CHAPTER

6

Analysis of Cost Estimation

An acceptable plant design must represent a plant that can produce a product which will sell at a profit. Initially, sufficient capital must be committed to construct all aspects of the facility necessary for the plant. Since net profit equals total income minus *all* expenses, it is essential that the chemical engineer be aware of the various types of costs associated with each manufacturing step. Funds must be available for direct plant expenses, such as those for raw materials, labor, and utilities, and for indirect expenses, such as administrative salaries, product sales, and distribution costs. In this chapter, investment and plant operation costs are reviewed as well as cash flw and gross and net profits.

CASH FLOW FOR INDUSTRIAL OPERATIONS

Cash Flow

Figure 6-1 shows a simplified representation of the flw of funds for an overall industrial operation based on a corporate treasury serving as a reservoir and source of capital. Inputs to the capital reservoir normally are in the form of loans, stock issues, bond sales, and other capital sources, and the cash flw from project operations. Outputs from the capital reservoir are in the form of capital investments in projects, dividends to stockholders, repayment of debts, and other investments.

Figure 6-1 illustrates capital inputs and outputs for an industrial operation using a tree growth analogy, depicting as the trunk the total capital investment, excluding land cost, necessary to initiate the particular operation. The total capital investment comprises the fixed-capital investment in the plant and equipment, including the necessary investment for auxiliaries, and nonmanufacturing facilities, plus the working-capital investment. Some of the capital investments can usually be considered to occur as a lump sum, such as the provision of working capital required at the start of operation

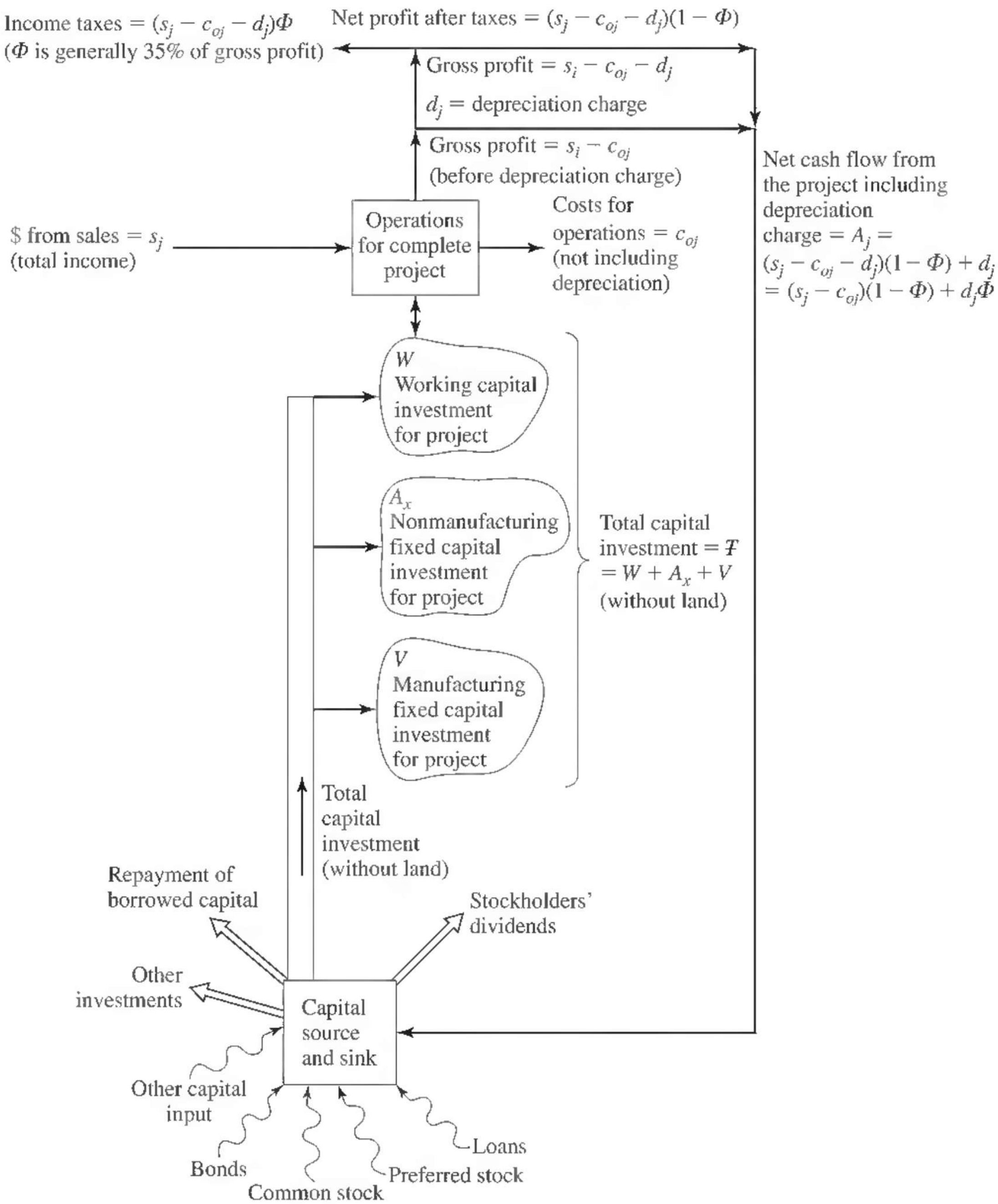

Figure 6-1
Tree diagram showing cash flow for industrial operations

of the completed plant. The flow of cash for the fixed-capital investment is usually spread over the entire construction period. Because income from sales and the costs of operation may occur on an irregular time basis, a reservoir of working capital must be available to meet these requirements.

The rectangular box near the top of Fig. 6-1 represents the operating phase for the complete project with working-capital funds maintained at a level acceptable for efficient operation. Cash flows into the operations box as dollars of income s_j from all sales while annual costs for operation, such as for raw materials and labor, but not including depreciation, are shown as outflow costs c_{oj}. These cash flows for income and operating expenses can be considered as continuous and represent rates of flow at a given time using the same time basis, such as dollars per day or dollars per year; the subscript j indicates the jth time period. Since, as discussed in Chap. 7, depreciation charges are in effect costs that are paid into the company capital reservoir, such charges are not included in the operation costs. The difference between the income and operating costs $s_j - c_{oj}$ is the *gross profit before depreciation charge* and is represented by the vertical line rising out of the operations box.

Depreciation is subtracted as a cost before income tax charges are calculated and paid, and net profits are reported to the stockholders. Consequently, removal of depreciation as a charge against profits is shown at the top of Fig. 6-1. The depreciation charge d_j is added to the net profit to make up the total *cash flow* for return to the capital reservoir. The resulting *gross profit* of $s_j - c_{oj} - d_j$ that accounts for the depreciation charge is taxable. The income tax charge is shown at the top of the diagram where it is removed in the amount $(s_j - c_{oj} - d_j)(\Phi)$, where Φ is the fixed income tax rate designated as a fraction of the annual gross profits. The remainder after income taxes are paid $(s_j - c_{oj} - d_j)(1-\Phi)$ is the *net profit* after taxes that is returned to the capital reservoir. When the depreciation charge d_j is added to the net profit, the total project-generated cash flow returned to the capital reservoir on an annual basis is

$$A_j = (s_j - c_{oj})(1-\Phi) + d_j\Phi \qquad (6\text{-}1)$$

where A_j is the *cash flow* from the project to the corporate capital reservoir resulting from the operation in year j in dollars, s_j the sales rate in year j in dollars, c_{oj} the cost of operation (depreciation not included) in year j in dollars, d_j is the depreciation charge in year j in dollars, and Φ the fractional income tax rate. This cash flow is used for new investments, dividends, and repayment of loans, as indicated by the various branches emanating from the capital source in Fig. 6-1, as well as for retained earnings.

Cumulative Cash Position

The cash flow diagram in Fig. 6-1 represents the rates of cash flow with s_j, c_{oj}, and d_j all based on the same time increment. Figure 6-2 is for the same type of cash flow for an industrial operation except that it depicts the situation as the *cumulative cash position* over the life cycle of a project. The numerical values are only for illustration.

In the situation depicted in Fig. 6-2, land value is included as part of the total capital investment to show clearly the complete sequence of steps in the full life cycle for an industrial project. The zero point on the time coordinate represents the point at which the plant has been completely constructed and begins start-up of operation. The total capital investment at the zero time point includes land cost, manufacturing and nonmanufacturing fixed-capital investment, and working capital. The cash position is negative by the amount of the total capital investment at zero time. In the ideal situation, revenues come in from the operation as soon as time is positive. Cash flow to the company treasury, in the form of net profits after taxes plus depreciation, starts to

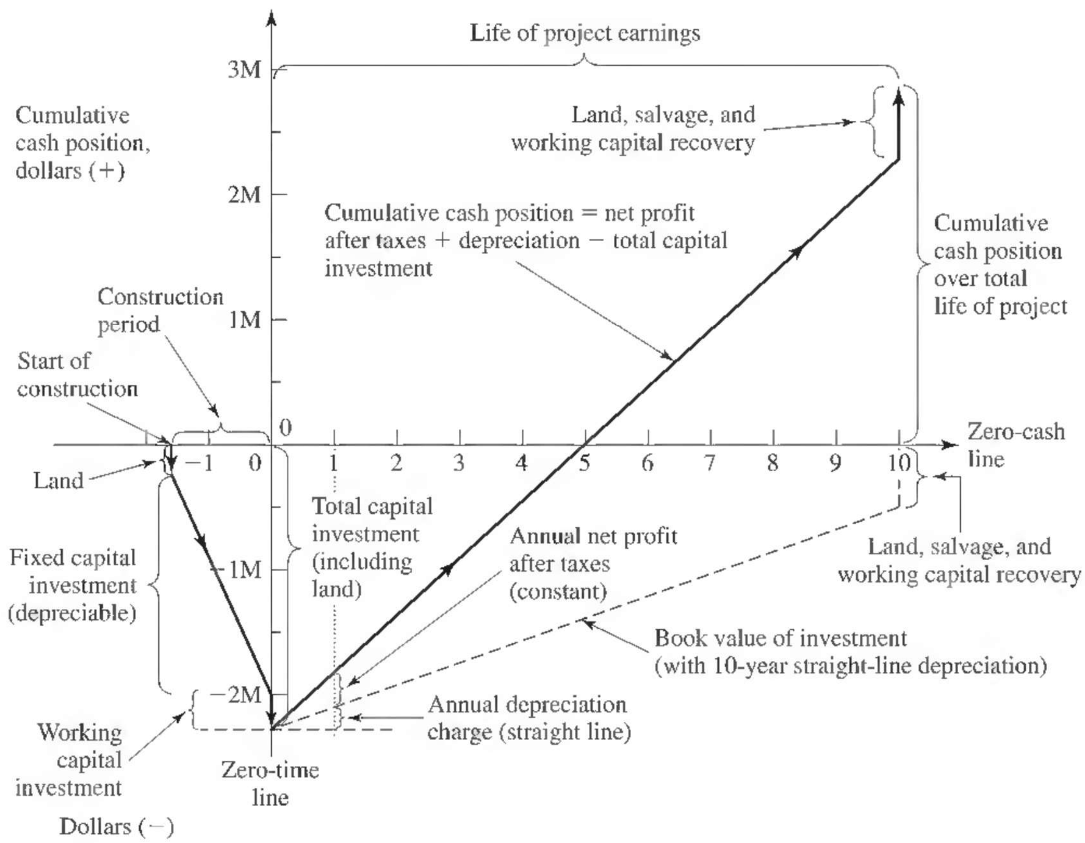

Figure 6-2
Graph of cumulative cash position showing effects of cash flow over the full life cycle for an industrial operation, neglecting the time value of money

accumulate and gradually repays the total capital investment. In the figure, a constant cash flow rate has been assumed from time zero until the end of operation, although in reality a constant cash flow would not be expected. For the conditions shown in Fig. 6-2, the total capital investment is repaid in 5 years, and the cumulative cash position is zero. After that time, profits accumulate on the positive side of the cumulative cash position until the end of the project life, when the plant is shut down and project operation ceases. At shutdown, the working capital and land value are recovered. The working capital is recovered by the sale of materials, supplies, and equipment. Land can be either sold or transferred to another company use. For evaluation purposes it is generally assumed that the dollar amount recovered for working capital and land is the same as that spent originally. Thus, the final cumulative cash position over the 10-year life of the project is shown in the upper right-hand bracket in Fig. 6-2.

The relationships presented in Fig. 6-2 are very important for the understanding of the factors to be considered in cost estimation. To put emphasis on the basic nature of the role of cash flow, Fig. 6-2 has been simplified considerably by neglecting the time value of money and using constant annual profit and constant annual depreciation. In the chapters to follow, more complex cases will be considered in detail.

FACTORS AFFECTING INVESTMENT AND PRODUCTION COSTS

When a chemical engineer determines costs for any type of industrial process, these costs should be of sufficient accuracy to provide reliable decisions. To accomplish this, the engineer must have a complete understanding of the many factors that can affect costs. For example, some companies have reciprocal arrangements with other companies whereby certain raw materials or types of equipment may be purchased at prices lower than the prevailing market prices. Therefore, if the chemical engineer bases the cost of the raw materials for the process on regular market prices, the result may be that the process could appear to be unprofitable rather than profitable. Accordingly, the engineer must be aware of actual prices for raw materials and equipment, company policies, government regulations, and other factors affecting costs.

Sources of Equipment

One of the major costs involved in any chemical process is for equipment. In many cases, standard types of tanks, reactors, or other equipment are used, and a substantial reduction in cost can be realized by employing idle equipment or by purchasing secondhand equipment. If new equipment must be bought, several independent quotations should be obtained from different manufacturers. When specifications are given to the manufacturers, the chances for a low-cost estimate are increased if overly strict limitations on the design are kept to a minimum.

Price Fluctuations

In today's economic market, prices may vary widely from one period to another. For example, plant operators or supervisors cannot be hired today at the same wage rate as in 1985. The same statement applies to comparing prices of equipment purchased at different times. The chemical engineer, therefore, must keep up to date on price and wage fluctuations. One of the most complete sources of information on existing price conditions is the *Monthly Labor Review,* published by the U.S. Bureau of Labor Statistics. This publication gives up-to-date information on present prices and wages for different types of industries.

Company Policies

Policies of individual companies have a direct effect on costs. For example, some companies have particularly strict safety regulations, and these must be met in every detail. Accounting procedures and methods for allocating corporate costs vary among companies. Company policies with reference to labor unions must be considered, because these can affect overtime labor charges and the type of work that operators or other employees can perform. Labor union policies may, for example, even dictate the amount of wiring and piping that can be done on a piece of equipment before it is brought into the plant and thus have a direct effect on the total cost of installed equipment.

Operating Time and Rate of Production

One of the factors that has a major effect on the profits is the fraction of time a process is in operation. If equipment stands idle for an extended period, raw materials and labor costs are usually low; however, many other costs, designated as fixed costs, for example, maintenance, protection, and depreciation, continue even though the equipment is not in active use. More importantly, anytime that a plant is not producing a product, it is also not producing revenue. Some time must be allowed periodically to perform scheduled routine maintenance; however, downtime should be kept to a necessary minimum, as it is one of the chief sources of poor profitability in process plants.

