4

MANUFACTURING COST

DETAILED ESTIMATES

Of equal importance to the capital cost estimate in an economic evaluation is the operating or manufacturing cost. It predicts the expense of producing the desired product, and thus, together with the capital cost and sales realization, allows the profitability and potential attractiveness of an operation to be evaluated. The manufacturing cost can be determined by gathering exact data on those factors which can be definitely established (taxes, insurance, utility needs, etc.), and making detailed estimates for the other factors involved based upon manning charts, local wage scales and manufacturer's expected maintenance schedules. Alternately, a factoring method may also be used.

Manufacturing costs are generally broken down into two broad categories: variable or controllable costs, and fixed costs. The plant manager has some ability to control the former items; the later are determined by the plant itself or other groups and are essentially "fixed." Table 4-1 gives a partial checklist of some of the components in each category. Naturally every plant has many items that are unique to it alone, and it is often debatable as to how controllable certain items are. For instance, operating labor is fairly well fixed for a certain number of hours of production per year, and wages may be specified by union negotiation. However, presumably overtime decisions, extra labor for special projects and the give-and-take of labor and automatic controls still allow the plant manager some flexibility in this area. Also, most of the service function jobs are more directly controllable, since they are not absolutely essential to production, and there is some leeway upon when and if they get done.

On-Stream Efficiency

No plant is capable of running all of the time, since mechanical breakdown, maintenance, power disruption, shortages of feed materials or sales, cleaning or catalyst change, and so forth, cause it to periodically shut down. Under ideal conditions many plants schedule major maintenance, or "turnaround" periods

Table 4-1. Partial Checklist for Manufacturing Costs.

Variable Costs (Controllable)
- Raw materials, additives, catalysts
- Utilities: fuel, electricity, water, steam, air, telephone, sewage
- Labor: operating, supervision, maintenance, technical service, engineering, safety, environmental, laboratory, clerical, accounting, legal, security, etc.
- Indirect labor charges; fringe benefits such as:
  - health insurance, retirement, social security, workman's compensation, disability insurance, vacation, holidays, sick leave pay, payroll taxes, overtime, bonuses, etc.
- Maintenance: material, services, contract maintenance
- General: office, plant, safety, lab supplies; books, subscriptions, dues, memberships; outside legal, accounting; consultants; travel, meetings; environmental; miscellaneous
- Transportation, freight
- Distribution, packaging, storage and sales expense
- Donations, public relations
- Research and development

Fixed Costs
- Depreciation
- Taxes, business and licensing fees, insurance
- General and administrative expenses, corporate overhead
- Patents and royalties
- Interest

of about two weeks per year. If this were their only downtime it would result in an on-stream efficiency (ose) of $50/52 = 96\%$, which is about as good as is obtainable. However, the current percent of design capacity operation for the entire industry is only about 80% because of limited sales and normal overcapacity. Based primarily upon maintenance considerations, standard preliminary design practice is to assume an optimistic 90 to 95% on-stream efficiency (or about 330–345 days per year), and a design rate of exactly the estimated sales quantity. If it turns out that the market actually is larger, it is usually assumed that modest "de-bottle necking" or increasing the capacity of only a few rate limiting pieces of equipment can provide a 10–20% capacity increase for a reasonable cost at a later time.

It is often difficult to know what manufacturing costs continue when the plant is not operating. Raw materials, catalysts, and chemical additives consumption is generally tied directly to production. Utilities and fuel are also mainly tied to production, although some usage continues during down time, but often this is small. The sales related costs actually do continue, but they are estimated based upon sales, so for estimating purposes their costs are also assumed to be proportional to production. All other costs continue, except perhaps occasionally labor if there are other jobs the staff can be shifted to and that will pay their salaries, but this is relatively uncommon.

Several of the manufacturing cost factors must be determined separately whether a detailed or factored estimate is made. They are discussed in the following sections.

Raw Materials

The raw materials required by the process may be calculated from the stoichiometry and a material balance for the process with an allowance for extra materials because of the plant's inevitable inefficiencies and losses, estimated from laboratory or pilot plant data, prior experience, or related processes. Included with the raw materials should be all major additives, treating agents, catalyst, filter aids, and so forth, that are required to complete the process. For many operations these additional raw material components can be a significant cost factor. The initial process requirements, such as catalyst charge to the system must be treated as a capital cost, but catalyst makeup, regeneration, and replacement are operating charges. The inventory of all raw materials, in-process, and finished products in storage are considered part of the working capital cost.

The *Chemical Marketing Reporter* (1988) is a weekly newspaper that prints the current list price of most chemicals, and provides a reasonable estimate of the cost of the raw materials and the sales price that might be obtained for the product. Often there are major discounts available on many of the commodities listed, and regional or local competition can dramatically change the price. Also, on occasion it is very difficult to find a manufacturer who will sell as cheaply as listed in the *Chemical Marketing Reporter* (CMR). A recent example of the uncertainties in chemical costs (for California) are: (1) sulfuric acid in mid-1987 was listed in CMR for the West Coast at \$85/ton, virgin, 100% basis, tank cars, FOB (''Free on Board''), meaning pure acid, the price for equivalent 100% H_2SO_4 (even if sold at a lower concentration) in tank car quantities, and the price at the manufacturer's plant: (2) smelter sulfuric acid, 100% basis, tank cars FOB Arizona, and so on, was listed at \$20/ton as by-product acid from the large western copper smelters. In this and many cases one must know where the manufacturer's plant is located and the freight charges to the desired location before the actual delivered price can be calculated for the manufacturing cost estimate. This adds additional uncertainty and inaccuracy, but it is an unavoidable part of the cost estimating process.

As a second example, an attempt was made to purchase carload quantities of another chemical by calling every producer listed in the *Chemical Buyer's Directory* (1987), and then calling CMR to check their sources. The closest price obtained was 30% greater than that listed. CMR may have listed imported material which was hard to track down, the listed price may have been for large customers only and not available to the occasional purchaser, it may have recently increased, or it may have been in error.

Various free publications, such as the *Chemical Buyers Directory* and others (*Chem Cyclopedia* 1987) list most of the manufacturers and distributors for a large number of chemicals, which will provide locations and telephone numbers in case one wishes to write or call for additional information on price. The manufacturer or distributor might also be able to estimate freight costs, but if not, your company's purchasing department should be able to provide a good estimate (and perhaps on the purchase price as well). As a last resort one can contact trucking companies or the railroad for freight estimates. Once this information is available you can then compare the purchase price plus freight from different locations to estimate the most favorable listed price. Later, as the project nears completion, the company's purchasing department may be able to obtain a more favorable price.

Utilities

The cost of utilities has now become one of the larger segments of a chemical plant's operating cost, and where there is often the greatest potential to economize. When most older plants were designed and the processes developed, energy was very cheap, so only moderate energy savings were attempted as the most economical balance between savings in the operating cost for energy, and the additional capital and operating cost for greater energy saving equipment. Now, however, this balance has been considerably shifted, and new equipment can be justified to greatly reduce energy consumption.

In manufacturing cost estimates energy requirements must be itemized and estimated for each plant, with the simplest method being to tabulate motor horsepower, steam consumption, fuel requirements, cooling water needs, and so on, directly from the flow sheet and heat and material balance. Adding these together, estimating other utilities that may not be listed (compressed air, room heating or air conditioning, telephone, etc.), and then applying reasonable on-stream factors should give a close approximation to the actual utility needs. The local price of the utilities should be readily available from either the accounting department or the company records, but if not, typical costs in the United States for the most common utilities are shown in Table 4-2. These numbers may vary widely and in a few plants the actual costs, based upon old purchase contracts or other favorable factors, may be much lower than the listed values.

Operating Labor

Another manufacturing cost that always must be itemized is the operating labor required to run the plant. In the factoring methods this does not include maintenance, supervision, analytical, clerical, or other types of totally necessary labor, since these staff costs will later be estimated from the operating labor or the plant capital cost. The simplest means of estimating the operating labor is to

Table 4-2.
Typical Common Utility Costs
(Southern California, 1987; CE Index 320)

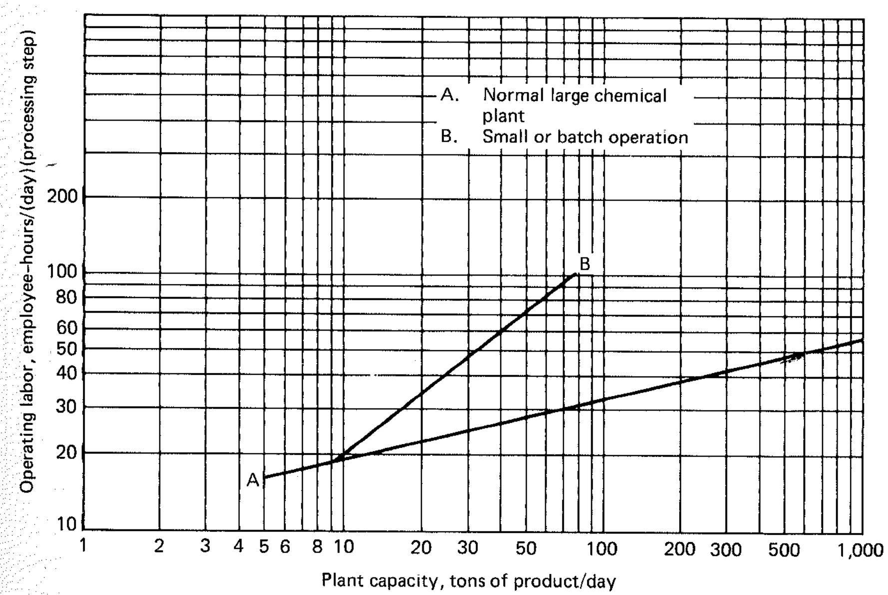
Electricity	\$0.08/kW hr
Gas	\$7/MM Btu
Fuel oil, low sulfur	\$7/MM Btu (\$20/bbl)
Steam, 250 psig (Jones 1987)	\$12/MM Btu
Cooling tower water	\$0.05/M gal
Process water: city water	\$0.20/M gal
well water	\$0.10/M gal
Recycled process water	\$0.25/10^3 gal
Recycled cooling tower water	\$0.20/10^3 gal
Softened water	\$0.55/10^3 gal
Demineralized water (or condensate) for high pressure boiler makeup	\$5/10^3 gal
Instrument air (dry)	\$0.30/M scf
Inert gas, low pressure	\$1/M scf
Nitrogen, purchased	\$2.20/10^3 scf
Refrigeration (ammonia to 30°F)	\$1.50/ton-day (288,000 Btu removed)

predict the labor requirements for each major piece of equipment or section of the flow sheet. Chemical plants do not require many operators, but instruments, controls, analyses, and operations must be frequently checked, and some parts of the plant actually require a number of physical manipulations. Usually each major piece of equipment and its supporting facilities and controls needs one operator, but if equipment is grouped together where a central control panel services much or all of one plant, the number can be considerably reduced. If the equipment is by itself or some distance from other facilities a second operator must be added for safety purposes.

To illustrate the labor requirements, in a boric acid extraction plant without extensive instrumentation and a central control room, one operator might be assigned to the incoming feed streams and the borate extraction mixer–settlers. A second would handle the solvent stripping mixer–settlers and the acid and solvent makeup. A third would watch the crystallizer and its steam source and cooling tower; a fourth the centrifuge, dryer elevator, and screens; and perhaps two would be required for product and raw material storage, loading, packaging, and shipping. This would make a total of six operators. With the normal modern (extensive) instrumentation and a single control room, the same operation could be handled by four operators (still two for shipping; two for operation). Maintenance expenses would be increased somewhat, however, to handle the routine maintenance (lubrication, etc.) and emergencies that were previously partly taken care of by the extra operators.

Various estimating charts, formulas, and tables have been suggested for the labor requirements of different equipment or plants, as indicated by Figure 4-1. Such a graph is useful to check the plant section-by-section estimate, and when no other data are available, but it is only a broad generalization, so it should be used with caution. A partial checklist of manpower that might be required in a new plant is given in Table 4-3.

Number of Shifts. If a plant operates around the clock, every day of the year, it requires four or five crews to be able to staff each shift and the days off for an approximately 40 hours per week schedule. This usually involves a rotating shift arrangement, with some overtime or plant downtime with the four-shift schedule to balance the total number of operating days each year. Figure 4-2 shows an example of a four-crew schedule, and Figure 4-3 illustrates a five-crew schedule. If each crew worked 40 hours per week, then around-the-clock continuous operation would require $365 \times 24/(40 \times 52) = 4.21$ crews, or four crews working 42.1 hours per week. Assuming 10 working days vacation, nine holidays, and 10 sick days per year, then $365 \times 24/40(52 - 29/7) = 4.58$ crews are required for complete coverage. On this later basis a four-crew operation would require $0.58/4 = 14\%$ overtime (or 45.8 hours per week) or plant downtime. The actual industry average work-week for 1986 was 42.09 hours (*Chemical and Engineering News* 1987). Alternatively, five crews would only



Source: Wessel 1952. Excerpted by special permission from *Chemical Engineering*, July 1952. Copyright © 1952, by McGraw-Hill, Inc., New York.

Figure 4-1. Chemical plant labor requirements.

Table 4-3.
Typical Checklist to Staff a New Production Operation

Department	*Job Title or Function*	*Department*	*Job Title or Function*
Administration	Manager	Technical Service	Director
	Administrative director		Engineers
	Safety director		Secretary
	Legal counsel (?)	Environmental	Director
	Purchasing agent		Engineers
	Secretaries, clerks		Secretary
	Nurse (?)	Laboratory	Chief chemist
Accounting	Financial manager		Chemists
	Accountants		Samplers
	Clerks		Secretary
	Secretaries	Operations	Superintendents
Sales Department	Manager		Shift foremen
	Technical sales manager		Operators
	Salesmen		Helpers, laborers
	Clerks		Secretary
	Secretaries	Shipping	Director
Maintenance	Superintendent		Shift foremen
	Craftsmen		Operators, packagers
	Helpers		Loaders, helpers
	Warehouse staff		Dispatcher
	Secretary, clerk		Secretary, clerk
Engineering	Director	Security	Guards
	Engineers		Fire protection
	Draftsmen		Emergency co-ordinator
	Secretary		

	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su
Crew A	1	1	1	1	1	X	X	X	X	3	3	3	3	3	3	3	X	X	2	2	2	2	2	2	2	X	1	1
Crew B	2	2	2	2	X	1	1	1	1	1	1	1	X	X	X	X	3	3	3	3	3	3	3	X	X	2	2	2
Crew C	3	3	X	X	2	2	2	2	2	2	2	X	1	1	1	1	1	1	1	X	X	X	X	3	3	3	3	3
Crew D	X	X	3	3	3	3	3	3	3	X	X	2	2	2	2	2	2	2	X	1	1	1	1	1	1	1	X	X

1 First shift of the day (normally dayshift)
2 Second shift of the day (swing or afternoon shift)
3 Third shift of the day (night or graveyard)
X Off-shift

Source: Rickey 1987. Excerpted by special permission from *Chemical Engineering*, May 11, 1987.

Figure 4-2. Typical continuous operation shift schedules, four crews.

	Su	M	T	W	Th	F	S
Crew A	3	3	X	X	1	1	1
Crew B	1	1	1	1	X	X	X
Crew C	X	X	X	X	X	2	2
Crew D	2	2	2	2	2	X	X
Crew E	X	X	3	3	3	3	3

1 First shift of the day
2 Second shift of the day
3 Third shift of the day
X Off-shift

Source: Rickey 1987. Excerpted by special permission from *Chemical Engineering*, May 11, 1987.

Figure 4-3. Shift schedules, five crews.

work an average of $4.58 \times 40/5 = 36.6$ hours per week. The assumption of five shifts has now become the most commonly accepted procedure for large companies when they estimate their manpower requirements because of the flexibility in scheduling, and the more assured coverage of illness and requested absence. Often the pay is maintained at an assumed 40-hour work-week. This convention should be assumed for estimating purposes unless the merits of four-shift or less operation is clear.

Salary. The average salary for the production operators varies widely with the job skill, responsibility, and hazard, as well as the presence or absence of a union, the section of the country, and other factors. The local wage rates should be readily available for estimating purposes, but if not, the national average is published periodically in *Chemical Week, Chemical and Engineering News,* and elsewhere. In 1986 it averaged $11.97 per hour (*Chemical and Engineering News* 1987) for the chemical industry. Shift differential (increased) pay is often about $0.30 per hour for the swing shift (early evening such as 3 to 11 P.M.) and $0.50 per hour for the graveyard shift (late evening, early morning, such as 11 P.M. to 7 A.M.).

FACTORING METHOD

As with capital costs estimating, detailed breakdowns and item-by-item accurate manufacturing costing are lengthy and expensive procedures, so for most preliminary estimates a more abbrievated method is required. Often this involves the use of estimating factors such as given in Table 4-4. In this table the items

Table 4-4.
Manufacturing Cost Estimating Factors

1. Raw materials	Itemize
2. Utilities	Itemize
3. Operating labor	Itemize
4. Interest (on loans, if any)	Itemize
5. Labor related costs	
A. Payroll overhead	22 -45% of labor[a]
B. Supervisory, miscellaneous labor	10 -30% of labor
C. Laboratory charges	10 -20% of labor
D. Total	42 -95% of labor
(Typical total)	60% of labor
6. Capital related cost	
A. Maintenance	2 -10% of plant cost[b]
B. Operating supplies	0.5- 3% of plant cost
C. Environmental	0.5- 5% of plant cost
D. Depreciation	5 -10% of plant cost
E. Local taxes, insurance	3 - 5% of plant cost
F. Plant overhead costs	1 - 5% of plant cost
G. Total	12 -38% of plant cost
(Typical total)	26% of plant cost
7. Sales related costs	
A. Patents and royalties	0 - 5% of sales
B. Packaging, storage	0 - 7% of sales
C. Administrative costs	2 -10% of sales
D. Distribution and sales	2 -10% of sales
E. R & D	0.5- 4% of sales
F. Total	4.5-37% of sales
(Typical total)	20% of sales

[a]Operating labor only
[b]Total plant cost, including start up and off-site facilities, but not working capital

have been listed for estimating convenience and not for the more logical or useful sequence desired by future managers of the potential operation. The cost components are shown in four general groupings. The first represents items that are totally specific to the process under study, and must be estimated directly from heat and material balances, heat or cooling loads, horsepower takeoffs from the flow sheet, operating labor estimates, and so on. Each requires individual, detailed estimates as noted in the previous sections; the remaining items may be either factored or estimated in detail, as desired.

The second category is labor related costs, in which operating labor (only) is used to estimate other labor and manufacturing costs that depend directly or indirectly (sometimes only vaguely) upon it. As with each of the other cost categories, many additional items (other labor requirements, etc.) could be added, but these are the more important ones. Note that a typical total is also

shown for each group to provide guidance that each individual estimate is similar to the norm, or if not, that there is a good reason for the difference.

The next grouping of costs are related to the total plant capital, generally based upon all of the plant costs, including start-up, auxiliary, or off-site facilities, but not working capital. An exception occasionally is made to not include some of the auxiliary equipment if their operation and maintenance are not part of the basic plant, and their costs are included in overhead charges. Many of the items in this category are exactly tied to the plant cost, such as depreciation, taxes, and insurance, while others are only related to capital in a more indirect manner.

The final category is sales related costs, where again, some items are directly tied to sales (royalties, packaging, etc.) and others such as the overhead items are only indirectly related to sales. These items are included, however, since many companies allocate their overhead costs to the various plants based upon the sales value of the products. A discussion of the manufacturing cost components that are usually factored follows.

Payroll Overhead

For each dollar spent on the direct payroll a certain fraction is spent on overhead or "fringe benefits." Some of this money is paid directly to the government for the employer's share of Social Security and disability insurance; some is paid for workman's compensation and the company's health insurance plan, pension funds, and other welfare programs; and finally some is paid for holidays, vacation, and sick leave pay. The total can be no less than about 22%; 38.3% was the 1986 average (Holzinger 1988); and with rising health care and benefit costs, many companies pay 40–45% of the total labor cost as fringe benefits.

Supervisory and Other Labor

Every plant requires supervisory, engineering, clerical, and other support labor to assist with the operation. Often this can be determined by listing the specific staff required and estimating their salaries. However, experience also has shown that these salaries as a group often run from 10 to 30% of the cost of the operating labor. For smaller operations the percentage is usually greater than for larger plants where it might be shared and spread over more of the operations.

Maintenance

The maintenance required for any plant varies considerably with the operating environment, age of the installation, management's commitment to do "preventative" maintenance (in advance of actual breakdowns) and most importantly, the original decisions and design engineer's skill in balancing initial cost with the quality and corrosion or wear resistance of the equipment. Normally the later factor would be based upon the most economic equipment over the life of the plant, but often limited initial capital, unavailability of the best equipment, or in the opposite direction, a strong desire for minimum operating costs will influence the equipment selection. Thus, maintenance expenses can vary widely, but usually are in the range of 2 to 10% of the original total plant cost per year, with about one-third of this expense often being in materials, and two-thirds in labor. As noted earlier, greater instrumentation, with the use of less operating labor, can raise maintenance costs to the top of, or beyond, this range. The type of plant is also a major factor, with more solids handling or less corrosive or severe processes requiring much less maintenance.

Examples of the maintenance requirements for various companies is presented in Table 4-5. It is seen that of the 38 companies listed maintenance varied from 1.2 to 13.9% per year of the original new equipment cost, and averaged 5.8%. Based upon the current depreciated equipment cost, the maintenance averaged 10.5%. This data would indicate that specialty chemical companies had 17% less maintenance expense, and diversified companies 24% more. However, this

Table 4-5. Typical Maintenance Costs.

	Maintenance Cost		Maintenance Cost as a Percentage of Plant, Property and Equipment	
	1986, million \$		*At Cost %*	*Depreciated %*
Industrial Chemical Companies				
Dow Chemical	\$756.0		5.9	14.1
Union Carbide	384.0		4.5	8.8
Monsanto	363.0		5.7	12.5
American Cyanamid	142.9		5.3	11.3
Hercules	119.9		5.4	10.4
Morton Thiokol	80.8		9.1	13.6
BF Goodrich	118.7		8.1	13.9
Olin	113.3		5.9	15.7
Ethyl	79.5		6.6	13.4
Pennwalt	44.5		5.2	10.2
Georgia Gulf	38.0		21.8	31.9
Witco	34.8		4.5	9.5
Liquid Air	24.9		3.1	5.2
Reichhold Chemicals	21.3		6.9	10.5
A. Schulman	3.9		4.9	8.9
Diamond Crystal Salt	6.3		8.5	14.0
		Average	6.0	11.8

Table 4-5. (*Continued*)

	Maintenance Cost		Maintenance Cost as a Percentage of Plant, Property and Equipment	
	1986, million \$		*At Cost %*	*Depreciated %*
Diversified Companies (Chemical Sales 25–50% of Total Sales)				
Du Pont	1,440.0		3.6	7.3
Allied-Signal	394.0		7.7	11.2
W.R. Grace	143.8		4.4	9.0
Borden	116.9		4.6	8.1
Koppers	115.9		11.6	31.0
Vulcan Materials	96.7		9.1	19.7
Nat'l Dist. and Chem.	81.8		4.2	5.9
Cabot Corp.	56.6		4.7	8.8
Engelhard	51.4		7.2	13.8
GAF Corp.	45.8		13.9	22.0
Tyler	28.8		10.8	20.8
Gulf Resources & Chem.	14.1		5.1	11.2
		Average	7.2	11.7
Specialty Chemical Companies				
Lubrizol	34.5		5.4	11.9
Ferro	28.7		9.1	18.7
Int'l Flavors & Frag.	17.4		5.2	9.3
Dexter Corp.	13.5		4.5	7.7
Nalco Chemical	10.5		1.9	3.7
Petrolite	5.5		2.7	6.2
Sigma-Aldrich	5.5		4.6	6.4
		Average	4.8	9.1
Biotechnology Companies				
Cetus	1.8		3.2	5.0
Biogen N.V.	0.7		1.9	3.7
Alza	0.6		1.2	1.6
		Average	2.1	3.4
		Total average	5.8	10.5

Source: Brooks 1987. Excerpted by special permission from *Chemical Week*, July 15, 1981. Copyright © 1987, by McGraw-Hill, Inc., New York.

wide difference is not always the case, and an overall industry average of about 6% is more nearly the normal maintenance value.

Additional survey information on industry maintenance experience is listed in Table 4-6. These general figures will allow estimates to be made of the size and makeup of maintenance staffs, and the amount of replacement and service

Table 4-6. Typical Maintenance Experience (1982 Through 1986).

1. Maintenance spending as a percent of total new capital investment—116%. Six to seven new maintenance staff per $10 million in new capital equipment.

2. Salaried maintenance employees: maintenance managers (38.6% of total); engineers (12.6%); planners (8.1%); others including some project engineers (40.7%). One employee per $260,000 spent on maintenance.

3. Hourly maintenance employees: one employee per $62,000 spent on maintenance. ($78,000 per "skilled" hourly employee). There was 14.1% overtime.

4. Maintenance material inventory value: $310 for each $1,000 spent per year on maintenance; 1.3% of the equipment replacement value; $354,000 per maintenance "stores" employee.

5. Amount of contractor maintenance used—6.7% of the total.

Source: Nolden 1987. Reprinted from *Plant Engineering*, July 1987. © 1987 by Cahners Publishing Company.

equipment needed in inventory. It also shows that during the period from 1982 to 1987 the chemical industry spent 16% more for maintenance than it did for new equipment purchases. This clearly demonstrates the high cost of maintenance and the need for excellent maintenance management, planning, and scheduling.

The longer-term record suggests that maintenance productivity is improving. In most chemical plants maintenance has been subsidiary to operations and engineering; it primarily reacted to breakdowns and what engineering and operations told it to do. Now maintenance departments often find themselves in the reliability business, not the fix-it business. Some have been turned into departments that focus on predicting and avoiding equipment failures. This requires that work be performed not according to a generalized schedule but according to the actual condition of the machine or process unit. Implicit in this concept is a need for practical and convenient ways to monitor the equipment operating performance and to store and analyze the data. Many companies now keep the performance records for each piece of machinery, and every time a machine fails or gets worked on it is noted. These performance and cost records are used to gauge reliability, work out a preventative maintenance plan, and select between competitive machines with new purchases. It includes noting the nature of an equipment failure, the reason for the failure, the amount of down time, the cost of the downtime, the time between breakdowns, and the cost of repairing or replacing the failed unit.

More and better training also is improving the performance of maintenance departments. Many companies try to develop craftsmen with multiple skills in order to have workers always available who can tackle all the required aspects of a maintenance job in the most rapid and effective manner. The cost saving

can be significant, but good training programs and union cooperation are required.

Operating Supplies, Laboratory Charges, Royalties

These items are all fairly self-descriptive, and their average values are listed in Table 4-4. Operating supplies are somewhat related to the plant cost, and thus are factored from it. They include all of the supplies not separately listed and that are needed to run the plant. Laboratory charges include lab supplies, as well as the labor required to perform all of the plant's quality and process control by means of analysis or testing. The cost is vaguely related to the total operating labor in the plant and thus is factored from it. Royalties, if involved (and not paid as a lump sum) are often charged on a yearly or tonnage production basis. They might vary from 0.25 to 2% of the total sales value, usually being on the lower end of this scale, and are factored from the total plant sales.

