much each year for the purchase of the lime, relative to the cost of the reagent in a limestone FGD. Each FGD has similar fixed O&M costs, but because a buffered lime FGD uses much less reagent, it requires less power to run - about half the power demand and about 40 percent of the productive loss of the limestone FGD. While these factors indicate
the wet buffered lime FGD may be a better alternative, the use of less reagent also means the production of less gypsum by-product - for about half the expected revenue generating capability of a limestone system. To make our selection, we must rely upon our financial tools.

The exercise does not lend itself to a payback analysis, even though there are revenues to be generated from the sale of the scrubber's byproduct. So long as annual costs exceed annual revenues, payback will not an alternative because there will be no net revenue to help offset the capital costs of the project. Furthermore, even if one were to ignore the cost component of the cash flow, the revenues from most pollution control devices are so low that their payback values are meaningless. For instance, the limestone and buffered lime scrubbers in this exercise have a simple payback (without considering costs) of 167 and 300 years, respectively. Consequently, the analyst must look to the more sophisticated tools available: cash flow analysis and net present value.

Table 2.6 shows the hypothetical cash flows from each alternative control in nominal dollars. You will notice that the cost for O&M and the revenues from selling the gypsum by-product are constant over time. That is because we have ignored any inflation rate change in prices and have created our cash flow analysis in real terms. This is the preferred way to approach this kind of analysis, since it relies on the most accurate information available (current prices) and does not try to extrapolate those prices into the future. Because we will perform our cash flow analysis in real dollars, we must use the real interest rate to determine net present values. We will assume AAE can borrow funds at will at a nominal interest rate of nine percent and that informed sources expect the inflation rate over the relevant range to be, on average, four percent. Consequently, the real rate of interest is (nine percent minus four percent) five percent. Using real dollars for revenues and costs and then using nominal interest rates for our discounting factors (nine percent) would have led to an understatement of the net present value of the projects, making them appear less beneficial to AAE.

Translating the costs in each future year to year zero values means applying the factors found in Table A.1 from Appendix A. From the 10 percent column, we applied the factors 0.90909, 0.82645, 0.75131, 0.68301, and 062092, respectively, to the net costs of years 1, 2, 3, 4, and 5 to determine the year zero costs, and then sum all of the values to derive the net present value for each control alternative. Based upon the information developed in the cash flow analysis and the NPV calculation, which control device is the best one for AAE to install? The answer is still not evident! Even with a twenty million dollar capital cost savings, the net present value of the wet buffered lime FGD is only about a half million dollars more expensive than the wet limestone FDG! This is a function of the other cash flow components - the higher operating cost of the buffered lime system versus the higher revenue generating capacity of the limestone FGD, both of which work to almost completely eliminate the capital cost advantage of the buffered lime scrubber. Clearly, relying on just the sticker price of the two units could have driven us to a potentially bad decision. So now what? Payback analysis does not offer any help, (nor will IRR, which also relies upon a positive net cash flow to work). Cash flow analysis tells us that, within our study-level estimation range, the two devices are almost identical. That in and of itself is important information, because the environmental engineer can be fairly certain that whichever device they choose, the affect of that choice on his company will be about the same. That leaves them free to look at other considerations: Twice as much limestone means twice as much storage and twice as much stockpiling of the gypsum by-product. Is that an important factor? Limestone is more caustic than buffered lime, but it takes less equipment to operate the system. Should the engineer opt for simplicity in design or potentially higher rates of repair? These are the sort of considerations that can now come into play in making a decision, now that the relative values of each device has been determined.

This does not mean that our process has failed. Far from it. If our input assumptions have been made correctly, then we have determined that from a cost standpoint, there does not seem to be an appreciably different risk to choosing one device over the other. However, other considerations may play a roll in making the choice clearer. For instance, the limestone scrubber will produce about twice as much gypsum as the wet buffered lime scrubber. Does the storage, transportation, or marketability of that amount of gypsum create a problem? Likewise, it takes about three times as much limestone to remove the same amount of sulfur, relative to the amount of lime needed, but the lime costs between five and seven times as much as the limestone. Do these considerations clarify the choice? Finally, the power demands for each device differ significantly, both in terms of operation and in lost productive capacity. Perhaps these considerations will make one device more attractive to the firm. The bottom line is that there is no clear-cut "cookbook" process through which the analyst will be able to make the right informed decision each time, and the formalized costing methodology employed by the Manual is only a part of that process. However, if the Manual's methodology is followed rigorously and in an unbiased manner, then the analyst can feel safe about the ROM-level cost of his alternative projects and can then move on to a more formal cost determination with the help of an engineering or consulting firm.