Sales demand, rate of production, and operating time are closely interrelated. The ideal plant should operate under a time schedule that gives the maximum production rate consistent with market demand, safety, maintainability, and economic operating conditions. In this way, the total cost per unit of production is minimized because the variable costs averaged over time are low. If the production capacity of the process is greater than the sales demand, the operation can be operated continuously at reduced capacity or periodically at full capacity.

Figure 6-3 shows the effect on costs and profits based on the rate of production. As indicated in this figure, the fixed costs remain constant, and the total product cost

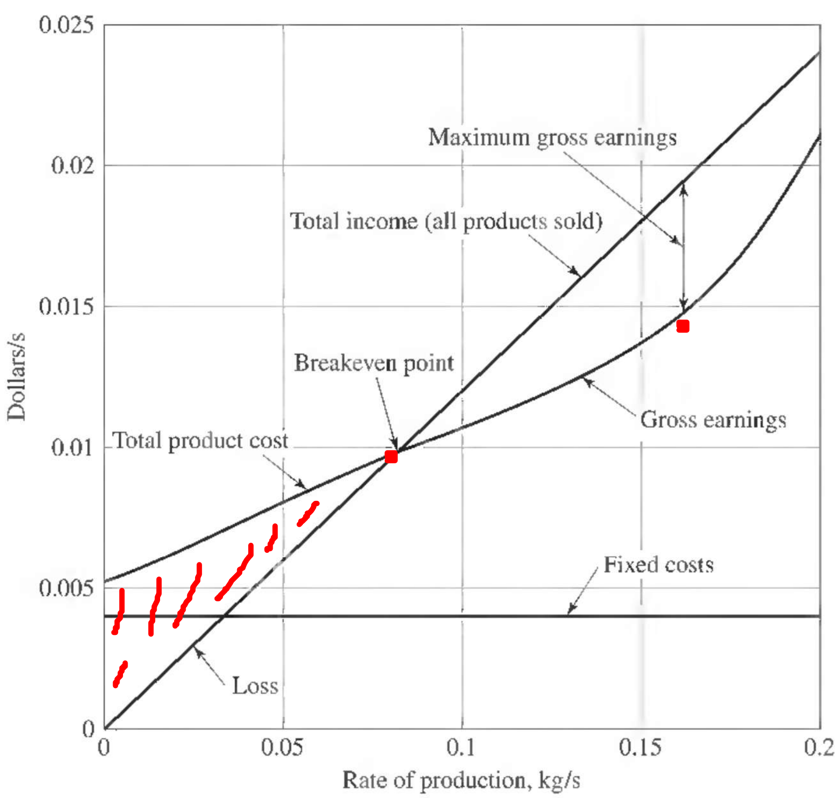

Figure 6-3
Breakeven chart for chemical processing plant

increases as the rate of production increases. The point where the total product cost equals the total income is designated as the *breakeven point.* Under the conditions shown in Fig. 6-3, a desirable production rate for this chemical processing plant would be approximately 5×10^6 kg/yr, because this represents the point of maximum gross and net profit. By considering sales demand along with the capacity and operating characteristics of the equipment, the engineer can recommend the production rate and operating schedules that will give optimal economic results.

Government Policies

The national government has many laws and regulations that have a direct effect on industrial costs. Some examples of these are import and export tariff regulations, depreciation rates, income tax rules, and environmental and safety regulations. Of these, income tax regulations and depreciation have the largest impact on most businesses.

As of the writing of this text, modifications of federal corporate tax laws were under consideration in the U.S. Congress. However, the last major change in federal corporate income tax rates was in 1993 and in depreciation was in 1988. The important point to remember is that tax law is subject to change at any time, and the design engineer must consult with tax experts to be sure that the most current tax codes are used in economic analyses. More details on tax policies may be found in Chap. 7.

CAPITAL INVESTMENT

A traditional economic definition of *capital* is "a stock of accumulated wealth." In an applied sense, capital is savings that may be used as the owner decides. One use of the savings is *investment;* that is, to use the savings ". . . to promote the production of other goods, instead of being available solely for purposes of immediate enjoyment" with ". . . the view of obtaining an income or profit."[†]

Before an industrial plant can be put into operation, a large sum of money must be available to purchase and install the required machinery and equipment. Land must be obtained, service facilities must be made available, and the plant must be erected complete with all piping, controls, and services. In addition, funds are required with which to pay the expenses involved in the plant operation before sales revenue becomes available.

The capital needed to supply the required manufacturing and plant facilities is called the *fixed-capital investment* (FCI), while that necessary for the operation of the plant is termed the *working capital* (WC). The sum of the fixed-capital investment and the working capital is known as the *total capital investment* (TCI). The fixed-capital portion may be further subdivided into *manufacturing fixed-capital investment,* also known as *direct cost,* and *nonmanufacturing fixed-capital investment*, also known as *indirect cost.*

[†]W. A. Neilson, ed., *Webster's New International Dictionary,* 2d ed., G. & C. Merriam Company, Springfield, MA, 1957.

Fixed-Capital Investment

Manufacturing fixed-capital investment represents the capital necessary for the installed process equipment with all components that are needed for complete process operation. Expenses for site preparation, piping, instruments, insulation, foundations, and auxiliary facilities are typical examples of costs included in the manufacturing fixed-capital investment.

The capital required for construction overhead and for all plant components that are not directly related to the process operation is designated the *nonmanufacturing fixed-capital investment.* These plant components include the land; processing buildings, administrative and other offices, warehouses, laboratories, transportation, shipping, and receiving facilities, utility and waste disposal facilities, shops, and other permanent parts of the plant. The *construction overhead cost* includes field office and supervision expenses, home office expenses, engineering expenses, miscellaneous construction costs, contractors' fees, and contingencies. In some cases, construction overhead is proportioned between manufacturing and nonmanufacturing fixed-capital investment.

Working Capital

The working capital for an industrial plant consists of the total amount of money invested in (1) raw materials and supplies carried in stock; (2) finished products in stock and semifinished products in the process of being manufactured; (3) accounts receivable; (4) cash kept on hand for monthly payment of operating expenses, such as salaries, wages, and raw material purchases; (5) accounts payable; and (6) taxes payable.

The raw material inventory included in working capital usually amounts to a 1-month supply of the raw materials valued at delivered prices. Finished products in stock and semifinished products have a value approximately equal to the total manufacturing cost for 1 month's production. Because credit terms extended to customers are usually based on an allowable 30-day payment period, the working capital required because of accounts receivable ordinarily amounts to the production cost for 1 month of operation.

The ratio of working capital to total capital investment varies with different companies, but most chemical plants use an initial working capital amounting to 10 to 20 percent of the total capital investment. This percentage may increase to as much as 50 percent or more for companies producing products of seasonal demand, because of the large inventories which must be maintained for appreciable periods.

ESTIMATION OF CAPITAL INVESTMENT

Most estimates of capital investment are based on the cost of the equipment required. The most significant errors in capital investment estimation are generally due to omissions of equipment, services, or auxiliary facilities rather than to gross errors in costing. Table 6-1 provides a checklist of items for a new facility and is an invaluable aid in making a complete estimation of the fixed-capital investment.

Table 6-1 Breakdown of fixed-capital investment items for a chemical process

Direct costs

1. *Purchased equipment*
   - All equipment listed on a complete flowsheet
   - Spare parts and noninstalled equipment spares
   - Surplus equipment, supplies, and equipment allowance
   - Inflation cost allowance
   - Freight charges
   - Taxes, insurance, duties
   - Allowance for modifications during start-up
2. *Purchased-equipment installation*
   - Installation of all equipment listed on complete flowsheet
   - Structural supports
   - Equipment insulation and painting
3. *Instrumentation and controls*
   - Purchase, installation, calibration, computer control with supportive software
4. *Piping*
   - Process piping utilizing suitable structural materials
   - Pipe hangers, fittings, valves
   - Insulation
5. *Electrical systems*
   - Electrical equipment switches, motors, conduit, wire, fittings, feeders, grounding, instrument and control wiring, lighting, panels
   - Electrical materials and labor
6. *Buildings (including services)*
   - Process buildings—substructures, superstructures, platforms, supports, stairways, ladders, access ways, cranes, monorails, hoists, elevators
   - Auxiliary buildings—administration and office, medical or dispensary, cafeteria, garage, product warehouse, parts warehouse, guard and safety, fire station, change house, personnel building, shipping office and platform, research laboratory, control laboratory
   - Maintenance shops—electric, piping, sheet metal, machine, welding, carpentry, instrument
   - Building services—plumbing, heating, ventilation, dust collection, air conditioning, building lighting, elevators, escalators, telephones, intercommunication systems, painting, sprinkler systems, fire alarm
7. *Yard improvements*
   - Site development—site clearing, grading, roads, walkways, railroads, fences, parking areas, wharves and piers, recreational facilities, landscaping
8. *Service facilities*
   - Utilities—steam, water, power, refrigeration, compressed air, fuel, waste disposal
   - Facilities—boiler plant incinerator, wells, river intake, water treatment, cooling towers, water storage, electric substation, refrigeration plant, air plant, fuel storage, waste disposal plant, environmental controls, fire protection
   - Nonprocess equipment—office furniture and equipment, cafeteria equipment, safety and medical equipment, shop equipment, automotive equipment, yard material-handling equipment, laboratory equipment, locker-room equipment, garage equipment, shelves, bins, pallets, hand trucks, housekeeping equipment, fire extinguishers, hoses, fire engines, loading stations
   - Distribution and packaging—raw material and product storage and handling equipment, product packaging equipment, blending facilities, loading stations
9. *Land*
   - Surveys and fees
   - Property cost

Table 6-1 ***Continued***

Indirect costs

1. *Engineering and supervision*
   - Engineering costs—administrative, process, design and general engineering, computer graphics, cost engineering, procuring, expediting, reproduction, communications, scale models, consultant fees, travel
   - Engineering supervision and inspection
2. *Legal expenses*
   - Identification of applicable federal, state, and local regulations
   - Preparation and submission of forms required by regulatory agencies
   - Acquisition of regulatory approval
   - Contract negotiations
3. *Construction expenses*
   - Construction, operation, and maintenance of temporary facilities, offices, roads, parking lots, railroads, electrical, piping, communications, fencing
   - Construction tools and equipment
   - Construction supervision, accounting, timekeeping, purchasing, expediting
   - Warehouse personnel and expense, guards
   - Safety, medical, fringe benefits
   - Permits, field tests, special licenses
   - Taxes, insurance, interest
4. *Contractor's fee*
5. *Contingency*

Types of Capital Cost Estimates

An estimate of the capital investment for a process may vary from a predesign estimate based on little information except the magnitude of the proposed project to a detailed estimate prepared from complete drawings and specifications. Between these two extremes of capital investment estimates, there can be numerous other estimates that vary in accuracy depending upon the stage of development of the project. These estimates are called by a variety of names, but the following five categories represent the accuracy range and designation normally used for design purposes:

1. *Order-of-magnitude estimate* (*ratio estimate*) based on similar previous cost data; probable accuracy of estimate over ± 30 percent.
2. *Study estimate* (*factored estimate*) based on knowledge of major items of equipment; probable accuracy of estimate up to ± 30 percent.
3. *Preliminary estimate* (*budget authorization estimate* or *scope estimate*) based on sufficient data to permit the estimate to be budgeted; probable accuracy of estimate within ± 20 percent.
4. *Definitive estimate* (*project control estimate*) based on almost complete data but before completion of drawings and specifications; probable accuracy of estimate within ± 10 percent.
5. *Detailed estimate* (*contractor's estimate*) based on complete engineering drawings, specifications, and site surveys; probable accuracy of estimate within ± 5 percent.

Figure 6-4 shows the information required for the preparation of these five levels of estimates and the approximate limits of error in these methods. There is a large probability that the actual cost will be more than the estimated cost when information is incomplete or during periods of rising costs. For such estimates, the positive spread is likely to be wider than the negative, say, +40 and −20 percent for a study estimate.

Predesign cost estimates (defined here as order-of-magnitude, study, and preliminary estimates) require much less detail than firm estimates such as the definitive or detailed estimates. However, the predesign estimates are extremely important for determining whether a proposed project should be given further consideration or comparing alternative designs. For this reason, much of the information presented in this chapter is devoted to predesign estimates, although it should be understood that the distinction between predesign and firm estimates gradually disappears as more and more details are included.

Predesign estimates may be used to provide a basis for requesting and obtaining a capital appropriation from company management. Later estimates, made during the progress of the design, may indicate that the project will cost more or less than the amount appropriated. Management is then asked to approve a *variance,* which may be positive or negative.

COST INDEXES

Most cost data that are available for making a preliminary or predesign estimate are only valid at the time they were developed. Because prices may have changed considerably with time due to changes in economic conditions, some method must be used for updating cost data applicable at a past date to costs that are representative of conditions at a later time.[†] This can be done by the use of cost indexes.

A cost index is an index value for a given time showing the cost at that time relative to a certain base time. If the cost at some time in the past is known, the equivalent cost at present can be determined by multiplying the original cost by the ratio of the present index value to the index value applicable when the original cost was obtained, namely,

$$\text{Present cost} = \text{original cost}\left(\frac{\text{index value at present}}{\text{index value at time original cost was obtained}}\right)$$

Cost indexes can be used to give a general estimate, but no index can take into account all factors, such as special technological advancements or local conditions. The common indexes permit fairly accurate estimates if the period involved is less than 10 years. Indexes are frequently used to extrapolate costs into the near future. For example, the cost estimator may project costs forward from the time a study is being done until the expected start-up time of a plant. Such projections are done by using extrapolated values of an index, or an expected inflation rate.

Many different types of cost indexes are published regularly. Some can be used for estimating equipment costs; others apply specifically to labor, construction, materials, or other specialized fields. The most common of these indexes are the *Marshall and*

[†]See Chap. 8 for a discussion of the effects of inflation or deflation on costs and revenues in the future.