Packaging, Storage

All products require some expense for storage, and most a packaging expense for a least part of the production (i.e., the rest may be shipped in bulk). Multi-layered paper bags in mid-1987 cost about $10–15 per ton of product; 55 gallon steel drums about $25 per drum, and plastic or lined drums about twice that (stainless steel was about $450 per drum) (see Appendix 1). Add to these packaging material costs the expense of storage, rehandling for shipment, bagging or filling drums, and so on, and the cost is often appreciable. For other products where entirely bulk shipments are involved, this cost can be very small and is included in the cost of sales or other items. Packaging and storage costs must be detailed if they are important in the total manufacturing cost.

Environmental

Almost every plant must have environmental, safety, and hazardous waste engineers or groups to handle these problems and interface with the regulatory enforcement staffs of governmental agencies and the public. There are endless meetings, training programs, inspections, citations, reports, and paperwork required by the government, plus the normal company desire for good public relations and the plant to be a safe, clean, nonpolluting activity. This has become an extremely demanding requirement for every chemical plant, and a very expensive one. It is estimated that it might currently involve a yearly cost of 0.5–5% of the plant capital, but very likely this figure will soon be many fold that for plants with any appreciable degree of hazard or visibility to the government and environmental groups. This area, incidentally, is one of the major fields that new chemical engineers are being employed for, or where they find some of their first industry assignments. The technical/regulatory problems facing the chemical industry are very demanding, with highly hostile environmental groups and government agencies, and great difficulty in solving the technical problems in a reasonably economical and government approved manner.

Depreciation

In computing income taxes on the profit of an operation the government allows a deduction for a fraction of the initial cost of the plant as a hypothetical "expense" to be subtracted from the actual gross profit for income tax calculations. This deduction, called depreciation, may be considered as a fund to allow eventual replacement of the plant, or the equivalent of acknowledging that the plant has worn or is becoming somewhat obsolete or less competitive with the passing of time. Land is not allowed to be depreciated. The Internal Revenue Service accepts various means of computing depreciation, but there is *only* one method to use for preliminary manufacturing cost estimates: straight line depreciation over the anticipated life of the plant. The government in mid-1987 allowed this to be 5 to 15 years on much of the process equipment and 25 to 45 years on most buildings. These depreciation period numbers have changed several times in the 1980s, and probably will change again. However, if one can prove that the life expectancy of a piece of equipment or a process is less, a shorter period may be used. The government has published an extensive list of allowable depreciation rates for many pieces of equipment and other items, and your company's accounting or financial departments will know what rates are generally acceptable for the type of equipment or processes used in the plant. The accounting department will almost always keep separate depreciation records on each piece of equipment for income tax and property tax assessment purposes. Depreciation credit stops when the total government-allowed useful life period has been used up, even if the equipment is still in service, but the asset value of the equipment may only be removed from the company books when the equipment has been removed from the premises. In other words, if equipment is worn out or obsolete and placed in a "boneyard" or scrap pile it theoretically must still be kept on the books as an asset.

Straight line depreciation provides for the same deduction each year over the (IRS-allowed) life of the item:

$$\frac{\text{(original plant cost—salvage value),\$}}{\text{plant or component life, years}} = \text{depreciation}$$

Often the salvage value is unknown or zero, since the cost to dismantle and sell the partially or totally worn out equipment is generally about equal to the value that would be received from a dealer for the sale of the old equipment, making the yearly straight line depreciation 20% (5-year life) to 6.7% (15-year life) of the initial plant cost per year. Ten percent is a good working average if more exact depreciation rates are not known.

For very precise manufacturing cost estimates, the company's accounting department (almost never the engineer) may use one of the IRS allowed so-called "rapid" depreciation procedures. They will usually use the method providing the greatest present value of the depreciation funds over the life of the plant. This might be the "*double declining balance*" method, where the first year's depreciation is two times the straight line depreciation, the second year is two times the straight line depreciation of the remainder, and so on, or

$$\frac{2 \times (\text{original plant cost} - \text{previous depreciation} - \text{salvage value})}{\text{life of plant or equipment}}$$

Other multiples, such as 1.25, 1.5, 1.75, and so on, are allowed for certain equipment or buildings.

Another accelerated depreciation method is the *sum-of-years digits* depreciation. Here the numbers for each year of the plant life are totaled (i.e., for a 10-year life, $1 + 2 + 3 + \dots + 10 = 55$), and each year the depreciation is: first year 10/55, second year 9/55, third year 8/55, and so on, to the tenth year which is the remainder. This procedure has the greatest present worth for plants with greater than five-year life, and thus will show the highest rate of return on investments, and should usually be preferred by the financial departments. However, most companies frown on any but straight line depreciation being used by the estimating engineer, and usually list income tax saving by a depreciation method other than straight line as "deferred taxes" on their balance sheet. A comparison of depreciation allowances by these methods is listed in Table 4-7, along with the present value of these depreciation allowances.

Local Taxes, Fees, Insurance, Interest

Every locality charges taxes (or business license fees) of various types, and there are many governmental permits, yearly charges, assessments, miscellaneous licenses, and so on. Also, each plant generally is required by its customers to carry product liability insurance, and other insurance (particularly personal and property liability) is almost a necessity, while fire, theft and property damage is desirable unless the company wishes to be self-insured. The total cost of such taxes and insurance is typically about 3% of the total plant cost, even though the personal and product liability insurances are rigorously based upon the total labor cost and product sales value, respectively. With a hazardous product, plant, or waste material the insurance cost can be many times this value, if available at all. Currently most chemical plants (and particularly small ones) are having great difficulty in obtaining liability insurance, and hazardous materials or waste liability insurance is essentially unavailable. A number of

Table 4-7.
Comparison of Depreciation Allowances by Various Methods
(Equipment Costing $100.00; 10-Year Life; No Salvage Value).

Year	*Straight Line, $*	*Sum of Digits, $*	*Double Declining Balance, $*
1	10.00	18.18	20.00
2	10.00	16.36	16.00
3	10.00	14.55	12.80
4	10.00	12.72	10.24
5	10.00	10.90	8.19
6	10.00	9.09	6.55
7	10.00	7.27	5.24
8	10.00	5.45	4.91
9	10.00	3.64	3.65
10	10.00	1.82	3.42
Total	100.00	100.00	100.00
Present value, 8% interest	67.87	75.54[a]	68.99
Present value, 8% interest; 5-year depreciation	79.85	83.94	84.22[a]

[a]Most profitable.

industry group insurance companies are being formed to provide basic insurance for their member companies. Liability insurance has become a major industry (and national) problem because of the very high court awards for "damages."

The interest charges on borrowed capital must be treated individually with each project. Most companies borrow some or much of the funds for all new plants, so the management must tell the engineer what fraction of the plant capital will be from loans, and what the interest rate will be. If such information is not available, then assume *no* borrowed capital (this is generally advisable in most cases), and carefully state this in the economic presentation. If part of the capital is borrowed, the engineer is faced with the decision of considering only the company's actual capital input and ignoring the loans as part of the capital requirement when making the final profitability analysis. Again, however, unless instructed otherwise, there is no question but that he should always use the total capital investment, since all of this is at risk with the project (and the company is usually liable for it). However, in some cases the company policy will be to only consider their portion of the capital (i.e., employ "leverage"), and then the estimator must comply.

Administration, Sales, and Research and Development

On every project a portion of the company's corporate and general overhead costs must be assigned to the new plant, and this is usually prorated to each project on the basis of its capital, sales value, or some other formula. Also, each plant requires a certain amount of operational expense to distribute and

Table 4-8.
Examples of General and Administrative, Sales, and R & D Overhead Costs.

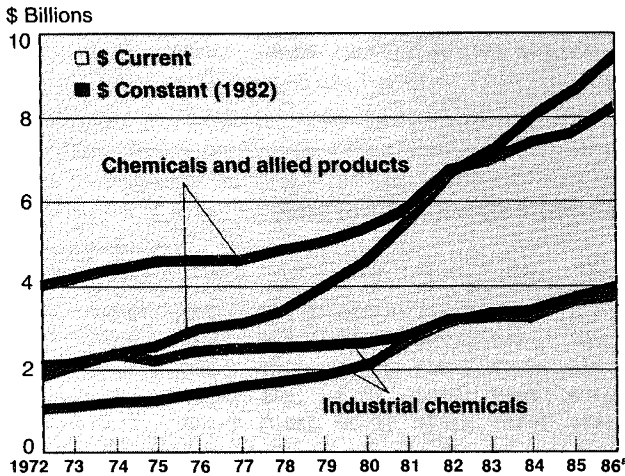
Company	*Type of Business*	*Total Sales, Million $ 1969*	*S & A (Including R & D), % Sales*	*S & A Costs (Excluding R & D), % Sales*
Related Process Industries				
Alcoa	Metals	1,580	9.2	
Texaco	Petroleum	6,270	9.1	
U.S. Gypsum	Building materials	470	15.9	
General Foods	Consumer products—food	2,060	28.0	
Procter & Gamble	Consumer products—soap	2,730	24.5	
Celanese	Textiles and chemicals	1,250	15.1	
General Electric	General equipment	8,550	18.9	
	Average		17.2	
Chemical Industry				
Stauffer	Chemicals (mainly Industrial)	500	11.3	8.8
Monsanto	Chemicals (some specialties)	1,900	16.6	11.4
Hercules	Chemicals (some specialties)	800	13.9	11.2
Union Carbide	Chemicals (some specialties)	2,900	13.1	10.6
American Cyanamid	Chemicals (considerable specialties)	1,200	20.2	16.5
DuPont	Chemicals (some specialties)	3,600	12.0	9.9
Nalco	Specialty chemicals	165	22.5	18.3
Eastman Kodak	Specialties and chemicals	2,750	16.9	11.5
	Average		15.8	12.3
	Total Average		16.5	

Ohsol 1971. Excerpted by special permission from *Chemical Engineering*, May 1971. Copyright © 1971 by McGraw-Hill, Inc., New York.

sell the product. Both of these values often range from 2 to 10% of sales, but can be considerably higher. Finally, general research and development usually runs from 0.5 to 5% of sales, and this amount must also be allocated to each new project. Table 4-8 lists some older data on administration, sales, and research and development expenses for a few chemical (or related) companies, showing a wide range of costs, but averaging about 16% of sales for these three overhead items. The average was well over 20% in 1987. Figures 4-4 and 4-5 show 1972–1986 research and development spending (alone) for industrial chemical producers, indicating their average to be about 4.5% of sales. However, the average for the entire chemical process industry (CPI) is only 1.5–1.6%, (Table 4-9), primarily because of the low research and development spending by the petroleum industry (for petrochemicals, etc.) and other sections of the CPI. Much of this "research" budget is actually spent for technical service work.

Total Manufacturing Cost

The sum of the individual charges described above are added to provide an estimate of the total manufacturing cost. It is seen that besides the itemized costs (raw materials, operating labor, utilities), a typical plant might accrue yearly operating expenses equal to about 165% of the cost of operating labor, plus 26% of the original total plant cost, and 20% of sales value of the plant's product. These items add a great deal to the manufacturing expense, but they



Source: *Chemical and Engineering News* (1987). Reprinted with permission from *Chemical and Engineering News*, June 8, 1987. © 1987, American Chemical Society.

Figure 4-4. R & D spending, $.

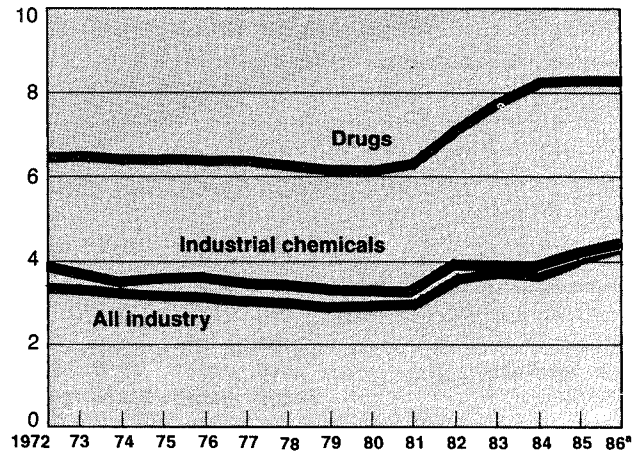


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Figure 4-5. R & D spending as % of net sales.

Table 4-9.
R & D Spending by Industry.

	Percent of Sales	
	1986	*1987*
Aerospace	18.7	19.8
Instruments	9.6	9.5
Electrical machinery	8.7	8.6
Nonelectrical machinery	5.4	5.5
Auto, trucks and parts	4.1	NA
Iron and steel	1.5	1.5
Fabricated metals	0.5	0.5
Chemical process industries		
Chemicals	4.5	4.4
Rubber and plastic	1.8	1.8
Petroleum	1.7	1.9
Nonferrous metals	1.3	1.2
Stone, clay and glass	1.2	1.1
Paper and pulp	0.8	0.8
Food and beverage	0.3	0.3
Textiles	0.3	0.3
CPI total	1.6	1.5
All manufacturing	3.5	3.5

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are realistic, and must be taken into account. The relative importance of each of these cost categories varies widely with the product, as illustrated by Table 4-10, so individual attention to each item is necessary. As with capital cost estimates the individual cost components should almost always be itemized rather than using only these three broad components: total labor, capital, and sales related costs. It is informative to see the individual costs, and many supervisors and reviewers will wish to see various items to compare with their knowledge of what these costs should be. Also, whenever sufficient detail is available each of the factors should be replaced by more complete and accurate estimates. The overall accuracy of such factored operating cost estimates should be similar, but usually somewhat greater, than the corresponding capital cost estimates previously made from Table 3-4.

ESTIMATING CHARTS AND TABLES

For a number of basic commodities, and some individual operations, complete tabulations and charts are available to estimate the manufacturing costs, as listed in Appendix 3. Some of this data on raw materials and utilities for large and complex plants are probably far more accurate than one could personally estimate. Many of these total manufacturing cost charts and tables, however, must still be considered only first approximations because of their age, changing technology, and variably increasing costs of labor and utilities. Nevertheless they have considerable value as a guide for the total product price of complex plants.

Many other manufacturing cost estimating procedures have been suggested, such as the generalized production rate versus fixed operating costs (all costs

Table 4-10.
Examples of Manufacturing Costs Breakdown

	% of Total Production Costs				
	Commodities			Specialties	
	TiO_2	*VAC*[a]	*GPPS*[b]	*DLTDP*[c]	*CPVC*[d]
Raw materials	40	64	76	37	49
Utilities	17	15	1	1	3
Labor related costs	18	4	7	30	14
Capital related costs	18	11	6	14	15
R & D, sales, G & A	7	6	10	18	19

Source: Kyle 1986. Reproduced by permission of the American Institute of Chemical Engineers.
[a]Vinyl acetate.
[b]General-purpose polystyrene.
[c]Dilauryl thiodipropionate.
[d]Chlorinated polyvinylchloride.

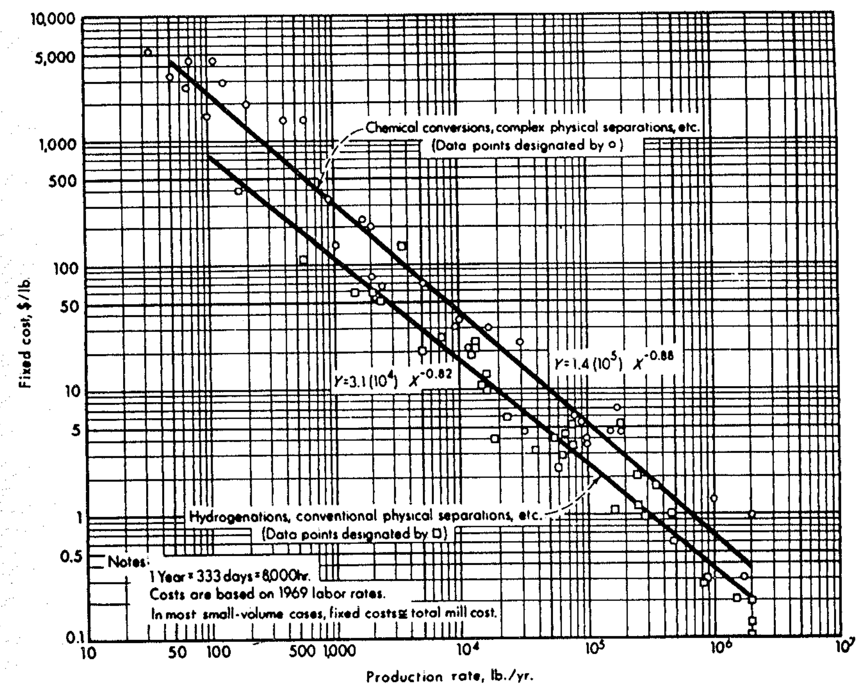

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Figure 4-6. Generalized relationship of fixed operating costs with production rates.

except raw materials and process energy, in this case) of Figure 4-6. Such correlations can be quite useful as rough approximations, but as with most such estimating methods, their accuracy and usefulness are quite limited.

REFERENCES

Brooks, Kenneth. 1987. Maintenance costs. *Chemical Week* (July 15):45.

— 1986. *Chemical Week* (July 16):36.

Chem Cyclopedia. 1987. American Chemical Society, 1155 16th St., N.W., Washington, D.C., 20036; *Chemical Sources-U.S.A.*, Directories Publishing Co., Inc. P. O. Box 1824, Clemson, S.C. 29633.

Chemical and Engineering News. 1987. Facts and figures for the chemical industry. (June 8):24–76.

Chemical Marketing Reporter. 1988. Schnell Publishing Co., Inc., 100 Church St., New York, NY 10007-2694.

Holzinger, Albert G. 1988. The Real Cost of Benefits. *Nation's Business* (February):30–32.

Jones, Kenneth C. 1987. Steam pricing. *Plant Engineering* (July 9):34–40.

Kyle, H. E. 1986. Effective use of technoeconomic resources. *Chemical Engineering Progress* (Aug.):17–20.

Nolden, Carol. 1987. Plant maintenance costs. *Plant Engineering* (July):38–42.
OPD Chemical Buyer's Director. 1987. Schnell Publishing Co., Inc., 100 Church St., New York, NY 10007-2694.
Ohsol, Ernest O. 1971. Estimating marketing cost. *Chemical Engineering* (May).
Peters, M. S., and K. D. Timmerhaus. 1980. *Plant Design and Economics for Chemical Engineers.* McGraw-Hill, New York.
Rawls, R. L. 1987. Facts and figures for chemical R & D. *Chemical and Engineering News* (July 27):32–62.
Rickey, P. 1987. Shift schedules. *Chemical Engineering* (May 11):69–73.
Sommerville, Robert F. 1970. New method gives accurate estimate of distillation cost. *Chemical Engineering* (May).
— 1970. Estimating mill costs at low production rates. *Chemical Engineering* (April).
Spalding, B. J. 1987. Chemical makers hike R & D spending. *Chemical Week* (July 8):18–19.
Wessel, Henry E. 1952. New graph correlates operating labor data for chemical processes. *Chemical Engineering* (July):209.

5

INTEREST CALCULATIONS; PRELIMINARY PROJECT EVALUATION

In previous chapters methods have been developed for estimating the cost of equipment, additions, modifications, and complete plants, and for the expense of manufacturing a product. This chapter will attempt to provide the initial procedures for evaluating the hoped-for profitability of chemical plant investments, and of estimating the relative attractiveness of different projects and capital expenditures. The first step involves three additional pieces of information that are needed: the product sales value, the company income tax requirements, and a knowledge of the effect that compound interest has upon investments. This later subject is not only important for the money that may be borrowed on a project, but even more so to examine how the project investment might compare with an alternate investment (including a purely financial one, such as bonds, CDs, etc.). This topic shall be reviewed first in the following section.

INTEREST: THE COST OF MONEY

From time immemorial the loaning of money has had a charge, or cost, called interest. Presumably the lender could have invested the money elsewhere and made a profit had he not loaned it, so the interest is his compensation for the otherwise lost profit. The amount of interest depends upon the scarcity of money at the time of the loan and what alternative investments might have yielded. It also depends upon the risk the lender feels that he is taking that the money might not be repaid, or what collateral or security may be pledged to the lender that has an equal or somewhat greater value. Some limited sums may be lent without such a tangible guarantee when the credit worthiness of the borrower is well established, but usually the lender wants to be assured that the money will be paid back, along with interest, using such collateral as the pawn shop's deposit of merchandise, the bank's taking title to property, stocks, or bonds upon default, or obtaining a more creditworthy cosigner.

In the business world the need for borrowing is even more demanding and generally required than with one's personal financing. Few companies can get started or maintain a reasonable vigor without debt. Also, tax laws, inflation, and profit potential generally make borrowing a very prudent option, up to a point. Collateral is still required, either directly for bank loans, or indirectly for the company's ability to sell bonds, debentures, or preferred stock. Interest is paid on these bonds or loans, with the rate depending upon the normal business factors existing at that time, and the creditworthiness of the company. Several financial services rate the potential repayment strength (for loans) of all the larger companies, using a nomenclature from triple A downward. These ratings have a major effect upon the company's ability to sell bonds and the interest rate that is paid.

Most companies maintain a mixture of types of debt, including bank loans that are usually short term (such as for one year or less), and which often are at least partially "rolled over" at the end of their term to give them a longer life. The interest rates on these loans are usually higher than the then-current long-term bonds, and the rate is generally variable and tied to the bank's current "prime rate." This is an interest rate that is some amount (i.e., 2%) higher than the bank can borrow funds from the Federal Reserve at their "discount rate." The banks might loan funds to a very few large, highly solvent firms at this prime rate, but for most business customers the interest charged would be 0.5 to 2.5% above prime, and would vary each time the prime changed.

Companies also sell bonds that are usually in denominations of $1,000, pledging the bond (loan) to the company's assets as collateral, and promising to pay a fixed percentage interest rate (usually semiannually) until a date 10 to 20 years in the future when the bond would be repayed. When a company has issued more bonds than their assets can conservatively guarantee, then subordinated debentures can be sold. They are identical to bonds, but have a secondary position to the bonds (or perhaps no security at all) in being guaranteed by company assets in case of a bankruptcy. They generally pay a slightly (i.e., 0.5 to 1%) higher interest rate than bonds.

The last step in loans with reduced security is a class of bonds called "junk bonds." These bonds are just like regular bonds, but are issued in very uncertain or high debt-to-equity conditions. They are often used to raise money in takeover, merger, or leveraged buy-outs of a company, but they can also be employed in exceptional cases for financing on-going businesses. They often command 2 to 4% additional interest, and are considered to be quite risky. To date, however, their failure rate has not been as high as their enhanced income would cover, and they have been very successful in helping companies become established which would not have been able to obtain normal credit.

INTEREST CALCULATIONS

There are many ways that money can be loaned and repayed, and an equal number of ways that money can accumulate, earn interest, and be dispensed. The mathematics of these procedures is usually fairly simple, even though often complex. In the following chapter some of the standard nomenclature and a few of the more basic calculations will be reviewed. Tables and computer programs are available for some of them, and many references cover their derivation and use. Hopefully with the background given here most engineers can derive any others they may later need.

Simple Interest

When money (capital or principal) is loaned the amount of money earned by a unit of principal in a unit of time (i.e., usually one year) is called the rate of interest. For example, if 10% were the interest agreed to for a loan of $1,000 for a period of one year, the principal would be $1,000 and the interest payment would be $0.10 \times 1{,}000 = \$100.00$ per year. "Simple interest" such as this requires yearly payment at a constant interest rate times the original principal. If $1,000 were loaned for five years at an interest rate of 10% and no payment was made on the principal, the simple interest earned would be $\$1{,}000 \times 0.1 \times 5 = \$500$.

In this book P will represent the principal, or original capital, n the number of yearly interest periods, i the interest rate for that interest period, and the amount of simple interest I earned during n interest periods. Thus, for simple interest,

$$I = Pin \tag{5-1}$$

The principal must be repaid eventually, so the entire amount S of principle plus simple interest due after n interest periods is

$$S = P + I = P(1 + in) \tag{5-2}$$

When borrowing money care must be taken to understand the interest charging basis. Banks have learned that there is a great deal of money to be made by controlling how interest is to be paid. For instance, when it is in their favor and an interest period of less than one year is involved, they may claim that the "ordinary" way to determine simple interest is to assume the year consists of twelve 30-day months, or 360 days. When they owe you, however, the "exact" method is often employed based upon the fact that there are 365 days in a normal year. In a related ploy, they will often delay crediting the deposit of checks into your account for a day or so on local checks, and perhaps as much as a month on out of state or foreign checks. With the advent of electronic fund transfers they usually have received a credit for the money almost immediately, and earn interest on the funds for themselves until they finally credit your account. With a little friendly discussion your banker can usually make these practices considerably more equitable.

Compound Interest

Simple interest is generally paid at the end of each time unit or at agreed upon intermediate intervals. However, interest has an important time value, and when ever the interest is paid the receiver can immediately put the interest to work if he desires and earn additional interest. This is called "compound interest" which assumes that the interest received is not withdrawn, but added to the principle, and interest is received upon this enlarged principal during the following period. Thus, an initial loan of $1,000 at an annual interest rate of 10% would require payment of $100 interest at the end of the first year. When compounded, the interest for the second year would be ($1,000 + $100) (0.10) = $110, and the total amount due after two years would be $1,000 + $100 + $110 = $1,210. The compound amount (S_n) due after any discreet number of interest periods can be determined as follows:

$$\text{first year:} \quad P + Pi = P(1 + i)$$

$$\text{second year:} \quad P + Pi(1 + i) = P(1 + i)^2$$

$$n\text{th year:} \quad P(1 + i)^n$$

Therefore, the total amount of principal plus compounded interest due after n interest periods, is

$$S_n = P(1 + i)^n \tag{5-3}$$

Normally the interest rate i is quoted on a yearly basis, and the time period n is the number of years involved. However, interest payments are actually often made on a more frequent basis, such as semiannually, quarterly, monthly, or even daily. To determine the compounded amount earned on this basis let m equal the number of interest periods per year, and Equation (5-3) then becomes

$$S = P(1 + i/m)^{mn} \tag{5-4}$$

Obviously, the more frequent the compounding period, the greater the return from the interest payments. The ultimate would be if the interest were paid and compounded continuously. It is difficult to imagine how this would occur in practice, but in the case of a multinational company (as most chemical compa-

nies now are), with interest being obtained from the funds received from sales around the world and deposited in local banks as received, the total interest that accrued might appear to be fairly continuous. Conversely, in considering the return on a production plant investment, with the bookkeeping on an "accrual" basis where every transaction, including credit for production, was entered on the books when it occurred regardless of when the cash was paid (for purchases) or received (for sale), then with around-the-clock production the profit and equivalent rate of return, or "interest" would be truly continuous.

Mathematically, if earnings are accrued on a continuous basis, the differential increase in the compounded amount dS, over a differential time interval dn is given by

$$dS = Sr\,dn \tag{5-5}$$

where r is the continuous interest rate, and n is the time.