2.6: Cash Flow Analyses Exercise (in thousands of dollars)

	0	1	2	3	4	5	6	7	8	9	10
Limestone Scrubber											
Income											
Gypsum Sales	0	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Salvage Value	0	0	0	0	0	0	0	0	0	0	500
Expenses											
Capital Investment	200,000	0	0	0	0	0	0	0	0	0	0
Annual O&M Costs	0	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Parasitic Power	0	950	950	950	950	950	950	950	950	950	950
Net Annual Cost	-200,000	-4,250	-4,250	-4,250	-4,250	-4,250	-4,250	-4,250	-4,250	-4,250	-3,750
Present Value	-200,000	-4,048	-3,855	-3,671	-3,496	-3,330	-3,171	-3,020	-2,877	-2,740	-2,302
NPV	-232,510										
Buffered Lime Scrubber											
Income											
Gypsum Sales	0	600	600	600	600	600	600	600	600	600	600
Salvage Value	0	0	0	0	0	0	0	0	0	0	500
Expenses											
Capital Investment	180,000	0	0	0	0	0	0	0	0	0	0
Annual O&M Costs	0	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Parasitic Power	0	375	375	375	375	375	375	375	375	375	375
Net Annual Cost	-180,000	-6,775	-6,775	-6,775	-6,775	-6,775	-6,775	-6,775	-6,775	-6,775	-6,275
Present Value	-180,000	-6,452	-6,145	-5,852	-5,574	-5,308	-5,056	-4,815	-4,586	-4,367	-3,852
NPV	-232,008										

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APPENDIX A

Net Present Value and Capital Recovery Factor Tables

Table A.1 displays the amount an individual would be willing to accept today for a dollar promised in the future. Select the year in which the dollar is supposed to be paid from the leftmost column and the discount rate from the top row. The value where the column and row intersect is the present value of that future dollar. For instance, if you were promised a dollar twelve years from now, and you believed the interest rate over that period would be 9.5 percent, then you would be willing to accept 33.7 cents for that dollar today.

Table A.1: Present Value Factors for a Dollar to Be Paid Now Instead of in a Future Year

	5.50%	6.00%	6.50%	7.00%	7.50%	8.00%	8.50%	9.00%	9.50%	10.00%
1	0.94787	0.9434	0.93897	0.93458	0.93023	0.92593	0.92166	0.91743	0.91324	0.90909
2	0.89845	0.89	0.88166	0.87344	0.86533	0.85734	0.84946	0.84168	0.83401	0.82645
3	0.85161	0.83962	0.82785	0.8163	0.80496	0.79383	0.78291	0.77218	0.76165	0.75131
4	0.80722	0.79209	0.77732	0.7629	0.7488	0.73503	0.72157	0.70843	0.69557	0.68301
5	0.76513	0.74726	0.72988	0.71299	0.69656	0.68058	0.66505	0.64993	0.63523	0.62092
6	0.72525	0.70496	0.68533	0.66634	0.64796	0.63017	0.61295	0.59627	0.58012	0.56447
7	0.68744	0.66506	0.64351	0.62275	0.60275	0.58349	0.56493	0.54703	0.52979	0.51316
8	0.6516	0.62741	0.60423	0.58201	0.5607	0.54027	0.52067	0.50187	0.48382	0.46651
9	0.61763	0.5919	0.56735	0.54393	0.52158	0.50025	0.47988	0.46043	0.44185	0.4241
10	0.58543	0.55839	0.53273	0.50835	0.48519	0.46319	0.44229	0.42241	0.40351	0.38554
11	0.55491	0.52679	0.50021	0.47509	0.45134	0.42888	0.40764	0.38753	0.36851	0.35049
12	0.52598	0.49697	0.46968	0.44401	0.41985	0.39711	0.3757	0.35553	0.33654	0.31863
13	0.49856	0.46884	0.44102	0.41496	0.39056	0.3677	0.34627	0.32618	0.30734	0.28966
14	0.47257	0.4423	0.4141	0.38782	0.36331	0.34046	0.31914	0.29925	0.28067	0.26333
15	0.44793	0.41727	0.38883	0.36245	0.33797	0.31524	0.29414	0.27454	0.25632	0.23939
16	0.42458	0.39365	0.3651	0.33873	0.31439	0.29189	0.2711	0.25187	0.23409	0.21763
17	0.40245	0.37136	0.34281	0.31657	0.29245	0.27027	0.24986	0.23107	0.21378	0.19784
18	0.38147	0.35034	0.32189	0.29586	0.27205	0.25025	0.23028	0.21199	0.19523	0.17986
19	0.36158	0.33051	0.30224	0.27651	0.25307	0.23171	0.21224	0.19449	0.17829	0.16351
20	0.34273	0.3118	0.2838	0.25842	0.23541	0.21455	0.19562	0.17843	0.16282	0.14864
21	0.32486	0.29416	0.26648	0.24151	0.21899	0.19866	0.18029	0.1637	0.1487	0.13513
22	0.30793	0.27751	0.25021	0.22571	0.20371	0.18394	0.16617	0.15018	0.1358	0.12285
23	0.29187	0.2618	0.23494	0.21095	0.1895	0.17032	0.15315	0.13778	0.12402	0.11168
24	0.27666	0.24698	0.2206	0.19715	0.17628	0.1577	0.14115	0.1264	0.11326	0.10153
25	0.26223	0.233	0.20714	0.18425	0.16398	0.14602	0.13009	0.11597	0.10343	0.0923