	Required information	Detailed estimate ± 5% range	Definitive estimate ± 10% range	Preliminary estimate ± 20% range	Study estimate ± 30% range	Order-of-magnitude estimate > ± 30% range
Site	Location	●	●	●	●	
	General description	●	●	●		
	Soil bearing	●	●	●		
	Location & dimensions R.R, roads, impounds, fences	●	●	●		
	Well-developed site plot plan & topographical map	●	●			
	Well-developed site facilities	●				
Process flowsheet	Rough sketches				●	
	Preliminary			●		
	Engineered	●	●			
Equipment list	Preliminary sizing & material specifications			●	●	
	Engineered specifications	●	●			
	Vessel sheets	●	●			
	General arrangement					
	(a) Preliminary		●	●		
	(b) Engineered	●				
Building and structures	Approximate sizes & type of construction			●	●	
	Foundation sketches		●	●		
	Architectural & construction	●	●	●		
	Preliminary structural design			●		
	General arrangement & elevations	●	●			
	Detailed drawings	●				
Utility requirements	Rough quantities (steam, water, electricity, etc.)				●	
	Preliminary heat balance			●		
	Preliminary flowsheets		●	●		
	Engineered heat balance	●	●			
	Engineered flowsheet	●				
	Well-developed drawings	●				
Piping	Preliminary flowsheet & specifications			●	●	
	Engineered flowsheet		●			
	Piping layouts & schedules	●	●			
Insulation	Rough specifications			●		
	Preliminary list of equipment & piping to be insulated		●			
	Insulation specifications & schedules	●	●			
	Well-developed drawings or specifications	●		●		
Instrumentation	Preliminary instrument list		●			
	Engineered list & flowsheet	●				
	Well-developed drawings	●				
Electrical	Preliminary motor list—approximate sizes			●	●	
	Engineered list & sizes	●	●			
	Substations, number & sizes, specifications	●	●	●		
	Distribution specifications	●				
	Preliminary lighting specifications			●		
	Preliminary interlock, control, & instrument wiring specs.		●			
	Engineered single-line diagrams (power & light)	●	●			
	Well-developed drawings	●				
Worker-hours	Engineering & drafting	●	●	●	●	
	Labor by craft	●				
	Supervision	●				
Product scope standard process	Product, capacity, location, & site requirements. Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements.					●

Figure 6-4
Cost-estimating information guide

Table 6-2 Cost indexes as annual averages

	Marshall and Swift installed-equipment indexes, 1926 = 100		*Eng. News-Record* construction index			Nelson-Farrar refinery construction index,	*Chemical Engineering* plant cost index, 1957–
Year	All industries	Process industry	1913 = 100	1949 = 100	1967 = 100	1946 = 100	1959 = 100
1987	814	830	4406	956	410	1121.5	324
1988	852	859.3	4519	980	421	1164.5	343
1989	895	905.6	4615	1001	430	1195.9	355
1990	915.1	929.3	4732	1026	441	1225.7	357.6
1991	930.6	949.9	4835	1049	450	1252.9	361.3
1992	943.1	957.9	4985	1081	464	1277.3	358.2
1993	964.2	971.4	5210	1130	485	1310.8	359.2
1994	993.4	992.8	5408	1173	504	1349.7	368.1
1995	1027.5	1029.0	5471	1187	509	1392.1	381.1
1996	1039.1	1048.5	5620	1219	523	1418.9	381.7
1997	1056.8	1063.7	5825	1264	542	1449.2	386.5
1998	1061.9	1077.1	5920	1284	551	1477.6	389.5
1999	1068.3	1081.9	6060	1315	564	1497.2	390.6
2000	1089.0	1097.7	6221	1350	579	1542.7	394.1
2001	1093.9	1106.9	6342	1376	591	1579.7	394.3
2002	1102.5‡	1116.9‡	6490‡	1408‡	604‡	1599.2‡	390.4†,§

†All costs presented in this text and in the McGraw-Hill website are based on this value for January 2002, obtained from the *Chemical Engineering* index unless otherwise indicated. The website provides the corresponding mathematical cost relationships for all the graphical cost data presented in the text.
‡Projected.
§Calculated with revised index; see *Chem. Eng.*, **109:** 62 (2002).

Swift all-industry and *process-industry equipment indexes,*† the *Engineering News-Record construction index,*‡ the *Nelson-Farrar refinery construction index,*§ and the *Chemical Engineering plant cost index.*¶ Table 6-2 presents a list of values for various types of indexes over the past 15 years.

There are numerous other indexes presented in the literature that can be used for specialized purposes. For example, cost indexes for materials and labor for various

†Values for the Marshall and Swift equipment cost indexes are published each month in *Chemical Engineering*. For a complete description of these indexes, see R. W. Stevens, *Chem. Eng.*, **54**(11): 124 (1947). See also *Chem. Eng.*, **85**(11): 189 (1978) and **92**(9): 75 (1985).

‡The *Engineering News-Record* construction cost index appears weekly in the *Engineering News-Record*. For a complete description of this index and the revised basis, see *Eng. News-Record*, **143**(9): 398 (1949), **178**(11): 87 (1967). A history is presented in the March issue each year; for example, see *Eng. News-Record*, **220**(11): 54 (1988).

§The Nelson-Farrar refinery construction index is published the first week of each month in the *Oil and Gas Journal*. For a complete description of this index, see *Oil Gas J.*, **63**(14): 185 (1965), **74**(48): 68 (1976), and **83**(52): 145 (1985).

¶The *Chemical Engineering* plant cost index is published each month in *Chemical Engineering*. A complete description of this index is found in *Chem. Eng.*, **70**(4): 143 (1963) with recapping and updating essentially every 3 years. The index is being revised in 2002 to provide a better relationship between the various cost factors involved in the index; see W. M. Vavatuk, *Chem. Eng.*, **109**(1): 62 (2002) for details.

types of industries are published monthly by the U.S. Bureau of Labor Statistics in the *Monthly Labor Review*. These indexes can be useful for special kinds of estimates involving particular materials or unusual labor conditions. Another example of a cost index which is useful for worldwide comparison of cost charges with time is published periodically in the *International Journal of Production Economics* (formerly *Engineering Costs and Production Economics*). This presents cost indexes for plant costs for various countries in the world including Australia, Belgium, Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Japan, Sweden, the United Kingdom, and the United States.[†]

All cost indexes are based on limited sampling of the goods and services in question; therefore, two indexes covering the same types of projects may give results that differ considerably. The most that any index can hope to do is to reflect general trends. These trends may at times have little meaning when applied to a specific case. For example, a contractor may, during a slack period, accept a construction job with little profit just to keep the construction crew together. On the other hand, if there are current local labor shortages, a project may cost considerably more than a similar project in another geographic location.

The Marshall and Swift equipment cost indexes and the *Chemical Engineering* plant cost indexes are recommended for process equipment and chemical-plant investment estimates. These two cost indexes give very similar results, while the *Engineering News-Record* construction cost index has increased with time much more rapidly than the other two because it does not include a productivity improvement factor. Similarly, the Nelson-Farrar refinery construction index has shown a very large increase with time and should be used with caution and only for refinery construction.

COST COMPONENTS IN CAPITAL INVESTMENT

Capital investment is the total amount of money needed to supply the necessary plant and manufacturing facilities plus the amount of money required as working capital for operation of the facilities. Let us now consider the proportional costs of each major component of fixed-capital investment, as outlined previously in Table 6-1. The cost factors presented here are based on a careful interpretation of recent sources[‡] with input based on industrial experience.

Table 6-3 summarizes these typical variations in component costs as percentages of fixed-capital investment (FCI) for multiprocess *grass-roots* plants or large *battery-limit* additions. A *grass-roots* plant is defined as a complete plant erected on a new site.

[†]For methods used, see *Eng. Costs Prod. Econ.*, **6**(1): 267 (1982).

[‡]K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control*, Craftsman Book Company of America, Solana Beach, CA, 1974; G. D. Ulrich, *A Guide to Chemical Engineering Process Design and Economics*, J. Wiley, New York, 1984; R. K. Sinnott, *An Introduction to Chemical Engineering Design*, Pergamon Press, Oxford, United Kingdom, 1983; P. F. Ostwald, *AM Cost Estimator*, McGraw-Hill, New York, 1988; D. R. Woods, *Process Design and Engineering Practice*, Prentice-Hall, Upper Saddle River, NJ, 1995; R. H. Perry and D. W. Green, eds., *Perry's Chemical Engineers' Handbook*, 7th ed., McGraw-Hill, New York, 1997.

Table 6-3 Typical percentages of fixed-capital investment values for direct and indirect cost segments for multipurpose plants or large additions to existing facilities

Component	Range of FCI, %
Direct costs	
Purchased equipment	15–40
Purchased-equipment installation	6–14
Instrumentation and controls (installed)	2–12
Piping (installed)	4–17
Electrical systems (installed)	2–10
Buildings (including services)	2–18
Yard improvements	2–5
Service facilities (installed)	8–30
Land	1–2
Indirect costs	
Engineering and supervision	4–20
Construction expenses	4–17
Legal expenses	1–3
Contractor's fee	2–6
Contingency	5–15

Investment includes all costs of land, site development, battery-limit facilities, and auxiliary facilities. A geographic boundary defining the coverage of a specific project is a *battery limit*. Usually this encompasses the manufacturing area of a proposed plant or addition, including all process equipment but excluding provision of storage, utilities, administrative buildings, or auxiliary facilities unless so specified. Normally this excludes site preparation and therefore may be applied to the extension of an existing plant.

EXAMPLE 6-1 Estimation of Fixed-Capital Investment Using Ranges of Process-Plant Component Costs

Make a study estimate of the fixed-capital investment for a process plant if the purchased-equipment cost is \$100,000. Use the ranges of process-plant component cost outlined in Table 6-3 for a process plant handling both solids and fluids with a high degree of automatic controls and essentially outdoor operation. Do not include land.

■ Solution

A percentage is selected within the range in Table 6-3 for each of the components of fixed-capital investment; this selection is somewhat arbitrary, with selection made of average values unless process-plant characteristics suggest lower or upper values. Generally, when all these percentages are added, they will not total 100 percent. Therefore, all the percentages must be normalized to a total of 100 by dividing each percentage by the total sum over 100. The estimated cost for a component cost is then calculated as \$100,000 multiplied by the normalized percentage for that component, and then divided by the normalized percentage for the purchased equipment. All values are rounded to the nearest \$1000.

These computations are summarized in the following table.

Components	Selected percentage of FCI	Normalized percentage of FCI	Estimated cost
Purchased equipment	25	22.9	$100,000
Purchased-equipment installation	9	8.3	36,000
Instrumentation (installed)	10	9.2	40,000
Piping (installed)	8	7.3	32,000
Electrical (installed)	5	4.6	20,000
Buildings (including services)	5	4.6	20,000
Yard improvements	2	1.8	8,000
Service facilities (installed)	15	13.8	60,000
Engineering and supervision	8	7.3	32,000
Construction expense	10	9.2	40,000
Legal expense	2	1.8	8,000
Contractor's fee	2	1.8	8,000
Contingency	8	7.3	32,000
Total	109	99.9	$436,000

It should be recognized that the $436,000 has a large uncertainty, on the order of ±30 percent.

■

Purchased Equipment

The cost of purchased equipment is the basis of several predesign methods for estimating capital investment. Sources of equipment prices, methods of adjusting equipment prices for capacity, and methods of estimating auxiliary process equipment are therefore essential to the estimator in making reliable cost estimates. The various types of equipment can often be divided conveniently into (1) processing equipment, (2) raw materials handling and storage equipment, and (3) finished-products handling and storage equipment.

The sizes and specifications of the equipment needed for a chemical process are determined from the equipment parameters fixed or calculated along with the material and energy balances. In a process simulation to obtain the material and energy balances for a distillation column, for example, the engineer must specify the number of equilibrium stages, reflux ratio, total or partial condensation of the overhead stream, and operating pressure at a particular point, such as at the top of the column. With these parameters and feed conditions, a distillation algorithm calculates the product compositions, temperatures, and pressures as well as the condenser and reboiler duties. The number of actual plates needed can be obtained by specifying the plate efficiency. This information plus the materials of construction is sufficient to make an estimate of the purchased cost of the column, condenser and reboiler, and associated piping. Similarly, for other types of process equipment the specifications required to complete the material and energy balances are usually sufficient to make a cost estimate.

The most accurate method for determining process equipment costs is to obtain firm bids from fabricators or suppliers. Often, fabricators can supply quick estimates that will be close to the bid price but will not take too much time. Second-best in reliability are cost values from the file of past purchase orders. When used for pricing new equipment, purchase-order prices must be corrected with the appropriate cost index ratio. Limited information on process-equipment costs has also been published in various engineering journals. Costs estimates for a large number of different types and capacities of equipment are presented in Chaps. 12 through 15.

Estimating Equipment Costs by Scaling

It is often necessary to estimate the cost of a piece of equipment when cost data are not available for the particular size or capacity involved. Predictions can be made by using the power relationship known as the *six-tenths factor rule,* if the new piece of equipment is similar to one of another capacity for which cost data are available. According to this rule, if the cost of a given unit b at one capacity is known, the cost of a similar unit a with X times the capacity of the first is $X^{0.6}$ times the cost of the initial unit.

$$\text{Cost of equipment } a = (\text{cost of equipment } b)X^{0.6} \tag{6-2}$$

The preceding equation indicates that a log-log plot of capacity versus cost for a given type of equipment should be a straight line with a slope equal to 0.6. Figure 6-5 presents a plot of this sort for shell-and-tube heat exchangers. The application of the 0.6 rule of thumb for most purchased equipment is, however, an oversimplification, since the actual values of the cost capacity exponent vary from less than 0.3 to greater than 1.0, as shown in Table 6-4. Because of this, the 0.6 power should be used only in

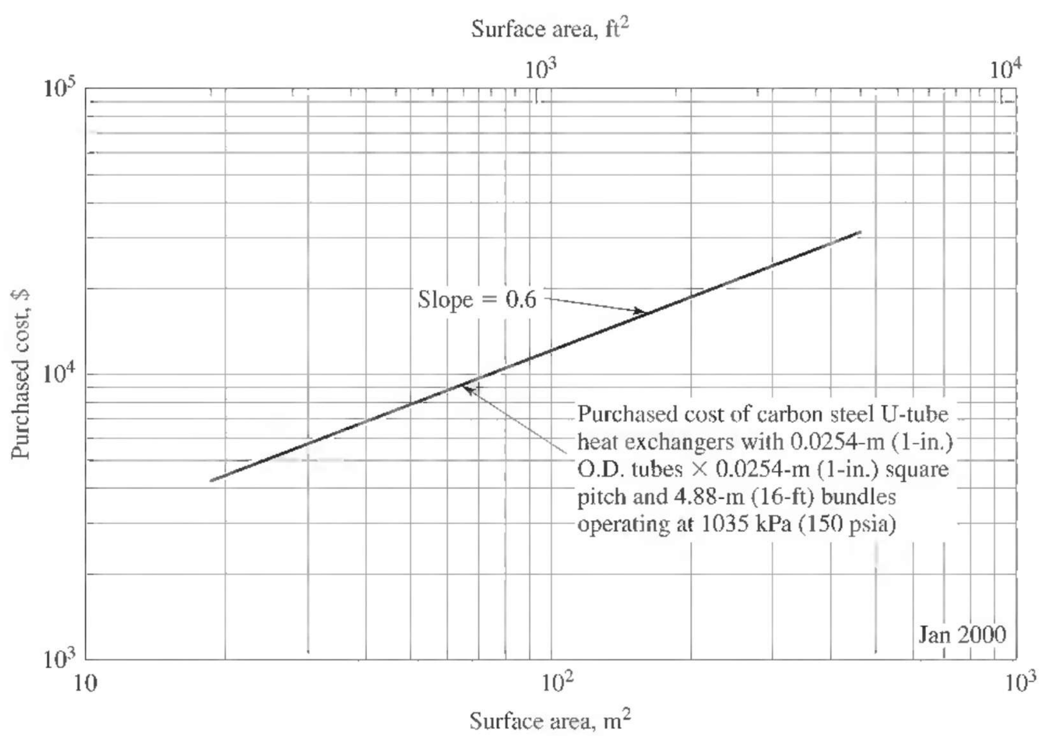

Figure 6-5
Application of "six-tenth factor" rule to costs for U-tube heat exchangers

