Section 1

Introduction

Chapter 2

Cost Estimation: Concepts and Methodology

John L. Sorrels
Thomas G. Walton
Air Economics Group
Health and Environmental Impacts Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

November 2017

Contents

2.1 Introduction

This chapter presents a methodology that will enable the user, having knowledge of the source being controlled, to produce study-level estimates of the costs incurred by regulated entities 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 other non-stack abatement methods.

There are several types of users for this Manual. Industrial users are the most common, but State, local, other officials, and other environmental stakeholders (e.g., environmental groups) are other users of the Manual. EPA strongly recommends that the methodology in this Manual be followed as part of compliance with various Clean Air Act programs.

The cost estimation methodology can be used in the development of assessing private compliance decisions/strategies or effects of permits as various alternatives are considered. If the regulation or permit prescribes a particular control technology (e.g., installation of a scrubber), then the costs of individual controls can be estimated for affected entities. If the regulation or permit establishes performance standards, with flexibility as to how the standards can be achieved, then the cost estimation methods can be used to estimate the costs of various options for achieving the standards.

We note that these cost estimation procedures are meant to support the calculation of the costs of purchasing and installing pollution control equipment, and then operating and maintaining this equipment, at a facility. Such costs are private costs because they reflect the private choices and decisions of the owners and operators of the facilities. Broader costs associated with the installation and operation of pollution control equipment, such as impacts on society (e.g., changes in prices to consumers due to the impact on a producer from additional pollution control) are analyzed using methods that assess the social costs of regulatory intervention.

Again, the methods provided in this Manual is to aid in assessing private choices that regulated entities may undertake in complying with regulation. Analyzing private decisions and the associated costs are important in and of itself and can be used as inputs to assessing the likely effects of regulations. In other words, the cost estimation methodology in this Manual is meant for private cost estimation, not social cost estimation. Information on social cost estimation can be found in the EPA Economic Guidelines and the U.S. Office of Management and Budget's Circular A-4. This Manual is not intended to assess the likely effects of federal regulations to society, but is intended to provide assessment of private actions which can be inputs to social impacts analysis.

Users with the role of developing or reviewing compliance plans can use this Manual to estimate private costs of installing and operating control equipment. Regulated entities facing regulation can use this Manual to help decide how to comply with the requirements they are facing.

2.2 Private Versus Social Costs

Before delving deeper into a discussion on estimating private costs, identifying the differences between private and social costs is important. The Manual focuses on private cost, which refers to the costs borne by a private entity for an action the private entity decides. For example, if the private entity pays for the cost of installing and operating pollution control equipment, among many options available to the entity, the entirety of these costs would be considered private costs.

The EPA's Guidelines for Preparing Economic Analysis define social cost as follows: "Social cost represents the total burden a regulation will impose on the economy; it can be defined as the sum of all opportunity costs incurred as a result of a regulation. These opportunity costs consist of the value lost to society of all the goods and services that will not be produced and consumed if firms comply with the regulation and reallocate resources away from production activities and towards pollution abatement. To be complete, an estimate of social cost should include both the opportunity costs of current consumption that will be forgone as a result of the regulation, and the losses that may result if the regulation reduces capital investment and thus future consumption."[1]

The term social cost refers to the overall cost of an action to society, not just to the private entity that incurs the expense to control pollution. Social cost is based on the concept of opportunity cost, the value associated with production and consumption that are reduced or changed as a result of reallocating resources to reduce pollution.

Assessing private cost is more straightforward because it attempts to tally up expenses that individual entities or facilities incur to purchase, finance, and operate pollution abatement equipment or strategies. Suppose a state government wanted to encourage pollution control for a certain industry and provided grants to pay half of the costs of a scrubber. The private cost for the industry would be 50% of the cost of a scrubber. Using another example, suppose a firm purchases equipment, pays sales tax on the item, and receives an immediate tax rebate. The private cost to the firm is the sum of the equipment price plus the sales tax amount minus the excise tax amount.

The estimation of private costs is the focus of the cost estimation procedures and data in this Manual. Both EPA and OMB have developed guidance on methods appropriate for use in estimating social costs for regulatory impact analysis or economic impact analysis where the social costs of government interventions are assessed. The guidelines presented in this Manual are not suitable in conducting regulatory impact analysis or economic impact analysis where the social costs of government interventions are assessed. Because this Manual focuses on private costs to facilities of installing and operating pollution control equipment, we will not present the

---

[1] U.S. Environmental Protection Agency, Office of Policy, National Center for Environmental Economics. Guidelines for Preparing Analysis. May 2014. Pp. 8-1 – 8-2.

methodologies for social cost calculations. For more information on social cost estimation methods, please see EPA's Economics Guidelines [5] and OMB Circular A-4 [6].

2.3 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 probable error 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 … [I]t can be prepared at relatively low cost with minimum data." [1] The accuracy of the study-level estimate is consistent with that for a Class 4 cost estimate as defined by the Association for Advancement of Cost Engineering International (AACEI), which AACEI defines as a "study or feasibility"-level estimate. [2]

Specifically, to develop a study estimate, the following must be known:

- Location of the plant;
- Location of the source within the plant;
- Design parameters, such as source size or capacity rating, uncontrolled pollutant concentrations, pollutant removal requirements, etc.
- 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, steam, water, and waste disposal);
- Quantity and cost materials consumed in the process (e.g., water, reagents, and catalyst);
- Preliminary flow sheet and specifications for ducts and piping; Approximate sizes of motors required;
- Economic parameters (e.g. annual interest rate, equipment life, cost year, and taxes.) [1]

Besides the labor requirements for construction and operation of a project, 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 probable 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, with probable error of 20%, 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. This estimate, with a probable error of 10%, requires yet more information than the scope estimates, especially concerning the site, equipment, and electrical requirements.
- Firm, Contractor's, or Detailed. This is the most accurate (probable error of 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]

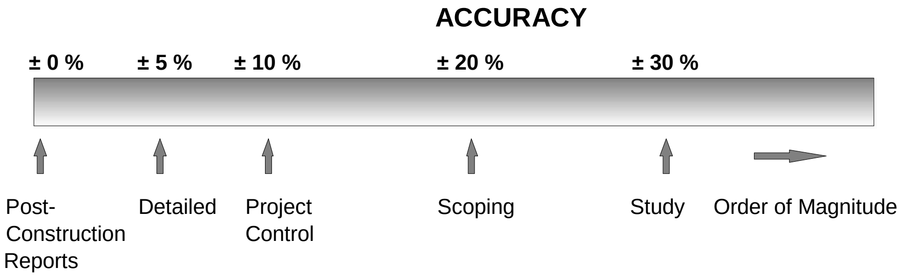


Figure 2.1: The Continuum of Accuracy for Cost Analyses

These error bands are attempts at assessing the probable errors associated with each estimation method based on past practices of the engineering cost-estimation discipline. However, the error bands do not shed any light on the distribution of the likely errors. The users of this Manual should not draw conclusions about probable errors that this Manual does not intend.