Holding r constant with respect to time, and integrating this equation from time zero (the reference point) to time n, one obtains

$$\int_P^S \frac{dS}{S} = \int_O^n r\,dn$$

$$\ln S/P = rn$$

$$S = Pe^{rn} \tag{5-6}$$

The following table shows a comparison of the total amounts due at different times for the cases where simple interest, discreet compound interest, and continuous compound interest are used. Assume that $100 was borrowed for 1 or 10 years at 10% interest, compounded either annually, semiannually, quarterly, daily, or continuously. The repayment, S, of interest plus principal would be

Period	*Annually*	*Semiannually*	*Quarterly*	*Daily*	*Continuously*
1 yr	$110.00	110.25	110.38	110.52	110.52
10 yr	259.37	265.33	268.51	271.79	271.83
% increase from annual		2.30	3.52	4.79	4.80

It is seen that the compounding period can make a small but important difference in the growth of the principal, but that daily and continuous compounding are nearly the same. Thus, in future project economic evaluations such as "discounted cash flow" (DCF) or "present worth" it can be assumed that the cash received from sales and deposited into the bank would be at least on a daily basis, so either daily or continuous compounding would be acceptable and almost identical to each other. Actually, in profitability calculations any mathematic relationship can be used, just so that consistency is employed.

Present Worth (or Present Value)

In project profitability calculations it is often necessary to determine the present value of funds that will be received at some definite periods in the future. If it is assumed that the principal and interest payments were not withdrawn, then interest compounding's effect upon the amount must be taken into consideration. The present worth (or present value) of a future amount on this basis is considered the present principal which if deposited at a given interest rate and compounded would yield the actual amount received at a future date. The relationship between the indicated future amount and the present worth is calculated by an equivalent "discount factor."

In Equation (5-3), S_n represents the amount available after n interest periods if the initial principal is P and the discreet compound interest rate is i. In other terms, S_n is the amount that would be received during year n. Therefore, the present worth can be determined by merely rearranging Equation (5-3):

$$\text{present worth} = P = S_n(1 + i)^{-n} \tag{5-7}$$

The term $(1 + i)^{-n}$ is referred to as the annual interest discount factor. It would become $(1 + i/m)^{-mn}$ for the more frequent period discount factor. Similarly, for the case of continuous interest compounding, Equation (5-6) gives

$$\text{present worth} = P = S_n^{-rn} \tag{5-8}$$

and e^{-rn} is the continuous interest discount factor.

Annuities

An annuity is a series of constant payments occurring at equal time intervals. Sequences such as this can be used to pay off debt (such as a house or car purchase), accumulate a desired amount of capital (such as an IRA savings plan), or pay periodic installments on a life insurance policy. Engineers often encounter annuity-type formulas in both personal investing and in financial analyses, such as the cost of replacement of equipment or calculations for certain cases of project profitability analyses.

One type of annuity involves payments which occur regularly at the end of each interest period, or year. Interest is received for both the capital and accumulated interest, making the interest compounded on each payment period. In this case the annuity term is the time from the beginning of the first period until the last payment is made. The amount that has been accumulated in the annuity is the sum of all the payments plus compounded interest (assuming no withdrawal) for the annuity term.

To calculate the annuity, let C represent the uniform periodic payment made during n years. The interest rate for the payment period is i, and S is the future accumulated total value of the annuity. The first payment of C is made at the end of the first period and will bear interest for $n - 1$ periods. Thus, at the end of the annuity term, this first payment will have accumulated according to Equation (5-3) to an amount of $C(1 + i)^{n-1}$. The second payment of C is made at the end of the second period and will bear interest for $n - 2$ periods giving an accumulated amount of $R(1 + i)^{n-2}$, and so forth. The amount of the annuity is the sum of each year's accumulated value, or

$$S_n = C(1 + i)^{n-1} + C(1 + i)^{n-2} + C(1 + i)^{n-3} + \cdots + C(1 + i) + C \tag{5-9}$$

To simplify Equation (5-9), multiply each side by $(1 + i)$ and subtract Equation (5-9) from the result. This gives

$$S_n = C\frac{(1 + i)^n - 1}{i} \tag{5-10}$$

As an example of an annuity calculation, if an engineer invested \$2,000 per year in an IRA retirement fund for 25 years, earning 10% interest per year compounded quarterly, how much would he have upon retirement?

$$\begin{aligned} S &= \$2{,}000\,\frac{[(1 + 0.10/4)^{4 \times 25} - 1]}{0.10/4} \\ &= 2{,}000\,\frac{[(1.025)^{100} - 1]}{0.025} \\ &= 2{,}000\,\frac{(11.8137 - 1)}{0.025} \\ &= 2{,}000 \times 432.55 = \$865{,}000 \end{aligned}$$

The expression for the case of continuous cash flow and interest compounding, equivalent to Equation (5-9) may be developed as follows.

Define C such that the differential change in S with n is equal to C, which is the constant contribution during the year. When the amount due to interest is added, $dS/dn = C + rS$. This expression can be integrated as follows to give

$$\int_0^S \frac{dS}{C + rS} = \int_0^n dn \tag{5-11}$$

$$\ln \frac{C + rS}{C} = rn \quad \text{or} \quad S = C\left(\frac{e^{rn} - 1}{r}\right) \tag{5-12}$$

Present Worth of an Annuity. The present worth of an annuity may be calculated by the discount factors that have previously been developed in Equations (5-7) and (5-8). If P represents the present worth of an ordinary annuity, combining Equation (5-3) with Equation (5-10) gives the present value for annual compounding

$$P = C\frac{(1 + i)^n - 1}{i(1 + i)^n} \tag{5-13}$$

As an example of the sum that would have to be deposited at this time in a bank to be equivalent to the value of an annuity, what is the present-day value of the 25-year annuity calculated above.

$$P = \$2{,}000\,\frac{[(1.025)^{100} - 1]}{0.025\,(1.025)^{100}}$$

$$2{,}000\,\frac{(10.8137)}{0.025(11.8137)}$$

$$2{,}000 \times 36.614 = \$73{,}228$$

For the case of continuous cash flow and interest compounding, combining Equations (5-4) and (5-12) results in the following equation for the present value under these conditions

$$P = C\frac{e^{rn} - 1}{re^{rn}} \tag{5-14}$$

Capitalized Cost

A method sometimes used to compare the total cost or value of competitive equipment considers the hypothetical cost of the unit if it were replaced perpetually. (Assuming a constant cost.) This type of calculation can take into account different equipment costs, service life, and even annual maintenance expense. As an example, if the equipment cost \$10,000, had a useful life of 10 years and no salvage value, and interest rates were 10%, then a fund P would be required to generate \$10,000 every 10 years. If the fund were to perpetuate itself it would have to be equal to \$10,000 (the amount removed each 10 years) plus P, or $S = \$10{,}000 + P = P(1 + i)^n$. Thus, if compounded annually the fund would need to be $\$10{,}000 = P(1 + 0.10)^{10} - P$; $P = \$10{,}000/1.1^{10} - 1 = \$6{,}274.55$. At this interest rate the fund would amount to $\$6{,}274.55(1 + 0.10)^{10} = \$16{,}274.55$ after 10 years. At the end of 10 years the equipment could be replaced for \$10,000 and \$6,274.55 would remain in the fund and the cycle could be repeated indefinitely. The total capital determined in this manner is called the capitalized cost.

The amount required for the replacement is earned as compounded interest over the life of the equipment. With P the amount of present principal (i.e., the present worth) which would accumulate to an amount S_n during n interest periods at interest rate i, $S_n = P(1 + i)^n$. If R is the equipment cost, combining Equations (5-3) and (5-10) gives

$$P = \frac{R}{(1 + i)^n - 1} \tag{5-15}$$

$$\text{capitalized cost} = \text{original cost}\left(1 + \frac{1}{(1 + i)^n - 1}\right) \tag{5-16}$$

With this brief introduction to compound interest calculations we can now return our attention to project profitability analysis, and the additional information that is required for such calculations.

PRODUCT SALES VALUE

In order to determine the income for any new project an estimate must be made of the quantity of product that can be sold, its FOB sales price, the exact product specifications, and any freight allowances or other charges that must be considered. Such information is generally obtained by studies of the existing and potential markets by means of "market research."

Market Research

Most large companies have organized market research groups of specialists that gather and project the sales information that is available on each new or changed product under consideration (Mackenzie and Thomas 1986). They then make presentations and recommendations to management and the sales department for their decision on the proposed new plant size, the product quality, specifications, inventory required, packaging, sales price, discounts, freight equalization, marketing methods, and so on. With other companies the sales department, product managers (or teams), and sometimes even members of the technical staff are assigned this market research responsibility. For most marketing studies a survey of all the available literature sources is first made to obtain as much information as possible on the product, including the amount sold, its growth pattern, the industries sold to, the end use, the size and location of competitors' plants, the price history and trends, shipment method, containers and product specifications. Some of this information is available from the Department of Commerce (1987) or other governmental surveys (Bureau of Mines 1987 on metals and minerals, etc.), trade magazine (*Chemical Marketing Reporter* 1987; *Chemical Week* 1987; etc.) articles or surveys, consulting companies [such as Stanford Research Institute (1987) compilations], and many other sources (International Trade Commission 1987). A second step then involves interviewing as many of the potential customers as possible, asking the same questions about their purchasing needs and whether they would buy the new product, and if so, under what conditions.

For well-established products this information can provide a fairly exact picture of the product's sales potential, and the sales department and management will have a good basis to establish the proposed new plant size and product specifications. They can then estimate the average net FOB price on various tonnages sold for the life of the plant. For newer or specialty products or markets there are much less data available, and sales and customer acceptance becomes a much greater uncertainty, but the estimates still must be made. If management or the sales department does not provide such detailed sales projections, then the estimating engineer will have to make the best guess possible based upon somewhat discounted or related prices from the *Chemical Marketing Reporter*, and assuming a gradual penetration into the market before the total plant capacity is sold.

The lower the fraction of the total market for a product that is assumed can be sold from a new plant, the lower the risk. Ten percent of an established market would normally be a maximum estimate unless there were some unusually favorable conditions for the new plant. For all economic estimates a number of *sensitivity analyses* should be made on possible different sales prices and amounts sold. This often indicates that below a certain capacity the project is not economically attractive, which helps explain the growing trend toward the construction of only very large plants.

INCOME TAX

After the product sales value and the manufacturing costs have been estimated, the difference between the two equals the *gross income* for the operation. This amount is the basis for determining the income tax that will be assessed by the

state and federal governments. These taxes change frequently, but for the 1987 period an example is shown below:

1. California income tax (franchise tax board) 9.6% of gross income. Other states vary from zero to slightly higher numbers.
2. U. S. Internal Revenue Service income tax. (Rates for corporate years beginning July 1, 1987 and later.)

Taxable Income	*Rate*
Not over \$50,000	15%
Over \$50,000 but not over \$75,000	25%
Over \$75,000	34% plus 5% on excess over \$100,000, or \$11,750, whichever is less

3. Maximum corporate capital gains rate increased from 28 to 34% for years beginning after December 31, 1986.

The federal government allows all other taxes, including state income tax to be considered as an expense, while some states (e.g., California) may not accept other taxes as deductions. The state (e.g., California) also may not allow losses from previous years being carried over, and usually have many more restrictions. However, assuming the same gross income, the combined California and IRS tax in 1987 would be

Gross Income, \$	*Combined Total Tax, %*
0–54,800 = 50,000 + 0.096 × 50,000	23.16 = 0.15 (income − income × 0.096) + income × 0.096 = income [0.15(1 − 0.096) + 0.096]
54,800–82,200	32.20
Over 82,200	40.34

For economic estimating purposes a combined maximum income tax figure of 40% is probably a good average value to use currently for the chemical industry, but the total amount of income tax varies with each state, and with each company. It is recommended (to be conservative) that any new project consider the maximum tax that may be due, unless management has specifically instructed estimators to use a different value. In actual practice there are many deductions that may be applied to taxes, and very few companies pay anywhere near the total amount that should be due on gross profit. The chemical industry prior to 1987 averaged well under 25% total taxes on gross profits, and the petroleum industry under 5–10% as shown in Table 5-1. Many chemical (and other CPI) companies pay no taxes at all, as shown for a few companies in

Table 5-1.
Tax Rates of Major U.S. Industries in 1982.

Automobiles	48%	Airlines	16%
Trucking	46	Metal manufacturing	10
Pharmaceuticals	36	Utilities	9
Electronics/appliances	29	Aerospace	7
Food processing	27	Petrochemicals	5
Industrial/farm equipment	24	Crude oil	3
Retailing	23	Commercial banks	2
Oil/refining	19	Railroads	8
Diversified financial	17	Paper/wood	14

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Table 5-2. With the tax law of 1987 it is estimated that there will be slight changes in the amount of taxes paid, with heavy industry (including chemicals) somewhat increasing. The oil and gas industry might increase from a 1987 average of 8.2% to about 12%, and so on (Mendes and Serever 1986).

For companies with international sales a major deduction results from receiving a foreign tax credit for having paid income taxes to foreign governments. Often such foreign income "taxes" are somewhat hypothetical, and in the United States would be considered as normal operating expenses, but the

Table 5-2.
Chemical Companies That Paid No Taxes in 1985.

	Tax Credits, \$ Million			*Tax Rate Overseas, %*	*U.S. Taxes*
	Investment Credit	*ACRS*[a]	*Other*		
1. American Cyanamid	10.05	5.97	19.81	43.70	0
2. DuPont	4.43	12.41	4.14	81.07	0
			51.73		
3. Goodyear Tire & Rubber	64	44			(20.7)
4. Hercules	8.18	20.86	22.88	33.78	(4.86)
5. International Mineral and Chemical	3.01	4.37	22.50	54.00	(5.29)
6. Pennwalt	59.30		(25.36)	33.99	0
7. W. R. Grace	2.47	29.92	(5.52)	47.84	0
8. Air Products & Chemical					0
9. Celenese					0
10. Sun Chemical					0
Total	139.91	117.53	38.45		0
Average	20.0	19.6	6.4	49.1%	0

Source: Katzenberg 1986; Excerpted by special permission from *Chemical Week* October 1, 1986 Copyright © 1986, by McGraw-Hill, Inc., New York. *Chemical and Engineering News* 1987. Reprinted with permission from *Chemical and Engineering News*, July 21, 19878; p. 15; © 1987, American Chemical Society.
[a]Accelerated cost recovery system. The IRS name for accelerated depreciation tax credit.

foreign tax designation allows a significant U. S. tax saving. For companies owning and producing mineral resources (such as oil), the reserves are considered to have a limited life which is being "depleted," and thus 5–28% of the mineral value that was sold each year may be deducted from gross profits as a depletion allowance. These and many other deductions greatly reduce the actual income tax payment, but as noted above, they should *not* be considered in preliminary cost estimates by the engineer unless it is the specific policy of the company.

Another exception to the use of a flat 40% income tax might be in the first year of operation, where various energy and other credits may apply. In prior years equipment or plants with a life of greater than three years received an investment credit of 10% of the capital cost. This amount was deducted directly from the federal income tax (i.e., it was credited much more than as an operating expense) for the year the capital investment occurred (but was not credited for the State tax). Various energy credits were also allowed, but they were, and now are more complicated, and some only apply to the state income tax, so should not be used unless one knows the precise details of the deduction. For instance, in 1985 the state of California allowed a 25% investment credit on many energy saving projects, and the federal government, 15%. These credits were very important to the profitability of some "alternate energy" projects', and when used needed to be carefully noted in the investment analysis presentations. Both have now been (almost completely) repealed.

RETURN ON INVESTMENT (ROI)

After the income taxes have been deducted from the gross or pretax income, the remainder, or *net income* is the amount that belongs free and clear to the corporation and may be used for paying dividends, reinvesting, or spent for any other purposes. This amount is also the basis for determining the simplest measure of the profitability of an investment, the rate of return that the investment is generating:

$$\frac{\text{net income per year}}{\text{total investment}} = \text{rate of return (after taxes)} = \text{ROI}$$

(total plant, including start-up, auxiliaries,

working capital, i.e., plant + working capital)

This rate of return may be compared with alternative investments, including putting the same amount of money in the bank or investing it in bonds, and gives a first approximation of how attractive the new project may be. Since the company management or others may wish to adjust this figure, one should always state what income tax rate and depreciation schedule were used, as well as note any interest on borrowed capital, the amount of product sold, and the sales price. With this data anyone can very simply convert the ROI to any basis they want, such as before taxes, a different depreciation method or period, other sales value, and so on. In general, ROI is a very simple concept that is easy to understand and apply, and for many estimates that are in an early stage of development, or quite simple, it may be all that is warranted. Every project should have an ROI estimate made on it, even if the profit varies from year to year. In this case an average may be assumed, or the profit after steady-state, or the hoped-for income a few years after start-up, is achieved.

PAYOUT PERIOD

An equally general, but perhaps more simplistic, piece of information that is also desirable for every project is how rapidly the project will pay for itself, or return the original investment. This "payout period" may be calculated as follows:

$$\frac{\text{total plant investment less working capital}}{\text{cash flow } (= \text{net yearly income after taxes plus depreciation})}$$

$$= \text{payout period, years}$$

This equation assumes that the working capital is returned at the end of the project life, and that there is no salvage value. Both of these assumptions are usually correct. Thus, the shorter the payout period, the more attractive a project. It also should be estimated for every project, no matter now complex.

REFERENCES

Bureau of Mines, 1987. U.S. Department of the Interior, Mineral Commodity Profiles; Mineral Facts and Problems; Mineral Yearbook; Mineral Industry Surveys.

Chemical Economics Handbook. 1987. Stanford Research Institute, (SRI) International, Menlo Park, CA.

Chemical and Engineering News. 1987. Top corporations avoid paying taxes. (July 21):15.

Chemical Marketing Reporter. 1987. Schnell Publishing Co., Inc., 100 Church St., New York, NY 10007-2694.

Department of Commerce. 1987. U.S. Bureau of the Census; U.S. Imports-Exports; Current Industrial Reports.

International Trade Commission. 1987. U.S. Synthetic Organic Chemical; U.S. Production and Sales.

Katzenberg, Daniel. 1986. Tax reform. *Chemical Week* (Oct. 1):18–19.

Labich, Kenneth. 1987. Tough times living with tax reform. *Fortune* (Nov. 9):113–121.

Mackenzie, Alan K., and Arthur L. Thomas. 1986. Chemical market analysis. *AIChE Plant Design and Cost Engineering* 1:1–11.

Mendes, Jushua, and Andrew E. Serever. 1986. New tax law. *Fortune* (Sept. 1).

Reich, Robert B. 1985. Industrial policy is shaped by unfair tax code. *L.A. Times* (May 12):V3.

6

PROFITABILITY ANALYSIS; DISCOUNTED CASH FLOW (DCF)

The evaluation method most frequently used in the chemical industry for the primary measure of a project's economic attractiveness is called either discounted cash flow (DCF) or internal rate of return (IRR) (even sometimes interest rate of return—IRR). These terms are used interchangeably, even though the words say that one is a cash flow and the others are rates of return. Sometimes to avoid semantic confusion the former is called discounted cash flow return on investment, DCF–ROI. They are a measure of the profitability of a project that takes into account the time value of money. This concept implies that receiving a dollar in income today is worth more than receiving a dollar next year, because today's dollar could be invested and next year be worth one dollar plus the interest that it earned. With any project the investment may be made over a period of time (i.e., plant construction usually takes from one to three years), and the income generated will be over a longer period of time (i.e., 10 to 30 years) and often be quite variable. This method relates all aspects of the cash flow (after tax profit plus depreciation; capital spending; etc.) to a common time basis. Competitive projects, with their quite different spending and income flow can then be compared equally.

Specifically, the discounted cash flow rate of return is a hypothetical interest rate such that when it is used to calculate the present value of all of the income cash flow (income after tax plus the depreciation) for each year or period (these are positive numbers) plus all of the capital expenditure or loss cash flows (these are negative numbers), the present value is zero. In other words, it is the interest rate that would be received if the same capital investment funds were to be placed in a bank for a given period (the life of the plant) and earn the same amount as the cash flow produced by the plant.

CASH FLOW

It has previously been noted that in the typical chemical process industries plant, operation profits (and thus cash flow) are received on a nearly continuous basis.

Most corporate financial departments accept and disperse money daily, and depreciation is shown in the books on at least a quarterly basis and often more frequently. Thus, with all capital investments regarded as a negative cash flow, and the after-tax profit plus depreciation considered as positive cash flows, the effective project earnings are similar to an interest rate which is continuously, or at least frequently, compounded. Such an assumption (or one taken on any other interest compounding basis) will allow calculations to be made on the time value of money in evaluating capital investment alternatives.

It has also previously been recommended that the project engineer understand the accelerated depreciation rules and procedures but that usually only the straight line method for determining depreciation be used unless otherwise instructed by management. In other words, it should normally be assumed that the value of property decreases linearly with time over the IRS allowed depreciation period. The various accelerated depreciation techniques tend to increase project profitability through maximizing cash flow in the early years of the project, and any project's profitability will be improved, just as with the (equally not recommended for engineers) assumption of considering only company funds when borrowed capital is used as part of the capital requirements. Often much of the financing for a new project is through debt, but if a project of marginal profitability were improved to an acceptable level by these techniques, management would not be seeing a consistent and basic analysis. However, if management or the financial department later wish to consider such changes, that is their prerogative and they will be fully aware of the potential risks and the affect on the corporate balance sheet.

DISCOUNTED CASH FLOW CALCULATIONS

The procedure for calculating discounted cash flow is to first tabulate all of the cash flows involved with the project and then discount them to a present (or a reference time) value by an assumed interest rate. These discounted present values are added together and the process repeated with different interest rates until the sum of the discounted cash flow values is zero. That interest rate is the discounted cash flow (DCF) or internal rate of return (IRR) for the project. The sum of each interest rate's total discounted cash flows obtained in reaching the final DCF value is the *present worth* or *present value* of the project at that interest rate (or *net* present worth or value, so named because of the addition of numerous positive and some negative cash flows).

This trial and error calculation is based upon establishing appropriate compound interest discount factors for each future cash flow to bring its value to the present time. Some of the formulas for these discount factors may be the same as previously calculated; others will be derived in the following section. It will be remembered that the discount factor, F_A, is defined as $F_A = P_0/S_n$, where P_0 is the initial or present value, and S_n is the value at time n after the equivalent compound interest was added to the initial value. For cash flow considerations, the discount factor times the cash flow for that year, period, or instant equals the present value, or

$$P_0 = S_n F_A \tag{6-1}$$

where S_n is now the future cash flow (in later calculations the cash flow may also be called C_n), and F_A is the appropriate discount factor for the compounding method decided upon and the nature of the cash flow.

The mathematics of a few of the discount factors that might commonly be used with capital expenditures or cash flows are as follows.

Instantaneous Cash Flows

For the compounding of simple periodic interest payments we have previously derived that $S_n = P_0(1 + i)^n$. If earnings were accrued on a continuous basis, and r is the continuous interest rate, the equivalent equation is $S_n = P_0 e^{rn}$. The corresponding discount factors are

$$F_A = (1 + i)^{-n} \text{ (Interest compounded annually)} \tag{6-2}$$

$$F_A = e^{-rn} \text{ (Interest compounded continuously)} \tag{6-3}$$

These factors may be used to discount a lump sum cash flow resulting from an instantaneous event, such as the recovery of salvage value or the working capital of a plant at the end of the useful project life to a present worth basis. Either of these equations may be used to calculate the discount factor; Table 6-1 contains continuous compounding discount factors calculated by using Equation (6-3) in perhaps a more convenient form. For example, if a lump sum is gained, or capital spent in an instant five years after the reference point, and a uniform continuous interest rate of 10% is applicable, then the corresponding discount factor F_A calculated from Equation (6-3) and shown in Table 6-1 is 0.6065.

In a similar manner, if the interest is compounded periodically and discounted by means of Equation (6-2) the discount values corresponding to the previous example for the salvage funds after five years at 10% interest are:

a. Yearly: $(1 + 0.10)^{-5} = 0.6209$
b. Quarterly: $(1 + 0.10/4)^{-5 \times 4} = 0.6103$
c. Monthly: $(1 + 0.10/12)^{-5 \times 12} = 0.6078$
d. Daily: $(1 + 0.10/365)^{-5 \times 365} = 0.6066$

Table 6-1

Instantaneous event discount factors

These continuous-interest discount factors give present worths for cash flows that occur in an instant at a point in time after the reference point.