Table 6-4 Typical exponents for equipment cost as a function of capacity

Equipment	Size range	Exponent
Blender, double cone rotary, carbon steel (c.s.)	1.4–7.1 m^3 (50–250 ft^3)	0.49
Blower, centrifugal	0.5–4.7 m^3/s (10^3–10^4 ft^3/min)	0.59
Centrifuge, solid bowl, c.s.	7.5–75 kW (10–10^2 hp) drive	0.67
Crystallizer, vacuum batch, c.s.	15–200 m^3 (500–7000 ft^3)	0.37
Compressor, reciprocating, air-cooled, two-stage, 1035-kPa discharge	0.005–0.19 m^3 (10–400 ft^3/min)	0.69
Compressor, rotary, single-stage, sliding vane, 1035-kPa discharge	0.05–0.5 m^3/s (10^2–10^3 ft^3/min)	0.79
Dryer, drum, single vacuum	1–10 m^2 (10–10^2 ft^2)	0.76
Dryer, drum, single atmospheric	1–10 m^2 (10–10^2 ft^2)	0.40
Evaporator (installed), horizontal tank	10–1000 m^2 (10^2–10^4 ft^2)	0.54
Fan, centrifugal	0.5–5 m^3/s (10^3–10^4 ft^3/min)	0.44
Fan, centrifugal	10–35 m^3/s (2×10^4–7×10^4 ft^3/min)	1.17
Heat exchanger, shell-and-tube, floating head, c.s.	10–40 m^2 (100–400 ft^2)	0.60
Heat exchanger, shell-and-tube, fixed sheet, c.s.	10–40 m^2 (100–400 ft^2)	0.44
Kettle, cast-iron, jacketed	1–3 m^3 (250–800 gal)	0.27
Kettle, glass-lined, jacketed	0.8–3 m^3 (200–800 gal)	0.31
Motor, squirrel cage, induction, 440-V, explosion-proof	4–15 kW (5–20 hp)	0.69
Motor, squirrel cage, induction, 440-V, explosion-proof	15–150 kW (20–200 hp)	0.99
Pump, reciprocating, horizontal cast-iron (includes motor)	1×10^{-4}–6×10^{-3} m^3/s (2–100 gpm)	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	4–40 $m^3/s\cdot kPa$ (10^4–10^5 gpm·psi)	0.33
Reactor, glass-lined, jacketed (without drive)	0.2–2.2 m^3 (50–600 gal)	0.54
Reactor, stainless steel, 2070-kPa	0.4–4.0 m^3 (10^2–10^3 gal)	0.56
Separator, centrifugal, c.s.	1.5–7 m^3 (50–250 ft^3)	0.49
Tank, flat head, c.s.	0.4–40 m^3 (10^2–10^4 gal)	0.57
Tank, c.s., glass-lined	0.4–4.0 m^3 (10^2–10^3 gal)	0.49
Tower, c.s.	5×10^2–10^6 kg (10^3–2×10^6 lb)	0.62
Tray, bubble cap, c.s.	1–3 m (3–10 ft) diameter	1.20
Tray, sieve, c.s.	1–3 m (3–10 ft) diameter	0.86

the absence of other information. In general, the cost capacity concept should not be used beyond a 10-fold range of capacity, and care must be taken to make certain the two pieces of equipment are similar with regard to type of construction, materials of construction, temperature and pressure operating range, and other pertinent variables. Nonetheless, this six-tenths rule is widely used in approximations of equipment and even total process costs.

Estimating Cost of Equipment Using Scaling Factors and Cost Index — EXAMPLE 6-2

The purchased cost of a 0.2-m^3, glass-lined, jacketed reactor (without drive) was $10,000 in 1991. Estimate the purchased cost of a similar 1.2-m^3, glass-lined, jacketed reactor (without drive) in 1996. Use the annual average *Chemical Engineering* plant cost index to update the purchase cost of the reactor.

■ **Solution**

The *Chemical Engineering* plant cost index in 1991 was 361 and in 1996 was 382 (Table 6-2). From Table 6-4 the equipment-cost versus capacity exponent is 0.54:

$$\text{Cost of reactor in 1996} = (\$10{,}000)\left(\frac{382}{361}\right)\left(\frac{1.2}{0.2}\right)^{0.54} = \$27{,}850$$

Purchased-equipment costs for vessels, tanks, and process and materials-handling equipment can often be estimated on the basis of weight. The fact that a wide variety of types of equipment have about the same cost per unit weight is quite useful, particularly when other cost data are not available. Generally, the cost data generated by this method are sufficiently reliable to permit study-estimates. ■

Purchased-Equipment Delivery

Purchased-equipment prices are usually quoted as f.o.b. (free on board, meaning that the purchaser pays the freight). Clearly freight costs depend upon many factors, such as the weight and size of the equipment, distance from source to plant, and method of transport. For predesign estimates, a delivery allowance of 10 percent of the purchased-equipment cost is recommended.

Purchased-Equipment Installation

Installation of process equipment involves costs for labor, foundations, supports, platforms, construction expenses, and other factors directly related to the erection of purchased equipment. Table 6-5 presents the general range of installation costs as a percentage of the purchased-equipment costs for various types of equipment. Installation labor cost as a function of equipment size shows wide variations and is difficult to predict.

Table 6-5 Installation cost for process equipment as a percentage of purchased-equipment cost†

Type of equipment	Installation cost, %
Centrifugal separators	20–60
Compressors	30–60
Dryers	25–60
Evaporators	25–90
Filters	65–80
Heat exchangers	30–60
Mechanical crystallizers	30–60
Metal tanks	30–60
Mixers	20–40
Pumps	25–60
Towers	60–90
Vacuum crystallizers	40–70
Wood tanks	30–60

†Modified from K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control*, Craftsman Book Company of America, Solana Beach, CA, 1974.

Analyses of a number of typical chemical plants indicates that the cost of the purchased equipment varies from 65 to 80 percent of the total installed cost depending upon the complexity of the equipment and the type of plant in which the equipment is installed. Installation costs for equipment, therefore, are estimated to vary from 25 to 55 percent of the delivered purchased-equipment cost. Expenses for equipment insulation and piping insulation are often included under the respective headings of equipment installation costs and piping costs. The total cost for the labor and materials required for insulating equipment and piping in ordinary chemical plants is approximately 8 to 9 percent of the delivered purchased-equipment cost. This is equivalent to approximately 2 percent of the total capital investment.

Instrumentation and Controls

Instrument costs, installation labor costs, and expenses for auxiliary equipment and materials constitute the major portion of the capital investment required for instrumentation. Total instrumentation and control cost depends on the amount of control required and may amount to 8 to 50 percent of the total delivered equipment cost.

For the normal solid-fluid chemical processing plant, a value of 26 percent of the delivered purchased-equipment cost is recommended as an estimate for the total instrumentation and control cost. This cost represents approximately 5 percent of the total capital investment.

Piping

The cost for piping covers labor, valves, fittings, pipe, supports, and other items involved in the complete erection of all piping used directly in the process. This includes raw material, intermediate-product, finished-product, steam, water, air, sewer, and other process piping. Since process-plant piping can run as high as 80 percent of delivered purchased-equipment cost or 20 percent of the fixed-capital investment, the importance of this item in capital cost estimation is clear.

Piping estimation methods involve either some degree of piping takeoff from detailed flowsheets or use of a factor technique when neither detailed drawings nor flowsheets are available. Factoring by percentage of purchased-equipment cost and percentage of fixed-capital investment is based strictly on experience gained from piping costs for similar previously installed chemical process plants. Table 6-6 presents a

Table 6-6 Estimated cost of piping

	Percent of purchased equipment			Percent of fixed-capital equipment
Types of process plant	Material	Labor	Total	
Solid[†]	9	7	16	4
Solid-fluid[‡]	17	14	31	7
Fluid[§]	38	30	68	13

† A coal briquetting plant would be a typical solid-processing plant.
‡ A shale oil plant with crushing, grinding, retorting, and extraction would be a typical solid-fluid processing plant.
§ A distillation separation system would be a typical fluid-processing plant.

rough estimate of the piping costs for various types of chemical processes. Additional information for estimating piping costs is presented in Chap. 12. Labor for installation is estimated as approximately 40 to 50 percent of the total installed cost of piping. Material and labor for pipe insulation are estimated to vary from 15 to 25 percent of the total installed cost of the piping and are influenced greatly by the extremes in temperature, which are encountered by the process streams.

Electrical Systems

The electrical systems consist of four major components, namely, power wiring, lighting, transformation and service, and instrument and control wiring. In most chemical plants the installed cost of electrical systems is estimated to be 15 to 30 percent of the delivered purchased-equipment cost or between 4 and 8 percent of the fixed-capital investment.

Buildings

The cost of buildings, including services, consists of expenses for labor, materials, and supplies involved in the erection of all buildings connected with the plant. Costs for plumbing, heating, lighting, ventilation, and similar building services are included. The cost of buildings, including services, for different types of process plants is shown in Table 6-7 as a percentage of purchased-equipment cost and fixed-capital investment.

Yard Improvements

Costs for fencing, grading, roads, sidewalks, railroad sidings, landscaping, and similar items are all considered part of yard improvements. The cost for these items in most chemical plants approximates 10 to 20 percent of the purchased-equipment cost. This is equivalent to approximately 2 to 5 percent of the fixed-capital investment.

Service Facilities

Utilities for supplying steam, water, power, compressed air, and fuel are part of the service facilities of a chemical process plant. Waste disposal, fire protection, and

Table 6-7 Cost of buildings including services based on purchased-equipment cost or on fixed-capital investment

Type of process plant	Percentage of purchased-equipment cost			Percentage of fixed-capital investment		
	New plant at new site[‡]	New unit at existing site[§]	Expansion at existing site	New plant at new site[‡]	New plant at existing site[§]	Expansion at existing site
Solid	68	25	15	18	7	4
Solid-fluid	47	29	7	12	7	2
Fluid	45	5–18[¶]	6	10	2–4[¶]	2

[†]See Table 6-6 for description of types of process plants.
[‡]Generally referred to as a grass-roots plant.
[§]Designated as a battery-limit plant.
[¶]Smaller figure is applicable to petroleum refining and related industries.

miscellaneous service items, such as shop, first aid, and cafeteria equipment and facilities, require capital investments that are included under the general heading of service facilities cost.

The total cost for service facilities in chemical plants generally ranges from 30 to 80 percent of the purchased-equipment cost with 55 percent representing an average for a normal solid-fluid processing plant. For a single-product, small, continuous process plant, the cost is likely to be in the lower part of the range. For a large, new multiprocess plant at a new location, the costs are apt to be near the upper limit of the range. The cost of service facilities, in terms of fixed-capital investment, generally ranges from 8 to 20 percent with 14 percent considered an average value. Table 6-8 lists the typical ranges in percentages of fixed-capital investment that can be encountered for various components of service facilities. Except for entirely new facilities, it is unlikely that all service facilities will be required in every process plant. This accounts to a large degree for the wide variation range assigned to each component in Table 6-8. The range also reflects the degree to which utilities requirements depend on energy balances for the process. Service facilities largely are functions of plant physical size and will be present to some degree in most plants. The omission of unneeded utilities tends to increase the relative percentages of the necessary service facilities for the plant. Recognition of this fact, coupled with a careful appraisal of the extent to which service facilities are used in the plant, should result in selecting from Table 6-8 a reasonable cost percentage applicable to a specific process design.

Health, Safety, and Environmental Functions

Over time, the requirements for occupational health and safety and environmental functions in plants have increased substantially. Table 6-8 includes modest allowances

Table 6-8 Typical variation in percent of fixed-capital investment for service facilities

Service facilities	Range, %	Typical value, %
Steam generation	2.6–6.0	3.0
Steam distribution	0.2–2.0	1.0
Water supply, cooling, and pumping	0.4–3.7	1.8
Water treatment	0.5–2.1	1.3
Water distribution	0.1–2.0	0.8
Electric substation	0.9–2.6	1.3
Electric distribution	0.4–2.1	1.0
Gas supply and distribution	0.2–0.4	0.3
Air compression and distribution	0.2–3.0	1.0
Refrigeration including distribution	0.5–2.0	1.0
Process waste disposal	0.6–2.4	1.5
Sanitary waste disposal	0.2–0.6	0.4
Communications	0.1–0.3	0.2
Raw material storage	0.3–3.2	0.5
Finished-product storage	0.7–2.4	1.5
Fire protection system	0.3–1.0	0.5
Safety installations	0.2–0.6	0.4

for these functions, but in reality, many plants require much higher expenditures than suggested here. There do not seem to be general guidelines for estimating these expenditures at this time. It is highly recommended that they all be considered in the design of a plant. These functions should not be mere add-ons, but should be integrated into the process design itself. Pollution prevention and pollutant minimization techniques should be part of the design strategy. Pollution minimization is sometimes the driving force for new process development, design, and construction.

Land

The cost for land and the accompanying surveys and fees depends on the location of the property and may vary by a cost factor per acre as high as 30 to 50 between a rural district and a highly industrialized area. As a rough average, land costs for industrial plants amount to 4 to 8 percent of the purchased-equipment cost or 1 to 2 percent of the total capital investment. By law, the cost of land cannot be depreciated; therefore it is usually not included in the fixed-capital investment. Rather, it is shown as a one-time investment at the beginning of plant construction.

Engineering and Supervision

The costs for construction design and engineering, including internal or licensed software, computer-based drawings, purchasing, accounting, construction and cost engineering, travel, communications, and home office expense plus overhead, constitute the capital investment for engineering and supervision. This cost, since it cannot be directly charged to equipment, materials, or labor, is normally considered an indirect cost in fixed-capital investment and is approximately 30 percent of the delivered-equipment cost or 8 percent of the fixed-capital investment for the process plant.

Legal Expenses

Legal costs result largely from land purchases, equipment purchase, and construction contracts. Understanding and proving compliance with government, environmental, and safety requirements also constitute major sources of legal costs. These usually total on the order of 1 to 3 percent of fixed-capital investment.

Construction Expenses

Another indirect plant cost is the item of construction or field expense and includes temporary construction and operation, construction tools and rentals, home office personnel located at the construction site, construction payroll, travel and living, taxes and insurance, and other construction overhead. This expense item is occasionally included under equipment installation, or more often under engineering, supervision, and construction. For ordinary chemical process plants, the construction expenses average roughly 8 to 10 percent of the fixed-capital investment for the plant.

Contractor's Fee

The contractor's fee varies for different situations, but it can be estimated to be about 2 to 8 percent of the direct plant cost or 1.5 to 6 percent of the fixed-capital investment.

Contingencies

A contingency amount is included in all but the smallest estimates of capital investment in recognition of the fact that experience shows there will be unexpected events and changes that inevitably increase the cost of the project. Events, such as storms, floods, transportation accidents, strikes, price changes, small design changes, errors in estimation, and other unforeseen expenses, will occur even though they cannot be predicted. Contingency factors ranging from 5 to 15 percent of the fixed-capital investment are commonly used, with 8 percent being considered a reasonable average value.

METHODS FOR ESTIMATING CAPITAL INVESTMENT

Various methods can be employed for estimating capital investment. The choice of any one method depends upon the amount of detailed information available and the accuracy desired. Seven methods are outlined in this chapter, with each method requiring progressively less detailed information and less preparation time. Consequently, the degree of accuracy decreases with each succeeding method.