Table A.1: Continued

	10.50%	11.00%	11.50%	12.00%	12.50%	13.00%	13.50%	14.00%	14.50%	15.00%
1	0.90498	0.9009	0.89686	0.89286	0.88889	0.88496	0.88106	0.87719	0.87336	0.86957
2	0.81898	0.81162	0.80436	0.79719	0.79012	0.78315	0.77626	0.76947	0.76276	0.75614
3	0.74116	0.73119	0.7214	0.71178	0.70233	0.69305	0.68393	0.67497	0.66617	0.65752
4	0.67073	0.65873	0.64699	0.63552	0.6243	0.61332	0.60258	0.59208	0.58181	0.57175
5	0.607	0.59345	0.58026	0.56743	0.55493	0.54276	0.53091	0.51937	0.50813	0.49718
6	0.54932	0.53464	0.52042	0.50663	0.49327	0.48032	0.46776	0.45559	0.44378	0.43233
7	0.49712	0.48166	0.46674	0.45235	0.43846	0.42506	0.41213	0.39964	0.38758	0.37594
8	0.44989	0.43393	0.4186	0.40388	0.38974	0.37616	0.36311	0.35056	0.3385	0.3269
9	0.40714	0.39092	0.37543	0.36061	0.34644	0.33288	0.31992	0.30751	0.29563	0.28426
10	0.36845	0.35218	0.33671	0.32197	0.30795	0.29459	0.28187	0.26974	0.25819	0.24718
11	0.33344	0.31728	0.30198	0.28748	0.27373	0.2607	0.24834	0.23662	0.2255	0.21494
12	0.30175	0.28584	0.27083	0.25668	0.24332	0.23071	0.2188	0.20756	0.19694	0.18691
13	0.27308	0.25751	0.2429	0.22917	0.21628	0.20416	0.19278	0.18207	0.172	0.16253
14	0.24713	0.23199	0.21785	0.20462	0.19225	0.18068	0.16985	0.15971	0.15022	0.14133
15	0.22365	0.209	0.19538	0.1827	0.17089	0.15989	0.14964	0.1401	0.1312	0.12289
16	0.2024	0.18829	0.17523	0.16312	0.1519	0.1415	0.13185	0.12289	0.11458	0.10686
17	0.18316	0.16963	0.15715	0.14564	0.13502	0.12522	0.11616	0.1078	0.10007	0.09293
18	0.16576	0.15282	0.14095	0.13004	0.12002	0.11081	0.10235	0.09456	0.0874	0.08081
19	0.15001	0.13768	0.12641	0.11611	0.10668	0.09806	0.09017	0.08295	0.07633	0.07027
20	0.13575	0.12403	0.11337	0.10367	0.09483	0.08678	0.07945	0.07276	0.06666	0.0611
21	0.12285	0.11174	0.10168	0.09256	0.08429	0.0768	0.07	0.06383	0.05822	0.05313
22	0.11118	0.10067	0.09119	0.08264	0.07493	0.06796	0.06167	0.05599	0.05085	0.0462
23	0.10062	0.09069	0.08179	0.07379	0.0666	0.06014	0.05434	0.04911	0.04441	0.04017
24	0.09106	0.0817	0.07335	0.06588	0.0592	0.05323	0.04787	0.04308	0.03879	0.03493
25	0.0824	0.07361	0.06579	0.05882	0.05262	0.0471	0.04218	0.03779	0.03387	0.03038