Study-level estimates represent a compromise between the less accurate order-of-magnitude estimates and the more accurate estimate types. The former is too imprecise to be of much value in the context of pollution control installation and operation, while the latter are very expensive for an entity to prepare, and require detailed site- and process-specific knowledge that some Manual users are unlikely to have. Over time, this Manual has become the standard for air pollution control costing methodologies for many State regulatory agencies. For example, Virginia requires that the Manual 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.[2] Texas accepts the Manual methodology "as a sound source for the quantitative cost analysis" for BACT analyses it reviews.[3]

The industrial user is more likely to have site-specific and detailed information than the average cost and sizing information used in a study estimate. The methodology laid out in this Manual can provide cost estimates that are more accurate when using detailed site-specific information. The anecdotal evidence from most testimonials volunteered by industrial users indicates that much greater accuracy than 30 percent probable error can be attained. However, this Manual does not assume that detailed site-specific information will always be available to estimate costs associated with installing and operating pollution abatement equipment at a much higher accuracy level. This Manual retains the conclusion that the cost methodology laid out in this chapter and information in each control measure chapter with 30% probable error is relevant to be used in air pollution control cost estimation for permitting actions. It is the affected industry source that bears the burden of providing information of sufficient quality that will yield cost estimates of at least a study-level estimate for permitting decisions pertaining to their facilities.

2.4 Cost Categories Defined

The terminology addressing cost categories used in the earlier editions of this Manual was adapted from the AACEI. [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 Cost (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.

2.4.1 Elements of Total Capital Investment

In assessing the total capital investment, this Manual takes the viewpoint of an owner, the firms making the investment, or those who have material interest in the project. 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.[4] Taxes, permitting costs, and other administrative costs are covered in Section 2.6.5.8. Financing costs

---

[2] State of Virginia, Department of Environmental Quality. Draft PSD Guidelines, August 4, 2011. Pp. 4-4 to 4-5.

[3] Texas Commission on Environmental Quality. Air Permits Division. Air Permit Reviewer Reference Guide, APDG 6110. Appendix G. p. 45. January 2011.

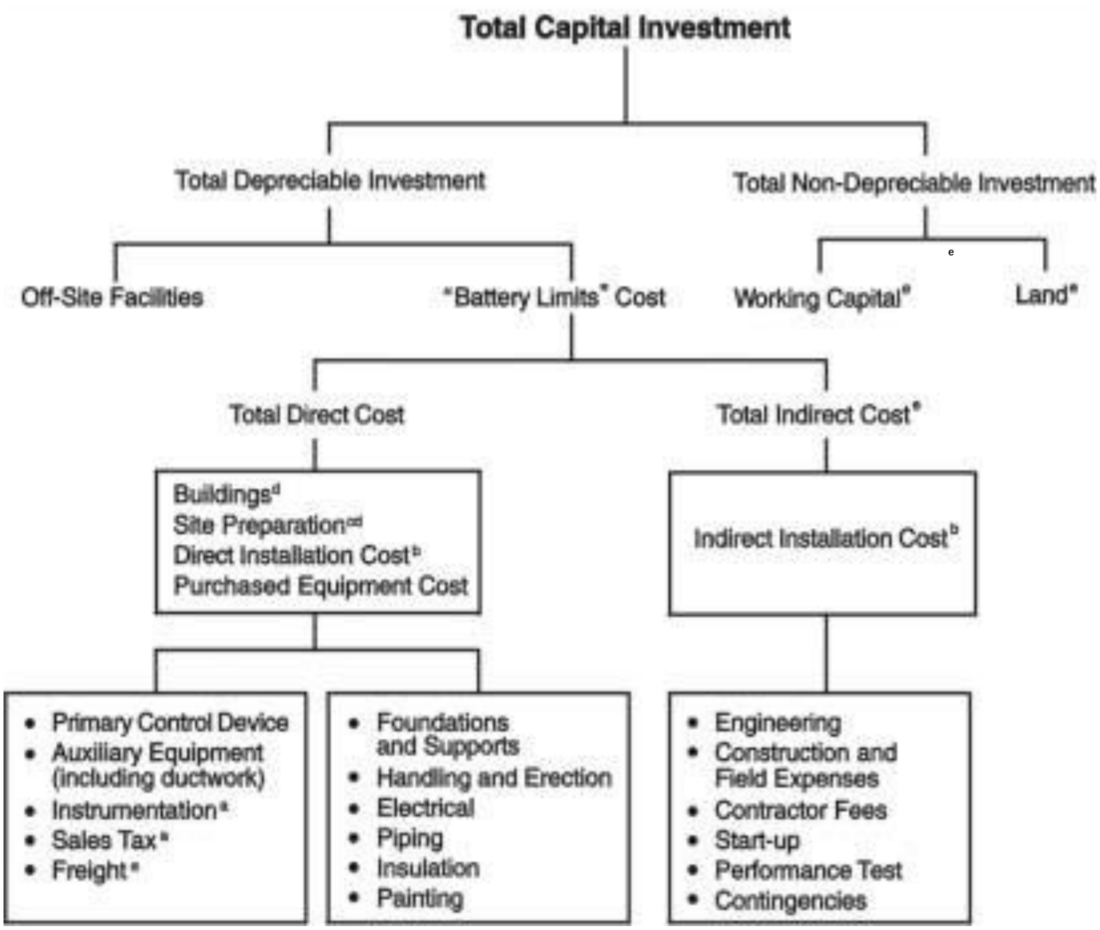
[4] Estimates of TCI for some control measures may not necessarily be calculated in this way due to availability of public information on capital investment costs and equations for those measures, such as the SNCR and SCR chapters in this Manual.

are covered in Sections 2.5.3 and 2.5.4. Foregone revenue associated with facility shut downs are covered in Section 2.6.4.2.

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. Another item within owner's costs, technology royalties, is not separately included with the Manual's methodology because technology royalties are assumed to be reflected within the purchased equipment costs. 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 discussed in more detail later in this chapter. Contingencies are not the same thing as uncertainty and retrofit factor costs, which are treated separately in this chapter. Escalation is not treated as part of contingencies. Please refer to section 2.6.4 for further discussion.

The elements of TCI 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. A battery limit is the geographic boundary defining the coverage of a specific project [3]. Usually this encompasses all equipment of interest (in this case, the pollution control equipment), but excluding provision of storage, utilities, administrative buildings, or auxiliary facilities unless so specified [3]. This estimate 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. Some pollution control systems do not generally have off-site capital units dedicated to them since these 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. For example, installation of a venturi scrubber, which often requires large amounts of electricity, would require including costs associated with off-site facilities.

Note, however, that the capital cost of a device does not include routine utility costs (which can include the cost of steam, electricity, process and cooling water, compressed air, refrigeration, waste treatment and disposal, and fuel), even if the device were to require an offsite facility. Utility costs are categorized as operating costs that covers both the investment and operating and maintenance costs for the utility. The utility costs associated with start-up operations are included in the "Start-Up" component of the indirect installation costs. Operating costs are discussed in greater detail below. In addition, not every air pollution control system installation will have all of the elements for its TCI that are listed below (e.g., buildings).



[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 some add-on control systems take up very little space (often a quarter-acre or less), this cost may 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 and remediation of existing land and property 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 is not depreciated for accounting purposes. The value of the land may fluctuate depending on the market conditions, but for accounting purposes and assessing private costs, land is not depreciated. 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. If the firm plans on dismantling the device at some future time, 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 analysis later, in section 2.5.4).