Method A: Detailed-Item Estimate A detailed-item estimate requires careful determination of each individual item shown in Table 6-1. Equipment and material needs are determined from completed drawings and specifications and are priced either from current cost data or preferably from firm delivered quotations. Estimates of installation costs are determined from accurate labor rates, efficiencies, and employee-hour calculations. Accurate estimates of engineering, field supervision employee-hours, and field expenses must be detailed in the same manner. Complete site surveys and soil data must be available to minimize errors in site development and construction cost estimates. In fact, in this type of estimate, an attempt is made to firm up as much of the estimate as possible by obtaining quotations from vendors and suppliers. Because of the extensive data needed and the large amounts of engineering time required to prepare such a detailed-item estimate, this type of estimate is almost exclusively prepared by contractors bidding on lump-sum work from finished drawings and specifications. An accuracy in the ± 5 percent range is expected from a detailed estimate.

Method B: Unit Cost Estimate The unit cost method results in good estimating accuracies for fixed-capital investment provided accurate records have been kept of previous cost experiences. This method, which is frequently used for preparing definitive and preliminary estimates, also requires detailed estimates of purchased price obtained either from quotations or index-corrected cost records and published data. Equipment installation labor is evaluated as a fraction of the delivered-equipment cost. Costs for concrete, steel, pipe, electrical systems, instrumentation, insulation, etc., are obtained by takeoffs from the drawings and applying unit costs to the material and labor needs. A unit cost is also applied to engineering employee-hours, number of drawings, and specifications. A factor for construction expense, contractor's fee, and contingency is estimated from previously completed projects and is used to complete this type of estimate. Equation (6-3) summarizes this method as†

$$C_n = \left[\sum(E + E_L) + \sum(f_x M_x + f_y M'_L) + \sum f_e H_e + \sum f_d d_n\right] f_F \qquad (6\text{-}3)$$

where C_n is the new capital investment, E the delivered purchased-equipment cost, E_L the delivered-equipment labor cost, f_x the specific material unit cost, M_x the specific material quantity in compatible units, f_y the specific material labor unit cost per employee-hour, M'_L the labor employee-hours for the specific material, f_e the unit cost for engineering, H_e the engineering employee-hours, f_d the unit cost per drawing or specification, d_n the number of drawings or specifications, and f_F the construction or field expense factor (always greater than 1). Depending on the detail included, a unit cost estimate should give ±10 to 20 percent accuracy.

Method C: Percentage of Delivered-Equipment Cost This method for estimating the fixed-capital and total capital investment requires determination of the delivered-equipment cost. The other items included in the total direct plant cost are then estimated as percentages of the delivered-equipment cost. The additional components of the capital investment are based on average percentages of the total direct plant cost, total direct and indirect plant costs, or total capital investment. This is summarized in the following cost equation:

$$C_n = \sum(E + f_1 E + f_2 E + f_3 E + \cdots + f_n E) = E \sum(1 + f_1 + f_2 + \cdots + f_n) \qquad (6\text{-}4)$$

where $f_1, f_2, f_3, \ldots, f_n$ are multiplying factors for piping, electrical, indirect costs, etc. The factors used in making an estimation of this type should be determined on the basis of the type of process involved, design complexity, required materials of construction, location of the plant, past experience, and other items dependent on the particular unit under consideration. Average values of the various percentages have been determined for typical chemical plants, and these values are presented in Table 6-9.

Estimating by percentage of delivered-equipment cost is commonly used for preliminary and study estimates. The expected accuracy is in the ±20 to 30 percent range. It yields more accurate results when applied to projects similar in configuration to recently constructed plants. For comparable plants of different capacity, this method sometimes has been reported to yield definitive estimate accuracies, that is, close to ±10 percent.

†H. C. Bauman, *Fundamentals of Cost Engineering in the Chemical Industry,* Reinhold, New York, 1964.

Table 6-9 Ratio factors for estimating capital investment items based on delivered-equipment cost

Values presented are applicable for major process plant additions to an existing site where the necessary land is available through purchase or present ownership.[†] The values are based on fixed-capital investments ranging from under $1 million to over $100 million.

	Percent of delivered-equipment cost for		
	Solid processing plant[‡]	Solid-fluid processing plant[‡]	Fluid processing plant[‡]
Direct costs			
Purchased equipment delivered (including fabricated equipment, process machinery, pumps, and compressors)	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical systems (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Total direct plant cost	269	302	360
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractor's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed-capital investment	397	428	504
Working capital (15% of total capital investment)	70	75	89
Total capital investment	467	503	593

[†]Because of the extra expense involved in supplying service facilities, storage facilities, loading terminals, transportation facilities, and other necessary utilities at a completely undeveloped site, the fixed-capital investment for a new plant located at an undeveloped site may be as much as 100 percent greater than that for an equivalent plant constructed as an addition to the existing plant.

[‡]See Table 6-6 for descriptions of types of process plants.

Estimation of Fixed-Capital Investment by Percentage of Delivered-Equipment Cost — EXAMPLE 6-3

Prepare a study estimate of the fixed-capital investment for the process plant described in Example 6-1 if the delivered-equipment cost is $100,000.

■ Solution

Use the ratio factors outlined in Table 6-9 with modifications for instrumentation and outdoor operation. Take instrumentation as 10 percent of fixed-capital investment, that is, 0.1(428/100), or 43 percent, of the purchased equipment delivered. Take buildings as 15 percent of purchased equipment.

Component	Cost
Purchased equipment (delivered), *E*	$100,000
Purchased equipment installation, 39%*E*	39,000
Instrumentation (installed), 43%*E*	43,000
Piping (installed), 31%*E*	31,000
Electrical (installed), 10%*E*	10,000
Buildings (including services), 15%*E*	15,000
Yard improvements, 12%*E*	12,000
Service facilities (installed), 55%*E*	55,000
Total direct plant cost, *D*	305,000
Engineering and supervision, 32%*E*	32,000
Construction expenses, 34%*E*	34,000
Legal expenses, 4%*E*	4,000
Contractor's fee, 19%*E*	19,000
Contingency, 37%*E*	37,000
Total indirect plant cost, *I*	126,000
Fixed-capital investment, $D + I$	$431,000

Figure 6-6 shows a spreadsheet for estimating the fixed and total capital investment by the delivered-equipment ratio factor method, as detailed in Table 6-9. Default factors for the three general process types—solid, solid-liquid, and liquid processing—are included. A set of these factors, or individual values, can be copied to the corresponding user input location. Alternatively, the user can supply values for as many of these factors as desired.

The user must supply the total purchased-equipment cost for the major equipment items, as determined from material and energy balances and equipment operating characteristics. These costs can be estimated from information supplied in Chaps. 12 through 15.

Method D: Lang Factors for Approximation of Capital Investment This technique, proposed originally by Lang[†] and used quite frequently to obtain order-of-magnitude cost estimates, recognizes that the cost of a process plant may be obtained by multiplying the equipment cost by some factor to approximate the fixed or total capital investment. These factors vary depending upon the type of process plant being considered. The percentages given in Table 6-10 are rough approximations that hold for the types of process plants indicated. These values may be used as Lang factors for estimating the fixed-capital investment or the total capital investment.

Greater accuracy of capital investment estimates can be achieved in this method by using not one but a number of factors. One approach is to use different factors for different types of equipment. Another approach is to use separate factors for installation of equipment, foundations, utilities, piping, etc., or even to divide each item of cost into material and labor factors.[‡] With this approach, each factor has a range of

[†]H. J. Lang, *Chem. Eng.*, **54**(10): 117 (1947); H. J. Lang, *Chem. Eng.*, **55**(6): 112 (1948).

[‡]Further discussions on these methods may be found in W. D. Baasel, *Preliminary Chemical Engineering Plant Design*, 2d ed., Van Nostrand Reinhold, New York, 1990; S. G. Kirkham, *AACE Bull.*, **15**(5): 137 (1972); C. A. Miller, *Cost Engineers' Notebook*, ASCE A-1000, 1978.

See Table 6-9 for details.					
Project Identifier:	Fraction of delivered equipment				
	Solid-processing plant	Solid-fluid processing plant	Fluid-processing plant	User values	Calculated values, $M
Direct costs					
Purchased equipment					
Delivery, percent of purchased equipment				0.10	
Subtotal: delivered equipment					
Purchased equipment installation	0.45	0.39	0.47		
Instrumentation and controls (installed)	0.18	0.26	0.36		
Piping (installed)	0.16	0.31	0.68		
Electrical systems (installed)	0.10	0.10	0.11		
Buildings (including services)	0.25	0.29	0.18		
Yard improvements	0.15	0.12	0.10		
Service facilities (installed)	0.40	0.55	0.70		
Total direct cost					
Indirect costs					
Engineering and supervision	0.33	0.32	0.33		
Construction expenses	0.39	0.34	0.41		
Legal expenses	0.04	0.04	0.04		
Contractor's fee	0.17	0.19	0.22		
Contingency	0.35	0.37	0.44		
Total indirect cost					
Fixed capital investment					
Working capital	0.70	0.75	0.89		
Total capital investment					

Figure 6-6
Estimation of capital-investment items based on delivered-equipment cost

values, and the chemical engineer must rely on past experience to decide, in each case, whether to use a high, average, or low figure.

Since tables are not convenient for computer calculations, it is better to combine the separate factors into an equation similar to the one proposed by Hirsch and Glazier†

$$C_n = f_I[E'(1 + f_F + f_p + f_m) + E_i + A] \qquad (6\text{-}5)$$

†H. Hirsch and E. M. Glazier, *Chem. Eng. Prog.*, **56**(12): 37 (1960).

Table 6-10 Revised Lang factors for estimation of fixed-capital investment or total capital investment

Factor × delivered-equipment cost = fixed-capital investment or total capital investment for major additions to an existing plant.

	Lang factors	
Type of plant	**Fixed-capital investment**	**Total capital investment**
Solid	4.0	4.7
Solid-fluid	4.3	5.0
Fluid	5.0	6.0

†See Table 6-6 for description of types of process plants.

where the three installation-cost factors are, in turn, defined by the following three equations:

$$\log f_F = 0.635 - 0.154 \log(0.001E') - 0.992\left(\frac{e}{E'}\right) + 0.506\left(\frac{f_v}{E'}\right) \quad (6\text{-}6)$$

$$\log f_p = -0.266 - 0.014 \log(0.001E') - 0.156\left(\frac{e}{E'}\right) + 0.556\left(\frac{p}{E'}\right) \quad (6\text{-}7)$$

$$\log f_m = 0.344 + 0.033 \log(0.001E') + 1.194\left(\frac{t}{E'}\right) \quad (6\text{-}8)$$

where E' is the purchased equipment on an f.o.b. basis, f_I the indirect cost factor that is always greater than 1 (normally taken as 1.4), f_F the cost factor for field labor, f_p the cost factor for piping materials, f_m the cost factor for miscellaneous items, including the materials cost for insulation, instruments, foundations, structural steel, building, wiring, painting, and the cost of freight and field supervision, E_i the cost of equipment already installed, A the incremental cost of corrosion-resistant alloy materials, e the total heat exchanger cost (less incremental cost of alloy), f_v the total cost of field-fabricated vessels (less incremental cost of alloy), p the total pump plus driver cost (less incremental cost of alloy), and t the total cost of tower shells (less incremental cost of alloy). Note that Eq. (6-5) is designed to handle both purchased equipment on an f.o.b. basis and completely installed equipment.

Method E: Power Factor Applied to Plant/Capacity Ratio This method for study or order-of-magnitude estimates relates the fixed-capital investment of a new process plant to the fixed-capital investment of similar previously constructed plants by an exponential power ratio. That is, for certain similar process plant configurations, the fixed-capital investment of the new facility is equal to the fixed-capital investment of the constructed facility C (adjusted by a cost index ratio), multiplied by the ratio R, defined as the capacity of the new facility divided by the capacity of the old facility, raised to a power x. This power has been found to average between 0.6 and 0.7 for many process facilities. Table 6-11 gives the capacity power factor x for various kinds of processing plants

$$C_n = C f_e R^x \quad (6\text{-}9)$$

where f_e is the cost index ratio at the time of cost C_n to that at the time of C.

Table 6-11 Capital cost data for chemical and petroleum processing plants (2000)[†]

Product or process	Process	Typical plant size	Fixed-capital investment, million $	Power factor x[‡] for specified process plant
		10^3 kg/yr (10^3 ton/yr)		
Acetic acid	CH_3OH and CO—catalytic	9×10^3 (10)	8	0.68
Acetone	Propylene-copper chloride catalyst	9×10^4 (100)	33	0.45
Ammonia	Steam reforming	9×10^4 (100)	29	0.53
Ammonium nitrate	Ammonia and nitric acid	9×10^4 (100)	6	0.65
Butanol	Propylene, CO, and H_2O—catalytic	4.5×10^4 (50)	48	0.40
Chlorine	Electrolysis of NaCl	4.5×10^4 (50)	33	0.45
Ethylene	Refinery gases	4.5×10^4 (50)	16	0.83
Ethylene oxide	Ethylene—catalytic	4.5×10^4 (50)	59	0.78
Formaldehyde (37%)	Methanol—catalytic	9×10^3 (10)	19	0.55
Glycol	Ethylene and chlorine	4.5×10^3 (5)	18	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	9×10^3 (10)	10	0.68
Methanol	CO_2, natural gas, and steam	5.5×10^4 (60)	15	0.60
Nitric acid (high-strength)	Ammonia—catalytic	9×10^4 (100)	8	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	4.5×10^3 (5)	4	0.60
Polyethylene (high-density)	Ethylene—catalytic	4.5×10^3 (5)	19	0.65
Propylene	Refinery gases	9×10^3 (10)	4	0.70
Sulfuric acid	Sulfur—contact catalytic	9×10^4 (100)	4	0.65
Urea	Ammonia and CO_2	5.5×10^4 (60)	10	0.70
		10^3 m^3/day (10^3 bbl/day)		
Alkylation (H_2SO_4)	Catalytic	1.6 (10)	23	0.60
Coking (delayed)	Thermal	1.6 (10)	31	0.38
Coking (fluid)	Thermal	1.6 (10)	19	0.42
Cracking (fluid)	Catalytic	1.6 (10)	19	0.70
Cracking	Thermal	1.6 (10)	6	0.70
Distillation (atm.)	65% vaporized	16 (100)	38	0.90
Distillation (vac.)	65% vaporized	16 (100)	23	0.70
Hydrotreating	Catalytic desulfurization	1.6 (10)	3.5	0.65
Reforming	Catalytic	1.6 (10)	34	0.60
Polymerization	Catalytic	1.6 (10)	6	0.58

[†]Adapted from K. M. Guthrie, *Chem. Eng.*, **77**(13): 140 (1970); and K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control*, Craftsman Book Company of America, Solana Beach, CA, 1974. See also J. E. Haselbarth, *Chem. Eng.*, **74**(25): 214 (1967), and D. E. Drayer, *Petro. Chem. Eng.*, **42**(5): 10 (1970).
[‡]These power factors apply within roughly a 3-fold ratio extending either way from the plant size as given.