*100rn**	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
0	1.0000	0.9901	0.9802	0.9704	0.9608	0.9512	0.9418	0.9324	0.9231	0.9139
10	0.9048	0.8958	0.8869	0.8781	0.8694	0.8607	0.8521	0.8437	0.8353	0.8270
20	0.8187	0.8106	0.8025	0.7945	0.7866	0.7788	0.7711	0.7634	0.7558	0.7483
30	0.7408	0.7334	0.7261	0.7189	0.7118	0.7047	0.6977	0.6907	0.6839	0.6771
40	0.6703	0.6637	0.6570	0.6505	0.6440	0.6376	0.6313	0.6250	0.6188	0.6126
50	0.6065	0.6005	0.5945	0.5886	0.5827	0.5770	0.5712	0.5655	0.5599	0.5543
60	0.5488	0.5434	0.5379	0.5326	0.5273	0.5220	0.5169	0.5117	0.5066	0.5016
70	0.4966	0.4916	0.4868	0.4819	0.4771	0.4724	0.4677	0.4630	0.4584	0.4538
80	0.4493	0.4449	0.4404	0.4360	0.4317	0.4274	0.4232	0.4190	0.4148	0.4107
90	0.4066	0.4025	0.3985	0.3946	0.3906	0.3867	0.3829	0.3791	0.3753	0.3716
100	0.3679	0.3642	0.3606	0.3570	0.3535	0.3499	0.3465	0.3430	0.3396	0.3362
110	0.3329	0.3296	0.3263	0.3230	0.3198	0.3166	0.3135	0.3104	0.3073	0.3042
120	0.3012	0.2982	0.2952	0.2923	0.2894	0.2865	0.2837	0.2808	0.2780	0.2753
130	0.2725	0.2698	0.2671	0.2645	0.2618	0.2592	0.2567	0.2541	0.2516	0.2491
140	0.2466	0.2441	0.2417	0.2393	0.2369	0.2346	0.2322	0.2299	0.2276	0.2254
150	0.2231	0.2209	0.2187	0.2165	0.2144	0.2122	0.2101	0.2080	0.2060	0.2039
160	0.2019	0.1999	0.1979	0.1959	0.1940	0.1921	0.1901	0.1882	0.1864	0.1845
170	0.1827	0.1809	0.1791	0.1773	0.1775	0.1738	0.1720	0.1703	0.1686	0.1670
180	0.1653	0.1637	0.1620	0.1604	0.1588	0.1572	0.1557	0.1541	0.1526	0.1511
190	0.1496	0.1481	0.1466	0.1451	0.1437	0.1423	0.1409	0.1395	0.1381	0.1367
200	0.1353	0.1340	0.1327	0.1313	0.1300	0.1287	0.1275	0.1262	0.1249	0.1237
210	0.1225	0.1212	0.1200	0.1188	0.1177	0.1165	0.1153	0.1142	0.1130	0.1119
220	0.1108	0.1097	0.1086	0.1075	0.1065	0.1054	0.1044	0.1033	0.1023	0.1013
230	0.1003	0.0993	0.0983	0.0973	0.0963	0.0954	0.0944	0.0935	0.0926	0.0916
240	0.0907	0.0898	0.0889	0.0880	0.0872	0.0863	0.0854	0.0846	0.0837	0.0829
250	0.0821	0.0813	0.0805	0.0797	0.0789	0.0781	0.0773	0.0765	0.0758	0.0750
260	0.0743	0.0735	0.0728	0.0721	0.0714	0.0707	0.0699	0.0693	0.0686	0.0679
270	0.0672	0.0665	0.0659	0.0652	0.0646	0.0639	0.0633	0.0627	0.0620	0.0614
280	0.0608	0.0602	0.0596	0.0590	0.0584	0.0578	0.0573	0.0567	0.0561	0.0556
290	0.0550	0.0545	0.0539	0.0534	0.0529	0.0523	0.0518	0.0513	0.0508	0.0503
300	0.0498	0.0493	0.0488	0.0483	0.0478	0.0474	0.0469	0.0464	0.0460	0.0455
310	0.0450	0.0446	0.0442	0.0437	0.0433	0.0429	0.0424	0.0420	0.0416	0.0412
320	0.0408	0.0404	0.0400	0.0396	0.0392	0.0388	0.0384	0.0380	0.0376	0.0373
330	0.0369	0.0365	0.0362	0.0358	0.0354	0.0351	0.0347	0.0344	0.0340	0.0337
340	0.0334	0.0330	0.0327	0.0324	0.0321	0.0317	0.0314	0.0311	0.0308	0.0305
350	0.0302	0.0299	0.0296	0.0293	0.0290	0.0287	0.0284	0.0282	0.0279	0.0276
360	0.0273	0.0271	0.0268	0.0265	0.0263	0.0260	0.0257	0.0255	0.0252	0.0250

Table 6-1 (*Continued*)

*100rn**	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
370	0.0247	0.0245	0.0242	0.0240	0.0238	0.0235	0.0233	0.0231	0.0228	0.0226
380	0.0224	0.0221	0.0219	0.0217	0.0215	0.0213	0.0211	0.0209	0.0207	0.0204
390	0.0202	0.0200	0.0198	0.0196	0.0194	0.0193	0.0191	0.0189	0.0187	0.0185
400	0.0183	0.0181	0.0180	0.0178	0.0176	0.0174	0.0172	0.0171	0.0169	0.0167
410	0.0166	0.0164	0.0162	0.0161	0.0159	0.0158	0.0156	0.0155	0.0153	0.0151
420	0.0150	0.0148	0.0147	0.0146	0.0144	0.0143	0.0141	0.0140	0.0138	0.0137
430	0.0136	0.0134	0.0133	0.0132	0.0130	0.0129	0.0128	0.0127	0.0125	0.0124
440	0.0123	0.0122	0.0120	0.0119	0.0118	0.0117	0.0116	0.0114	0.0113	0.0112
450	0.0111	0.0110	0.0109	0.0108	0.0107	0.0106	0.0105	0.0104	0.0103	0.0102
460	0.0101	0.0100	0.0099	0.0098	0.0097	0.0096	0.0095	0.0094	0.0093	0.0092
470	0.0091	0.0090	0.0089	0.0088	0.0087	0.0087	0.0086	0.0085	0.0084	0.0083
480	0.0082	0.0081	0.0081	0.0080	0.0079	0.0078	0.0078	0.0077	0.0076	0.0075
490	0.0074	0.0074	0.0073	0.0072	0.0072	0.0071	0.0070	0.0069	0.0069	0.0068
100rn	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
500	0.0067	0.0061	0.0055	0.0050	0.0045	0.0041	0.0037	0.0033	0.0030	0.0027
600	0.0025	0.0022	0.0020	0.0018	0.0017	0.0015	0.0014	0.0012	0.0011	0.0010
700	0.0009	0.0008	0.0007	0.0007	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004
800	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001
900	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
1000	0.0000									

*r = nominal interest compounded continuously; percent/100; n = number of years.

Source: Leibson & Trischman 1971. Excerpted by special permission from *Chemical Engineering*, December 1971. Copyright © 1971, by McGraw-Hill, Inc., New York.

As in previous examples it is seen that continuous and frequent interest compounding give very similar results, and the accuracy (or lack of accuracy) between compounding periods is probably less than the other inaccuracies in the profitability calculations. However, there is enough difference that a consistent calculation method should be used, and the compounding period specified along with the results. If a calculator is used for discounted cash flow or present value calculations, and the compounding method is not stated, then a simple present worth calculation such as the example above will quickly determine the formula programmed into the machine. Small factory programmed hand-held calculators appear to usually employ periodic (annual) compounding.

Income Cash Flows

The case in which a project (continuously) produces a different cash flow each year of its life is a common one. The cash flow may be assumed to be uniform during the year, but the cash flow from one year to the next may not necessarily be equal. For this case, within any year (n), the differential rate of appreciation of the compounded amount (S) is

$$\frac{dS}{dn} = C_n + rS \tag{6-4}$$

where C_n is the cash flow occurring in year n.

Holding r constant with respect to time (n), and integrating this equation from ($n - 1$) to n, the following is obtained

$$\int_0^{S_n} \frac{dS}{C_n + rs} = \int_{n-1}^{n} dn$$

$$\frac{1}{r} \ln \frac{C_n + rS_n}{C_n} = 1$$

$$C_n + rS_n = C_n e^r$$

$$S_n = C_n\left(\frac{e^r - 1}{r}\right) \tag{6-5}$$

Equation (6-5) calculates the compounded amount for a uniform, continuous, yearly cash flow with continuous interest compounding. The corresponding present worth of cash flow C_n converted from the year n to the reference point is obtained by combining Equation (6-3) with Equation (6-5).

$$P_0 = S_n e^{-rn} = C_n\left(\frac{e^r - 1}{r}\right) e^{-rn} \tag{6-6}$$

The corresponding discount factor (F_B) is

$$F_B = \left(\frac{e^r - 1}{r}\right) e^{-rn} \tag{6-7}$$

This may be used to discount cash flows that occur continuously and uniformly over one-year periods after the reference point to give the corresponding present worth. Table 6-2 contains discount factors calculated by use of Equation (6-7).

For example, for the cash flow for the fifth year of a project ($n = 5$, or from year number 4 to year number 5 after the reference point), with 10% interest ($r = 0.10$), the corresponding discount factor (F_B) calculated from Equation (6-7) and shown in Table 6-2 is 0.6379.

In a similar manner, the corresponding compounding of periodic cash flow for each year is $C_n(1 + i)$ for a single cash flow received at the beginning of the year, C_n for a single cash flow received at the end of the year, and

$$\frac{(C_n/m)[(1 + i/m)^m - 1]}{i/m} = \frac{C_n[(1 + i/m)^m - 1]}{i} \tag{6-8}$$

for each cash flow received for m periods within the year, but at the end of each period. Each of these three periodic cash flow and compounding possibilities would be converted to the present by dividing by $(1 + i/m)^{nm}$. In the previous example for the period from year 4 to 5, 10% interest, with daily cash flow and compounding, the discount factor would be

$$\frac{(1 + 0.1/365)^{365} - 1}{0.1} = \frac{(1.000274)^{365} - 1}{0.1} = \frac{1.10516 - 1}{0.1}$$

$$= 1.0516; \quad \frac{1}{(1.00274)^{5 \times 365}} = 0.60654$$

The discount factor is thus $1.0516 \times 0.60654 = 0.6378$.

It is to be noted that in this case periodic daily compounding and continuous compounding again give results that are not much different from each other, just as in the previous calculation with instantaneous cash flows.

Initial Plant Investment

Most major plant construction projects require from one to three years for completion. The shape of the cash spending curve usually varies to some extent, depending on the arrangements with the contractor (e.g., lump sum, fixed payment schedule, cost plus, or other) and the type of facility involved. The cash spending curve is typically S-shaped for most projects.

If the spending schedule is forecast or preset by contract, then plant investment capital can be discounted to reflect its value at the reference point (i.e., plant start-up, initial construction, etc.) by using the appropriate discount factors. However, such calculations are usually not easily accomplished because the capital spending pattern can seldom be rigorously defined at the time the economic justification is being prepared. Thus, the period of capital spending is often neglected in profitability evaluations of alternative investment opportunities. Time zero is frequently set when the plant starts production, with no discount factor used on the initial capital investment. Such a practice often causes less than 5% error in evaluating project alternatives, which hopefully is

Table 6-2

Uniform one year period discount factors

These continuous-interest discount factors give present worths for cash flows that occur uniformly over one-year periods after the reference point.

*Year**	*1%*	*2%*	*3%*	*4%*	*5%*	*6%*	*7%*	*8%*	*9%*	*10%*
0–1	0.9950	0.9901	0.9851	0.9803	0.9754	0.9706	0.9658	0.9610	0.9563	0.9516
1–2	0.9851	0.9705	0.9560	0.9418	0.9278	0.9141	0.9005	0.8872	0.8740	0.8611
2–3	0.9753	0.9512	0.9278	0.9049	0.8826	0.8608	0.8396	0.8189	0.7988	0.7791
3–4	0.9656	0.9324	0.9004	0.8694	0.8395	0.8107	0.7829	0.7560	0.7300	0.7050
4–5	0.9560	0.9140	0.8737	0.8353	0.7986	0.7635	0.7299	0.6979	0.6672	0.6379
5–6	0.9465	0.8959	0.8479	0.8026	0.7596	0.7190	0.6806	0.6442	0.6098	0.5772
6–7	0.9371	0.8781	0.8229	0.7711	0.7226	0.6772	0.6346	0.5947	0.5573	0.5223
7–8	0.9278	0.8607	0.7985	0.7409	0.6874	0.6377	0.5917	0.5490	0.5093	0.4726
8–9	0.9185	0.8437	0.7749	0.7118	0.6538	0.6006	0.5517	0.5068	0.4655	0.4276
9–10	0.9094	0.8270	0.7520	0.6839	0.6219	0.5656	0.5144	0.4678	0.4254	0.3869
10–11	0.9003	0.8106	0.7298	0.6571	0.5916	0.5327	0.4796	0.4318	0.3888	0.3501
11–12	0.8914	0.7946	0.7082	0.6312	0.5628	0.5016	0.4472	0.3986	0.3553	0.3168
12–13	0.8825	0.7788	0.6873	0.6065	0.5353	0.4724	0.4169	0.3680	0.3248	0.2866
13–14	0.8737	0.7634	0.6670	0.5827	0.5092	0.4449	0.3888	0.3397	0.2968	0.2593
14–15	0.8650	0.7483	0.6473	0.5599	0.4844	0.4190	0.3625	0.3136	0.2713	0.2347
15–16	0.8564	0.7335	0.6282	0.5380	0.4608	0.3946	0.3380	0.2895	0.2479	0.2123
16–17	0.8479	0.7189	0.6096	0.5169	0.4383	0.3716	0.3151	0.2672	0.2266	0.1921
17–18	0.8395	0.7047	0.5916	0.4966	0.4169	0.3500	0.2938	0.2467	0.2071	0.1739
18–19	0.8311	0.6908	0.5741	0.4772	0.3966	0.3296	0.2740	0.2277	0.1893	0.1573
19–20	0.8228	0.6771	0.5571	0.4584	0.3772	0.3104	0.2554	0.2102	0.1730	0.1423
20–21	0.8147	0.6637	0.5407	0.4405	0.3588	0.2923	0.2382	0.1940	0.1581	0.1288
21–22	0.8065	0.6505	0.5247	0.4232	0.3413	0.2753	0.2221	0.1791	0.1445	0.1165
22–23	0.7985	0.6376	0.5092	0.4066	0.3247	0.2593	0.2071	0.1653	0.1320	0.1054
23–24	0.7906	0.6250	0.4941	0.3907	0.3089	0.2442	0.1931	0.1526	0.1207	0.1954
24–25	0.7827	0.6126	0.4795	0.3753	0.2938	0.2300	0.1800	0.1409	0.1103	0.0863
25–30	0.7596	0.5772	0.4386	0.3334	0.2535	0.1928	0.1466	0.1115	0.0849	0.0646
30–35	0.7226	0.5223	0.3775	0.2730	0.1974	0.1428	0.1033	0.0748	0.0541	0.0392
35–40	0.6874	0.4726	0.3250	0.2235	0.1538	0.1058	0.0728	0.0501	0.0345	0.0238
40–45	0.6538	0.4276	0.2797	0.1830	0.1197	0.0784	0.0513	0.0336	0.0220	0.0144
45–50	0.6219	0.3869	0.2407	0.1498	0.0933	0.0581	0.0362	0.0225	0.0140	0.0087

not too significant compared with the potential error in other inputs (e.g., sales price and volume, capital cost, profit, etc.), especially if all projects are consistently evaluated on this basis. For the most rigorously accurate economic evaluations, however, all cash flows prior to the plant start-up should also be discounted.

The effect of land value, research and development, and prior engineering

Table 6-2 (*Continued*)

*Year**	*11%*	*12%*	*13%*	*14%*	*15%*	*16%*	*17%*	*18%*	*19%*	*20%*	*21%*
0–1	470	0.9423	0.9377	0.9332	0.9286	0.9241	0.9196	0.9152	0.9107	0.9063	0.9020
1–2	8483	0.8358	0.8234	0.8112	0.7993	0.7875	0.7759	0.7644	0.7531	0.7421	0.7311
2–3	600	0.7413	0.7230	0.7053	0.6879	0.6710	0.6546	0.6385	0.6228	0.6075	0.5926
3–4	808	0.6574	0.6349	0.6131	0.5921	0.5718	0.5522	0.5333	0.5150	0.4974	0.4804
4–5	6099	0.5831	0.5575	0.5330	0.5096	0.4873	0.4659	0.4455	0.4259	0.4072	0.3894
5–6	0.5463	0.5172	0.4895	0.4634	0.4386	0.4152	0.3931	0.3721	0.3522	0.3334	0.3156
6–7	0.4894	0.4588	0.4299	0.4029	0.3775	0.3538	0.3316	0.3108	0.2913	0.2730	0.2558
7–8	0.4385	0.4069	0.3775	0.3502	0.3250	0.3015	0.2798	0.2596	0.2409	0.2235	0.2074
8–9	0.3928	0.3609	0.3314	0.3045	0.2797	0.2569	0.2360	0.2168	0.1992	0.1830	0.1681
9–10	0.3519	0.3201	0.2910	0.2647	0.2407	0.2189	0.1991	0.1811	0.1647	0.1498	0.1363
10–11	0.3152	0.2839	0.2556	0.2301	0.2072	0.1866	0.1680	0.1513	0.1362	0.1227	0.1105
11–12	0.2824	0.2518	0.2244	0.2000	0.1783	0.1590	0.1417	0.1264	0.1126	0.1004	0.0895
12–13	0.2530	0.2233	0.1970	0.1739	0.1535	0.1355	0.1196	0.1055	0.0932	0.0822	0.0726
13–14	0.2266	0.1981	0.1730	0.1512	0.1321	0.1154	0.1009	0.0882	0.0770	0.0673	0.0588
14–15	0.2030	0.1757	0.1519	0.1314	0.1137	0.0984	0.0851	0.0736	0.0637	0.0551	0.0477
15–16	0.1819	0.1558	0.1334	0.1143	0.0979	0.0838	0.0718	0.0615	0.0527	0.0451	0.0387
16–17	0.1629	0.1382	0.1172	0.0993	0.0842	0.0714	0.0606	0.0514	0.0436	0.0369	0.0313
17–18	0.1460	0.1225	0.1029	0.0864	0.0725	0.0609	0.0511	0.0429	0.0360	0.0303	0.0254
18–19	0.1308	0.1087	0.0903	0.0751	0.0624	0.0519	0.0431	0.0358	0.0298	0.0248	0.0206
19–20	0.1171	0.0964	0.0793	0.0653	0.0537	0.0442	0.0364	0.0299	0.0246	0.0203	0.0167
20–21	0.1049	0.0855	0.0697	0.0568	0.0462	0.0377	0.0307	0.0250	0.0204	0.0166	
21–22	0.0940	0.0758	0.0612	0.0493	0.0398	0.0321	0.0259	0.0209	0.0169	0.0136	
22–23	0.0842	0.0673	0.0537	0.0429	0.0343	0.0274	0.0218	0.0175	0.0139	0.0111	
23–24	0.0754	0.0596	0.0472	0.0373	0.0295	0.0233	0.0184	0.0146	0.0115	0.0091	
24–25	0.0676	0.0529	0.0414	0.0324	0.0254	0.0199	0.0156	0.0122	0.0095	0.0075	
25–30	0.0492	0.0374	0.0285	0.0217	0.0165	0.0126	0.0096	0.0073	0.0056	0.0043	
30–35	0.0284	0.0205	0.0149	0.0108	0.0078	0.0057	0.0041	0.0030	0.0022	0.0016	
35–40	0.0164	0.0113	0.0078	0.0054	0.0037	0.0025	0.0018	0.0012	0.0008	0.0006	
40–45	0.0094	0.0062	0.0041	0.0027	0.0017	0.0011	0.0008	0.0005	0.0003	0.0002	
45–50	0.0054	0.0034	0.0021	0.0013	0.0008	0.0005	0.0003	0.0002	0.0001	0.0001	

*Year indicates one-year period in which cash flow occurs.
Source: Leibson and Trischman 1971. Excerpted by special permission from *Chemical Engineering*, December, 1971.

expenses being compounded from the time of expenditure to plant start-up may be similarly neglected in most cases without serious problem for most practical situations in the chemical process industries. Thus, DCF return on investment on this simplified basis is that value of r for which the following equation applies

$$\sum_{n=0}^{n=\text{project life}} = C_n\left(\frac{e^r-1}{r}\right)e^{-rn} + \begin{pmatrix}\text{plant salvage value}\\ \text{plus working capital}\end{pmatrix}e^{-rn} - \begin{pmatrix}\text{total plant investment,}\\ \text{including land value}\end{pmatrix} = 0 \qquad (6\text{-}9)$$

Example

A trial and error solution is required to find the value of r that satisfies Equation (6-9) using the terms in the equation or discount factors given in Tables 6-1, 6-2, and 6-4. An example of such a calculation is as follows.

PROBLEM. You have estimated that the total capital requirement for a new project is \$25 million, including \$2.5 million working capital. The project would be allowed a 10-year (straight line) depreciation period, but would actually be an efficient operation for 20 years. At the end of that time there would be no salvage value. The estimated after-tax (40%) profits are \$0.25, \$0.50, \$0.75, \$1.00, \$1.25, and \$1.50 MM/yr for the first six years, and then the pretax rate is constant for the life of the project. Assume continuous compounding, and using the tables, what is the project's discounted cash flow rate of return?

ANSWER. It is first necessary to assume a time zero and then calculate the cash flow for each year of the project's life. It is best to enter this information in a table, as shown in Table 6-3, to simplify the record keeping of the multiple step, trial and error calculation that will be required. For simplicity let's assume that time zero occurs when the plant is ready to start operating, and that all of the capital expense has occurred instantaneously at that time. This will then be entered in the table as a negative \$25 million, with a discount factor of 1.00. Cash flows can next be tabulated for the first 10 years as depreciation plus after tax profit. The depreciation is (total capital − working capital)/allowed depreciation period = (25 − 2.5)/10 = \$2.25 million. Adding this to the specified after tax profit gives the first 10 years' cash flow.

For the last 10 years there is no longer any depreciation, so after-tax profits will appear larger, but the cash flow will be smaller. With the after-tax profit in year 10 = \$1.50 MM, and the tax rate 40%, the pretax profits must have been $0.6 \times P = 1.50$, or \$2.50 MM. Since \$2.25 MM depreciation "expenses" had reduced this amount, the pretax, predepreciation profit must be for years 11–20, 2.25 + 2.50 = \$4.75 MM. The after-tax profit would then be $4.75 \times 0.6 =$ \$2.85 MM, which is also the cash flow for this period.

Finally, at the end of year 20 (again for simplicity assume it to occur in an instant) the working capital (\$2.50 MM) and salvage value (\$0.00 MM) would be recovered as one final cash flow entry.

Table 6-3.
Working Table for DCF Calculations.

		10% Interest			12% Interest	
Year	*Cash Flow, \$ MM*	*10% Discount Factor*	*From Table*	*Present Value, \$ MM*	*12% Discount Factor*	*Present Value, \$ MM*
0	−25.00	1.0		−25.0000	1.0	−25.0000
0–1	2.50	0.9516	6-2	2.3790	0.9423	2.3558
1–2	2.75	0.8611	6-2	2.3680	0.8358	2.2985
2–3	3.00	0.7791	6-2	2.3373	0.7413	2.2239
3–4	3.25	0.7050	6-2	2.2913	0.6574	2.1366
4–5	3.50	0.6379	6-2	2.2327	0.5831	2.0409
5–10	3.75 × 5 =	0.7869	6-4		0.7520	
	18.75	×0.6065	6-1		×0.5488	
		=0.4773		8.0495	=0.4127	7.7381
10–20	2.85 × 10 =	0.6321	6-4		0.5823	
	28.5	×0.3679	6-1		×0.3012	
		=0.2326		6.6277	=0.1754	4.9986
20	2.50	0.1353	6-1	0.3383	0.0907	0.2268
Present value (Total)				\$2.5228 MM		\$−0.9808 MM

(Δ = 3.5036)

Extrapolation: $\dfrac{2.5228}{3.5036} = 0.72 \times 2 = 1.54$

DCF = 11.54%

With the cash flows now established each one can be discounted to its present value at an assumed interest rate. When the correct interest rate has been established the sum of the cash flows will be zero. Thus, a trial and error series of guesses and discount calculations must be made on interest rates until a zero present value of cash flow is bracketed, and then the DCF can be extrapolated.

For this calculation a rough approximation of (early) steady-state cash flow divided by the total capital is 3.75/25 = 15%, so an initial DCF guess of 10% interest will probably be low, but may be in the correct range. Using this interest rate, Table 6-2 could be used if desired for the discount factor for every year (except for year 20 with the working capital and salvage return), but it is perhaps easiest to only use it for the first five years. Thus, for the first year, in Table 6-2, along the 0–1 year line, under the 10% column the discount factor is found to be 0.9516. When this number is multiplied by the first year's cash flow, \$2.50 MM, the present value (at time zero) becomes \$2.3790 MM. This step is repeated for each of the first five years.

For the periods 5–10 and 10–20 years a more rapid calculation can be made using Table 6-4. This table provides the discount factor for (in this case) the 5-

Table 6-4
Later period yearly discount factors

These continuous-interest discount factors give present worths for cash flows that occur uniformly over a period of T years after the reference point.

100rT*	0	1	2	3	4	5	6	7	8	9
0	1.0000	0.9950	0.9901	0.9851	0.9803	0.9754	0.9706	0.9658	0.9610	0.9563
10	0.9516	0.9470	0.9423	0.9377	0.9332	0.9286	0.9241	0.9196	0.9152	0.9107
20	0.9063	0.9020	0.8976	0.8933	0.8891	0.8848	0.8806	0.8764	0.8722	0.8681
30	0.8639	0.8598	0.8558	0.8517	0.8477	0.8438	0.8398	0.8359	0.8319	0.8281
40	0.8242	0.8204	0.8166	0.8128	0.8090	0.8053	0.8016	0.7979	0.7942	0.7906
50	0.7869	0.7833	0.7798	0.7762	0.7727	0.7692	0.7657	0.7622	0.7588	0.7554
60	0.7520	0.7486	0.7452	0.7419	0.7386	0.7353	0.7320	0.7288	0.7256	0.7224
70	0.7192	0.7160	0.7128	0.7097	0.7066	0.7035	0.7004	0.6974	0.6944	0.6913
80	0.6883	0.6854	0.6824	0.6795	0.6765	0.6736	0.6707	0.6679	0.6650	0.6622
90	0.6594	0.6566	0.6537	0.6510	0.6483	0.6455	0.6428	0.6401	0.6374	0.6348
100	0.6321	0.6295	0.6269	0.6243	0.6217	0.6191	0.6166	0.6140	0.6115	0.6090
110	0.6065	0.6040	0.6016	0.5991	0.5967	0.5942	0.5918	0.5894	0.5871	0.5847
120	0.5823	0.5800	0.5777	0.5754	0.5731	0.5708	0.5685	0.5663	0.5641	0.5618
130	0.5596	0.5574	0.5552	0.5530	0.5509	0.5487	0.5466	0.5444	0.5424	0.5402
140	0.5381	0.5361	0.5340	0.5320	0.5299	0.5279	0.5259	0.5239	0.5219	0.5199
150	0.5179	0.5160	0.5140	0.5121	0.5102	0.5082	0.5064	0.5044	0.5026	0.5007
160	0.4988	0.4970	0.4952	0.4933	0.4915	0.4897	0.4879	0.4861	0.4843	0.4825
170	0.4808	0.4790	0.4773	0.4756	0.4739	0.4721	0.4704	0.4687	0.4671	0.4654
180	0.4637	0.4621	0.4605	0.4588	0.4571	0.4555	0.4540	0.4523	0.4508	0.4491
190	0.4476	0.4460	0.4445	0.4429	0.4414	0.4399	0.4383	0.4368	0.4354	0.4338
200	0.4323	0.4308	0.4294	0.4279	0.4265	0.4250	0.4236	0.4221	0.4207	0.4193
210	0.4179	0.4165	0.4151	0.4137	0.4123	0.4109	0.4096	0.4082	0.4069	0.4055
220	0.4042	0.4029	0.4015	0.4002	0.3989	0.3976	0.3963	0.3950	0.3937	0.3925
230	0.3912	0.3899	0.3887	0.3874	0.3862	0.3849	0.3837	0.3825	0.3813	0.3801
240	0.3789	0.3777	0.3765	0.3753	0.3741	0.3729	0.3718	0.3706	0.3695	0.3683
250	0.3672	0.3660	0.3649	0.3638	0.3627	0.3615	0.3604	0.3593	0.3582	0.3571
260	0.3560	0.3550	0.3539	0.3528	0.3517	0.3507	0.3496	0.3486	0.3476	0.3465
270	0.3455	0.3445	0.3434	0.3424	0.3414	0.3404	0.3393	0.3384	0.3374	0.3364
280	0.3354	0.3344	0.3335	0.3325	0.3315	0.3306	0.3296	0.3287	0.3277	0.3268
290	0.3259	0.3249	0.3240	0.3231	0.3221	0.3212	0.3203	0.3194	0.3185	0.3176
300	0.3167	0.3158	0.3150	0.3141	0.3132	0.3123	0.3115	0.3106	0.3098	0.3089
310	0.3080	0.3072	0.3064	0.3055	0.3047	0.3039	0.3030	0.3022	0.3014	0.3006
320	0.2998	0.2990	0.2982	0.2974	0.2966	0.2958	0.2950	0.2942	0.2934	0.2926
330	0.2919	0.2911	0.2903	0.2896	0.2888	0.2880	0.2873	0.2865	0.2858	0.2850
340	0.2843	0.2836	0.2828	0.2821	0.2814	0.2807	0.2799	0.2792	0.2785	0.2778
350	0.2771	0.2764	0.2757	0.2750	0.2743	0.2736	0.2729	0.2722	0.2715	0.2709
360	0.2702	0.2695	0.2688	0.2682	0.2675	0.2669	0.2662	0.2655	0.2649	0.2642

Table 6-4 (*Continued*)

100rn*	0	1	2	3	4	5	6	7	8	9
370	0.2636	0.2629	0.2623	0.2617	0.2610	0.2604	0.2598	0.2591	0.2585	0.2579
380	0.2573	0.2567	0.2560	0.2554	0.2548	0.2542	0.2536	0.2530	0.2524	0.2518
390	0.2512	0.2506	0.2500	0.2495	0.2489	0.2483	0.2477	0.2471	0.2466	0.2460
400	0.2454	0.2449	0.2443	0.2437	0.2432	0.2426	0.2421	0.2415	0.2410	0.2404
410	0.2399	0.2393	0.2388	0.2382	0.2377	0.2372	0.2366	0.2361	0.2356	0.2350
420	0.2345	0.2340	0.2335	0.2330	0.2325	0.2319	0.2314	0.2309	0.2304	0.2299
430	0.2294	0.2289	0.2284	0.2279	0.2274	0.2269	0.2264	0.2259	0.2255	0.2250
440	0.2245	0.2240	0.2235	0.2230	0.2226	0.2221	0.2216	0.2212	0.2207	0.2202
450	0.2198	0.2193	0.2188	0.2184	0.2179	0.2175	0.2170	0.2166	0.2161	0.2157
460	0.2152	0.2148	0.2143	0.2139	0.2134	0.2130	0.2126	0.2121	0.2117	0.2113
470	0.2108	0.2104	0.2100	0.2096	0.2091	0.2087	0.2083	0.2079	0.2074	0.2070
480	0.2066	0.2062	0.2058	0.2054	0.2050	0.2046	0.2042	0.2038	0.2034	0.2030
490	0.2026	0.2022	0.2018	0.2014	0.2010	0.2006	0.2002	0.1998	0.1994	0.1990
500	0.1987	0.1949	0.1912	0.1877	0.1843	0.1811	0.1779	0.1749	0.1719	0.1690
600	0.1663	0.1636	0.1610	0.1584	0.1560	0.1536	0.1513	0.1491	0.1469	0.1448
700	0.1427	0.1407	0.1388	0.1369	0.1351	0.1333	0.1315	0.1298	0.1282	0.1265
800	0.1250	0.1234	0.1219	0.1206	0.1190	0.1176	0.1163	0.1149	0.1136	0.1123
900	0.1111	0.1099	0.1087	0.1075	0.1064	0.1053	0.1043	0.1031	0.1020	0.1010
1000	0.1000	0.0990	0.0980	0.0971	0.0962	0.0952	0.0943	0.0935	0.0926	0.0917
1100	0.0909	0.0901	0.0893	0.0885	0.0877	0.0869	0.0862	0.0855	0.0847	0.0840
1200	0.0833	0.0826	0.0820	0.0813	0.0806	0.0800	0.0794	0.0787	0.0781	0.0775
1300	0.0769	0.0763	0.0758	0.0752	0.0746	0.0741	0.0735	0.0730	0.0725	0.0719
1400	0.0714	0.0709	0.0704	0.0699	0.0694	0.0690	0.0685	0.0680	0.0676	0.0671
1500	0.0667	0.0662	0.0658	0.0654	0.0649	0.0645	0.0641	0.0637	0.0633	0.0629
1600	0.0625	0.0621	0.0617	0.0613	0.0610	0.0606	0.0602	0.0599	0.0595	0.0592
1700	0.0588	0.0585	0.0581	0.0578	0.0575	0.0571	0.0568	0.0565	0.0562	0.0559
1800	0.0556	0.0552	0.0549	0.0546	0.0543	0.0541	0.0538	0.0535	0.0532	0.0529
1900	0.0526	0.0524	0.0521	0.0518	0.0515	0.0513	0.0510	0.0508	0.0505	0.0502
2000	0.0500	0.0497	0.0495	0.0492	0.0490	0.0487	0.0485	0.0483	0.0481	0.0478

*r = nominal interest compounded continuously; percent/100; $T = n$ = number of years in time period.