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) to 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.

In addition, the TCI of controls for sources that affect fan capacity (e.g., FGD scrubbers, SCRs) may be impacted by the unit's elevation with respect to sea level. Cost calculations for the control measures within the Manual have typically been developed for systems located at sea level. For systems located at higher elevations (generally over 500 feet above sea level), the purchased equipment cost and balance of plant cost should be increased based on the ratio of the atmospheric pressure between sea level and the location of the system, i.e., atmospheric pressure at sea level divided by atmospheric pressure at the elevation of the unit.[5]

The method for estimating TCI in this Manual is an "overnight" estimation method. This method estimates capital cost as if no interest was incurred during construction and therefore estimates capital cost as if the project is completed "overnight." An alternate way of describing this method is the present value cost that would have to be paid as a lump sum up front to completely pay for a construction project. Cost items such as Allowance for Funds Used During Construction (AFUDC), which is defined as the costs of debt and equity funds used to finance plant construction, and is an amount credited on the firm's statement of income and charged to construction in progress on the firm's balance sheet, is treated separately in Section 2.5.3 in this Manual. This item is an estimate that is incurred over the timespan of construction. For example, this is considered as a cost item within the electric power industry.[6] [15] Other cost items similarly treated separately include escalation of costs to a future year due to inflation in Section 2.5.4. We provide more discussion later in this chapter on these cost items that are not included in this section.

---

[5] One instance of this is the estimates of costs for the recently revised SNCR and SCR Control Cost Manual chapters, which are available at http://www.epa.gov/ttn/ecas/costmodels.html.

[6] See the National Energy Technology Laboratory's "Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance."

2.4.2 Elements of Total Cost

Total Cost (TC) refers to costs that are incurred yearly. TC has three elements: direct costs (DC), indirect costs (IC), and recovery credits (RC), which are related by the following equation:

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

The basis of direct costs and recovery credits 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.) [4] The various annual costs and their interrelationships are displayed in Figure 2.3. Some indirect costs are not incurred on an annual basis. Purchase, installation, and start-up of pollution abatement capital equipment often take multiple years. To incorporate these multi-year costs with other annual costs, the capital costs are amortized and converted into capital recovery. If the timing between direct costs and indirect costs are different, then an alternative approach for estimating total cost is to calculate the present value of these costs before summing them.

Variable costs are those that vary with 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. Semi-variable costs also vary with some measure of production, but have a positive cost even when production is zero.

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 present the cost components accurately

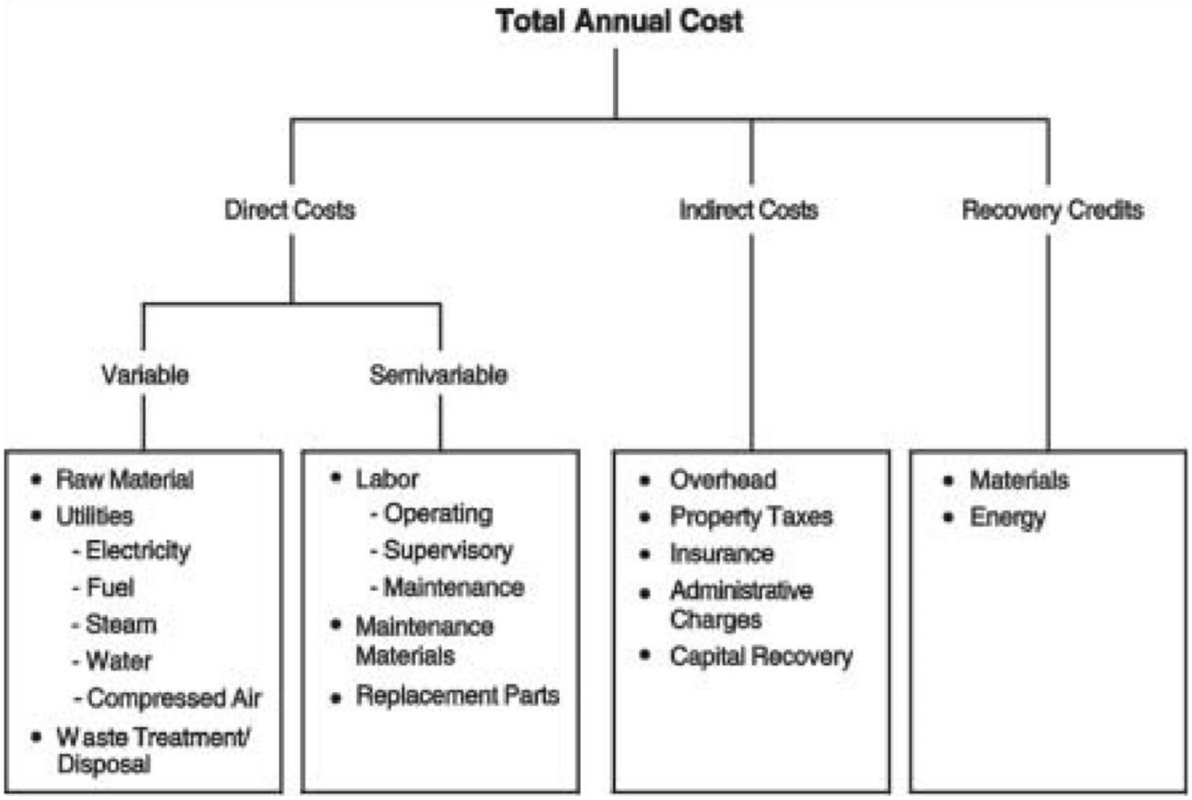


Figure 2.3: Elements of Total Annual Cost

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, administrative charges including permitting costs and capital cost amortized into capital recovery.

Capital is depreciable, indicating that, as the capital is used, it wears out and that lost value cannot be recovered. Economic depreciation, which is the lost value due to wear and tear, is different than accounting depreciation, the declared lost value, that is usually used in a cost analysis. 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.

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 a FGD scrubber. As the lime or limestone reagent reacts with the sulfur in the exhaust gas stream, it becomes transformed into $CaSO_4$ - 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 judgment 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 provided in Section 2.6

2.5 Financial Concepts

Firms have latitude in developing compliance strategies. For standards that are performance oriented, firms have great latitude. Even for standards that are fairly prescriptive and technical in nature, firms still have to make some choices on how to comply. How do they compare these choices or alternatives?

Alternatives will usually have expenditures at multiple times. Not only may the expenditures be different but the timing of expenditures may also be different. 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 are needed to make a meaningful comparison. They include: selection of an appropriate timeframe, addressing the time value of money, adjusting for prices over time, and selection of the appropriate measure of cost.

2.5.1 Time Frame

To compare two alternatives in a meaningful way, the comparison is more meaningful when the alternatives are examined over the same time frame or calculate the net present value of the alternatives. For example, if one alternative uses a control device that lasts two years and another alternative uses a device that lasts three years, the alternatives may be difficult to compare directly because of the inconsistent lifetimes of the devices. One approach to developing a more meaningful comparison would be to assume a common time frame by using each type of device for six years, with the two-year alternative being replaced two times and the three-year alternative being replaced once. Another approach is to calculate the net present value of the two alternatives. Amortization or the EUAC method also can be helpful in comparing alternatives with different lifetimes.