Table 6-12 Relative labor rate and productivity indexes in chemical and allied products industries for the United States (1999)†

Geographic area	Relative labor rate	Relative productivity factor
New England	1.14	0.95
Middle Atlantic	1.06	0.96
South Atlantic	0.84	0.91
Midwest	1.03	1.06
Gulf	0.95	1.22
Southwest	0.88	1.04
Mountain	0.88	0.97
Pacific Coast	1.22	0.89

†Adapted from J. M. Winton, *Chem. Week,* **121**(24): 49 (1977), and updated with data from M. Kiley, ed., *National Construction Estimator,* 37th ed., Craftsman Book Company of America, Carlsbad, CA, 1989. Productivity, as considered here, is an economic term that gives the value added (products minus raw materials) per dollar of total payroll cost. Relative values were determined by taking the average of Kiley's weighted state values in each region divided by the weighted-average value of all the regions. See also Tables 6-14 and 6-15.

A closer approximation for this relationship which involves the direct and indirect plant costs has been proposed as

$$C_n = f(DR^x + I) \tag{6-10}$$

where f is a lumped cost index factor relative to the original facility cost, D the direct cost, and I the total indirect cost for the previously installed facility of a similar unit on an equivalent site. The value of the power factor x approaches unity when the capacity of a process facility is increased by adding identical process units instead of increasing the size of the process equipment. The lumped cost index factor f is the product of a geographic labor cost index, the corresponding area labor productivity index, and a material and equipment cost index. Table 6-12 presents the relative median labor rate and productivity factors for various geographic areas in the United States.

EXAMPLE 6-4 Estimating Relative Costs of Construction Labor as a Function of Geographic Area

If a given chemical process plant is erected near Dallas, Texas (Southwest area), with a construction labor cost of \$100,000, what would be the construction labor cost of an identical plant if it were erected at the same time near Los Angeles (Pacific Coast area) for the time when the factors given in Table 6-12 apply?

■ Solution

Relative median labor rates from Table 6-12 are 0.88 and 1.22 for the Southwest and Pacific Coast areas, respectively. The relative productivity factors for these same geographic areas are 1.04 and 0.89, respectively.

Relative labor rate ratio $= \frac{1.22}{0.88} = 1.3864$

Relative productivity factor ratio $= \frac{0.89}{1.04} = 0.8558$

Labor cost for Pacific Coast relative to Southwest $= \frac{1.3864}{0.8558} = 1.620$

Labor cost at Los Angeles $= (1.62)(\$100{,}000) = \$162{,}000$

■

Estimation of Fixed-Capital Investment with Power Factor Applied to Plant/Capacity Ratio — EXAMPLE 6-5

If the process plant described in Example 6-1 was erected in the Dallas area for a fixed-capital investment of \$436,000 in 1990, estimate the fixed-capital investment in 1998 for a similar process plant located near Los Angeles with twice the process capacity but with an equal number of process units. Use the power factor method to evaluate the new fixed-capital investment, and assume the factors given in Table 6-12 apply.

■ Solution

If Eq. (6-9) is used with a 0.6 power factor and the Marshall and Swift all-industry index (Table 6-2), the fixed-capital investment is

$$C_n = C f_e R^x$$
$$= 436{,}000\left(\frac{1062}{915}\right)(2)^{0.6} = \$767{,}000$$

If Eq. (6-9) is used with a 0.7 power factor and the Marshall and Swift all-industry index, the fixed-capital investment is

$$C_n = 436{,}000\left(\frac{1062}{915}\right)(2)^{0.7} = \$822{,}000$$

If Eq. (6-10) is used, the fixed-capital investment is given by

$$C_n = f(DR^x + I)$$

where $f = f_E f_L e_L$ and D and I are obtained from Example 6-1. With a 0.6 power factor, the Marshall and Swift all-industry index (Table 6-2), and the relative labor and productivity indexes (Table 6-12), the result is

$$C_n = \left(\frac{1062}{915}\right)\left(\frac{1.22}{0.88}\right)\left(\frac{1.04}{0.89}\right)[(316{,}000)(2)^{0.6} + 120{,}000] = \$1{,}126{,}000$$

Changing the power factor to 0.7 gives

$$C_n = (1.161)(1.620)[(316{,}000)(2)^{0.7} + 120{,}000] = \$1{,}191{,}000$$

Results obtained by using this latter procedure have shown high correlation with fixed-capital investment estimates that have been obtained with more detailed techniques. Properly used, these power factor methods can yield quick fixed-capital investment requirements with accuracies sufficient for preliminary estimates.

■

Method F: Investment Cost per Unit of Capacity Many data have been published giving the fixed-capital investment required for various processes per unit of annual production capacity. Such values may be obtained from Table 6-11 by dividing investment values by the corresponding capacity in the preceding column. Although these values depend to some extent on the capacity of the individual plants, it is possible to determine the unit investment costs which apply for average conditions. An order-of-magnitude estimate of the fixed-capital investment for a given process can then be obtained by multiplying the appropriate investment cost per unit of capacity by the annual production capacity of the proposed plant. The necessary correction for change of costs with time can be made with the use of cost indexes.

Method G: Turnover Ratio A rapid evaluation method suitable for order-of-magnitude estimates is known as the *turnover ratio* method. The turnover ratio is defined as the ratio of gross annual sales to fixed-capital investment

$$\text{Turnover ratio} = \frac{\text{gross annual sales}}{\text{fixed-capital investment}} \tag{6-11}$$

where the product of the annual production rate and the average selling price of the commodities is the gross annual sales figure. The reciprocal of the turnover ratio is sometimes called the *capital ratio* or the *investment ratio*.[†] Turnover ratios of up to 4 are obtained for some business establishments while some are as low as 0.2. For the chemical industry, as a very rough rule of thumb, the ratio can be approximated as 0.5.[‡]

ESTIMATION OF REVENUE

Thus far in this chapter methods for estimating the total capital investment required for a given plant have been presented. Determination of the necessary capital investment is only one part of a complete cost estimate. The revenue generated by plant operation clearly is very important. Revenue comes from sale of the product or products produced by the plant. The total annual revenue from product sales is the sum of the unit price of each product multiplied by its rate of sales.

$$\text{Annual sales revenue, \$/yr} = \sum (\text{sales of product, kg/yr})(\text{product sales price, \$/kg}) \tag{6-12}$$

A plant is designed for a specific rate of production of the major product. Rates of production of other products (by-products) are determined in turn by the chemistry and operating characteristics of the process. Mass balances for the process establish the by-product flow rates.

In conducting an economic analysis of a process, the engineer must establish production rates, as a fraction or percentage of the design capacity, for each year of process operation. It is common in preliminary economic studies to use 50 percent for the first year of operation because, during the start-up period, production rates are very low, the length of the start-up period is uncertain, and the time of the year for the beginning of start-up is unknown. After the first year, it is common to use the design annual capacity of the plant as the production and sales rate for each subsequent year. This is based on the usual practice of rating the annual capacity of chemical plants as the actual annual production, with an allowance for downtime. This downtime

[†]When the term *investment ratio* is used, the investment is usually considered to be the total capital investment which includes working capital as well as other capitalized costs.

[‡]R. H. Perry and D. W. Green, eds., *Perry's Chemical Engineers' Handbook,* 7th ed., McGraw-Hill, New York, 1997.

allowance is typically 10 to 20 percent, based on a 24 h/day, 7 days/week, 52 weeks/year production for continuous processes. So the actual operating time is from approximately 300 to 330 days per year. This number is usually established as part of the plant design basis, based on experience. For 90 percent operating time, the hourly production rate during operation must be the annual output rate divided by 0.90 times the 8760 h/yr.

Product prices are best established by a market study. For established products, price information is available in sources such as the *Chemical Market Reporter.* More information on chemical prices is given in the next section.

Other sources of revenue may include sale of obsolete equipment, recovery of working capital, and sale of other capital items. Revenue from such one-time events is included at the time it is expected to occur. But revenues due to product sales occur regularly, and more or less continuously, throughout the operating life of the product.

ESTIMATION OF TOTAL PRODUCT COST

The third major component of an economic analysis is the total of all costs of operating the plant, selling the products, recovering the capital investment, and contributing to corporate functions such as management and research and development. These costs usually are combined under the general heading of *total product cost.* The latter, in turn, is generally divided into two categories: *manufacturing costs* and *general expenses.* Manufacturing costs are also referred to as *operating* or *production costs.* Further subdivision of the manufacturing costs is somewhat dependent upon the interpretation of variable, fixed, and overhead costs.

Accuracy is as important in estimating total product cost as it is in estimating capital investment costs. The most important contribution to accuracy is to include all the costs associated with making and selling the product. The largest sources of error in total product cost estimation often are those of overlooking one or more elements of cost. A tabular form is very useful for estimating total product cost and provides a valuable checklist to preclude omissions. Figure 6-7 displays a suggested checklist of all the costs involved in chemical processing operations and is presented in the form of a spreadsheet in Fig. 6-8. The entries in Figs. 6-7 and 6-8 are discussed in detail below.

Figure 6-8 shows the user inputs that are required and provides default values for the other quantities needed to calculate the total product cost. The required user inputs include fixed-capital investment, annual amounts and unit prices of raw materials, operating labor, utilities, catalysts, and solvents. The remaining items are supplied with default values that can be changed. Depreciation is calculated separately because it changes from year to year under the most used method. However, if desired, the depreciation can be charged at a constant rate for a fixed number of years, such as 20 percent per year for 5 years.[†]

Total product costs are commonly calculated on one of three bases: namely, daily basis, unit of product basis, or annual basis. Annual cost is probably the best choice for

[†]Constant annual depreciation for a fixed number of years is appropriate if the time value of money is not to be considered. See Chap. 7 for a discussion of depreciation.

Raw materials	
Operating labor	
Operating supervision	
Utilities	
Electricity	
Fuel	
Refrigeration	
Steam	
Waste treatment and disposal	
Water, process	
Water, cooling	
Maintenance and repairs	
Operating supplies	
Laboratory charges	
Royalties (if not on lump-sum basis)	
Catalysts and solvents	
	Subtotal: Variable production costs
Depreciation	
Taxes (property)	
Financing (interest)	
Insurance	
Rent	
	Subtotal: Fixed charges
Medical	
Safety and protection	
General plant overhead	
Payroll overhead	
Packaging	
Restaurant	
Recreation	
Salvage	
Control laboratories	
Plant superintendence	
Storage facilities	
	Subtotal: Plant overhead costs
	Total of above = Manufacturing costs
Executive salaries	
Clerical wages	
Engineering	
Legal costs	
Office maintenance	
Communications	
	Subtotal: Administrative expenses
Sales offices	
Sales personnel expenses	
Shipping	
Advertising	
Technical sales service	
	Subtotal: Distribution and marketing expenses
Research and development	
	Total of administrative, distribution and marketing, R&D = General expenses
	Total of all above = Total product cost

Figure 6-7
Costs involved in total product cost for a typical chemical process plant

Title:		Date:
Product:		Capacity, kg/h:
Operating time, h/yr:		Capacity, kg/s:
Capacity, kg/yr:		Fixed Capital Investment (FCI)

	Suggested factor	User variables: Rate or quantity per year	User variables: Cost per rate or quantity unit		Calculated values, $M
Raw materials					
1					
2					
3					
4				**Total**	
Operating labor†					
Operating supervision	0.15	of operating labor			
Utilities†					
Water					
Cooling					
Process					
Electricity					
Fuel					
Refrigeration					
Steam					
Waste treatment and disposal					
Maintenance and repairs	0.07	of FCI			
Operating supplies	0.15	of maintenance and repairs			
Laboratory charges	0.15	of operating labor			
Royalties (if not on lump-sum basis)	0.04	of TPC without depreciation			
Catalysts and solvents					
				Total variable production costs	
Depreciation—calculated separately below					
Taxes (property)	0.02	of FCI			
Financing (interest)	0.00	of FCI			
Insurance	0.01	of FCI			
Rent	0.00	of FCI			
Depreciation‡					—
				Fixed charges (without depreciation)	
				Plant overhead costs	
				Administrative costs	
				Distribution + marketing costs	
				Research and development	
				General expenses	
				Total product cost (without depreciation)	

‡Calculated according to MACRS 5-year schedule. (See Chap. 7 for details.)

Year	Depreciation: % of FCI	Depreciation: d_j, \$/yr	TPC = $(d_j + c_o)$, \$/yr
1	20		
2	32		
3	19.2		
4	11.52		
5	11.52		
6	5.76		
7	0		
⋮	⋮		
20	0		

†See Table 6-14 for suggested general utility and labor costs.

Figure 6-8
Spreadsheet for first-year, annual total product cost for 100 percent capacity

the purpose of economic analyses. Moreover, annual estimates (1) smooth out the effect of seasonal variations, (2) include plant on-stream time or equipment operation, (3) permit more rapid calculation of operating costs at less than full capacity, and (4) provide a convenient way of considering large expenses that occur infrequently such as annual planned maintenance shutdowns.

The best source of information for total product cost estimates is data from similar or identical projects. Most companies have extensive records of their operations, so that quick, reliable estimates of manufacturing costs and general expenses can be obtained from existing records. Adjustments for increased costs due to inflation must be made, and differences in plant site and geographic location must be considered. Methods for estimating total product cost in the absence of specific information are discussed in the following paragraphs.

Manufacturing Costs

All expenses directly connected with the manufacturing operation or the physical equipment of a process plant itself are included in the manufacturing costs. These expenses, as considered here, are divided into three classifications: (1) variable production costs, (2) fixed charges, and (3) plant overhead costs.

Variable production costs include expenses directly associated with the manufacturing operation. This type of cost involves expenditures for raw materials (including transportation, unloading, etc.), direct operating labor, supervisory and clerical labor directly applied to the manufacturing operation, utilities, plant maintenance and repairs, operating supplies, laboratory supplies, royalties, catalysts, and solvents. These costs are incurred for the most part only when the plant operates, hence the term *variable costs*. It should be recognized that some of the variable costs listed here as part of the direct production costs have an element of fixed cost in them. For instance, maintenance and repair costs decrease with reduced production level, but some maintenance and repair still occurs when the process plant is shut down.

Fixed charges are expenses which are practically independent of production rate. Expenditures for depreciation, property taxes, insurance, financing (loan interest), and rent are usually classified as fixed charges. These charges, except for depreciation, tend to change due to inflation. Because depreciation is on a schedule established by tax regulations, it may differ from year to year, but it is not affected by inflation.

Plant overhead costs are for hospital and medical services; general plant maintenance and overhead, safety services, payroll overhead including social security and other retirement plans, medical and life insurance, and vacation allowances, packaging, restaurant and recreation facilities, salvage services, control laboratories, property protection, plant superintendence, warehouse and storage facilities, and special employee benefits. These costs are similar to the basic fixed charges since they do not vary widely with changes in production rate.

Variable Production Costs

Raw Materials In the chemical industry, one of the major costs in a production operation is for the raw materials used in the process. The category *raw materials* refers in general to those materials that are directly consumed in making the final products; this includes chemical reactants and constituents and additives included in the product. Materials necessary to carry out process operations but which do not become part of the final product, such as catalysts and solvents, are listed separately.