Source: Leibson & Trischman 1971. Excerpted by special permission from *Chemical Engineering*, December, 1971.

and 10-year intervals. For the 5-year interval in Table 6-3, $T = 5$ and $r = 0.10$, so the "0" column on the 50 line shows a discount factor of 0.7869 for that interval. To bring that period back to time zero, Table 6-1 for year 5 and 0.10 interest (50 line) gives a second discount factor of 0.6065. The multiple of these two discount factors is $0.7869 \times 0.6065 = 0.4773$ which is the average discount factor for the 5-year interval between years 5 and 10. Multiplying this number by the cash flow for the period ($3.75 MM) times the number of years (5) gives the present worth for the entire 5-year period. In a similar manner the 10–20 year period can be discounted for a 10-year interval (Table 6-3), and then discounted again to bring it to time zero (i.e., 0.6321 × 0.3679 × 10 × 2.85 = $6.6277 MM). In both of these intervals a year by year tabulation could have been made from Table 6-2 to give the identical answer, but using Tables 6-4 and 6-1 is faster.

The final cash flow is the working capital and salvage value return discounted from Table 6-1. All of the present worths' are then added, yielding in this case a fairly large positive value ($2.52 MM), indicating that the interest rate guess was too low. A second tabulation was consequently made assuming a 12% interest rate. This gave a negative number, so an extrapolation between 10 and 12% indicated an 11.5% DCF for the project. A third trial at 11% interest would have given a more accurate estimate, but this accuracy is seldom warranted because of all of the other uncertainties involved.

PRESENT WORTH (OR PRESENT VALUE)

Most companies have a criterion for the return on investment (ROI) expected to be realized on all new projects. The present worth (PW) or present value (PV) method of comparing investment opportunities takes this into account by discounting the annual cash flows calculated for a new project to their present value using the normal discount factors and this company desired ROI interest rate. Thus, a direct project evaluation is possible without a trial and error calculation. With this method the project alternative having the greatest present worth is the one selected, assuming that risk and other factors are equal.

Present worth is most valid for the comparison of projects that have similar lives or cover comparable time spans. The interest rate used for discounting the annual cash flows of the project represents the minimum desired return on investment capital to the company. Investments made in future years of the venture are also discounted back to their present value using the same rate factor, just as in DCF calculations. The present worth method is particularly useful in comparing small with large projects, since an actual dollar value is calculated for the excess return over the assumed minimum acceptable return rate. The same holds true for comparing projects with large DCF values since again, actual dollar returns are shown.

In the previous DCF example the present worth of the project at 10% interest would be $2.52 million. This number could be used to compare with other projects, but just as with the DCF analysis, this number or an 11.5 DCF return are extremely low values, and considering all of the uncertainties and risks with any new project, for most companies neither would be acceptable, or if they were, the decision to proceed might well be based upon other considerations.

SIMPLIFIED CALCULATION METHODS

It has been noted in the previous section that DCF can be calculated by formula or charts in a trial and error manner. This procedure is laborious and time consuming for multiple calculations, but does have the advantage of providing a feel for the importance of all of the cash flow input into the analysis, and the rapidity with which time changes (decreases) the value and importance of cash flow. At the same time present worth values are automatically determined by these calculations.

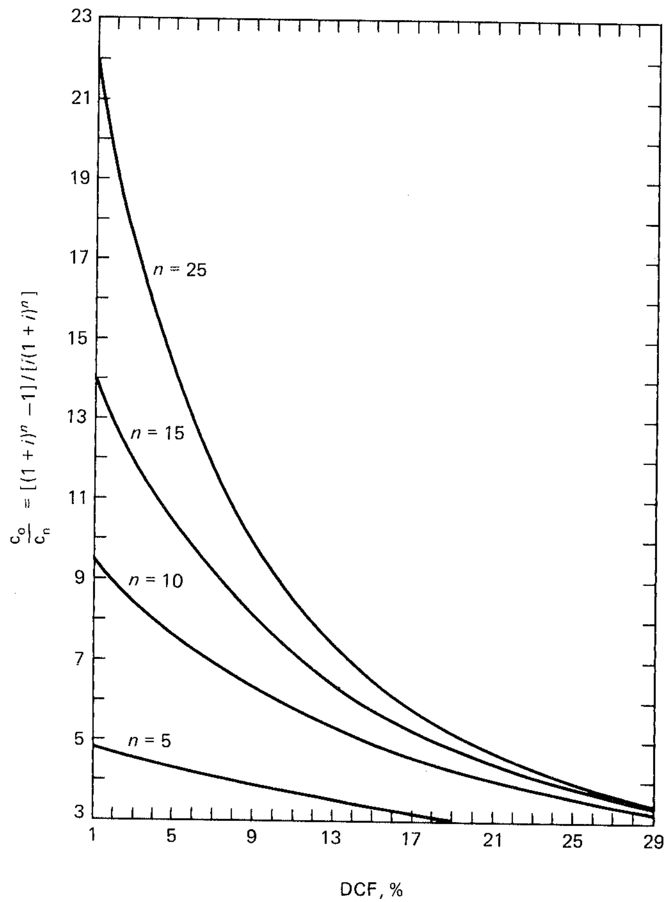
There are many ways by which the DCF calculations can be made easier, such as for simplified problems by graphical presentations. An example of such a graph is shown in Figure 6-1. In this case it was assumed that the initial investment (C_0) was made at time zero, and that all future cash flows (C_n) were constant over the project life (n years). Cash flow was assumed to be received at one time at the end of each year, and compounded on an annual basis. Salvage and working capital recovery were ignored. With the original investment and cash flow known, the DCF can be read from the graph for any project life. This becomes essentially an annuity calculation.

If financial calculations are to be made very often, however, because of the very low cost, accuracy, and speed of small hand-held calculators (or any computer), essentially all DCF calculations are now made with them. Every engineer is strongly urged to obtain a hand-held calculator or computer with financial calculation programs, and preferably one that can be used at work. It is essentially the only practical means of making frequent or repetitive DCF calculations with any reasonable speed and consistency. The same calculators or software programs can also solve present worth and many other compound interest calculations.

DATA PRESENTATION; PRO FORMA ANALYSIS

Since there are several different methods of calculating the discount factor involved with compounding both the interest and cash flow (yearly increments; more frequent intervals such as quarterly, monthly, daily, etc.; and continuously), one must specify which method is being used in the project financial analysis and comparison presentations. The difference is comparatively small, and usually far less than the inaccuracy of estimating the capital, operating cost, and sales value of the product, but nevertheless it should be noted. Likewise, each of the major discretionary variables, such as the method and period of depreciation, income tax percentage, life of the project, sales revenue, operating cost, amount and period of capital expenditure, working capital, salvage value, and so on, should also be listed when the data are reported.

The easiest way to do this is to prepare a chart with columns listing these variables for each year over the life of the project. The cash flow totals for each



Source: Horowitz 1980. Excerpted by special permission from *Chemical Engineering* May 19, 1980. Copyright © 1980, by McGraw-Hill, Inc., New York.

Figure 6-1. Graphical solution for simplified DCF calculation (constant cash flow, compounded annually, no salvage or working capital return).

year will then be the input for the DCF calculations, and as with an ROI presentation, any reader can adjust the variables as they desire. An example of a presentation of this type is shown in Table 6-5. It is part of what would be called a *pro forma* analyses, or a detailed economic presentation of a project. Unless the economic analysis is summarized in such a manner one can be assured that most financial departments, and thus the management whom they advise, will not take it seriously until it is redone on this basis. Usually when the financial department reviews such estimates they will increase the DCF based upon their more precise knowledge of depreciation and income tax, but decrease it

Table 6-5.
Abbreviated Example of a Pro Forma Analysis.

Proposed plant to produce ______ tons per year of ______________

	Years								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9 . . .*
Capital spending									
Working capital									
Salvage value anticipated									
Sales volume, t/yr									
Sales price, $/ton									
Sales, $/yr									
Production cost, $/yr									
Pretax profit, $									
Income tax (--%),[a] $									
Net profit after tax, $									
Depreciation, $[b]									
Cash flow, $									
Interest expense, $[c]									
Present worth at --% interest[d]									
Discounted cash flow, DCF[e] (synonomous with internal rate of return, IRR—one entry only)									

[a]List assumed state and federal tax rates.
[b]List depreciation method and IRS-allowable life of the plant.
[c]List amount of borrowed funds and interest rate.
[d]Only list this if of interest.
[e]Note compounding basis; total capital or company funds only; and all other pertinent factors.

by adding additional contingency to the capital cost, and assuming a lower sales realization (the sales price less freight and discount allowances, etc.). It is seldom that the engineer is involved with the financial department's review, so one must anticipate needing extra profitability in the engineer's estimate to meet the company's minimum DCF requirements.

MINIMUM ACCEPTABLE DCF

Most companies establish a lower limit and a desired DCF for new capital projects to be accepted. The risk of any new project is always the most important consideration, since sales price and quantity are always a calculated gamble, and historically the industry as a whole only operates at about 80% of capacity because of limited sales. However, assuming the best, one of the factors used in considering the DCF limit is an evaluation of the *cost of debt* for the corporation or the income that could be made from purely financial and relatively safe and secure investments such as purchasing short-term bonds or certificates of deposits (CDs in a bank). As an example of such an analysis for the minimum acceptable DCF, assume that $100 could be used to purchase bonds earning 10% interest, or be invested in a new plant with a 10-year life earning the same income. Assume that the working capital is \$10, (part of the \$100), that there would be no plant salvage value, and that the actual total income tax rate is 25%. Also assume that the return of the original investment through depreciation is roughly the same as selling the bonds (to return the capital) 10 years hence.

The bonds would yield \$10 per year gross income, less \$2.5 taxes, or \$7.5 after tax income. The plant investment would provide (\$100 − \$10 working capital)/10 = \$9/yr depreciation, which would reduce taxes by 9 × 0.25 = \$2.25/yr, making the equivalent after-tax income (to the bonds) 7.50 − 2.25 = \$5.25/yr. The plant's cash flow would be \$9 + 5.25 = \$14.25 for 9 years, and 24.25 on the tenth year (with the return of working capital). On an annual interest compounding basis this would yield a DCF of 8.05%. If we wanted the new plant investment to earn its share of the stockholder's dividend payment, assume that one-third of the profit goes to the shareholders, so $(1/3)(5.25 + x) = x$; $x = \$2.625$. The total profit then needs to be \$7.875 per year, and the DCF = 11.66%.

By an analogous calculation if the company borrowed the \$100 at 11% interest, the equivalent DCF's that should be earned to just equal this amount of interest on an after-tax basis would be 9.11 and 13.15%, respectively. It is seen that these numbers would change with the current interest rate, the income tax rate, depreciation schedules, and obviously many other items, but in general this estimated range of minimum DCF of 8–13% is about correct for the values that might be competitive with low-risk alternative investments or be equal to the cost of borrowed money, and thus should be about the lowest rate that a project's DCF should return.

Inflation

Also, there are two other basic considerations to take into account. The first is inflation. Generally in DCF calculations this is ignored as a first approximation since it is very hard to predict, and it usually can be assumed that the value of the product roughly rises with inflation, as does profits. The income numbers some years hence may not be the same as originally calculated, but on a constant dollar basis the results and DCF should normally be approximately the same. This is not always true, however, so it is another uncertainty that makes management desire a higher initial DCF, and sometimes a correction for anticipated inflation should be made if it is suspected that profits may not rise commensurately with inflation. The far greater likelihood, however, is that in the above minimum DCF calculation inflation would disproportionately reduce the potential earnings from other (financial-type) investments or reduce the cost of borrowed money. Realistically, therefore, the acceptable minimums for plant investments usually should be lowered somewhat in proportion to the anticipated inflation rate.

Basic Businesses

The second consideration in establishing the minimum DCF is the broad balancing of risk, rate of return, and the value a project may have for the company. Profitability could be considerably reduced for the basic or core businesses of the company, or with projects with high potential for future growth. As an example, a company that is strong in the field of chlorinated hydrocarbons certainly should be willing to accept any reasonable DCF from needed new capacity, or much more efficient plants, to make chlorine-caustic. This is an integral basic building block operation with very little risk and technical or marketing uncertainty. Considering the very low effective DCF that most chemical companies' existing operations now produce (i.e., 2–8%), any reasonable DCF number (i.e., >10%) should be very attractive for such a basic, important operation.

In a similar manner, if a company has emphasized research in a new field such as biotechnology, lower DCF values might be quite appropriate for the first plants to help "get a foot in the door" or to speed developing production and marketing know-how.

For most projects and most companies, however, considering the risk of any new project, and/or the desire of the company to improve its financial position, a DCF of 15% is usually considered the absolute minimum, and +20% a target value. This range is the cutoff objective for most chemical companies, with the exact limit being set by the uncertainty of the project and the availability of other attractive projects.

Considerable skill must be employed by management in evaluating DCF rate of return numbers, since even though it is an excellent measurement tool for comparing projects, it does not: (1) consider project size or the total dollars involved; (2) it does not consider project risk or uncertainty. A number of statistical probability additions have been suggested to augment DCF analysis (i.e., "Decision Trees," etc.) but it is very rare that enough data exist to make the risk estimations any better than management's basic knowledge, skill and, judgment; and (3) many mitigating factors enter into the project selection, such as previously discussed. Any management that relies too heavily on minimum DCF standards, or judges projects solely on the highest DCF numbers will surely pass up many excellent projects, will (probably unwisely) favor one group or division over another, and will probably be deluding itself on their accuracy and reliability.

SENSITIVITY ANALYSIS

Once a DCF rate has been calculated for a project, and it appears to show an attractive economic potential, a number of additional calculations should be made before the project is presented to management (Neal 1982). A typical method of presentation would be as shown in Figure 6-2, along with perhaps simplified work sheets or pro forma analyses of the type shown in Table 6-5. These "sensitivity analyses" attempt to provide some data on the question, "What if the initial estimate was wrong on each or several of the major variables?" Since this examination is done with quick checks of less accuracy than the original estimate, comparatively small curves, as in Figure 6-2, provide a somewhat more appropriate presentation of the influence of changes in these variables. If the curves indicate a great DCF sensitivity for a certain variable, and it is one that could in its lower values make the project unattractive, then more precise data would be required to provide greater accuracy for that variable, and management must be informed of this possibility. Sometimes the sensitivity analysis will show that the plant size that has been selected is too small to provide an adequate profit, and the sales department will have to redetermine whether they can sell the output of a more economically sized plant.

The desirability of such a large number of DCF estimates for the sensitivity analysis of a project underscores the strong need for using a hand-held calculator or computer in the calculations. The estimation and tabulation of capital and operating costs is quite laborious in itself, but to recalculate the DCF values by trial and error each time would make this an extremely time consuming job, plus would often not provide the accuracy desired for comparison purposes. There are also many software programs for computers that are not only set up for DCF calculations, but also allow a complete array of sensitivity analyses to be made.

The calculation of after-tax earnings for each new case in a sensitivity analyses is usually accomplished by shortcut methods. For instance, if the plant size is to be considered larger or smaller than the base case, then the new capital costs are usually obtained by using exponent factors unless more accurate data (actual price quotations, etc.) are available. If the sizing exponent is not known, use the value 0.6 or 0.64 for first approximations. Thus, if a plant 20% larger than the $10 million base case is to be considered, the new cost may be estimated at $10 \times (1.2)^{0.64} = \$11.2$ million.

In a similar manner manufacturing costs may be adjusted by changing only those variables involved: labor may remain constant, or raw materials, utilities, and operating labor changed in direct proportion to the production rate; the labor related costs by the previously discovered total factor, such as 1.60 times operating labor; capital related charges by its percentage of capital (e.g., 26% of capital); sales related cost by its factor, such as 20% of sales; working capital by its fraction of manufacturing cost (e.g., 10–35%) or total plant cost (e.g., 10–20%); and so on. For example, in the above 20% plant size increase case, the cost of raw materials and utilities might increase by 20%, the capital related manufacturing costs by 26%, or perhaps $0.26 \times \$1.2$ MM = $312,000/yr, the sales related costs by 20%, the working capital by perhaps 15% of the plant

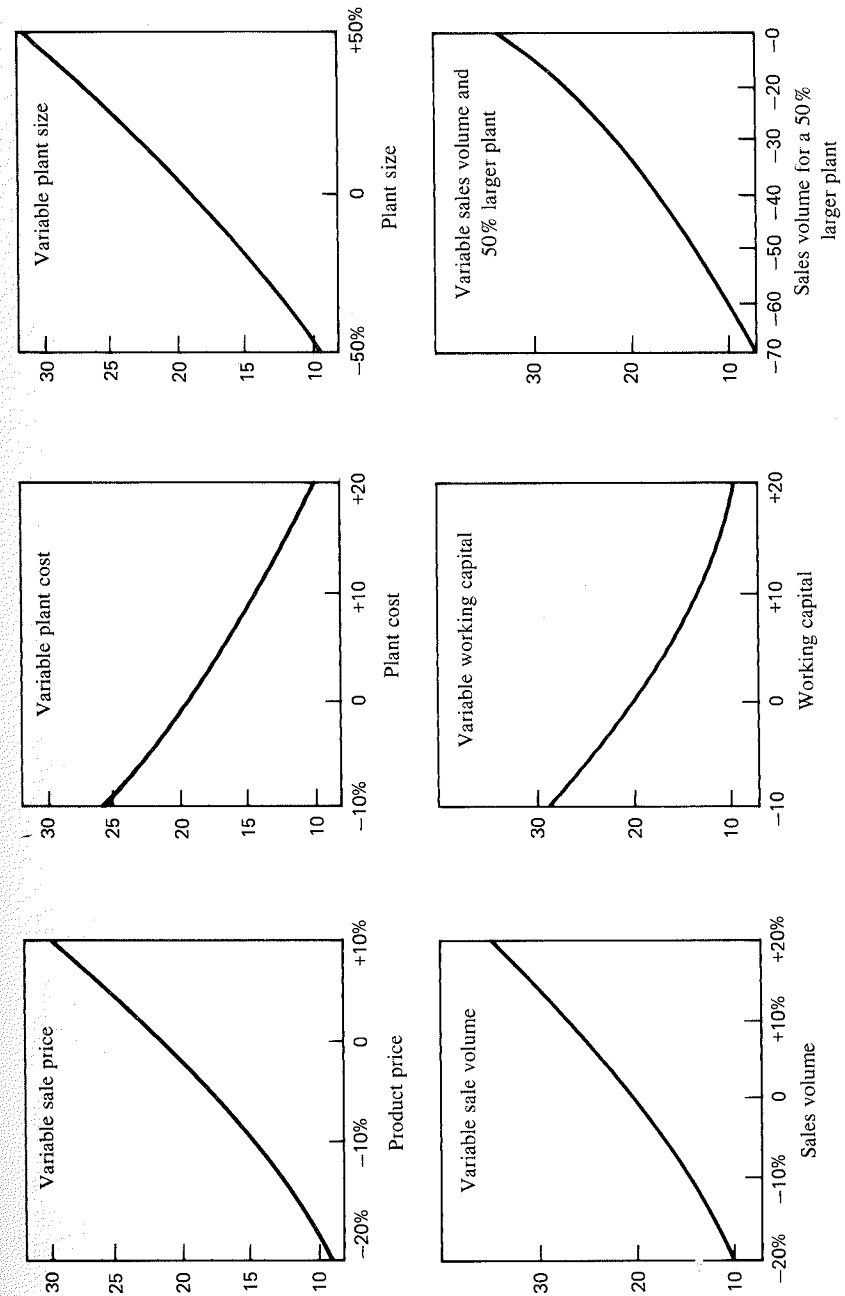


Figure 6-2. Examples of DCF sensitivity analysis.

cost, or perhaps \$11.2 MM $\times$ 0.15 = \$1.68 MM, and the depreciation by 12% (perhaps to become \$1.12 MM/yr). Care must be taken to consider all of the items that change when making the sensitivity analysis, but shortcut methods such as the above should reduce the time and effort required in preliminary analyses. Of course, much more detail and firm data would be required for more definitive analyses and many more of the individual cost components would change.

EFFECT OF BORROWED CAPITAL; LEVERAGE

The leverage on profitability resulting from borrowing part of the capital required for a project is frequently an essential part of new major capital expenditures. However, even before being discussed in more detail, it should be cautioned that generally the design engineer should not consider leverage in his evaluations. Management can and will factor it into their projections, and thus more fully appreciate the risks involved as well as the gain with this maneuvering of the company's cash flow and debt position.

Most companies have the capability of borrowing some, or even a large fraction of the funds required for any new project. Consequently, the company money invested in a project is almost always less than the total, and if the project realizes an adequate profit, the return on the company's money is leveraged, or greatly increased. Furthermore, since interest paid on a loan is tax deductible, and inflation reduces the value of the funds repaid, not all of the loan's cost is actually a drain on the project (Barna 1984).

For instance, consider a \$10,000,000 capital cost project (including \$1,000,000 working capital) with several different potential amounts borrowed at 10% interest and depreciation, and \$1,000,000 after-tax profit for the no-debt case. Any debt will be repaid at the end of the 10-year project life. The results are shown in Table 6-6.

From this simplified example it is seen that the more capital borrowed, the greater the profitability on the company funds, but since bankers generally dislike greater than about a 0.5 debt to equity ratio for a company, the middle case is probably somewhat more typical of the average project, although each company's current debt and policy on this matter varies widely.

In addition to increasing the ROI and DCF, borrowing naturally allows many more projects to be implemented, providing greater growth. Thus, it has become a somewhat necessary and constructive tool for most progressive managements. Remember, however, that the company is usually at risk for the entire amount of capital involved in the project, so the process engineer should generally ignore debt in his evaluations unless directly told not to. The profitability on a nondebt basis should be the basic decision making consideration and then management can analyze the entire corporate position before deciding upon debt.

Table 6-6.
Example of Leverage upon DCF and ROI.

	Entirely Company Capital	*\$3,333,000 Borrowed*	*\$5,000,000 Borrowed*
Company capital, \$	10,000,000	6,667,000	5,000,000
Interest on loan, \$/yr	0	333,000	500,000
Interest deduction from after-tax profit at 40% tax, \$/yr	0	200,000	300,000
After-tax profit, \$/yr	1,000,000	800,000	700,000
Cash flow, \$/yr	1,900,000	1,700,000	1,600,000
Payout period on company capital, yrs	4.7	3.3	2.5
Rate of return on company capital, %	10	12.0	14.0
DCF (annual compounding) on company capital, %	14.4	20.4	27.1
Debt to equity ratio	0	0.50	1.00

An interesting example of how the use of debt can be both good and bad is seen from a recent analysis of farm profitability, as shown in Table 6-7. For the first period shown, the greater the use of debt, the greater the farmer prospered, and there was a rush to more borrowing, or high debt to equity ratios. Then interest rates increased, farm prices dropped, and land values (their principal equity) dramatically decreased. This resulted in greatly decreased profits, and caused a major farm crisis for most of the country. Those farmers with reasonable debt to equity ratios were not seriously effected. A comparable

Table 6-7.
Results of Alternative Farm Financial Strategies over the Periods 1972–1977 and 1979–1983

Initial Debt to Equity Ratio, %	*Results After 5 Years of Operation: Change in Net Worth*	*Average Annual Rate of Return on Equity*
	1972–1977	
25	+13%	+20%
75	+20%	+54%
	1979–1983	
25	+3%	+2%
75	−35%	−9%

Table 6-8. Effect of Leverage with Decreasing Income. (Example as Table 6-6, but with Variable Income.)