2.5.2 Interest Rates

Firms may borrow to finance the expenses associated with their compliance strategies. The interest rate at which a firm borrows is a key component in estimating the total costs of compliance. Financial markets set different interest rates for different activities depending on many factors.

The three factors that are relevant to this Manual are: time value of money, inflation risk, and credit risk of borrowers.

Time value of money reflects the timing aspect of borrowing money—a firm would like to borrow now and pay back later and a financial institution would like to lend now and collect later. The time value of money is also known as the real interest rate. Financial institutions know that the price of goods and services will probably increase in the future, but they don't know by how much. So they hedge against this risk by building in a premium for this risk. The credit risk of borrowers refers to the risk associated with whether the loan will be paid back. The credit risk premium will depend on the credit rating of the borrowing firms.

The interest rates that firms face are nominal interest rates. For the rest of the discussion, this Manual assumes that the credit risk of borrowers is essentially zero. Removing the inflation adjustment from the nominal interest rate yields the real rate of interest - the actual cost of borrowing from a societal perspective. In equation form, the nominal interest rate (i) equals the ex ante real interest rate (i_r) plus the expected rate of inflation (p^e) plus the product of the expected inflation rate and the real interest rate as seen in Equation 2.3.

$$i = i_r + p^e + i_r p^e \tag{2.3}$$

This is the well-known Fisher Equation. Since the product of the ex ante real interest rate and expected inflation is small, Equation 2.3 simplifies to:

$$i = i_r + p^e$$

When performing cost analysis, it is important to ensure that the correct interest rate is being used. Because this Manual is concerned with estimating private costs, the correct interest rate to use is the nominal interest rate, which is the rate firms actually face. Accounting for inflation should be done separately rather than using the real interest rate.

The determination of appropriate private nominal interest rates is important for analyses of private costs done for permit applications where the costs assessed are for the permitted source. Different firms may structure how they finance their purchases differently. Some may choose to finance their purchases through cash holding or other means of equity; some may choose to borrow to finance their investment. When firms choose to borrow, depending on the size of the investment, borrowing could be structured very differently at very different interest rates given the choices firms have for financing an investment. For permit applications, if firm-specific nominal interest rates are not available, then the bank prime rate can be an appropriate estimate for interest rates given the potential difficulties in eliciting accurate private nominal interest rates since these rates may be regarded as confidential business information or difficult to verify. The bank prime rate is published by the Board of Governors of the Federal Reserve

System.[7] The bank prime rate is the "rate posted by a majority of the top 25 (by assets in domestic offices) insured U.S. chartered commercial banks. The bank prime rate is one of several base rates used by banks to price short-term business loans."[8] Analysts should use the bank prime rate with caution as these base rates used by banks do not reflect entity and project specific characteristics and risks including the length of the project, and credit risks of the borrowers.

For input to analysis of rulemakings, assessments of private cost should be prepared using firm-specific nominal interest rates if possible, or the bank prime rate if firm-specific interest rates cannot be estimated or verified. If neither of these types of private nominal rates are available, then the cost analysis should use 3% or 7%, rates that are used for social cost estimation as discussed later in this section, as a default. Analysts should be especially cautious using 3% and 7% rates in assessing cost of short term assets or projects. These rates represent long-run, real interest rates as described later in this section. Conflating real and nominal interest rates may lead to different conclusions than using consistent interest rates throughout the analysis. Private interest rates are but one component of the overall cost analysis, which will include social cost estimation to reflect relevant guidance from OMB.

To clarify potential confusion that might arise, this Manual discusses the difference between private interest rate and social discount rate. If capital markets are perfect with no distortions (e.g., no taxes, no risk), then the return to savings (the consumption rate of interest) equals the return on private sector investments. Therefore, when the government needs to convert future costs and benefits into present value terms in the same way as the affected individuals would do so, it should also discount using this single market rate of interest. In other words, in this "first best" world, the private market interest rate would be an unambiguous choice for the social discount rate. However, 'real-world' issues make the issue much more complicated. For example, private sector investment returns are taxed (often at multiple levels), capital markets are not perfect, and capital investments often involve risks reflected in market interest rates (i.e., lenders charge riskier projects higher rates of interest to compensate for lenders' risk). All of these factors drive a wedge between the social rate at which consumption can be traded through time (the pre-tax rate of return to private investments) and the rate at which individuals can trade consumption over time (the post-tax consumption rate of interest).

As stated earlier, interest rate accounts for the time value of money, inflation, and other premiums, including risks, faced by lenders. The social discount rate is the rate at which society can trade consumption through time (i.e., the time value of money). When assessing the societal effect of regulations, such as for EPA rulemakings that are economically significant according to Executive Order 12866, analysts should use the 3% and 7% real discount rates as specified in the U.S. Office of Management and Budget (OMB)'s Circular A-4 [6]. The 3% discount rate represents the social discount rate when consumption is displaced by regulation and the 7% rate

---

[7] Board of Governors of the Federal Reserve System. "Selected Interest Rate (Daily) – H.15." Available at: https://www.federalreserve.gov/releases/h15/ (Accessed August 4, 2017).

[8] Board of Governors of the Federal Reserve System. "Selected Interest Rate (Daily) – H.15." Available at: https://www.federalreserve.gov/releases/h15/ (Accessed August 4, 2017).

represents the social discount rate when capital investment is displaced. Regardless, these are real social discount rates that are riskless. Therefore, they are not appropriate to use to assess private costs that will be incurred by firms in making their investment decisions. In assessing these private decisions, interest rates that face firms must be used, not social rates.

2.5.3 Prices and Inflation

With changes in prices over time for all relevant goods and services such as capital equipment, engineering services, other materials and reagents used in the construction and operation of control equipment, inflation's impacts on prices and their effect on cost estimates is of concern to Manual users. The prices in the Manual were not standardized. Some chapters had prices for materials and reagents 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 standardize all prices into a particular base year's dollar in subsequent editions of the Manual to reduce the chance for analytical error. In the sixth edition of the Manual, EPA updated all the costs to at least 1990. For the seventh edition of the Manual, EPA will update the costs to at least 2012.

Updating costs for this Manual is an effort with a goal of standardizing all costs to one base year for a particular analysis. Each chapter of the Manual fully discloses the limitations of the costing information found in that chapter. This allows the analyst to make any adjustment they deem necessary, provided sufficient basis exists, and assuming the approval of the appropriate regulatory agency.

To develop the costs used in each of the chapters of this Manual, we attempted to survey the largest possible group of vendors and collected information from industry literature and other technical reports to determine an industry average price for each cost component. In many cases, this involved contact with a number of vendors, including trade associations, 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 robustness 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 robust prices for some components. While recognizing the difficulties in providing manufacturer-specific or site-specific information, this Manual also knowledges that timeliness of such information is important. If the survey information is not timely, errors to the cost estimation would be introduced in unknown ways. Thus, every effort is made to update the information in as timely a manner as possible.