Direct price quotations from prospective suppliers are desirable for the raw materials. When these are not available, published prices are used. For preliminary cost analyses, market prices are often used for estimating raw material costs. Prices for many commercial chemicals are published weekly in the *Chemical Market Reporter.* Prices for some commodity chemicals, such gases as hydrogen, oxygen, and nitrogen, are published occasionally in *Chemical and Engineering News* and *Chemical Week.* Other price sources are industry organizations and their publications. Chemical prices are usually quoted on an f.o.b. (free-on-board) basis. Any transportation charges should be included in the raw material costs when available; they may be estimated as 10 percent of the raw material cost, but are highly variable.

The amounts of raw materials that must be supplied per unit of time or per unit of product are determined from process material balances. One of the most important steps of the design process is to calculate accurate material balances for the process; these are essential to establishing the process raw materials requirements. Usually the basis for a process design is the production rate of a key product, that is, an output. Mass balances are nearly always calculated by starting with inputs. Thus, mass balance calculations begin by setting the flow rate of a key feed stream as a basis. This basis often is set as the amount of the feed required to yield the key product rate for ideal conversion of that feed to product. Alternatively, a conversion efficiency may be assumed, especially if there is past experience on which to make this assumption. The feed rates of other raw materials are set in relation to the key feed rate, using the process chemistry and conversion assumptions. The process mass balances are conducted with this set basis, and the rates of production of the products are calculated. The calculated production rate of the key product will usually not agree with that specified as the plant design basis. The feed rates of the raw materials are then adjusted so as to meet the output target, and the mass balances are repeated until convergence is obtained.

The ratio of the cost of raw materials to total product cost varies considerably for different types of plants. In chemical plants, raw material costs are usually in the range of 10 to 60 percent of the total product cost.

Operating Labor In general, operating labor may be divided into skilled and unskilled labor. Hourly wage rates for operating labor in different industries at various locations can be obtained from the U.S. Bureau of Labor publication entitled *Monthly Labor Review.* For chemical processes, operating labor usually amounts to about 10 to 20 percent of the total product cost.

In preliminary cost analyses, the quantity of operating labor can often be estimated either from company experience with similar processes or from published information on similar processes. The relationship between labor requirements and production rate is not a linear one; a 0.2 to 0.25 power of the capacity ratio when plant capacities are scaled up or down is often used.

Table 6-13 Typical labor requirements for process equipment†

Type of equipment	Workers/unit/shift
Blowers and compressors	0.1–0.2
Centrifugal separator	0.25–0.50
Crystallizer, mechanical	0.16
Dryer, rotary	0.5
Dryer, spray	1.0
Dryer, tray	0.5
Evaporator	0.25
Filter, vacuum	0.125–0.25
Filter, plate and frame	1.0
Filter, rotary and belt	0.1
Heat exchangers	0.1
Process vessels, towers (including auxiliary pumps and exchangers)	0.2–0.5
Reactor, batch	1.0
Reactor, continuous	0.5

†For expanded process equipment labor requirements see G. D. Ulrich. *A Guide to Chemical Engineering Process Design and Economics,* J. Wiley, New York, 1984.

If a flowsheet and drawings of the process are available, the operating labor may be estimated from an analysis of the work to be performed. Consideration must be given to such items as the type and arrangement of equipment, multiplicity of units, amount of instrumentation and control for the process, and company policy in establishing labor requirements. Table 6-13 indicates some typical labor requirements for various types of process equipment.

Another method of estimating labor requirements as a function of plant capacity is based on adding the various principal processing steps on the flowsheet. In this method, a process step is defined as any unit operation, unit process, or combination thereof that takes place in one or more units of distillation, evaporation, drying, filtration, etc. Once the plant capacity is fixed, the number of employee-hours per day per step is obtained from Fig. 6-9 and multiplied by the number of process steps to give the total employee-hours per day. Variations in labor requirements from highly automated processing steps to batch operations are provided by selection of the appropriate curve on Fig. 6-9.

EXAMPLE 6-6 Estimation of Labor Requirements

Consider a highly automated processing plant having an output rate of 1.0 kg/s of product and requiring principal processing steps of heat transfer, reaction, and distillation. What are the operating labor requirements for an annual operation of 300 days?

■ Solution

The process plant is considered to require three process steps. From Fig. 6-9, for a capacity of 1.0 kg/s (8.6×10^4 kg/day) the highly automated process plant requires approximately 33 employee-hours/(day)(processing step). Thus, for 300 days of annual operation, operating labor required = (3)(33)(300) = 29,700 employee-hours/year.

■

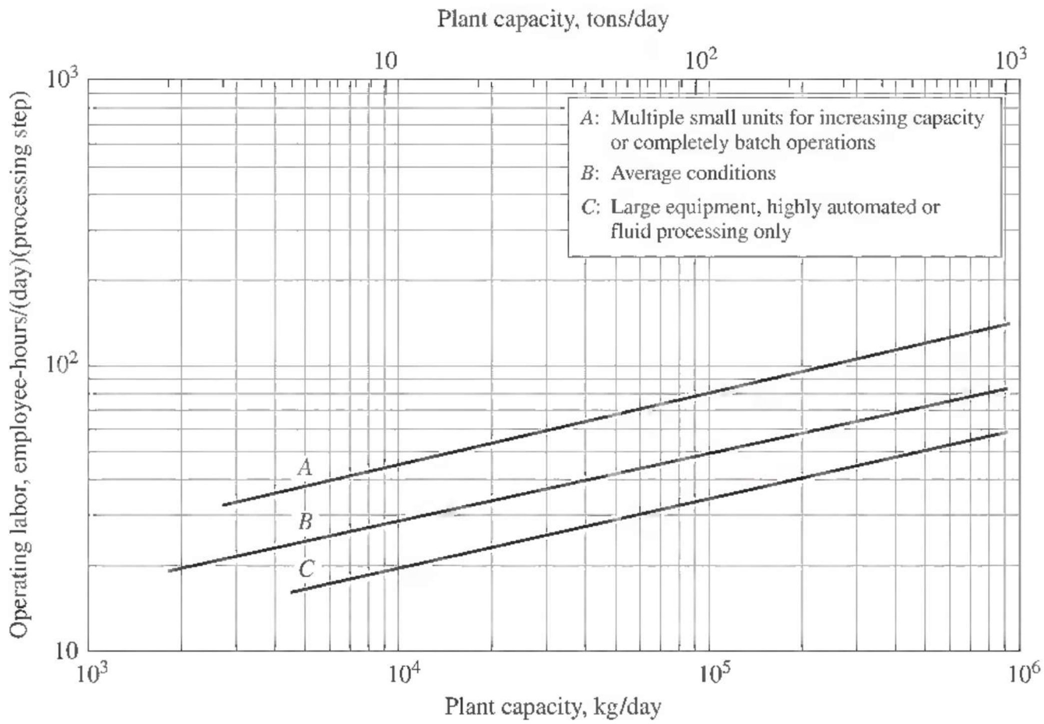

Figure 6-9
Operating labor requirements in the chemical process industry

Because of new technological developments including computerized controls and long-distance control arrangements, the practice of relating employee-hour requirements directly to production quantities for a given product can give inaccurate results unless very recent data are used. As a rule of thumb, the labor requirements for a fluids processing plant, such as an ethylene oxide plant, would be in the low range of 0.33 to 2 employee-hours per 1000 kg of product; for a solid-fluids plant, such as a shale-oil plant, the labor requirement would be in the intermediate range of 2 to 4 employee-hours per 1000 kg of product; for plants primarily engaged in solids processing, such as a coal briquetting plant, a range of 4 to 8 employee-hours per 1000 kg of product would be reasonable.

Certainly better estimates for the labor requirements than those obtained from the preceding rule of thumb can be made based on experience with similar processes. In determining costs for labor, account must be taken of the type of worker required, geographic location of the plant, prevailing wage rates, and worker productivity. Table 6-12 presents data that can be used as a guide for relative median labor rates and productivity factors for workers in various geographic areas of the United States. Table 6-14 gives some average labor rates. The *Engineering News-Record* provides data on prevailing labor rates in many U.S. cities, as shown in Table 6-15.

Operating Supervision and Clerical Assistance A certain amount of direct supervisory and clerical assistance is always required for a manufacturing operation. The necessary amount of this type of labor is closely related to the total amount of operating labor, complexity of the operation, and product quality standards. The cost for direct

Table 6-14 Cost tabulation for selected utilities and labor

Utility	Cost
Electricity	0.045 \$/kWh[a]
Fuel	
Coal	0.35 \$/GJ[b]
Petroleum	1.30 \$/GJ[b]
Petroleum coke	0.17 \$/GJ[b]
Gas	1.26 \$/GJ[b]
Refrigeration, to temperature	
5°C	20.0 \$/GJ[c]
−20°C	32.0 \$/GJ[c]
−50°C	60.0 \$/GJ[c]
Steam, saturated	
10^3–10^4 kPa (150–1500 psi)	4.40 \$/1000 kg[e,d]
Wastewater	
Disposal	0.53 \$/1000 kg[e]
Treatment	0.53 \$/1000 kg[e]
Waste	
Hazardous	145.00 \$/1000 kg[c]
Nonhazardous	36.00 \$/1000 kg[c]
Water	
Cooling	0.08 \$/1000 kg[e,f]
Process	0.53 \$/1000 kg[e]
Labor	
Skilled	33.67 \$/h[g]
Common	25.58 \$/h[g]

[a]Based on U.S. Department of Energy, Energy Information Administration form EIA-861, 2001. U.S. average for year 2000.
[b]Based on U.S. Department of Energy, Energy Information Administration form EIA-0348, 2001. U.S. average for year 2000.
[c]R. Turton, R. C. Bailie, W. B. Whiting, and J. A. Shaeiwitz, *Analysis, Synthesis, and Design of Chemical Processes,* Prentice-Hall, Upper Saddle River, NJ, 1998.
[d]U.S. Department of Energy, Office of Industrial Technologies, DOE/GO-102000-1115, December 2000.
[e]U.S. Department of Energy, Office of Industrial Technologies, DOE/GO-10099-953, June 2001.
[f]M. S. Peters and K. D. Timmerhaus, *Plant Design and Economics for Chemical Engineers,* 4th ed., McGraw-Hill, New York, 1991.
[g]*Engineering News-Record* indexes, December 2001.

supervisory and clerical labor averages about 15 percent of the cost for operating labor. For reduced capacities, supervision usually remains fixed at the 100 percent capacity rate.

Utilities The cost for utilities, such as steam, electricity, process and cooling water, compressed air, natural gas, fuel oil, refrigeration, and waste treatment and disposal, varies widely depending on the amount needed, plant location, and source. A detailed list of ranges of rates for various utilities is presented in App. B. Some typical costs for utilities are given in Table 6-14.

The required types of utilities are established by the flowsheet conditions; their amount can sometimes be estimated in preliminary cost analyses from available information about similar operations. More often the utility requirements are determined

Table 6-15 ***Engineering News-Record*** **labor indexes†‡**

Location	Common labor 1997	1998	1999	2000	2001	Skilled labor 1997	1998	1999	2000	2001
Atlanta	6,305	6,305	6,563	7,195	7,326	3,623	3,698	3,850	4,152	4,393
Baltimore	8,442	8,442	8,592	8,745	8,745	4,587	4,671	4,704	4,917	4,917
Birmingham	7,853	7,853	8,432	8,747	9,300	3,589	3,659	3,914	4,084	4,205
Boston	14,605	15,132	15,526	15,526	15,526	6,560	6,820	6,951	7,360	7,360
Chicago	13,974	15,168	15,842	16,553	16,552	6,074	6,553	6,810	7,139	7,235
Cincinnati	11,184	11,316	11,789	12,211	12,211	4,659	4,716	4,839	5,198	5,198
Cleveland	12,771	13,156	13,350	14,232	14,753	5,544	5,701	5,846	6,002	6,201
Dallas	6,637	6,742	6,742	6,742	6,911	3,289	3,383	3,386	3,474	3,819
Denver	7,739	8,255	8,387	8,926	8,926	3,892	4,033	4,189	4,442	4,517
Detroit	13,668	14,216	14,742	15,374	16,032	6,123	6,410	6,631	6,886	7,177
Kansas City	11,621	12,053	12,053	12,834	13,437	4,875	5,015	5,260	5,503	5,653
Los Angeles	14,011	14,458	14,458	15,018	15,574	5,852	5,953	5,953	6,111	6,285
Minneapolis	13,368	13,979	14,532	15,084	15,953	5,429	5,672	5,937	6,222	6,580
New Orleans	6,842	6,842	6,842	6,995	7,274	3,358	3,359	3,587	3,669	3,848
New York	19,284	19,955	20,597	21,368	23,176	9,132	9,416	9,535	9,906	10,634
Philadelphia	14,605	15,211	15,737	16,000	16,974	6,450	6,705	6,978	7,158	7,476
Pittsburgh	11,884	12,234	12,497	12,839	13,195	5,438	5,584	5,733	5,911	6,099
St. Louis	13,726	14,121	14,553	15,000	15,474	5,447	5,696	5,874	6,094	6,252
San Francisco	14,157	14,411	14,411	16,005	16,011	6,477	6,740	6,740	7,057	7,142
Seattle	14,026	14,811	15,300	15,879	15,879	5,425	5,671	5,975	6,173	6,343
Montreal	12,379	12,379	12,742	13,074	13,674	5,381	5,387	5,520	5,685	5,988
Toronto	16,579	16,611	16,913	16,897	16,897	6,320	6,350	6,522	6,651	6,738
National labor index	11,835	12,233	12,547	13,063	14,461	5,294	5,473	5,635	5,873	6,067
Wages, $/h	22.48	23.24	23.84	24.82	25.58	29.38	30.37	31.27	32.6	33.67

†Published in December issues of *Engineering News-Record* (with permission from *Engineering News Record,* McGraw-Hill, New York).
‡Indexes = 100 in 1913.

from material and energy balances calculated for the process. A utility may be purchased at a predetermined rate from an outside source, or the service may be available within the company. If the company supplies its own service and this is utilized for just one process, the entire cost of the service installation is usually charged to the manufacturing process. If the service is utilized for the production of several different products, the service cost is apportioned among the different products at a rate based on the amount of individual consumption.

Steam requirements include the amount consumed in the manufacturing process plus that necessary for auxiliary needs. An allowance for radiation and line losses must also be made.

Electric power must be supplied for lighting, motors, and various process-equipment demands. These direct power requirements should be increased by a factor of 1.1 to 1.25 to allow for line losses and contingencies. As a rough approximation, utility costs for ordinary chemical processes amount to 10 to 20 percent of the total product cost.

The cost for pollution control and waste disposal is best estimated from pollutant quantities calculated from the process material balances. These quantities may require

Table 6-16 Estimation of costs for maintenance and repairs

Type of operation	Maintenance cost as percentage of fixed-capital investment (on annual basis) Wages	Materials	Total
Simple chemical processes	1–3	1–3	2–6
Average processes with normal operating conditions	2–4	3–5	5–9
Complicated processes, severe corrosion operating conditions, or extensive instrumentation	3–5	4–6	7–11

special attention in simulation programs. Some estimates for the unit costs of treatment of various wastes are included in Table 6-14.†

Maintenance and Repairs Annual costs for equipment maintenance and repairs may range from 2 to 20 percent of the equipment cost. Charges for plant buildings average 3 to 4 percent of the building cost. In the process industries, the total plant cost per year for maintenance and repairs ranges from 2 to 10 percent of the fixed-capital investment, with 7 percent being a reasonable value. Table 6-16 provides a guide for estimation of maintenance and repair costs as a function of process conditions.