Table A.2 displays the annual payment you would have to make for a specific number of years to equal the present value of a single dollar borrowed today. Select the number of years you will make payments from the leftmost column and the discount rate from the top row. The value where the column and row intersect is annual payment on that borrowed dollar. For example, if you plan on making equal payments for twelve years at 9.5 percent interest to repay a dollar borrowed toaday, you would make annual payments of 14.3 cents.

Table A.2: Capital Recovery Factors for Equal Payments on a Dollar over a Number of Years

	5.50%	6.00%	6.50%	7.00%	7.50%	8.00%	8.50%	9.00%	9.50%	10.00%
1	1.055	1.06	1.065	1.07	1.075	1.08	1.085	1.09	1.095	1.1
2	0.54162	0.54544	0.54926	0.55309	0.55693	0.56077	0.56462	0.56847	0.57233	0.57619
3	0.37065	0.37411	0.37758	0.38105	0.38454	0.38803	0.39154	0.39505	0.39858	0.40211
4	0.28529	0.28859	0.2919	0.29523	0.29857	0.30192	0.30529	0.30867	0.31206	0.31547
5	0.23418	0.2374	0.24063	0.24389	0.24716	0.25046	0.25377	0.25709	0.26044	0.2638
6	0.20018	0.20336	0.20657	0.2098	0.21304	0.21632	0.21961	0.22292	0.22625	0.22961
7	0.17596	0.17914	0.18233	0.18555	0.1888	0.19207	0.19537	0.19869	0.20204	0.20541
8	0.15786	0.16104	0.16424	0.16747	0.17073	0.17401	0.17733	0.18067	0.18405	0.18744
9	0.14384	0.14702	0.15024	0.15349	0.15677	0.16008	0.16342	0.1668	0.1702	0.17364
10	0.13267	0.13587	0.1391	0.14238	0.14569	0.14903	0.15241	0.15582	0.15927	0.16275
11	0.12357	0.12679	0.13006	0.13336	0.1367	0.14008	0.14349	0.14695	0.15044	0.15396
12	0.11603	0.11928	0.12257	0.1259	0.12928	0.1327	0.13615	0.13965	0.14319	0.14676
13	0.10968	0.11296	0.11628	0.11965	0.12306	0.12652	0.13002	0.13357	0.13715	0.14078
14	0.10428	0.10758	0.11094	0.11434	0.1178	0.1213	0.12484	0.12843	0.13207	0.13575
15	0.09963	0.10296	0.10635	0.10979	0.11329	0.11683	0.12042	0.12406	0.12774	0.13147
16	0.09558	0.09895	0.10238	0.10586	0.10939	0.11298	0.11661	0.1203	0.12403	0.12782
17	0.09204	0.09544	0.09891	0.10243	0.106	0.10963	0.11331	0.11705	0.12083	0.12466
18	0.08892	0.09236	0.09585	0.09941	0.10303	0.1067	0.11043	0.11421	0.11805	0.12193
19	0.08615	0.08962	0.09316	0.09675	0.10041	0.10413	0.1079	0.11173	0.11561	0.11955
20	0.08368	0.08718	0.09076	0.09439	0.09809	0.10185	0.10567	0.10955	0.11348	0.11746
21	0.08146	0.085	0.08861	0.09229	0.09603	0.09983	0.1037	0.10762	0.11159	0.11562
22	0.07947	0.08305	0.08669	0.09041	0.09419	0.09803	0.10194	0.1059	0.10993	0.11401
23	0.07767	0.08128	0.08496	0.08871	0.09254	0.09642	0.10037	0.10438	0.10845	0.11257
24	0.07604	0.07968	0.0834	0.08719	0.09105	0.09498	0.09897	0.10302	0.10713	0.1113
25	0.07455	0.07823	0.08198	0.08581	0.08971	0.09368	0.09771	0.10181	0.10596	0.11017