In collecting and using prices in estimating pollution control costs, one should be cognizant of the effect of inflation. We can define prices in "real" and "nominal" terms. Real and nominal prices act in the same way as real and nominal interest rates. Nominal prices are actual prices (i.e., the sticker or spot price) and represent the value of a particular good at a particular point in time. Real prices remove the effect of inflation. The reason for using real price is that purchases may happen over several years especially for projects that invest heavily in capital. Because purchasing power in any given year may be different than other years, combining nominal prices is like mixing apples and oranges.

This Manual uses real prices for estimation of capital costs (in this case, an older capital cost to a more recent year), and other costs for any given cost analysis, not nominal prices. Using a price of reagent, catalyst, or other cost input to reflect possible price changes over the equipment lifetime is not correct in adjusting for inflation. Hence, the inclusion of price inflation via escalation estimates or having input prices reflect price changes over time as part of capital cost estimation is not allowed under the Control Cost Manual Methodology. The capital cost should be estimated for the time that the cost estimate is prepared, and should not be escalated to some future year, such as an anticipated date that construction will be completed or some other future year unless the analyst has a robust method to forecast future inflation. A linear extrapolation of past inflation is not a robust method of forecasting future 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:

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

For example, if the price of a reagent in 2010 is 100, and we want a reagent price for 2012, then an index value of 1.2 for that reagent price between 2012 and 2010 will yield a 2012 price of 120. 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), the Producer Price Index (PPI) and Gross Domestic Price (GDP) implicit deflator, which investigate the change in prices across the entire economy. The most relevant price index for private cost estimation is PPI, and PPI is provided at the 6-digit North American Industry Classification System (NAICS) level. However, for some equipment and materials, even a 6-digit NAICS code level PPI may be too general for the specific needs of industry in the course of an analysis and should only be used if other indexes, particularly well-documented indexes for specific industries, materials, or uses, are not available.

The CPI is not recommended because the price change of interest is among consumer goods and services which have little relevance to capital project spending or industrial intermediate goods such as raw materials such as reagents [8]. The Gross Domestic Product (GDP) implicit price deflator measures broad price changes in the economy rather than CPI, which is a measure of only goods bought by consumers. PPI is a measure of inflation faced by industries.[9] Other indexes are also available from industry and academic sources through the Internet, industry publications, trade journals, and financial institutions. One index that has been used extensively by EPA for escalation purposes is the Chemical Engineering Plant Cost Index (CEPCI), an index that tracks costs of equipment, construction labor, buildings, and supervision in chemical process industries.[10] Other cost indexes exist, such as Marshall & Swift (M&S), another equipment cost index that is widely used.[11]

It should be noted that the accuracy associated with escalation (and its reverse, de-escalation) declines the longer the time period over which this is done. Escalation with a time horizon of more than five years is typically not considered appropriate as such escalation does not yield a reasonably accurate estimate. [9] Thus, obtaining new price quotes for cost items is advisable beyond five years. If longer escalation periods are unavoidable due to limited recent cost data that is reasonably available, then the analysis should use the principles in this Manual chapter to provide as accurate an escalation as possible consistent with the Manual given the limitations of the cost analysis. The appropriate length of time for escalation can vary as a result of significant changes in the cost of major production inputs (e.g., energy, steel, chemical reagents, etc.) and technological changes in control measures, particularly if these changes occur in an unusually short period of time. Hence, shorter time periods for escalation and de-escalation are clearly preferred over longer ones.

2.5.4 Financial Analysis

Firms make purchase decisions that occur at different times for different durations and schedule paybacks which also occur at different times as well. Because of these reasons, the following financial analysis tools are necessary because they allow firms, state regulators, and other users of the Manual to be able to compare the costs of different compliance strategies.

2.5.4.1 Net Present Value

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 (NPV) analysis. In either case, the calculation is the same: adjust the value of future money to values based on the same year (generally year zero of the project), employing an appropriate interest (discount) rate and then add them together, after all income and expenses have been converted into the same year dollar using appropriate price indices.

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

---

[9] U.S. Bureau of Labor Statistics. "Comparing the Consumer Price Index with the gross domestic product price index and gross domestic product implicit price deflator." Monthly Labor Review. March 2016.

[10] This index is available at http://www.chemengonline.com/pci. It is also available in Chemical Engineering magazine. Mention of this index is not meant to offer commercial endorsement by EPA.

[11] More information on this cost index can be found at http://www.corelogic.com/products/marshall-swift-valuation-service.aspx.

  - Identification of alternatives. For example, the choice between a fabric filter/baghouse 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 offers detailed costing information on specific air pollution control devices and equipment.

  - Determination of an appropriate real interest or discount rate(s). The appropriate interest rate in private cost assessment is the private interest rate for each firm affected. Determining private interest rates may be difficult due to the firm-specific nature of the private nominal interest rates faced by firms. If firm-specific private nominal interest rates are available, then the appropriate rates are simply the difference between the nominal interest rate minus the prevailing inflation in the industry. Industrial and other users of this Manual should consult with their financial officers and/or trade associations for input regarding such rates. More extensive discussion of interest rates can be found earlier in this Manual in Section 2.5.2. If discounting is performed using the same rate across all alternatives, ranking of alternatives by cost will always yield the same order, no matter which rate is used.

  - For each alternative: Calculate a discounting factor for each year over the life of the equipment. The discount factor formula is: $DF_t=\{1/(1+i)^t\}$ where i is the discount rate and t is the number of years. For example, using a 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.

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

$$NPV = \sum NCF_t * [i/(1-(1+i)^{-t})] \qquad (2.6)$$

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

If discounting is performed using a uniform rate across different mutually exclusive alternatives, ranking of alternatives by cost or net cash flow will always yield the same order, no matter which rate is used or cost approach is employed.

2.5.4.2 Amortization: Equivalent Uniform Annual Cost and Annualization

Net present value (NPV) analysis allows us to evaluate between investments by summing the present value of all future incomes and expenses, but that does not give us an insight into the expected cash flows that will actually occur. NPV allows for comparison of alternatives by compressing the value of cost streams or return on investments over same or different time horizons to a single point in time. It's as though regulated entities are paying up front for all the future costs of installation, maintenance, and operation of a pollution control device. However, firms may want to pay back their expenses in equal sums over the life of the control. A common engineering cost tool for this sort of evaluation is called the equivalent uniform annual cash flow (EUAC) approach. [4] In the finance literature, this approach is called amortization.

EPA uses the EUAC approach as the basis for the Control Cost Methodology for the following reason:

- The methodology is general enough to be used for estimating costs for any pollution control measure applied to any industry. In this respect, the EUAC is different from the levelized cost method (LCM), which is a method specific to the electric power industry and requires relatively extensive information to be applied properly as compared to application of the EUAC. The EUAC thus provides consistency in cost analysis of pollution control measures for sources in all industries as part of actions for which the Control Cost Manual is applicable. [7]

Annualization is a process similar to EUAC but is not limited to constant cash flows. It involves determining the NPV of each alternative equipment investment and then determining the equal 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:

$$PM\,T = NPV^*(i/1-(1+i)^{-n}) \qquad (2.7)$$

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

This payment is the capital recovery cost (*CRC*), which is calculated by multiplying the *NPV* of the investment by the capital recovery factor (*CRF*):

$$CRC = NPV \times CRF \qquad (2.8)$$

where *CRF* is defined according to the formula:

$$CRF = i(1+i)^n / ((1+i)^n - 1) \qquad (2.8a)$$

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 interest rates between 5.5 percent and 15 percent for annualization periods from one to 25 years.