For operating rates less than plant capacity, the maintenance and repair cost is generally estimated as 85 percent of that at 100 percent capacity for a 75 percent operating rate, and 75 percent of that at 100 percent capacity for a 50 percent operating rate.

Operating Supplies Consumable items such as charts, lubricants, test chemicals, custodial supplies, and similar supplies cannot be considered as raw materials or maintenance and repair materials, and these are classified as operating supplies. The annual cost for these types of supplies is about 15 percent of the total cost for maintenance and repairs.

Laboratory Charges The cost of laboratory tests for control of operations and for product quality control is covered in this manufacturing cost. This expense is generally calculated by estimating the employee-hours involved and multiplying this by the appropriate rate. For quick estimates, this cost may be taken as 10 to 20 percent of the operating labor.

Patents and Royalties Patents cover many products and manufacturing processes. To use patents owned by others, it is necessary to pay for patent rights or a royalty based on the amount of material produced. Even when the company involved in the operation obtained the original patent, a certain amount of the total expense involved in the development and procurement of the patent rights should be borne by the plant as an operating expense. In cases of this type, these costs are usually amortized over the legally protected life of the patent. Although a rough approximation of patent and

†R. Turton, R. C. Bailie, W. B. Whiting, and J. A. Shaeiwitz, *Analysis, Synthesis and Design of Chemical Processes,* Prentice-Hall, Upper Saddle River, NJ, 1998.

royalty costs for patented processes is 0 to 6 percent of the total product cost, costs specific to the patent position in question are always preferred.

Catalysts and Solvents Costs for catalysts and solvents can be significant and should be estimated based on the catalyst and solvent requirements and prices for the particular process.

Fixed Charges Costs that change little or not at all with the amount of production are designated as *fixed costs* or *fixed charges*. These include costs for depreciation, local property taxes, insurance, and loan interest. Expenses of this type are a direct function of the capital investment and financing arrangement. They should be estimated from the fixed-capital investment. Rent is usually taken as zero in preliminary estimates. As a rough approximation, these charges amount to about 10 to 20 percent of the total product cost.

Depreciation The equipment, buildings, and other material objects comprising a manufacturing plant require an initial investment that must be paid back, and this is done by charging depreciation as a manufacturing expense. Since depreciation rates are very important in determining the amount of income tax, the Internal Revenue Service, under U.S. tax law, determines the rate at which depreciation may be charged for various types of industrial facilities.

In the most widely used method of depreciation calculation (MACRS), the amount of depreciation changes year by year. Therefore, depreciation is calculated separately in the table in the bottom of the spreadsheet in Fig. 6-8. In economic studies in which the time value of money is not to be considered, it is acceptable to use a constant yearly depreciation rate for a fixed period.

Financing *Interest* is considered to be the compensation paid for the use of borrowed capital. A fixed rate of interest is established at the time the capital is borrowed; therefore, interest is a definite cost if it is necessary to borrow the capital used to make the investment for a plant. Although the interest on borrowed capital is a fixed charge, there are many persons who claim that interest should not be considered as a manufacturing cost, but that it should be listed as a separate expense under the general heading of management or financing cost. Annual interest rates amount to 5 to 10 percent of the total value of the borrowed capital. For income tax calculations, interest on money supplied by the corporation cannot be charged as a cost. In design calculations, however, interest can be included as a cost if the required funds need to be borrowed from external sources.

Local Taxes The magnitude of local property taxes depends on the particular locality of the plant and the regional laws. Annual property taxes for plants in highly populated areas are ordinarily in the range of 2 to 4 percent of the fixed-capital investment. In less populated areas, local property taxes are about 1 to 2 percent of the fixed-capital investment.

Property Insurance Insurance rates depend on the type of process being carried out in the manufacturing operation and on the extent of available protection facilities. These rates amount to about 1 percent of the fixed-capital investment per year.

Rent Annual costs for rented land and buildings amount to about 8 to 12 percent of the value of the rented property. In preliminary estimates, rent is usually not included.

Plant Overhead Costs

The costs considered in the preceding sections are directly related to the production operation. In addition, however, many other expenses are always involved if the complete plant is to function as an efficient unit. The expenditures required for routine plant services are included in *plant overhead costs*. Nonmanufacturing machinery, equipment, and buildings are necessary for many of the general plant services, and the fixed charges and direct costs for these items are part of the plant overhead costs. Other components of the overhead are listed in Fig. 6-7. These charges are closely related to the costs for all labor directly connected with the production operation. The plant overhead cost for chemical plants is about 50 to 70 percent of the total expenses for operating labor, supervision, and maintenance.

General Expenses

In addition to the manufacturing costs, other general expenses are involved in the operations of a company. These general expenses may be classified as (1) administrative expenses, (2) distribution and marketing expenses, and (3) research and development expenses.

Administrative Costs The expenses connected with executive and administrative activities cannot be charged directly to manufacturing costs; however, it is necessary to include the administrative costs if the economic analysis is to be complete. Salaries and wages for administrators, secretaries, accountants, computer support staff, engineering, and legal personnel are part of the administrative expenses, along with costs for office supplies and equipment, outside communications, administrative buildings, and other overhead items related to administrative activities. These costs may vary markedly from plant to plant and depend somewhat on whether the plant under consideration is a new one or an addition to an existing plant. In the absence of more accurate cost figures from company records, or for a preliminary estimate, the administrative costs may be approximated as 15 to 25 percent of operating labor.

Distribution and Marketing Costs These types of general expenses are incurred in the process of selling and distributing the various products. From a practical viewpoint, no manufacturing operation can be considered a success until the products have been sold or put to some profitable use. Included in this category are salaries, wages, supplies, and other expenses for sales offices, salaries, commissions, and traveling expenses for sales representatives, shipping expenses, cost of containers, advertising expenses, and technical sales service.

Distribution and marketing costs vary widely for different types of plants depending on the particular material being produced, other products sold by the company, plant location, and company policies. These costs for most chemical plants are in the range of 2 to 20 percent of the total product cost. The higher figure usually applies to a new product or to one sold in small quantities to a large number of customers. The lower figure applies to large-volume products, such as bulk chemicals.

Research and Development Costs New methods and products are constantly being developed in the chemical industries as a result of research and development. Any progressive company that wishes to remain in a competitive industrial position incurs research and development expenses. Research and development costs include salaries and wages for all personnel directly connected with this type of work, fixed and operating expenses for all machinery and equipment involved, costs for materials and supplies, and consultants' fees. In some industries, such as pharmaceuticals, research may be the largest component of the total product cost. In the chemical industry, these costs amount to about 2 to 5 percent of every sales dollar, or about 5 percent of total product cost.

GROSS PROFIT, NET PROFIT, AND CASH FLOW

The product sales revenue minus the total product cost gives the *gross profit,* also called *gross earnings.* Gross profit is expressed both with and without depreciation included as follows:

$$g_j = s_j - c_{oj} \tag{6-13}$$

where g_j is gross profit, depreciation not included, in year j, and

$$G_j = s_j - c_{oj} - d_j \tag{6-14}$$

where G_j is gross profit, depreciation included, in year j.

Net profit, also called *net earnings,* is the amount retained of the profit after income taxes have been paid

$$N_{pj} = G_j(1-\Phi) \tag{6-15}$$

where N_{pj} is the net profit in year j.

The cash flow resulting from process operations is given by Eq. (6-1) and also by

$$A_j = N_{pj} + d_j \tag{6-16}$$

Breakeven Point, Gross and Net Profit for a Process Plant — EXAMPLE 6-7

The annual variable production costs for a plant operating at 70 percent capacity are \$280,000. The sum of the annual fixed charges, overhead costs, and general expenses is \$200,000, and may be considered not to change with production rate. The total annual sales are \$560,000, and the product sells for \$4/kg. What is the breakeven point in kilograms of product per year? What are the gross annual profit G_j (depreciation included) and net annual profit for this plant at 100 percent capacity if the income tax rate is 35 percent of gross profit?

■ Solution

The breakeven point (Fig. 6-3) occurs when the total annual product cost equals the total annual sales. The total annual product cost is the sum of the fixed charges (depreciation included), overhead, and general expenses, and the variable production costs. Total annual sales are the product of the number of kilograms of each product and corresponding selling price per kilogram. Thus,

$$\text{Direct production cost/kg} = \frac{\$280{,}000}{\$560{,}000/(\$4/\text{kg})} = \$2/\text{kg}$$

and the kg/yr needed for a breakeven point are given by

$$\$200{,}000 + (\$2)(\text{kg/yr}) = (\$4)(\text{kg/yr})$$

$$\text{kg/yr required} = 100{,}000$$

Since the annual capacity is

$$\frac{\$560{,}000}{(\$4/\text{kg})0.70} = 200{,}000 \text{ kg}$$

the breakeven point is

$$\frac{100{,}000}{200{,}000}(100) = 50\% \text{ of capacity}$$

The gross annual profit = total annual sales − total annual costs. So at 100 percent capacity

$$G_j = (\$4/\text{kg})(200{,}000) - [\$200{,}000 + (200{,}000 \text{ kg})(\$2/\text{kg})]$$

$$= \$200{,}000$$

and the annual net profit = $200,000 − (0.35)($200,000), so

$$N_{pj} = \$130{,}000$$

CONTINGENCIES

Unforeseen events, such as strikes, storms, floods, price variations, and other *contingencies,* may have an effect on the costs for a manufacturing operation. Contingencies are usually taken into account for product costs in estimating the number of operating days per year.

SUMMARY

This chapter has outlined the economic considerations necessary when a chemical engineer prepares estimates of capital investment cost or total product cost for a project. Predesign cost estimates purposely have been emphasized because of their importance in determining the feasibility of a proposed investment in comparison to alternative designs. It should be remembered, however, that predesign estimates are approximations with ±20 percent or greater uncertainty. Tables 6-17 and 6-18 summarize the predesign estimates for capital investment costs and total product costs, respectively. The percentages indicated in both tables give the ranges encountered in typical chemical plants. Because of the wide variations in different types of plants, the factors presented should be used *only* when more accurate data are not available.

Table 6-17 Estimation of capital investment cost (showing individual components)

The percentages indicated in the following summary of the various costs constituting the capital investment are approximations applicable to ordinary chemical processing plants. It should be realized that the values given vary depending on many factors, such as plant location, type of process, and complexity of instrumentation.

I. **Direct costs** = material and labor involved in actual installation of complete facility (65–85% of fixed-capital investment)
   A. Equipment + installation + instrumentation + piping + electrical + insulation + painting (50–60% of fixed-capital investment)
      1. Purchased equipment (15–40% of fixed-capital investment)
      2. Installation, including insulation and painting (25–55% of purchased-equipment cost)
      3. Instrumentation and controls, installed (8–50% of purchased-equipment cost)
      4. Piping, installed (10–80% of purchased-equipment cost)
      5. Electrical, installed (10–40% of purchased-equipment cost)
   B. Buildings, process, and auxiliary (10–70% of purchased-equipment cost)
   C. Service facilities and yard improvements (40–100% of purchased-equipment cost)
   D. Land (1–2% of fixed-capital investment or 4–8% of purchased-equipment cost)

II. **Indirect costs** = expenses which are not directly involved with material and labor of actual installation of complete facility (15–35% of fixed-capital investment)
   A. Engineering and supervision (5–30% of direct costs)
   B. Legal expenses (1–3% of fixed-capital investment)
   C. Construction expense and contractor's fee (10–20% of fixed-capital investment)
   D. Contingency (5–15% of fixed-capital investment)

III. **Fixed-capital investment** = direct costs + indirect costs

IV. **Working capital** (10–20% of total capital investment)

V. **Total capital investment** = fixed-capital investment + working capital

Table 6-18 Estimation of total product cost (showing individual components)

The percentages indicated in the following summary of the various costs involved in the complete operation of manufacturing plants are approximations applicable to ordinary chemical processing plants. It should be realized that the values given vary depending on many factors, such as plant location, type of process, and company policies.

I. **Manufacturing cost** = direct production costs + fixed charges + plant overhead costs
   A. Direct production costs (about 66% of total product cost)
      1. Raw materials (10–80% of total product cost)
      2. Operating labor (10–20% of total product cost)
      3. Direct supervisory and clerical labor (10–20% of operating labor)
      4. Utilities (10–20% of total product cost)
      5. Maintenance and repairs (2–10% of fixed-capital investment)
      6. Operating supplies (10–20% of maintenance and repair costs, or 0.5–1% of fixed-capital investment)
      7. Laboratory charges (10–20% of operating labor)
      8. Patents and royalties (0–6% of total product cost)
   B. Fixed charges (10–20% of total product cost)
      1. Depreciation (depends on method of calculation—see Chap. 7)
      2. Local taxes (1–4% of fixed-capital investment)
      3. Insurance (0.4–1% of fixed-capital investment)

(Continued)

Table 6-18 ***Continued***

4. Rent (8–12% of value of rented land and buildings)
5. Financing (interest) (0–10% of total capital investment)

C. Plant overhead costs (50–70% of cost for operating labor, supervision, and maintenance; or 5–15% of total product cost) include costs for the following: general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, recreation, salvage, laboratories, and storage facilities

II. General expenses = administrative costs + distribution and selling costs + research and development costs (15–25% of the total product cost)

A. Administrative costs (about 20% of costs of operating labor, supervision, and maintenance; or 2–5% of total product cost) include costs for executive salaries, clerical wages, computer support, legal fees, office supplies, and communications

B. Distribution and marketing costs (2–20% of total product cost) include costs for sales offices, salespeople, shipping, and advertising

C. Research and development costs (2–5% of every sales dollar, or about 5% of total product cost)

III. Total product cost = manufacturing cost + general expenses

IV. Gross earnings cost (gross earnings = total income − total product cost; amount of gross earnings cost depends on amount of gross earnings for entire company and income tax regulations; a general range for gross earnings cost is 15–40% of gross earnings)

†If desired, a contingency factor can be included by increasing the total product cost by 1–5%.

NOMENCLATURE

A = incremental cost of corrosion-resistant alloy materials, dollars
A_j = annual cash flow in year j, dollars
A_x = nonmanufacturing fixed-capital investment, dollars
c_o = first-year cost of operation, all total product costs except depreciation, at 100% of capacity, dollars
c_{oj} = total product costs except depreciation in year j, dollars
C = original capital investment, dollars
C_n = new capital investment, dollars
d_j = depreciation charge in year j, dollars
d_n = number of drawings and specifications
D = total direct cost of plant, dollars
e = total heat exchanger cost (less incremental cost of alloy), dollars
e_L = labor efficiency index in new location relative to cost of E_L and M'_L
E = purchased-equipment cost (delivered), dollars
E' = purchased-equipment cost on f.o.b. basis, dollars
E_i = installed-equipment cost (delivered and installed), dollars
E_L = purchased-equipment labor cost (base), dollars
f = lumped cost index relative to original installation cost
f_1, f_2, f_3 = multiplying factors for piping, electrical, instrumentation, etc., dimensionless
f_d = unit cost per drawing and specification, dollars per drawing or specification