	Entirely Company Capital	*$3,333,000 Borrowed*	*$5,000,000 Borrowed*
Company capital, $	10,000,000	6,667,000	5,000,000
a. Profit on sales, one-half normal[a]	500,000	300,000	200,000
After-tax profit, $/yr			
ROI, % (on company funds)	5	4.5	4.0
DCF, % (on company funds)	6.64	7.29	8.55
b. Profit on sales, zero[a]			
After tax profit, $/yr	0	−333,000	−500,000
ROI, % (on company funds)	0	−5.0	−10.0
DCF, % (on company funds)	0	0	0

a. For the entirely company capital case.

situation can exist within the chemical and process industries at any time as indicated in the example of Table 6-8.

PRODUCTION RATE; BREAK-EVEN POINT

A second form of sensitivity analysis is required to consider the economics of operating a plant at less than full capacity. During the start-up period (which may last for years in exceptional cases), other periods of operating difficulty, and with decreased sales the plant will only operate at partial capacity. The industry average operating percentage for all products in the mid-1980s was somewhat below 80%, and in some cases it takes many years to build up to even this sales capacity. Predicting the effect of reduced operation leads to a very important secondary point of information, the break-even capacity for the plant. This is the amount of production that it takes to just pay all of the bills, and neither make a profit nor take a loss. Cash flow break-even is when all costs, excluding depreciation, are just equal to the sales realization. With sales below this number there is an actual out-of-pocket loss for the operation.

Such calculations require holding all facets of operating cost constant (as if at full production) except for raw materials, utilities, and sales expenses. These items theoretically vary in direct proportion to the production rate, but in point of fact utilities and sales expense may not change much, and in such cases should be separately analyzed. If sales are made with company staff, the number of salesmen may not decrease with decreasing sales (and might even increase). Likewise, standby utility charges may cut into the decreased useage savings, and reduced production may decrease the efficiency of raw material conversion. On the other hand, some of the other manufacturing cost items should also decrease with reduced production, such as shared or even directly reduced

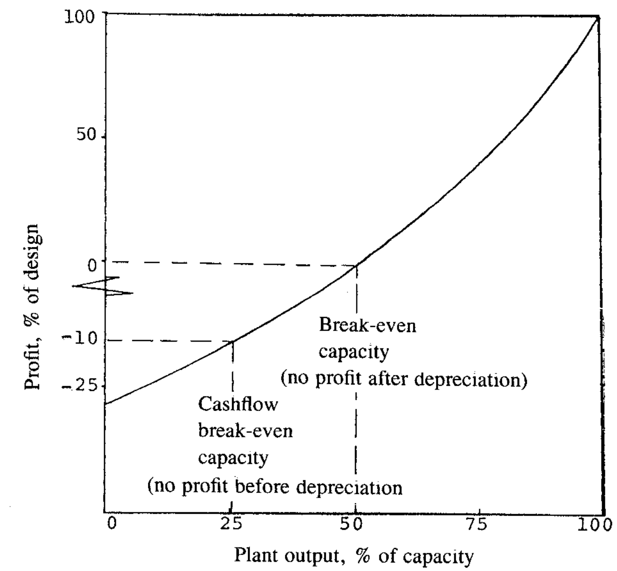


Figure 6-3. Example of a project break-even curve.

manpower. The net result of such calculations are usually shown in a break-even graph like Figure 6-3.

COMPARISON OF PROJECT EVALUATION METHODS

Several project evaluation methods have now been discussed: discounted cash flow (DCF or IRR), present worth (PW or PV), rate of return (ROI), payback period, and capitalized cost. Three of these utilize the time value of money, and all are useful. Each method allows a comparison of projects: DCF and PW based upon their present value, assuming for PW a desired return (interest) rate and discounting all of the cash flows with it. This avoids trial and error calculations, but provides two numbers for the comparison, the assumed interest rate and the net present worth. In some cases it is the simpler method to work with, and of course, it is obtained as the intermediate total for each DCF trial at an assumed interest rate. DCF calculates the equivalent effective interest rate of the project. Capitalized cost is an alternative method for considering the time value of money for the comparison of different equipment purchases.

It has also been suggested that simple rate of return or return on investment (ROI) and payback period calculations be performed on every project no matter how complex, since these are very basic and easily understood project measurements. For simple and small projects they may be all that is required.

Finally, there are numerous other economic comparison methods, each with some individual advantages or virtues, and many excellent project evaluation books (Allen 1980; Clark and Lorenzoni 1985; Holland et al. 1974; Kurtz 1984; Newman 1983; Riggs 1982; United Nations 1972) and articles (Berkoff et al 1986; Carlson 1984; Pinches 1984; Powell 1985; Shinnar and Dressler 1986; Ward 1986) frequently are published. However, the above evaluation methods have become the major ones in common use, so the other more complex or statistical (based upon uncertainty considerations) procedures will not be considered here. Once the simple ROI, payback, and DCF concept of the time value of money are understood, any other method can be quickly learned if needed at a later date.

REFERENCES

Allen, Derek H. 1980. *A Guide to Economic Evaluation of Projects.* Rugby, Warks, England: Institute of Chemical Engineering.

Barna, Bruce A. 1984. Leverage, risk and project economics. *Chemtech* (May):295–297.

Berkoff, Charles E. et al. 1986. The process profile. *Chemtech* (Sept.):552–559.

Carlson, Rodney O. 1984. Avoiding the game in project evaluation. *Chemical Engineering Progress* (Nov.):11–13.

Clark, Forrest D., and A. B. Lorenzoni 1985. *Applied Cost Engineering.* Marcel Dekker, New York.

Holland, F. A., F. A. Watson, and J. K. Wilkinson. 1974. *Introduction to Process Economics.* John Wiley & Sons, London.

Horwitz, Benjamin A. 1980. The mathematics of discounted cash flow analysis. *Chemical Engineering* (May 19):169–174.

Kurtz, Max. 1984. *Handbook of Engineering Economics.* McGraw-Hill, New York.

Leibson, Irving, and Charles A. Trischman, Jr. 1971. When and how to apply discounted cash flow and present worth. *Chemical Engineering* (Dec.).

Neal, Gordon W. 1982. Project evaluation. *Chemical Engineering* (Sept. 6; Nov. 1; Dec. 22).

Newman, D. G. 1983. *Engineering Economic Analysis.* Engineering Press, San Jose, CA.

Pinches, George E. 1984. Effective use of capital budgeting techniques. *Chemical Engineering Progress* (Nov.):11–13.

Powell, Terence E. 1985. Project evaluation. *Chemical Engineering* (Nov. 11):187–194.

Riggs, J. L. 1982. *Essentials of Engineering Economics.* McGraw-Hill, New York.

Ruben, Allen G. 1984. Choose process units via present worth index. *Chemical Engineering* (Oct. 15).

Shinnar, Reuel, and Ofer Dressler 1986. Return on investment; myth and reality. *Chemtech* (Jan.):30–41.

United Nations Publication. 1972. *Guidelines for Project Evaluation.*

Ward, Thomas J. 1986. Profitability analysis. *AIChE Plant Design and Cost Engineering* 1:22–32.

7

ECONOMY OF THE CHEMICAL INDUSTRY

The chemical industry has been a major component of the world's manufacturing activities since the early days of the industrial revolution. The Leblanc process for making soda ash (Na_2CO_3, initially used to aid in the bleaching of cloth for the emerging textile industry) from salt and sulfuric acid in 1791 was truly the start of the large-scale synthetic production of chemicals. Sulfuric acid was being produced commercially before then, but in many small facilities, and it was not until later that it became a tonnage product with the advent of the Chamber process. These two commodities became essential to the then-infant industrialization of the world's economy, and the chemical industry has been a large, vital, and prosperous force ever since.

INDUSTRY STATISTICS

The production of chemicals has become so widespread, and practiced by so many other industries that it is hard to define exactly which companies are part of the "chemical industry." For this purpose there are two broad categories considered by the U. S. Commerce Department in gathering industrial statistics that shall be used in this book.

Chemical Process Industries (CPI)

This grouping of industries includes chemicals and allied products where chemical production, processing, or processing equipment is employed; pulp, paper, and paperboard; the processing of petroleum and natural gas; rubber and plastic products; products of stone, clay, and glass; primary nonferrous metals; sugar refining, wet corn milling, and similar processing of foods and beverages; textile dyeing and finishing; leather tanning; dry cell and storage batteries; semiconductor materials; carbon and graphite products; and hard-surface floor coverings. It is a very large segment of U. S. industry, with the value of its shipments in 1986 and 1988 (est.) being 16.6 and 17.7%, respectively, of the total U. S. gross national product. The health and vigor of this industry is quite obviously a major factor in the U. S. economy.

The Chemical Industry

This grouping of industries is a part of the chemical process industries, but only includes companies with a major chemical production: pharmaceuticals, detergents, and other sanitizing and polishing preparations, toiletries and cosmetics, paints and coatings, fertilizers and pesticides, printing inks, carbon black, adhesives, additives and catalysts, as well as industrial chemicals and synthetic materials. For 1986 and 1988 (est.) the chemical industry was only 35.4 and 33.9%, respectively, the size of chemical process industries, and 5.9 and 6.0%, respectively, of the total U. S. gross national product. This is still a reasonably large industrial group with about $230 billion in sales, 580 thousand production workers, and disproportionately large in such areas as maintaining a positive balance of trade for the United States in the world's markets. Some of the statistical data for these industry groupings and the total U. S. production are given in Table 7-1.

Industry Data

Largest Companies. Very few chemical manufacturing companies now produce only chemicals, so company size can be measured by either the company's total business or the size of its chemical operations alone. Using the later criteria, Table 7-2 lists the 50 largest companies for 1986. Table 7-3 lists the 15 largest of these companies on the basis of their total sales (of all commodities) for the same period. It is seen that the top 50 companies in chemical sales only averaged 53.7% of their total sales in chemicals, and that they consisted of a wide range (11) of other industrial groups than chemicals and petroleum. It is also seen that 10 of the country's 50 largest chemical producers are in the petroleum business, and about half of the country's largest companies produce at least some chemicals.

Financial Analyses. Some additional financial data for a selected group of the larger chemical companies with a relatively high percentage of chemical sales in 1986 are given in Table 7-4. Figures 7-1 to 7-10 present much of the same data, but as industry averages and in a graphical form. It is seen that as an industry the profit margin determined either as after-tax income as a percent of sales or of stockholder equity is relatively low. About one-third of their total assets have been obtained by borrowing (a debt to equity ratio of 0.5), and their yearly sales value is about equal to their total (depreciated) assets. Their plants are about 50% depreciated, and in the mid-1980s only ran at about 77% of capacity. The industry manpower requirements (per unit of investment or sales)

Table 7-1
General Data on the U.S. Economy, Chemical and Chemical Process Industries

	1986	*1987*	*1988 est.*
The U. S. Economy			
Gross national product adjusted for inflation (billions of 1982 dollars)	$3,679.0	$3,814.8	$3,882.3
Consumption expenditures (billions of 1982 dollars)	$2,412.8	$2,498.2	$2,528.8
Industrial production index (1977 average = 100)	125.0	129.4	131.9
Corporate cash flow, after taxes (billion dollars)	$377.5	$369.5	$358.4
Merchandise trade deficit (billion dollars)	$145.3	$152.0	$134.6
The Chemical Process Industries			
Value of shipments (billion dollars)	$611.8	$625.1	$687.2
Production index (1977 average = 100)	126.7	131.6	135.5
Average operating rate (percentage of capacity)	86.7%	85.3	83.5
Capital spending (billion dollars)	$43.7	$45.1	$52.0
The Chemical Industry			
Value of shipments (billion dollars)	$216.8	$214.6	$233.2
Production index (1977 average = 100)	133.5	139.7	144.4
Average operating rate (percentage of capacity)	76.9%	81.1	80.2
Producers' price index (1967 average = 100)	299.6	336.2	351.7
Capital spending (billion dollars)	$16.9	$16.6	$19.3
Production workers (thousands)	571.0	568.0	580.0
Workers' average earnings (dollars/hour)	$11.96	$12.38	$12.87
Chemical exports (billion dollars)	$22.9	$26.0	$29.3
Chemical imports (billion dollars)	$15.5	$16.7	$18.2

Source: *Chemical Week* 1988; 1987. Excerpted by special permission from *Chemical Week*, January 6–13, 1988 and January 7–14, 1987. Copyright © 1987 and 1988, by McGraw-Hill, Inc., New York.

Table 7-2
50 Largest Chemical Producers in 1986 (Based upon Their Chemical Sales Only)

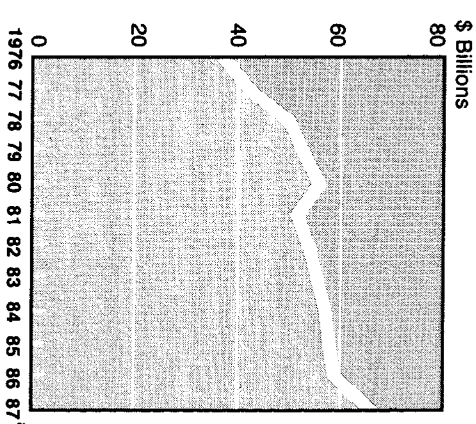
Rank 1986	*Chemical sales 1986, $ millions*	*Chemical sales as % of total sales*	*Industry classification*	*Chemical operating profits, $ millions*	*Chemical operating profits as % of total operating profits*	*Identifiable chemical assets, $ millions*	*Chemical assets as % of total assets*
1 Du Pont	$11,839	43.6%	Diversified	$1764	52.1%	$8739	36.2%
2 Dow Chemical	8,863	79.8	Basic chemicals	978	76.1	8139	66.5
3 Exxon	6,079	8.1	Petroleum	817	9.9	5508	7.9
4 Union Carbide	5,001	78.8	Basic chemicals	748	94.6	5047	74.3
5 Atlantic Richfield	4,915	32.8	Petroleum	398	64.7	2085	9.7
6 Monsanto	4,701	68.3	Basic chemicals	896	141.1	3860	46.7
7 BASF Wyandotte	3,600	100.0	Basic chemicals	na	na	na	na
8 Shell Oil	3,292	19.6	Petroleum	648	35.1	3447	13.1
9 Amoco	2,928	14.5	Petroleum	467	23.0	2545	11.0
10 Celanese	2,891	100.0	Basic chemicals	258	100.0	na	na
11 Allied-Signal	2,819	23.9	Diversified	346	32.9	2161	19.2
12 W. R. Grace	2,492	66.9	Specialty chemicals	285	1187.5	1633	53.1
13 Mobil	2,391	4.8	Petroleum	205	4.5	2103	5.7
14 Eastman Kodak	2,379	20.6	Photo equipment	227	31.4	2266	17.6
15 Chevron	2,378	9.1	Petroleum	147	20.6	3207	9.3
16 General Electric	2,331	6.3	Diversified	424	9.8	3602	10.4
17 Occidental Petroleum	2,088	13.0	Petroleum	176	36.2	2393	13.7
18 Rohm & Haas	2,067	100.0	Basic chemicals	280	100.0	1470	100.0
19 American Cyanamid	1,821	47.7	Basic chemicals	135	38.3	1275	49.6
20 Air Products	1,798	90.7	Basic chemicals	363	129.4	2173	80.3
21 Mobay	1,710	100.0	Basic chemicals	150	100.0	na	na
22 Hercules	1,709	65.4	Basic chemicals	101	49.5	1464	71.6
23 Phillips Petroleum	1,698	17.0	Petroleum	299	30.3	1053	8.5
24 Borden	1,638	32.7	Dairy products	176	35.3	1399	40.3
25 Ciba-Gelgy	1,490	61.3	Specialty chemicals	na	na	na	na
26 Ashland Oil	1,477	20.3	Petroleum	71	15.0	527	13.9
27 B. F. Goodrich	1,458	57.1	Rubber products	134	79.9	1199	82.5
28 FMC	1,399	46.6	Machinery	224	71.6	1344	50.0
29 American Hoechst	1,331	77.8	Basic chemicals	na	na	na	na
30 Texaco	1,279	4.0	Petroleum	91	3.9	1114	3.2
31 Ethyl	1,272	57.0	Basic chemicals	247	69.0	829	48.4
32 Olin	1,114	65.3	Basic chemicals	80	50.3	840	59.6
33 National Distillers	1,087	62.8	Alcoholic beverages	124	67.0	1385	47.7
34 Dow Corning	1,085	100.0	Specialty chemicals	111	100.0	na	na
35 International Minerals	1,077	87.1	Agrochemicals	35	57.1	2042	84.1
36 National Starch	1,064	100.0	Specialty chemicals	140	100.0	743	100.0
37 Unocal Corp.	1,056	12.6	Petroleum	46	26.1	722	7.1
38 Borg-Warner	1,043	30.9	Auto equipment	153	43.8	562	23.6
39 Lubrizol	889	91.0	Specialty chemicals	140	108.6	589	67.1
40 PPG Industries	843	18.0	Glass products	103	14.8	1185	25.5
41 Aluminum Co. of America	840	18.0	Nonferrous metals	na	na	na	na
42 Pennwalt	777	70.1	Basic chemicals	93	78.8	649	73.8
43 Cabot	769	58.7	Specialty metals	138	69.3	494	32.7
44 CF Industries	766	100.0	Agrochemicals	−45	def	842	100.0
45 Reichhold Chemicals	766	100.0	Basic chemicals	53	100.0	458	100.0
46 Aristech	751	100.0	Basic chemicals	98	100.0	na	na
47 Naico Chemical	736	100.0	Specialty chemicals	108	100.0	586	100.0
48 NL Industries	734	57.2	Petroleum services	na	na	na	na
49 Eli Lilly	699	18.8	Drugs	53	5.8	766	16.7
50 Engelhard	666	29.1	Specialty metals	77	80.5	607	58.2
Average		53.7			56.6		44.8

Source: *Chemical and Engineering News* 1987*e*. Reprinted with permission from Chemical and Engineering News, June 8, 1987 and April 13, 1987, © 1987, American Chemical Society; na = not available; − or def = deficit.

Table 7-3
15 Largest U. S. Companies Producing Chemicals in 1986.

	Rank in					Overall Rate of Return as % of		
Company	*Size*	*Income*	*Chem. Prod.*	*Sales, \$ Millions*	*Net Income, \$ Millions*	*Sales*	*Assets*	*Stock Holders Equity*
Exxon	2	1	3	69,888	5,360	7.7	7.7	16.7
Mobil	5	8	15	44,866	1,407	3.1	3.6	9.2
General Electric	6	5	14	35,211	2,492	7.1	7.2	15.5
Texaco	8	17	31	31,613	725	2.3	2.1	5.3
E. I. Du Pont	9	6	1	27,148	1,538	5.7	5.8	11.5
Chevron	10	18	11	24,351	715	2.9	2.1	4.6
Amoco	13	15	9	18,281	747	4.1	3.2	6.6
Shell Oil	15	12	7	16,833	883	5.3	3.4	6.2
Proctor & Gamble	18	19	—	15,439	709	4.6	5.4	11.9
Occidental Petro.	19	96	22	15,344	181	1.2	1.0	3.4
Atlantic Richfield	20	25	6	14,586	615	4.2	2.9	11.7
USX	22	476	32	14,000	(8,833)	—	—	—
Allied Signal	25	27	17	11,794	605	5.1	5.4	15.6
Eastman Kodak	26	50	13	11,550	374	3.2	2.9	5.9
Dow Chemical	27	16	2	11,113	732	6.6	6.0	14.2
					Average	4.2	3.9	9.3

Source: *Fortune* 1987. Courtesy of Fortune, April 27, 1987,
( ) = loss.



Source: Storck 1988. Reprinted with permission from *Chemical and Engineering News*, February 22, 1988. © 1988, American Chemical Society.

Figure 7-1. Annual sales.[a]

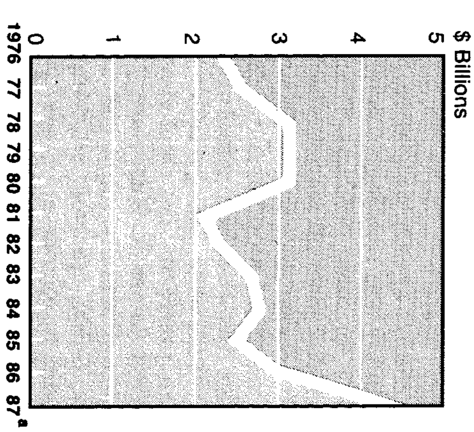


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Figure 7-2. Annual earnings.[a]

[a]30 major chemical companies

Table 7-4.
1986 Financial Analysis for Various of the Larger Chemical Companies.

Chemical Sales, % of Total	Rel. Size in Chem.			Profit Margin[a]	Return on Investment[b]	Debt as % Debt Plus Equity	% Total Sales Abroad[c]	% Total Assets Abroad[d]	Sales per Employee[e]	Dividends As % of Net Income	Capital Spending[f] As % of Sales	Capital Spending[f] As % of Net Plant	R & D As % of Sales	Sales As % of Assets	Net Plant As % of Gross Plant
90.7	20	Air Products	1986	6.9%	3.3%	38.9%	19.5%	25.0%	$119.4	32.9%	18.5%	20.0%	3.1%	73.3%	53.2%
			1985	7.8	3.8	30.9	17.3	18.8	97.8	26.6	21.4	22.0	2.8	70.5	56.1
47.7	19	American	1986	5.3	4.4	25.4	33.6	24.2	110.7	43.6	6.9	20.7	7.3	104.1	47.4
		Cyanamid	1985	3.4	2.7	25.8	29.6	21.9	97.1	76.0	5.7	18.0	7.1	103.9	44.3
58.7	43	Cabot	1986	5.6	4.1	41.9	38.4	16.9	198.5	35.4	5.5	11.3	2.6	86.8	53.0
			1985	5.1	4.1	37.9	28.8	15.7	182.8	41.4	10.1	22.7	2.3	88.3	56.3
79.8	2	Dow Chemical	1986	6.7	4.3	39.7	53.5	49.4	216.6	49.1	8.0	16.6	5.4	90.8	42.1
			1985	0.5	0.4	40.0	54.8	46.6	216.9	587.9	7.0	15.7	4.7	97.5	43.2
57.0	31	Ethyl	1986	11.3	10.7	30.2	19.6	8.7	150.4	24.0	8.5	22.5	3.0	92.1	49.3
			1985	7.6	7.5	33.6	28.3	9.2	147.3	31.7	5.8	16.1	3.0	99.4	50.6
57.1	27	B. F. Goodrich	1986	0.5	0.6	34.4	19.1	14.3	214.6	289.9	5.6	16.9	2.2	140.3	58.3
			1985	0.3	0.3	41.7	15.4	15.1	122.2	374.5	6.3	19.4	2.0	141.6	55.1
66.9	12	W. R. Grace	1986	1.2	0.9	45.6	32.3	16.9	90.0	263.0	5.3	12.6	2.5	90.9	48.3
			1985	2.5	1.9	38.8	25.4	16.4	58.3	111.7	6.7	13.4	1.8	95.8	57.1
65.4	22	Hercules	1986	8.7	6.8	24.3	21.1	15.4	104.1	41.4	9.8	22.3	2.7	89.7	51.4
			1985	5.1	4.4	26.5	25.0	14.9	101.7	64.9	9.1	23.4	2.9	97.3	50.1
87.1	35	International	1986	def	def	48.1	13.2	9.7	84.7	def	8.0	7.5	2.8	48.5	57.7
		Minerals	1985	7.3	4.4	23.9	17.3	8.3	187.0	59.5	7.1	10.3	na	83.1	52.3
91.0	39	Lubrizol	1986	8.0	7.1	8.4	51.6	31.8	203.4	59.3	4.1	14.0	5.2	111.3	45.0
			1985	6.7	5.7	12.4	47.7	29.5	173.7	78.1	4.4	13.6	4.8	105.7	48.3
68.3	6	Monsanto	1986	6.3	4.7	30.1	32.6	21.2	133.1	46.0	7.6	17.9	8.7	83.2	46.0
			1985	2.7	1.8	38.0	28.5	18.8	120.3	102.7	9.6	21.3	8.1	76.0	44.4
62.8	33	National	1986	3.2	1.8	37.6	na	na	na	136.1	5.9	7.3	na	59.6	71.9
		Distillers	1985	3.4	3.3	23.2	na	na	na	96.9	3.3	8.5	na	113.3	60.0
65.3	32	Ollin	1986	4.4	3.0	29.7	6.1	8.6	129.3	45.6	7.5	17.8	3.3	110.5	37.6
			1985	2.3	1.6	34.0	7.2	10.3	117.5	86.9	8.8	21.5	3.0	109.6	39.3
18.0	40	Pennwalt	1986	4.7	3.9	33.6	23.5	21.1	115.4	68.0	4.9	12.5	4.1	111.1	50.7
			1985	1.1	0.9	30.1	19.8	18.3	102.4	319.6	8.9	20.7	3.9	105.7	53.3
70.1	42	PPG Industries	1986	6.8	5.1	32.8	25.5	27.4	128.4	35.3	7.6	13.4	4.3	101.0	58.2
			1985	7.0	5.5	35.4	21.5	23.7	115.9	36.4	10.4	18.2	4.0	106.4	59.3
100.0	18	Rohm & Haas	1986	6.7	5.4	21.7	38.7	28.4	171.4	39.1	8.7	27.6	6.4	112.2	39.8
			1985	6.9	5.8	20.7	32.5	26.6	173.2	34.8	7.8	27.4	6.0	118.3	38.7
78.8	4	Union Carbide	1986	2.1	1.2	75.3	28.6	33.2	124.2	110.8	8.4	12.0	2.4	82.5	51.2
			1985	2.3	1.4	30.3	29.2	28.9	98.4	113.4	7.2	11.2	3.1	85.1	54.2
40.1	61	Witco	1986	4.8	5.5	17.0	16.7	15.8	169.4	35.9	4.4	16.3	1.6	165.3	47.8
			1985	3.9	4.3	24.7	14.0	13.5	na	38.4	4.9	19.7	na	178.8	39.3
66.9		Median 1986		5.5%	4.2%	33.2%	25.5%	21.1%	$129.3	44.5%	7.6%	16.5%	3.1%	91.5%	50.0%
		Median 1985		3.7%	3.6%	30.6%	25.2%	18.6%	$118.9	77.1%	7.2%	16.8%	3.1%	101.7%	52.8%

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Notes: Net income is from continuing operations, excluding extraordinary and nonrecurring items where possible.

a. Net income as a percentage of sales.

b. Net income as a percentage of current assets plus gross plant.

c. Consolidated sales only.

d. Foreign identifiable assets as a percentage of total assets.

e. Thousands of dollars.

f. Actual spending on construction of new facilities and purchase of new equipment and land in consolidated businesses

na = not available

def = deficit

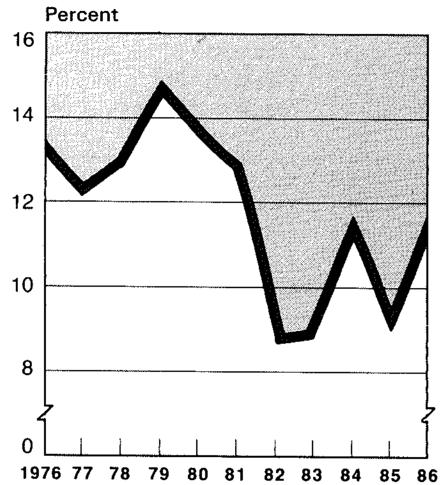

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Figure 7-3. Return on equity.[a]

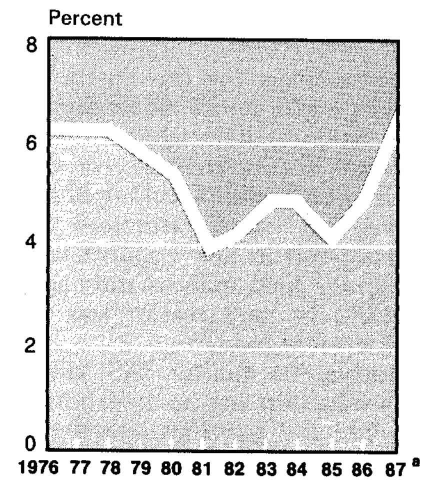

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Figure 7-4. Annual profit margins.[a]
(After-tax earnings as % of sales.)