The life of the control is defined in this Manual as the equipment life. This is the expected design or operational life of the control equipment. This is not an estimate of the economic life, for there are many parameters and plant-specific considerations that can yield widely differing estimates for a particular type of control equipment.

The life of the control is appropriate to use when the analytic timeline or the length of the analysis is longer than the useful life of the control equipment. If the analytic timeline is shorter than the useful life of the control equipment, use the analytic timeline to annualize the capital cost.

It is crucial that the analyst use the same interest or discount rate to estimate costs using NPV and when amortizing (i.e., EUAC).

2.6 Estimating Procedure

The estimating procedure used in the Manual consists of five steps: (1) obtaining the facility parameters and compliance options for a given facility; (2) preparing 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.

2.6.1 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).

Compliance 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 or end-of-pipe 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 Compliance Options

Facility Parameters	Compliance Options
Intensive	**No control**
Facility status (new or existing, location)	
Gas Characteristics (temperature, pressure, moisture control)	**Add-on 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

2.6.2 Control System Design

Preparing the control system design for an end of pipe device at a plant 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 for a typical add-on control device (e.g., a coal fired FGD scrubber), several questions may need to be answered, among others, depending on the specific control device:

- What is the fuel’s (in this case, coal’s) sulfur content? What is the content of other toxic substances in the fuel (heavy metals, mercury)?

- How many absorber modules will be needed?

- 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., particulate control equipment, which will likely be in operation at the source) before it enters the control device?

- Will the captured pollutants be disposed of or recycled? How will this be done? Will a salable byproduct be produced (e.g., gypsum for drywall)?

- Can the on-site capacity (e.g., utilities, stockpiling space) accommodate the added requirements of the control system? Is additional wastewater and solid waste disposal capacity needed?

2.6.3 Sizing the Control System

Once the system components have been selected, they must be sized (i.e., the correct size of components must be determined). 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 equipment 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 as long as the analytic length exceeds the useful life of the equipment. 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 include a comprehensive list of the specific parameters that must be considered for each device.

Table 2.3: Examples of Typical Control Device Parameters [3]

General	**Device-Specific**
Material of construction: carbon steel	Gas-to-cloth ratio (critical parameter): 3.0 to 1
Insulated? Yes	Pressure drop: 6.0 in w.c. (inches water column)
Equipment life: 30 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. Please note that values in this table are shown only for illustrative purposes.

2.6.4 Estimating Total Capital Investment

2.6.4.1 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.[12]

As mentioned previously, most of the costs in each of the subsequent sections of this Manual were derived from data obtained from reputable control equipment vendors. For many control devices there are many vendors, which allowed us to offer robust average costs of components submitted by large samples of vendors in response to Agency survey efforts. [10] 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 as many vendors or we did not receive sufficient number of responses to our inquiries, resulting in small samples. Thus, there could be a limited number of observations in the data sets available for estimation of average costs. In these cases, we offer these average costs and the cost discussion in that control’s particular chapter offers appropriate caveats 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 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.

---

[12] Estimates of TCI for some control measures may not necessarily be calculated in this way due to availability of public information on capital investment costs and equations for those measures, such as the SNCR and SCR chapters in this Manual.

Generally, vendor quotes are “F.O.B.” (free-on-board) for 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. [10] 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 - 0.10	0.05
Sales Tax	0 - 0.08	0.03
Instrumentation	0.05- 0.30	0.10

To some extent, the application of an appropriate factor requires the subjective application of the analyst’s best judgment. 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. [10] The sales tax factors simply reflect the range of local and state tax rates currently in effect in the United States. [10] 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. [10] 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.

Regarding the amount of labor for construction and installation of a control device, EPA has prepared a number of analyses that include estimates for power plants in particular. These analyses are extensive in nature, and we refer readers wanting more information to appendixes in several recent Regulatory Impact Analyses (RIAs) that include employment data for various add-on control devices, including some of the control devices found in the Control Cost Manual.[13]

---

[13] One example of this is Appendix 6A in the RIA for the Mercury and Air Toxics Standards (MATS), which provides an estimate of the labor necessary to construct and install an FGD scrubber on a coal-fired power plant

2.6.4.2 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 thousands of square feet and may be installed directly behind a boiler’s combustion chamber to offer the best environment for NOx removal. Many of the utility boilers currently considering or have installed an SCR reactor to meet Federal or other 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 often 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 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 expected (but reasonable) extra costs for demolition and installation. Such expected but extra 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. The retrofit factor is calculated as a multiplier applied to the TCI. For instance, if a retrofit factor of as much as 50 percent can be justified, then the retrofit factor in the cost estimate is 1.5. For systems installed at the end of the stack, such as flares, retrofit uncertainty is typically a factor. In these cases, an appropriate retrofit factor may be as little as 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 being used.

Since each retrofit installation is unique, no general factors can be developed. Nonetheless, if necessary, some general information can be given concerning the kinds of system modifications one might expect to be considered in developing a retrofit factor:

1. 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

---

boiler. This RIA can be found at http://www.epa.gov/ttn/ecas/regdata/RIAs/matsriafinal.pdf. In addition, the RIA for the Cross-State Air Pollution Rule (CSAPR) provides estimates of the labor necessary to construct and install an SCR, dry sorbent injection (DSI) and FGD scrubber on coal-fired power plant boilers. The CSAPR RIA can be found at http://www.epa.gov/airtransport/pdfs/FinalRIA.pdf.

significantly if special means (e.g., helicopters) are needed to get the equipment on roofs or to other inaccessible places.

2. 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 zero or decreases, since most of this work would have been done when the original facility was built [11]. 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. As mentioned earlier in the chapter, if additional land is purchased to accommodate the installation of the control equipment, this cost needs to be added in as well. If other production related equipment must be relocated to allow for the installation of the control equipment, the cost associated with the relocation needs to be included.

3. 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.

4. Limited Space for Staging Equipment. During construction, materials and equipment are transported, received, and stored on site. These commodities are marked, arranged, and placed in a sequence for retrieval by construction crews prior to final installation. In many ways, the storage yard on a construction site represents a depot with shipments being received from vendors and commodities being constantly repositioned to facilitate retrieval to meet a scheduled installation sequence. For large sites, repositioning becomes less of an issue; however, for small limited area sites, repositioning items in the construction queue becomes a major logistical effort, and in some cases, requires JIT (just-in-time) delivery to allow for direct off-loading from carrier and then straight to installation. To allow schedule flexibility (for the unseen), equipment can be stored off-site (for a fee) or at the fabricator's shop (once again, for a space rental fee).

5. Transportation. The delivery of equipment is more than the arrival of commodities at plant site. It is the examination of the destination route from shop to plant site with all special aspects taken into consideration, such as: road bearing limitations, bridge overpass height restrictions, permits for oversized shipments (extra wide loads), required special escorts, time-of-day transit limitations (non-traffic hour, weekends only), railway restrictions, waterway provisions (locks, docking, piloting), tunnel limitations. Depending on the site's location in relationship to the origin point, the typical transit route for normal cargo shipments yields to alternate routes and times for large special shop fabricated assemblies.