Table A.2: Continued

	10.50%	11.00%	11.50%	12.00%	12.50%	13.00%	13.50%	14.00%	14.50%	15.00%
1	1.105	1.11	1.115	1.12	1.125	1.13	1.135	1.14	1.145	1.15
2	0.58006	0.58393	0.58781	0.5917	0.59559	0.59948	0.60338	0.60729	0.6112	0.61512
3	0.40566	0.40921	0.41278	0.41635	0.41993	0.42352	0.42712	0.43073	0.43435	0.43798
4	0.31889	0.32233	0.32577	0.32923	0.33271	0.33619	0.33969	0.3432	0.34673	0.35027
5	0.26718	0.27057	0.27398	0.27741	0.28085	0.28431	0.28779	0.29128	0.29479	0.29832
6	0.23298	0.23638	0.23979	0.24323	0.24668	0.25015	0.25365	0.25716	0.26069	0.26424
7	0.2088	0.21222	0.21566	0.21912	0.2226	0.22611	0.22964	0.23319	0.23677	0.24036
8	0.19087	0.19432	0.1978	0.2013	0.20483	0.20839	0.21197	0.21557	0.2192	0.22285
9	0.17711	0.1806	0.18413	0.18768	0.19126	0.19487	0.19851	0.20217	0.20586	0.20957
10	0.16626	0.1698	0.17338	0.17698	0.18062	0.18429	0.18799	0.19171	0.19547	0.19925
11	0.15752	0.16112	0.16475	0.16842	0.17211	0.17584	0.1796	0.18339	0.18722	0.19107
12	0.15038	0.15403	0.15771	0.16144	0.16519	0.16899	0.17281	0.17667	0.18056	0.18448
13	0.14445	0.14815	0.1519	0.15568	0.1595	0.16335	0.16724	0.17116	0.17512	0.17911
14	0.13947	0.14323	0.14703	0.15087	0.15475	0.15867	0.16262	0.16661	0.17063	0.17469
15	0.13525	0.13907	0.14292	0.14682	0.15076	0.15474	0.15876	0.16281	0.1669	0.17102
16	0.13164	0.13552	0.13943	0.14339	0.14739	0.15143	0.1555	0.15962	0.16376	0.16795
17	0.12854	0.13247	0.13644	0.14046	0.14451	0.14861	0.15274	0.15692	0.16112	0.16537
18	0.12586	0.12984	0.13387	0.13794	0.14205	0.1462	0.15039	0.15462	0.15889	0.16319
19	0.12353	0.12756	0.13164	0.13576	0.13993	0.14413	0.14838	0.15266	0.15698	0.16134
20	0.12149	0.12558	0.1297	0.13388	0.1381	0.14235	0.14665	0.15099	0.15536	0.15976
21	0.11971	0.12384	0.12802	0.13224	0.13651	0.14081	0.14516	0.14954	0.15396	0.15842
22	0.11813	0.12231	0.12654	0.13081	0.13512	0.13948	0.14387	0.1483	0.15277	0.15727
23	0.11675	0.12097	0.12524	0.12956	0.13392	0.13832	0.14276	0.14723	0.15174	0.15628
24	0.11552	0.11979	0.1241	0.12846	0.13287	0.13731	0.14179	0.1463	0.15085	0.15543
25	0.11443	0.11874	0.1231	0.1275	0.13194	0.13643	0.14095	0.1455	0.15008	0.1547

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16. ABSTRACT
In Spanish, this document provides a detailed methodology for the proper sizing and costing of numerous air pollution control devices for planning and permitting purposes. Includes costing for volatile organic compounds (VOCs); particulate matter (PM); oxides of nitrogen (NOx); SO2, SO3, and other acid gasses; and hazardous air pollutants (HAPs).

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