[a]30 major chemical companies

are quite low. Capital spending has only averaged slightly higher than the industry's depreciation rate.

Industry Products. The chemical process industries make an amazingly large variety of products, with the 50 largest basic chemicals on a tonnage basis, and the major plastics and fibers listed in Tables 7-5 and 7-6. The total output for most commodities has been slowly rising as shown in Figure 7-5, with modest annual growth rates. It is seen that the production of inorganic chemicals has risen about 1% per year since 1976, even though declining about 1.5% during the mid-1980s. Plastics have increased 5.5%, synthetic fibers 1.3%, and all organics 2.9% during the mid-1970s to mid-1980s.

All of these factors show the chemical industry to be very large, with generally slowly rising sales, and steady or declining profits until 1986. Its reinvestment in new capital equipment has been modest (Figures 7-7 and 7-8), its environmental spending (Figure 7-11) heavy, and its research and development (R & D) spending (Figures 7-4 and 7-5; Tables 7-9 and 7-4) not very aggres-

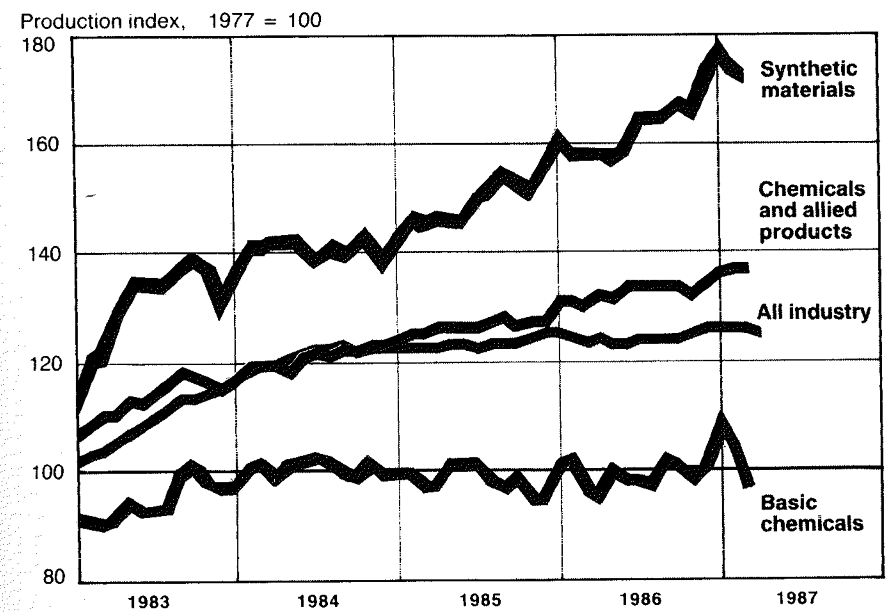

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Figure 7-5. Relative yearly sales.

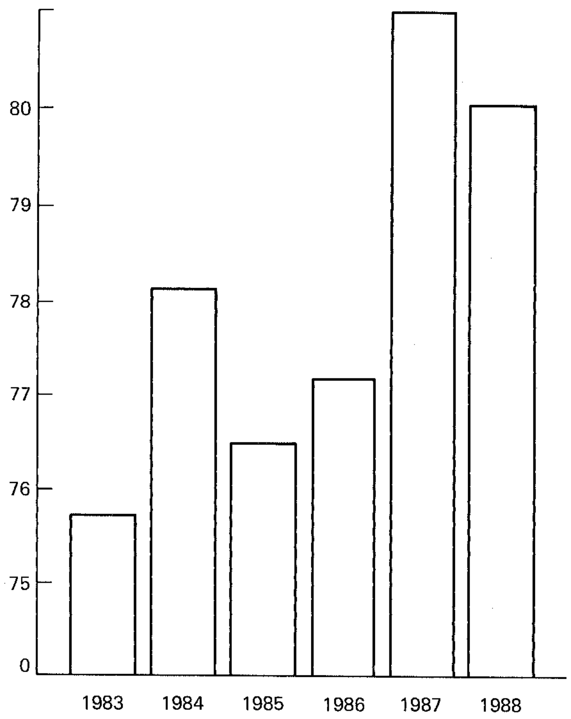

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Figure 7-6. U. S. chemical industry average operating rate.

sive, at least compared to its foreign competition. It has become a large and diversified, but mature industry that still has an excellent positive trade balance (Figures 7-8, 7-9, and 7-10) (export sales minus import sales), but is increasingly having difficulty meeting worldwide competition. It would appear to be in the decision period of its history between allowing a conservative, nontechnical or long-range thinking management letting it become slowly more obsolete and noncompetitive (like the steel industry), or continuing to be a more aggressive industry investing in new innovations, processes, and equipment as a large net exporter. This decision point will be examined in more detail in the following sections.

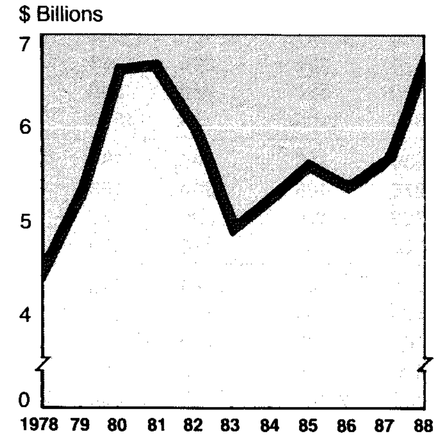

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Figure 7-7. Capital spending,[a] $.

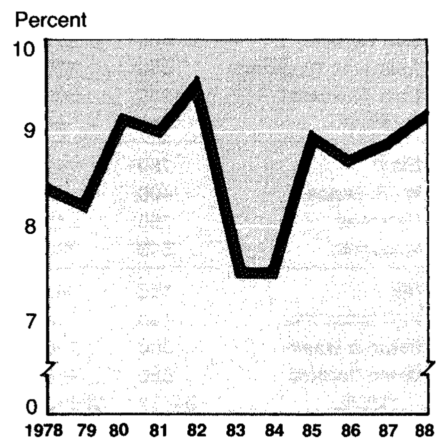

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Figure 7-8. Capital spending,[a] % of sales.

[a]12 major chemical companies

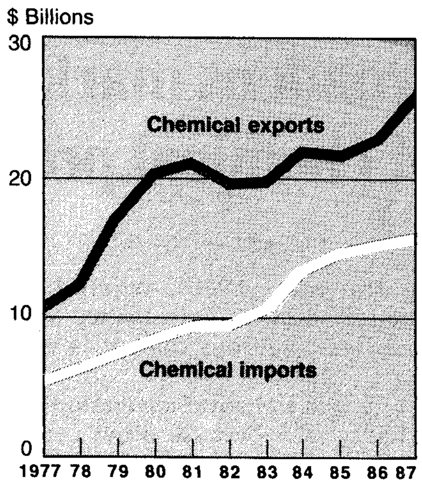

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Figure 7-9. U. S. chemical exports, imports, $.

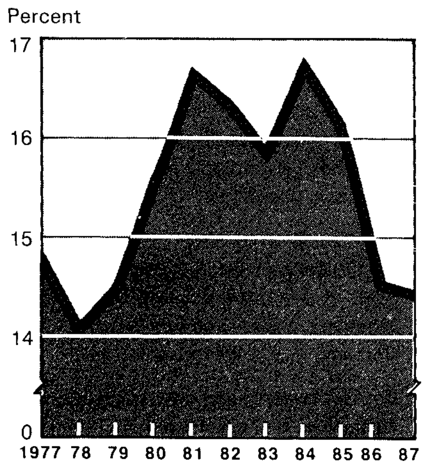

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Figure 7-10. U. S. chemical exports, % of world total.

PROFITABILITY

The U. S. chemical industry was founded, and continued all through its early years on the basis of: (a) a strong and innovative technical capability, and (b) a technical and venturesome management that was willing to invest in sound new research and development opportunities. Companies such as Dow Chemical, Monsanto, and du Pont have continuously had some of the strongest and most brilliant research and development and engineering groups in the world, and their management has in the past funded and brought into production one major new development after another. All of this made the U.S. chemical industry in its pre-1960 days a very high-profit, dynamically growing industry that generally dominated world chemical production, if not by export quantities alone, by licensing its processes and serving as the world's role model for most chemical production.

Since the mid-1950s, however, this has slowly changed. Figures 7-12 and 7-13 show the decline in the rate of return, based upon constant dollar values (corrected for inflation) and a pseudo-DCF measurement. The numbers from 1980 through 1986 indicate a slight further decline to an industry average pseudo-DCF of only about 4.3%. It is seen that the return on investment was very high following WWII because of the technical and managerial excellence noted above, and since there was only limited competition. This began to change during the 1950s as new production was built, largely with U. S. know-how and foreign aid, in Europe and Japan. These plants were new and employed the most modern technology, providing the initial competition for the U. S. producers. Some profits fell, but they still stayed comparatively high. This foreign competitive pressure, however, has steadily increased and grown more vigorous over the intervening years.

This brought on the next surge of competition which was from other U. S. companies, predominately the lower profit oil industry in the 1960s and 1970s, who had surplus funds to invest, but were generally less well (and nontechnically) managed. Their new plants were often very large, and resulted in many commodities having excess production capacity over the market demand, which reduced industry operating rates and profits. This situation initiated a profound change in the makeup of the chemical industry, for as seen in the current top 50 chemical producers (Table 7-5), the chemical companies started to diversify into other fields, and companies in many other fields became chemical producers. In most cases the newcomers' research and development capability was limited, and the management did not know the chemical business or technology too well. Fewer new research and development projects were conceived, and far fewer were commercialized, which further reduced the overall industry rate of return.

In the mid-1970s the OPEC oil cartel was formed, and energy prices increased as much as 20-fold over a relatively short period of time. This was costly for

Table 7-5
Top 50 Chemicals Produced in the United States

Rank			Billions of lb		Common Units[b]		Average Annual Growth			
1986	1985		1986	1985	1986	1985	1985–86	1984–85	1981–86	1976–86
1	1	Sulfuric acid	73.64	79.30	36,822 tt	39,651 tt	−7.1%	−5.1%	−2.0%	0.5%
2	2	Nitrogen	48.62	47.46	671 bcf	655 bcf	2.4	−0.9	6.5	8.8
3	4	Oxygen	33.03	32.53	399 bcf	393 bcf	1.5	2.1	−1.5	0.4
4	6	Ethylene	32.81	29.85	32,811 mp	29,847 mp	9.9	−4.9	2.2	3.9
5	5	Lime	30.34	31.60	15,172 tt	15,800 tt	−4.0	−1.2	−4.3	−2.3
6	3	Ammonia	28.01	34.64	14,005 tt	17,319 tt	−19.1	3.8	−6.0	−1.8
7	7	Sodium hydroxide	22.01	21.79	11,007 tt	10,893 tt	1.0	−0.2	1.1	0.5
8	9	Chlorine	20.98	20.79	10,489 tt	10,395 tt	0.9	−2.8	−0.5	0.1
9	8	Phosphoric acid	18.41	21.04	9,206 tt	10,518 tt	−12.5	−7.5	−1.6	1.5
10	11	Propylene	17.34	14.89	17,343 mp	14,887 mp	16.5	−4.3	5.2	5.6
11	10	Sodium carbonate	17.20	17.19	8,600 tt	8,597 tt	0.0	1.0	0.8	5.1
12	15	Ethylene dichloride	14.53	12.10	14,529 mp	12,101 mp	20.1	13.0	7.8	6.1
13	12	Nitric acid	13.12	14.73	6,562 tt	7,364 tt	−10.9	−4.7	−6.3	−1.7
14	14	Urea	12.06	13.36	6,029 tt	6,678 tt	−9.7	−10.2	−5.6	4.4
15	13	Ammonium nitrate	11.11	13.55	5,556 tt	6,776 tt	−18.0	−5.2	−8.9	−2.5
16	17	Benzene	10.23	9.39	1,389 mg	1,275 mg	8.9	−3.3	1.2	−0.3
17	20	Ethylbenzene	8.92	7.39	8,915 mp	7,386 mp	20.7	−2.3	2.7	4.4
18	18	Carbon dioxide	8.50	9.25	4,252 tt	4,623 tt	−8.0	1.3	2.3	8.0
19	16	Vinyl chloride	8.42	9.46	8,415 mp	9,463 mp	−11.1	55.5	4.1	4.0
20	19	Styrene	7.84	7.62	7,838 mp	7,622 mp	2.8	−1.1	3.3	2.2
21	21	Terephthalic acid	7.68	6.49	7,684 mp	6,490 mp	18.4	9.8	4.3	0.6
22	27	Methanol	7.33	5.00	7,327 mp	5,003 mp	46.5	−38.9	−3.1	1.6
23	22	Hydrochloric acid	5.97	5.61	2,983 tt	2,807 tt	6.3	2.7	3.0	1.6
24	24	Ethylene oxide	5.94	5.43	5,943 mp	5,430 mp	9.4	−4.7	2.9	3.6
25	22	Formaldehyde (37% basis)	5.89	5.61	5,885 mp	5,606 mp	5.0	−3.6	0.6	0.8
26	26	Toluene[j]	5.82	5.07	802 mg	699 mg	14.7	−4.0	−1.2	−2.2
27	25	Xylene	5.55	5.31	771 mg	738 mg	4.5	−13.6	−2.6	0.7
28	30	Ethylene glycol	4.76	4.18	4,759 mp	4,178 mp	13.9	−13.4	2.8	3.6
29	28	*p*-Xylene	4.67	4.78	4,669 mp	4,779 mp	−2.3	12.1	0.6	4.8
30	29	Ammonium sulfate	4.17	4.19	2,086 tt	2,093 tt	−0.3	1.3	−0.9	0.4
31	31	Cumene	3.70	3.35	3,695 mp	3,345 mp	10.5	−10.9	2.2	3.1
32	32	Acetic acid	2.93	2.90	2,931 mp	2,897 mp	1.2	10.6	−0.9	1.8
33	34	Phenol	2.92	2.78	2,921 mp	2,777 mp	5.2	−3.9	2.5	3.3
34	39	Butadiene	2.59	2.34	2,593 mp	2,340 mp	10.8	−4.6	−2.8	−3.0
34	35	Carbon black	2.59	2.57	2,585 mp	2,571 mp	0.5	−11.1	−1.1	−1.6
36	33	Potash (K_2O basis)	2.58	2.84	1,169 tmt	1,288 tmt	−9.2	−17.6	−11.5	−6.0
37	36	Aluminum sulfate	2.52	2.54	1,258 tt	1,268 tt	−0.8	12.3	−0.6	0.5
38	37	Propylene oxide	2.48	2.40	2,480 mp	2,400 mp	3.3	34.9	6.1	3.1
39	38	Acrylonitrile	2.31	2.35	2,314 mp	2,346 mp	−1.4	5.7	3.0	4.3
40	40	Vinyl acetate	2.25	2.11	2,249 mp	2,112 mp	6.5	4.3	3.0	4.3
41	41	Methyl *tert*-butyl ether	2.24	1.89	2,237 mp	1,891 mp	18.3	37.4	24.1	nm
42	44	Cyclohexane	2.07	1.66	2,071 mp	1,657 mp	25.0	−16.9	2.6	−0.5
43	42	Acetone	1.94	1.79	1,936 mp	1,788 mp	8.3	−4.0	−2.0	0.4
44	43	Titanium dioxide	1.83	1.72	917 tt	860 tt	6.6	3.0	3.8	2.5
45	48	Sodium silicate	1.57	1.44	786 tt	721 tt	9.0	−3.9	0.4	0.5
46	46	Calcium chloride	1.56	1.88	780 tt	940 tt	−17.0	−10.4	−3.2	−4.2
47	45	Sodium sulfate	1.55	1.65	775 tt	827 tt	−6.3	−5.2	−6.9	−4.5
48	47	Adipic acid	1.52	1.45	1,522 mp	1,453 mp	4.7	4.5	2.0	0.0
49	50	Isopropyl alcohol	1.28	1.24	1,275 mp	1,235 mp	3.2	−11.4	−5.2	−4.1
50	49	Sodium tripolyphosphate	1.27	1.25	634 tt	625 tt	1.4	−7.4	−1.8	−1.3
Total organics			188.00	172.16			9.2%	−1.9%	1.8%	2.9%
Total inorganics			350.60	369.56			−5.1%	−2.0%	−1.5%	0.8%
Grand total			538.60	541.72			−0.6%	−2.0%	−0.5%	1.5%

b. tt = thousands of tons, bcf = billions of cubic feet, mp = millions of pounds, mg = millions of gallons, tmt = thousands of metric tons

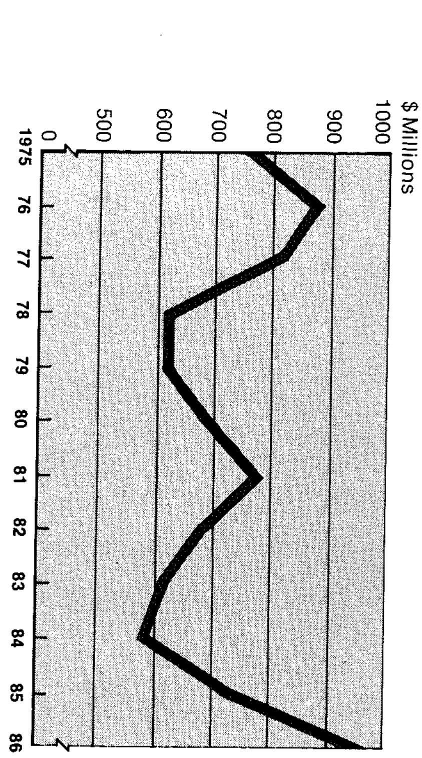

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Figure 7-11. Chemical firms spending on pollution abatement.

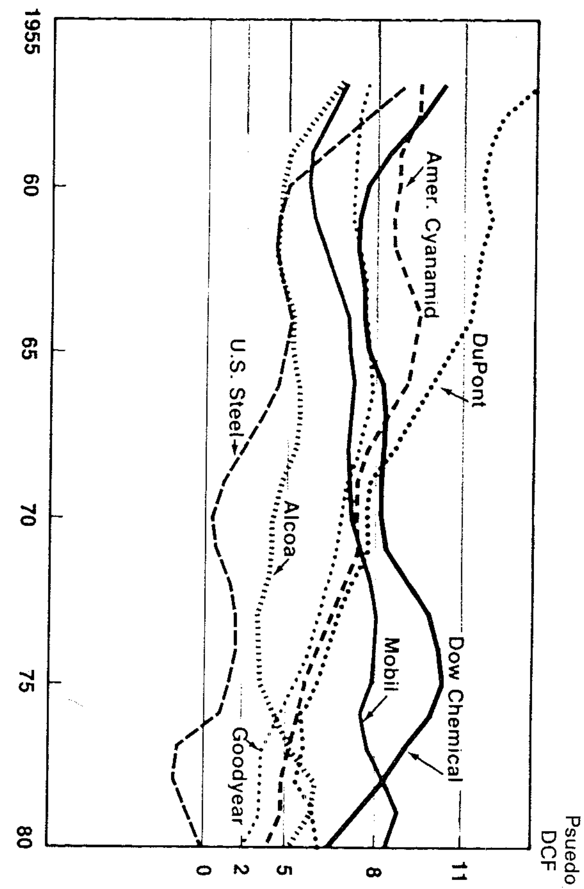

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Figure 7-12. Estimated Psudo DCF returns for various companies.

Table 7-6
Total Polymers Production in the United States

	Billions of lb		*Common Units*					*Average Annual Growth*			
	1986	*1985*	*1986*	*1985*	*1984*	*1981*	*1976*	*1985–86*	*1984–85*	*1981–86*	*1976–86*
PLASTICS			millions of lb								
Thermosetting resins	5.83	5.63	5,834	5,631	5,549	5,010	3,633	3.6%	1.5%	3.1%	4.9%
Phenol, other tar acid resins	2.72	2.62	2,721	2,621	2,502	2,333	1,340	3.8	4.8	3.1	7.3
Urea resins	1.27	1.21	1,271	1,210	1,199	1,165	821	5.0	0.9	1.8	4.5
Polyesters (unsaturated)	1.27	1.22	1,271	1,223	1,232	997	1,042	3.9	−0.7	5.0	2.0
Epoxies (unmodified)	0.40	0.39	398	385	406	336	244	3.4	−5.2	3.4	5.0
Melamine resins	0.17	0.19	173	192	210	179	186	−9.9	−8.6	−0.7	−0.7
Thermoplastic resins	33.57	31.53	33,569	31,525	30,036	25,671	19,481	6.5%	5.0%	5.5%	5.6%
Low-density polyethylene	8.89	8.89	8,888	8,889	8,413	7,693	5,813	0.0	5.7	2.9	4.3
PVC and copolymers	7.26	6.77	7,256	6,772	6,760	5,707	4,716	7.1	0.2	4.9	4.4
High-density polyethylene	7.17	6.67	7,171	6,671	6,085	4,695	3,125	7.5	9.6	8.8	8.7
Polystyrene	4.44	4.05	4,442	4,054	3,838	3,621	3,195	9.6	5.6	4.2	3.4
Polypropylene	5.81	5.14	5,812	5,139	4,940	3,955	2,632	13.1	4.0	8.0	8.2
Total	39.40	37.16	39,403	37,156	35,585	30,681	23,114	6.0%	4.4%	5.1%	5.5%
SYNTHETIC FIBERS			millions of lb								
Cellulosics	0.62	0.56	619	558	589	770	791	10.9%	−5.3%	−4.3%	−2.4%
Rayon	0.40	0.35	404	353	390	509	493	14.4	−9.5	−4.5	−2.0
Acetate	0.22	0.21	215	205	199	261	298	4.9	3.0	−3.8	−3.2
Noncellulosics	7.82	7.56	7,815	7,564	7,473	7,982	6,615	3.3%	1.2%	−0.4%	1.7%
Polyester	3.30	3.34	3,304	3,341	3,392	4,173	3,341	−1.1	−1.5	−4.6	−0.1
Nylon	2.52	2.34	2,515	2,343	2,412	2,333	2,076	7.3	−2.9	1.5	1.9
Olefin	1.38	1.25	1,380	1,249	998	785	577	10.5	25.2	11.9	9.1
Acrylic	0.62	0.63	616	631	671	691	621	− 2.4	−6.0	−2.3	−0.1
Total	8.43	8.12	8,434	8,122	8,062	8,752	7,406	3.8%	0.7%	−0.7%	1.3%
SYNTHETIC RUBBER			thousands of metric tons								
Styrene-butadiene	1.75	1.62	792	735	958	1,032	1,333	7.8	−23.3	−5.2	−5.1
Polybutadiene	0.72	0.73	325	330	359	342	352	−1.5	−8.1	−1.0	−0.8
Ethylene-propylene	0.51	0.47	230	215	215	178	130	7.0	0.0	5.3	5.9
Nitrile	0.13	0.12	58	53	67	66	73	9.4	−20.9	−2.6	−2.3
Other	1.28	1.11	582	505	556	404	416	15.2	−9.2	7.6	3.4
Total	4.38	4.05	1,987	1,838	2,155	2,022	2,304	8.1%	−14.7%	−0.3%	−1.5%

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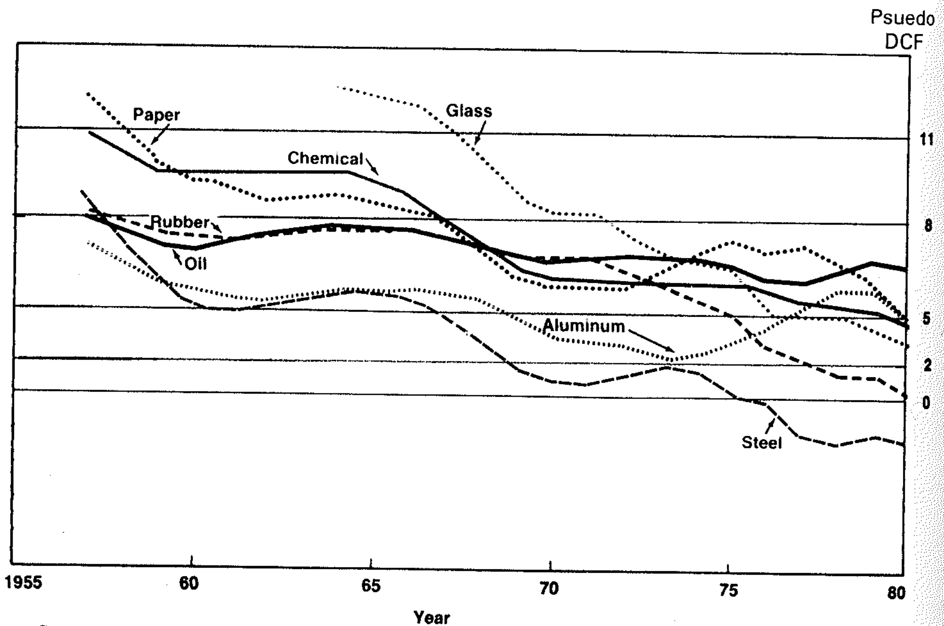

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Figure 7-13. Estimated Psuedo DCF returns for selected industries.