6. Lost Production. The shut-down for installation of a control device into the system should be a well-planned and anticipated event, and typically occurs during routine, scheduled outages. 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 if they happen could impose significant costs on the system. 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. If the shut-downs do not occur in a well planned and routine manner, any additional foregone production of goods and products would need to be included as a private cost attributable to the retrofit cost.

It is important to consider the type of contract and its influence on contingency factors. The two types of major contract vehicles that exist for the buyer (owner) to issue to a seller (vendor) are: lump-sum / fixed price and cost-plus. Between these extremes, a myriad of hybrids exists. The lump-sum contract vehicle stipulates a fixed price for delivery of a product performing to specified conditions set by the buyer with all materials, services, engineering/ design, installation, and commissioning supplied by the seller. Under this fixed price, the seller is at financial risk for delivering a conforming product at the contracted price; corrections to attain conformance and cost overruns are at the seller's expense; however, realized savings are solely to the seller's benefit. The buyer's risk involves changes to the supplied product outside of contractually agreed upon conditions due to unforeseen events or issues. Under such contracts, the engineering contractor assumes the majority of the risk. A cost-plus vehicle allows the buyer to pay for actual expenses incurred by the vendor (materials, labor, engineering / design, etc.) without mark-up plus an agreed upon surcharge to cover the vendor's overhead and profit. The owner is at risk because this type of contract can become open-ended; however, the buyer has extreme control over the cost process and can terminate the project at any time without penalty. The seller settles for minor risk while forgoing the chance to realize cost efficient savings; however, an assured profit margin exists. This is also known as a "time and materials" contract. In between these two extreme contract vehicles, a multitude of blended hybrids exist to suit both buyer and seller and blend the likenesses of each; for example: lump sum + fee, cost-plus + award with shared savings / overruns, lump sum on materials / cost plus on labor, and many more. Contingency cost placement differs between the two vehicles. For cost-plus contracts, the owner determines the contingency amount set aside; for lump-sum / fixed price contracts, the seller determines contingency allowances, (which is reflected in the price).

Project execution typically follows one of two forms: Design-Build (DB) or Design, Bid, Build (DBB) [12]. A contract issued under Design-Build conditions allows the buyer to have a single entity contact (supplier) which performs the engineering, design, purchasing and installation for the vended product plus retains responsibility for that product. DB project execution operates under shorter time schedule since the single entity can design, procure, and construct simultaneously from commencement through completion. The owner's main disadvantage becomes losing control over the design process and selection of equipment, which consequently affects cost. While DB is a common term, it is better known as EPC (engineer, procure, construct), EPCM (engineer, procure, construct, manage), and EPM (engineer, procure, manage with construction under separate contract). DBB project execution follows a more deliberate path with each phase completed before the next. The design phase involves hiring an architect/engineering firm (via contract vehicle) create a complete documentation package for a product. This involves specifications, drawings, fabrication drawings, construction drawings, and all documentation necessary for competitive bid to supply materials, commodities, and construction services for installation. General contractors bid on this design package and a bid is selected. This type of project execution distinctly separates the design/engineering phase from the procurement and installation phase, but takes longer to implement. The method's main advantage allows revising design before equipment and services are procured.

Regardless of execution form selected (DB or DBB), the buyer tends to become involved with the vendor's process (to varying degrees) to coordinate activities between the owner's staff and the supplier's personnel. There is one exception to this case, and it is termed the "turnkey" project. In its purest sense, the buyer's involvement on a turnkey project is negligible; the owner meets the supplier on the first day to award the contract and returns on the final day to receive ownership. In reality, the buyer exercises minor involvement to ensure ongoing progress.

Lump-sum or EPC contracts are generally awarded on the basis of a competitive tender and often lead to the lowest direct cost compared to other type of contracts. These contracts are often turnkey in nature. Thus, these contracts will have larger contingencies than engineer, procure, construction, and management (EPCM) contracts. EPCM contractors are paid when their costs are incurred (cost-reimbursable contracts) and the owner assumes more of the risk (though the owner has more flexibility to specify changes during construction). Most contracts awarded to pollution control vendors are EPC or turnkey due to their shorter time schedules.

Contingency also accounts for inadequacies in cost estimating methods and for expected unknowns that may arise during project execution. The contingency funds are born by the owner or by the supplier, depending on contract vehicle issued. In any case, it is reflected in the TCI. Contingency is inversely proportional to the level of accuracy for a cost estimate. A study-level cost estimate, which is the level of analysis accuracy for estimates arrived at using the Control Cost Methodology, will have a higher contingency as compared for a more accurate (20% probable error) cost estimate that was arrived at with a greater amount of data and effort. Contingency can also vary depending primarily on the age of the technology. For mature control technologies, which reflect the control technologies covered in the other chapters of this Manual, the contingency can range from 5 to 15% of the TCI [3] This contingency is quite consistent with general cost guidance for mature or well-known technologies.[14] Finally, contingency should not account for events such as price escalation, work stoppages, and disasters. [13]

2.6.5 Estimating Annual Costs

Determining the total annual cost is the last step in the estimating procedure. As mentioned in Section 2.3 the total annual cost is comprised of three components—direct and indirect costs and recovery credits. Some cost items are annual; others are multi-year. 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 cost. (Values/factors for these costs are given in the chapters for individual devices.)

2.6.5.1 Raw Materials

Raw materials may be needed with control systems. Examples 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 on average. Specifying one or several sources for a recent reagent cost should be sufficient for cost estimation that is consistent with the Control Cost Methodology. Costs for chemicals are available from vendors, governmental sources such as the U.S. Geological Survey (USGS), and from ICIS Chemical Business, IHS Chemical Week, and similar well-recognized business publications.[15] A list of well-regarded sources for chemicals used as reagents in pollution control operations and other industrial chemical operations and processes can be found at university library web sites, with one maintained by Texas A&M's University Library being a particularly good example.[16] If the price of these reagents and raw materials become more volatile and deviate significantly from historical price trends, then the analyst is advised to take this into account in assessing the cost of material.

2.6.5.2 Labor

This section discusses the amount of labor required to operate and maintain a pollution control system. The necessary labor depends on the system's size, complexity, level of automation,

---

[14] Hollman, John K. "Improving Your Contingency Estimates for More Realistic Project Budgets." Chemical Engineering, December 2014. Available at http://www.chemengonline.com/improve-your-contingency-estimates-for-more-realistic-project-budgets/?printmode=1#disqus_thread.

[15] No endorsement by US EPA is made or implied of any publication that is named here, or anywhere else in the Manual.

[16] The link is at http://guides.library.tamu.edu/chemicalengineering. Click on "Chemical Prices" for industrial chemical data sites and publications.

and operating mode (i.e., batch or continuous). The labor is usually estimated on an hours-per-shift basis. As a rule, though, data showing explicit correlations between the labor requirement and capacity are often hard to obtain. One non-linear correlation found in the literature is shown below: [3]

$$L_2/L_1 = (V_2/V_1)^y \qquad (2.9)$$

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. [13] 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. [13] 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 industries at the national level. For cost assessments, these wages (adjusted for inflation through an appropriate cost index) should be adequate for study level purposes.

Finally, please 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.)

2.6.5.3 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 [3] suggests a factor of 100% of the maintenance labor to cover the maintenance materials cost.

2.6.5.4 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: [10]

$$C_e = 0.746\, Q\, \Delta P\, s\, \Theta p_e / 6356\eta \qquad (2.10)$$

Where

Q = gas flow rate (actual ft^3 /min, acfm)
P = pressure drop through system (inches of water, column) (Values for P 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[17] ($/kw-hr)

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

2.6.5.5 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 costs of waste treatment and disposal should be estimated where appropriate and consistent with the Control Cost Methodology. If installation of control equipment is expected to increase the waste generation from the current level, the difference between the expected level and the current level is attributable to the control equipment and should be accounted for in the cost estimate. Estimation of costs is accounted for in the chapters for specific control measures where waste treatment and disposal is a concern (e.g., gas absorbers, carbon adsorbers).

---

[17] The electricity cost in this equation is the cost to the power plant to generate its electricity, or busbar cost. Data on busbar costs is collected in Form 1 of the Federal Energy Regulatory Commission (FERC). Information on Form 1 can be found at http://www.ferc.gov/docs-filing/forms/form-1/data.asp.

2.6.5.6 Replacement Materials

The cost of 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 the present value of these costs in constant dollar must be calculated before being annualized by taking into account the life of the material (see section 2.5.5.3, 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:

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

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 analyst can choose to keep the length of the analysis as same as the life of the control system, and input the cost of the replacement materials accordingly before annualizing or annualize the replacement material cost stream separately from the control system. 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. Either way, this approach is appropriate when only the cost is under consideration in the overall analysis.

2.6.5.7 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 [3], while others factor it from the total labor costs alone. [3]

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 [3]. The factors recommended therein range from 50 to 70% [3]. An average value of 60% is used in this Manual.

2.6.5.8 Property Taxes, Insurance, Administrative Charges and Permitting Costs

The first 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 cover 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. These estimates can serve for cost estimates if sources do not have any reliable and accurate information on these indirect operating costs. This is the standard approach used in actions for which the cost methodology in this Cost Manual is a basis.

The permitting costs are costs borne by the facilities to get the necessary approval to design and install the control equipment. This is a site-specific cost where the costs borne by one facility may not translate well into another facility. However, because of potentials for delays, re-design and other considerations, permitting costs should be included in the overall cost assessment. While the cost of re-design and lost production are explicitly taken into account, analysts should carefully the effects of permitting process and their associated costs on the overall cost assessment.

2.7 Example

As an illustrative example of applying the cost methodology discussed in this chapter, consider the hypothetical All-American Electrical (AAE) [1] that operates a single 600 MWe tangentially fired high sulfur bituminous coal-fired boiler to produce steam to power its generators.

It emits an uncontrolled 50,000 tons of sulfur dioxide per year, and because it is planning on a major renovation, it must install devices to reduce its sulfur emissions to less than 1,000 tons per year (98 percent removal efficiency). After careful study of the available technologies, AAE has determined that either a wet limestone flue gas desulfurization (FGD) scrubber 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 thirty years, after which the scrubbers could be sold as scrap for a salvage value of about $500,000. We also provide an estimate of annual gypsum sales in the overall calculation given that gypsum can be a by-product of FGD scrubber operation. 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 (Including Revenue Streams) 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	$1,800,000
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

[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 dollars. 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 sources the company consults expect the inflation rate over the relevant range to be, on average, two percent. Consequently, the real rate of interest is (nine percent minus two percent) seven 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 FGD! 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 internal rate of return (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 effect of that choice on his company will be about the same. That leaves them free to look at other considerations that are not accounted for easily within this cost analysis: 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, some numerical and can be accounted for in the cost analysis, and some not, 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 role 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 study-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.

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

Years	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										

References

[1] Perry, Robert H., and Chilton, Cecil H., *Perry's Chemical Engineers' Handbook* (Eighth Edition), McGraw-Hill, New York, 2008, Chapter 9.

[2] Association for the Advancement of Cost Engineering International. Recommended Practices, No. 17R-97, *Cost Estimate Classification System*, and No. 18R-97, *Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries. June 15, 2011.*

[3] Peters, M.S. and Timmerhaus, K.D., *Plant Design and Economics for Chemical Engineers* (Fifth Edition), McGraw-Hill, New York, 2002.

[4} Grant, E.L., Ireson, W.G., and Leavenworth, R.S., *Principles of Engineering Economy*, Eighth Edition, John Wiley & Sons, New York, 1990.

[5] U.S. Environmental Protection Agency, Office of Policy, National Center for Environmental Economics. *Guidelines for Preparing Economic Analyses*. May 2014. Available on the Internet at http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

[6] Executive Office of the President, Office of Management and Budget. "Circular A-4: Regulatory Analysis.", September17,2013. Available at https://www.whitehouse.gov/omb/circulars_a004_a-4/.

[7] Vatavuk, W.M. "The OAQPS Control Cost Method vs. the Levelized Cost Method," *Environmental Progress*, Winter 2000. Vol. 19, No. 4.

[8] Association for the Advancement of Cost Engineering International. Recommended Practices, No. 58R-10, *Escalation Estimating Principles and Methods Using Indicies. May 25, 2011.*

[9] Vatavuk, W.M. "Updating the CE Plant Cost Index." *Chemical Engineering*, January 2002. Available at http://www.chemengonline.com/Assets/File/CEPCI_2002.pdf.

[10] Vatavuk, W.M. and Neveril, R.B. "Estimating Costs of Air-Pollution Control Systems— Part I: Parameters for Sizing Systems," *Chemical Engineering*, October 6, 1980, pp. 165-168.

[11] Vatavuk. W.M. Estimating Cost of Air Pollution Control. Lewis Publishers. 1990. p. 60.

[12] Design-Build Institute of America. "Choosing a Project Delivery Method, A Design Build Done Right Primer." April 2015. Available at http://www.dbia.org.

[13] Vatavuk, W.M. and Neveril, R.B. “Estimating Costs of Air Pollution Control Systems— Part II: Factors for Estimating Capital and Operating Costs,” *Chemical Engineering*, November 3, 1980, pp. 157-162.

[14] Crundwell, F.K. Finance for Engineers: Evaluation and Funding for Capital Projects. Springer-Verlag London Limited. 2008. pp. 95-96.

[15] U.S. Department of Energy, National Energy Technology Laboratory. “Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance,” DOE/NETL-2011/1455, April 2011. Available at https://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/QGESSNETLCostEstMethod.pdf (accessed on August 1, 2017).

APPENDIX A

Net Present Value and Capital Recovery Factor Tables

Table A.1 shows an example of present value calculations that includes illustrative discount rates and illustrative investment lifespans.[18] The table displays the amount an individual would be willing to accept today for a dollar promised in the future assuming the illustrative discount rates and investment lifespans. 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

---

[18] The example calculations in Table A.1 are all illustrative in nature. Nothing in this example is meant to contradict language earlier in this chapter concerning the appropriate use of interest rates, equipment life, and the EUAC in cost analysis to which the Control Cost Methodology is a basis.

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 today, 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