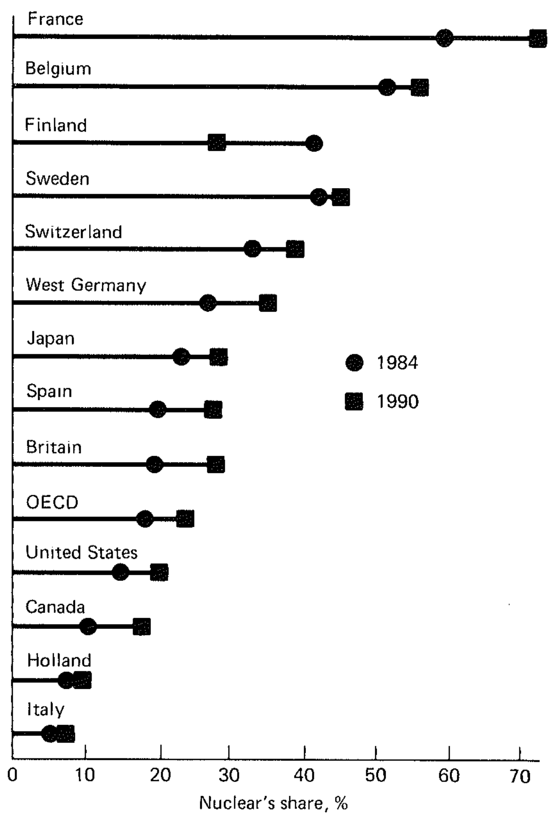
the energy intensive chemical industry, since the original design of most chemical processes was based upon very inexpensive energy. It resulted in a massive shift in the economic balance between operating cost (energy), and capital cost (heat exchangers, etc.). The resultant need for more energy efficient new processes and equipment is still present. Shortly after the energy profit squeeze was first felt, the U. S. environmentalists also began a massive crusade, first with air and water pollution legislation, and more recently focusing on hazardous materials and hazardous wastes. This has resulted in governmental laws and "enforcement" supervision that appears to be far more punitive in its effect than helpful in attempting to solve problems. Other countries have become equally concerned about the environment, but in general their governments have worked with industry in a cooperating rather than a punishing mode which has been both more effective and far less damaging to their industries.

As a final and more recent factor reducing the rate of return and the competitiveness of the U. S. chemical industry certain chemicals began being sold on the world market at relatively low costs because of either: (a) state subsidies for their production, or (b) very low cost raw materials. An example of the former are the government controlled companies producing potash (potassium chloride) in Israel, Russia, and Canada. All three countries would like to sell their product at the highest price possible (i.e., the "world price"), but particularly in the case of Israel, they must sell it at any price to keep this large segment of their industrial economy employed, so they undercut price if they must, and U. S. private industry either must meet the reduced price or sell what they can (a reduced amount) at the higher price. Both actions hurt profitability. Russia can control the price either for political purposes or to obtain much needed foreign currency, and Canada has very cheap potash, but can also control the price as a matter of policy.

A more serious problem which is only now beginning to have an important impact, and which will become much more dominant in the future, is chemical production from areas where there are very inexpensive natural resources. A good example of this is the large number of basic chemicals that can be made from natural gas and cheap energy. When crude oil is produced, natural gas is always a coproduct and sometimes the major product. In remote or undeveloped areas this gas must be flared (burned) merely to get rid of it so that the oil can be produced. For some time less developed areas like Alaska, Mexico, and Venezuela have been producing ammonia from this gas. The cost of the gas is only that of the gathering equipment, perhaps $0.05 to $0.50 per Mscf, while competitive plants in the United States have to pay $1.50–3.30 per Mscf (in 1987). This gives the low cost countries a $45–100 per ton of ammonia manufacturing cost advantage on a $70–140 per ton commodity (again, in 1987), which is far greater than the freight cost to ship the ammonia to the United States. This means that U. S. production must be displaced or sold at very low margins to be competitive. Ammonia is now also supplied by the Middle East, Russia, Canada, and other low priced gas countries.

This same trend is steadily growing with a wide variety of basic petrochemicals such as vinyl chloride, ethylene, methanol, and many others which have a similar low cost gas or energy base. Saudi Arabia has rapidly built plants to become a world leader with such products, and a number of other oil rich countries are adding to the flow (Block 1987). These countries are also doing more complete refining of their crude oil, which provides a further diversification to their upgraded fuel and chemical production through intermediates such as benzene, naphtha, and separate hydrocarbon cuts. The United States will definitely have to adjust its operations to consider these chemical sources in the future.

A final (and lesser) consideration, but also important for the economics of the chemical industry in the future, is the cost of utilities. Despite the abundance of intrinsically cheap utility fuels, oil, gas, coal and lignite, in the United States the problems with acid rain, sulfur dioxide, and NO_x emissions, and perhaps more pressure in the future on the "greenhouse" effect caused by CO_2, have resulted in U. S. electric prices rising far faster than those of our worldwide competitors. The obvious answer for most of the industrialized world is nuclear power (see Figure 7-14), but the U. S. antinuclear lobbying groups have caused the government to make building and operating nuclear power plants in the United States extremely time consuming and expensive, which has stopped



Source: Nuclear Energy Agency; Adapted from The *Economist*, May 24, 1986. Copyright 1986. *The Economist*. Reprinted with permission from the *New York Times* Syndication Sales Corporation.

Figure 7-14. Nuclear power as a percent of each country's total electric generation

almost all new construction. Because of this it has been predicted that by the year 2000 electric rates in the United States will be about double that of much of the rest of the world, and the U. S. chemical industry costs will be further increased.

Natural gas has a similar problem but for different reasons. First, there is considerable competition for this premium fuel, and even though it was plentiful in the mid-1980s, it should be in shorter supply within 5–10 years. Also, the natural gas distributing companies are private, but they are heavily regulated by the government, pressured by environmentalists, and basically work on a "cost plus" basis. There is little incentive for efficiency of operation, and many times no competition, so within reason the more it costs the gas companies to operate, the more profit they make. The regulatory agencies generally are not skilled in the concepts of processing technology or efficiency, so gas prices are now high in the United States by worldwide standards, and will be going higher.

All of these factors have contributed toward placing the U. S. chemical industry in the low profit and highly competitive position that it is now facing. We shall examine what the industry is doing about these problems in the next section.

PRESENT AND FUTURE CHANGES

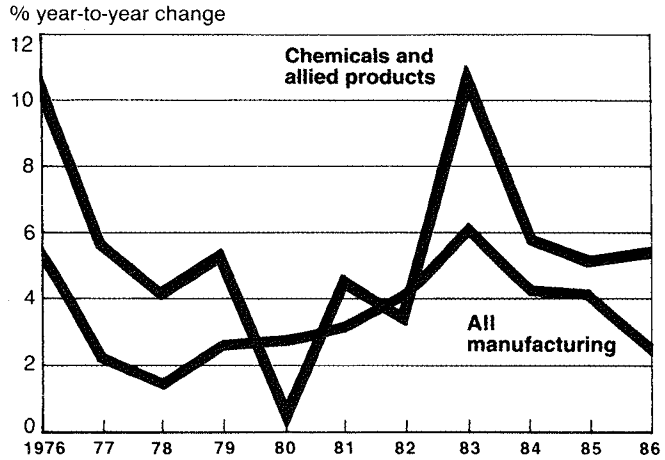
As discussed above, by the mid-1980s the chemical industry found itself to be a mature industry with a quite low rate of return on its investments. The U. S. market for most of its products was growing at a very slow rate, some export markets (such as heavy-debtor nations) (*Chemical and Engineering News* 1987 *c*) were disappearing, and there was increasingly severe foreign competition. Many foreign companies had equal or better processing technology, equal or newer plants, and generally lower operating costs. Foreign competitors also generally had their government's assistance or at least general support, while in the United States the government often took a more adversary position against industry in environmental, monopoly, and many matters relating to trade, financing, and competition. This has resulted in the top management of many companies spending most of their time, and often being selected because of their skill in dealing with the government, handling legal matters, and satisfying the financial community with short-term profits and growth. All of these factors would tend to indicate that the U. S. chemical industry should continue to decline and eventually follow the exact pattern of the steel industry. What actually is happening to counteract this pattern, to change it, or perhaps to eventually succumb to it?

Cutting Costs

As the above situation became more clear to management in the mid-1980s, essentially every chemical process industries company went through a major cost cutting and efficiency program. A strong catalyst for this movement, however, and one of the reasons that it occurred so universally and rapidly, actually was from quite a different motivation. A small oil company, Messa Petroleum, and its president, T. Boone Pickens, came to the conclusion that most of the major oil companies were poorly managed and making such low returns on their investments that their stockholders were not being adequately compensated. Also, the total value of all of their stock was often less than the value of the assets of the companies. He believed that because of this his company could either take over companies more than 10 times his size, or at least greatly profit in the attempt by buying some of their stock cheaply (i.e., 5–15% of the total) at its original price, offering much more for the rest of the stock to purchase the company, and if need be, selling the original stock after his takeover attempt had failed. He did exactly that with a number of companies in succession, and in every case it worked perfectly. Most of the larger oil companies immediately gave in and rushed into the arms of a "white knight" (another company) to avoid him, while a few encumbered themselves with massive debt and sold off highly profitable divisions to make themselves less attractive. In either case they or their white knights repurchased his stock at an attractive price.

Since that time other "raiders" have emulated Picken's technique in many industrial and commercial fields, generally with success. This naturally created some panic among many in management (since in a takeover or merger they would probably loose their jobs), and most companies immediately instituted major cost cutting and efficiency programs. This efficiency effort has been very beneficial to the industry, but most raiding now appears to have been taken to the point of being relatively harmful to the industry's long-term well-being. In T. Boone Picken's case he appeared to be fully prepared to operate any company that he made a bid for, and with his innovative ideas, deep knowledge of the industry, and ability to promote efficiency, he probably would have done so better than the existing management. Many of the other raiders, however, are either strictly financial people or groups, or nondevelopment oriented companies, and when they gain control of a company they (at least partly) liquidate, since the value of the divisions is usually greater than the company as a whole, or operate it strictly for the short-term gain. Research and development and new capital investment on new or improved products or equipment have little part in their plans. With the extraordinary skill that will be required to make the chemical industry remain vital and dominant, there would appear to be little or no possibility that the financial groups or other raiders can maintain this vigor. Once strong technical companies were acquired, like Stauffer Chemical, Mallinckrodt, and Borg Warner, they would appear to be in a very weakened position. Nevertheless, the efficiency moves that the raiders indirectly helped to initiate for the rest of the industry have been very important to its strengthened future by resulting in a much more diligent management and a reduced, more efficient operation.

Staff Reductions. The principal cost cutting technique used during this period has been through staff reduction, also called "downsizing," which has often resulted in massive employee layoffs. (See Figure 7-15.) Sometimes companies instead have practiced the "golden handshake" technique, where bonuses were given for early retirement. Headquarter staffs were often also severely trimmed to reduce the overhead costs (general and administrative, G & A), and as a result the productivity for the CPI rose (Figure 7-15) and the unit labor costs fell, as seen in Figure 7-16. This in turn increased profits



Note: Productivity is output per workhour, calculated by dividing indexes for production by indexes for workhours of production employees. Unit labor costs are labor costs per unit of output, calculated by dividing indexes for wages by indexes for output per workhour. **Sources:** Department of Labor, Federal Reserve Board, C&EN calculations

Source: Storck 1987. Reprinted with permission from *Chemical and Engineering News*, March 9, 1987. © 1987, American Chemical Society.

Figure 7-15. Chemical productivity.

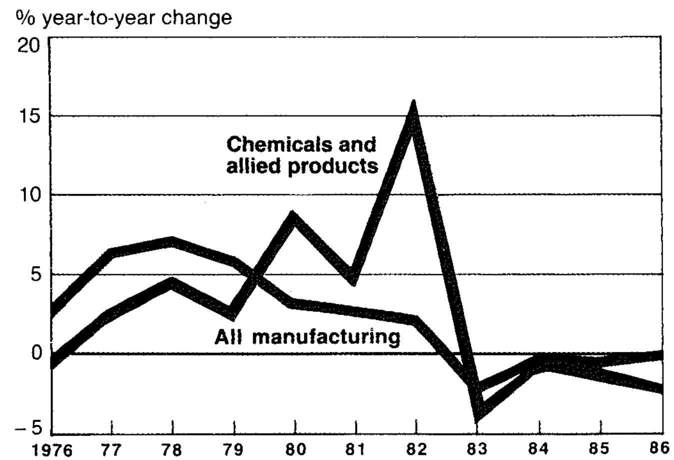


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Figure 7-16. Unit labor costs.

considerably, which was greeted so enthusiastically by the financial community that the stock prices (Figure 7-17) and price per earnings (dividend) ratios rose to all time highs in mid-1987.

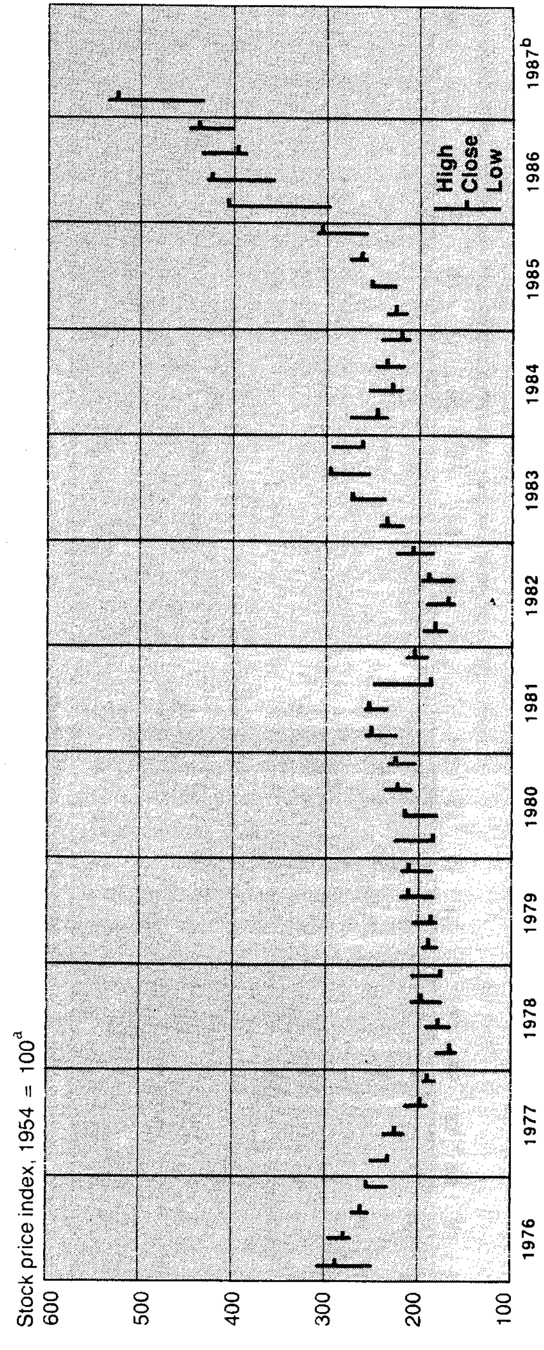
An example of such staff reductions is Monsanto, who in 1985 announced a major transition program to its employees. It was aimed at controlling costs and increasing productivity by decentralizing staff groups by moving them under line responsibility, and streamlining management. They also initiated a program of voluntary early retirement, and of the 3,880 employees eligible, 2,340 accepted. The du Pont company also went from a 141,000-person work force in 1982 to 112,000 in 1987. Exxon reduced its employees by 17%. Its U. S. work force of 40,000 was cut by 7,000; 6,200 through voluntary separation under a special early retirement or termination inducement package, and another 800 from layoffs. In the 1970s, there were more than 2,000 people at headquarters; in 1987 there were 325. At the same time, Exxon consolidated several regional operating organizations, and eliminated various headquarters divisions.

There is little doubt that reduced manpower has been beneficial for most companies, especially where bureaucratic-type overhead could be reduced (some feel that most U. S. companies are still overstaffed by 15–20% in their administrative offices), or obvious worker related costs such as union "feather bedding" or jurisdictional restrictions could be eliminated. However, in many cases engineering, technical, or research and development staffs were the first to be let go, and beyond the point of upgrading or removing nonproductive groups, this could be very damaging to the industry's long-term position. Even though all companies saw their profits rise from staff reduction, for only those who did it carefully and thoughtfully was it a large step toward more efficient and competitive future production. For those who did it more randomly, or focused on technical groups, many will have to quickly undo it, or probably suffer severe future problems.

Such was the case of a large fertilizer complex who were advised by management consultants that they had too many engineers. Most of the engineers were then fired, and almost immediately operating problems began to accumulate to the point that production and profits were severely reduced. When new engineers were hired the plant began to run well again, but in many cases equipment deterioration had occurred, and customers considered the company unreliable and with product quality problems. This case involved a management with unusual naivete or incompetence, but even though the example is exaggerated, the general point is a valid one for the current staff reduction programs.

Divestitures

A second efficiency step that often accompanied staff reduction was the sale or closing down of businesses that were losing money, not making an adequate profit, or were felt to not fit in with the new direction of the company. This



a C&EN weighted stock price index of American Cyanamid Dow Chemical W R Grace Hercules Monsanto Rohm & Haas and Union Carbide; weighted according to number of shares outstanding for each company b First quarter

Source: *Chemical and Engineering News* 1987e. Reprinted with permission from *Chemical and Engineering News*, June 8, 1987 © 1987, American Chemical Society

Figure 7-17. Prices of chemical stocks.

practice has always been an option of management, but in the mid-80s it became almost an obsession, and very large numbers of divisions from many companies were divested. In general there was an active interest from companies desiring to purchase the unwanted groups, since often that manufacturing facility or division might fit better with another company where there would be related, final product, or raw material production facilities to make a more integrated product line. Also, other companies, such as foreign operators, were actively looking for an entry into the United States or that product line, or to obtain that know-how, or more modern facilities. For all of these reasons and many others there usually have been customers even for divested plants or divisions that have not made a profit, and there has been lively bidding on the more attractive operations.

Leveraged Buy-outs. When corporate customers were not available, however, or would not offer a reasonable price, the parent company had one further divestiture profit opportunity, the ''leveraged buy-out,'' usually through an ''ESOP'' (employee stock ownership plan). This type of purchase contract was originally designed to sell an operation to the employees, and the tax laws were changed to provide an incentive for financial groups to loan the funds, such as the lender only having to pay taxes on half of the principal loaned, and some of the debt repayment to be considered as an operating cost. Only a small amount of investor cash was required (i.e., usually 0 to 10%), so the purchase was highly ''leveraged.'' Since a currently operated business was involved, the purchase price could be set fairly high, making it attractive to the seller, and the financial group could examine prior and anticipated profits to determine if enough cash flow (after tax profits plus depreciation) could be generated to pay the interest and repay the debt. If this wasn't adequate, the new owners could consider selling off some of the assets to see if they could then make the required profit. Usually a purchase price and loan agreement could be worked out that was attractive to everyone.

As leveraged buy-outs (LBO) became more common they were dominated by financial groups who became the majority owners, although some employees had to be included to satisfy the government's tax requirements. Generally the LBO companies have a dedicated and knowledgeable management, and operate with a very low overhead (McGuire 1987). This often gives them a reasonable profit potential, but since all of their energies are directed toward interest and debt repayment, they must sell their output, no matter what the demand, and cost cutting and sales discounts often result. This makes them difficult competitors, but also weakens them. In other cases they have ''gone public'' (i.e., sold stock to the general public) in order to raise money; some for the company's operation, perhaps more for the LBO organizer's profit (Goldhaum and Lune 1987). It is too early to know the percentages, but with an economic downturn many would fail (Loomis 1987), while with increased product demand and prices most should slowly become ''normal'' companies, developing new products and processes, and reinvesting in enough research and development to become stable competitors.

An example of a large financial group's leveraged buy-out is the Sterling Group, Inc. They formed Cain Chemical, Inc. to operate seven LBO petrochemical plants, as shown in Table 7-7. Cain Chemical emerged as a billion dollar company with 1,500 employees, and was almost wholly owned by the financial group (Sterling), management, and employees. Each of the plants produce bulk, highly competitive, slow growth, and usually oversupplied commodities with a history of up and down, and generally low profits. None of the original companies were well integrated from raw materials through to finished products, while Cain Chemical consumes about 80% of its ethylene in its own derivatives plants. It became a relatively well-balanced, integrated olefins business, supported by a low-overhead management, but with limited technical service capability. The divesting companies had fairly modern plants, with some expansion capability, which gave Cain a reasonable (but certainly not guaranteed) chance for success. Sterling sold the operation to the Occidental Petroleum Corp. in 1988 after a turn in the economy caused the market demand for their products to rise dramatically (Reisch 1988).

Mergers and Acquisitions

One of the major avenues for corporate growth has always been through purchasing other companies, or by mergers or acquisitions. Du Pont and Allied became dominant chemical producers in the 1920s by acquiring a number of large basic operations. In a similar manner in the 1970s and 1980s some of the current major chemical manufacturers also obtained their present size by mergers and acquisitions. As noted previously, in the mid-1980s acquisitions (just as divestitures) became almost epidemic, as indicated in Table 7-8 (*Chemical Week* 1987*a*; Goldbaum 1987, etc.). Typical examples were:

Some groups were most active in divesting, such as Union Carbide who was struggling under the financial uncertainty of the Bopal disaster (poisonous gas escape, killing thousands in India) and the heavy debt to fight off GAF Corp.'s take over attempt. They sold their consumer products business to First Brands, a leveraged-buyout (LBO) company for $800 million; the Eveready Battery business to Ralston Purina for $1.4 billion; and their agrichemicals business to France's Rhone-Poulenc for $575 million. Also, in a $340.5 million lease-back deal Carbide sold its headquarters complex at Danbury, Conn. Several companies that were involved in previous major acquisitions were later acquired, such as Chesebrough-Pond's, which in 1985 took over Stauffer Chemical, and was acquired itself in 1986 by Unilever, the British-Dutch consumer products giant for $3.1 billion. Unilever then sold the Stauffer operations (in 1987) to ICI for

Table 7-7
Cain Chemical Company Acquisitions

Divesting Company	Facility: Location	Operation	Product	Capacity
Du Pont	Chocolate Bayou, Alvin, TX	Ethylene cracker	Ethylene Propylene Butadiene Benzene	1 billion lb 650 million lb 135 million lb 90 million gal
	Mategora, TX (Bay City)	High density poly-ethylene	HDPE	460 million lb
	Orange, TX	High density poly-ethylene	HDPE	(205) 200 million lb
	Victoria, TX	High density poly-ethylene	HDPE	250 million lb
	Ponca City, OK	High density poly-ethylene	HDPE	Pilot plant
Corpus Christie Petrochemical	Corpus Christi, TX	Ethylene cracker	Ethylene Propylene Butadiene Benzene	1.4 billion lb 560 million lb 200 million lb[a] 60 million gal
ICI America	Bayport, TX	Ethylene glycol	Ethylene glycol	520 million lb
		Ethylene oxide	Glycol ethers, acetates and amines	150 million lb (450)
PPG Industries (Interest in PPG/Du Pont plant)	Beaumont, TX	Ethylene glycol	Ethylene glycol	620 million lb (570)
Summary:	% of U. S. Production	U. S. Rank		
	7	6	Ethylene	2.4 billion lb
	7	4	Benzene	150 million gal
	13	2	Ethylene glycol	1.09 million lb
			Propylene	1.2 billion lb
			Butadiene	300 million lb
			Benzene	150 million gal
			Glycol and derivatives	900 million

[a]Being expanded and updated. ( ) alternate estimate

Source: *Chemical Week* 1987c; Excerpted by special permission from *Chemical Week*, June 10, 1987. Copyright © 1987, by McGraw-Hill Inc., New York.

Table 7-8
Chemical Industry Acquisitions

Year	No. of Transactions	Value, $ Million
1980	79	947
1981	89	4,197
1982	80	2,307
1983	71	1,446
1984	117	2,820
1985	139	12,298
1986	700	33,000 (Chemical Processing 1987)
1987 (est.)	—	47,000 (*L.A. Times* 1987)

Source: Nordhoy 1987. Chemical Engineering Progress, February, 1987, 9–13, Reproduced by permission of the American Institute of Chemical Engineers.

$1.7 billion (Reisch 1987), who in turn sold Stauffer's specialty chemicals division to Akzo America for $625 million, and the basic chemicals groups to Rhone-Poulenc for $522 million. Other business areas were later sold.

Occidental Petroleum's chemical division purchased various commodity-type chemicals in the chlorine and vinyl chloride field, (Brockington 1987), including Firestone's PVC operations, Diamond Shamrock's chemical plants, Shell Oil's vinyl chloride monomer business, Du Pont's Corpus Christi chlor-alkali production, and Tenneco's polyvinyl chloride operations.

Most mergers, however, were in specialty chemicals and pharmaceuticals, such as in 1986 International Minerals buying Mallinckrodt for $675 million from Avon who had acquired it only four years earlier. Eli Lilly bought Hybritech for $300 million, and Bristol-Meyers paid $294 million for Genetic Systems. Key Pharmaceuticals, with its new drug delivery systems, became a part of Schering-Plough in an $800 million acquisition. Revlon sold its USV Pharmaceutical and Armour Pharmaceutical operations to the Rorer Group for $690 million. Britain's Boots also increased its stake in the U. S. pharmaceutical market with its $555 million purchase of Baxter Travenol's Flint Laboratories, as did Du Pont by the purchase of another Baxter Travenol unit, American Critical Care. In specialties and biotech, Eli Lilly purchased Hybri-tech for $300 million, and Bristol Meyers purchased Genetic Systems for $294 million.

These limited examples of major corporate restructurings were typical of what was happening to the U. S. chemical industry during the 1980s with companies selling large and small units which no longer meshed with their strategies, or to raise capital, and which other companies were eager to buy. Non-U. S. companies did a great deal of the purchasing in order to strengthen their U. S. holdings and improve their global marketing strategies (*Chemical and Engineering News* 1987*b*). Table 7-9 shows the beginning of this foreign purchase trend, which grew much stronger in the following years because of

Table 7-9
Number of U. S. Versus Foreign Acquirers, Chemicals and Allied Products

Acquisitions	1981	1982	1983	1984	1985	Total 1981–85	Cost, Billion $ 1986	Cost, Billion $ 1987
U. S. abroad	12	34	48	59	83	236	—	—
Foreign in United States	18	43	25	76	121	283	22.9	26[a]
U. S. excess (deficit)	(6)	(9)	23	(17)	(38)	(47)	—	—

Source: Nordhoy 1987. Chemical Engineering Progress, February 1987, 9–13. Reproduced by permission of the American Institute of Chemical Engineers.
[a]About 70% of all 1987 CPI acquisitions (Kiesche 1988).

this divestiture "fad," and the sharply falling dollar (value compared to foreign currencies). Gaining access to valuable technologies also proved to be a key incentive to acquisitions, especially in the most popular areas of acquisition, downstream products, specialty chemicals, pharmaceuticals and other health care items, and fabricated plastics and rubber.

There are obviously many good reasons for acquisitions and divestitures, and just as obviously many of them have been of considerable advantage to both the acquiring and acquired company. When a strong chemical company acquires another company it is probable that they will build upon the capability and expertise acquired, add more capital and research and development support, and both groups will prosper. Unfortunately, however, many (and perhaps even most) acquisitions do not work out so well, and are not that beneficial to the acquiring or acquired company, or the industry as a whole. Acquisitions have at least partly become popular because it is much easier for management to spend their time searching for and acquiring other companies than constructively building or improving their own. Acquisitions provide immediate entry into fields with considerable gain in sales and income which are very visible to the financial community, while the possible poor performance of their basic operations, debt, or stockholder dilution incurred from the purchase or merger are far less noticeable.

It has become almost a rule with few exceptions that new discoveries, innovations, or improvements are first commercialized in the United States by smaller, better managed companies, and then when the technology is more visible and widely accepted, larger companies acquire the smaller ones to obtain the new technology, or are themselves willing to build the "second generation" plants. This is comparatively safe and effective for the large company managers, but has the following disadvantages: (a) generally only smaller or less expensive new developments can be executed this way because of the limited resources of the smaller companies, and (b) foreign competitors can introduce the new technology when the small U. S. companies do, or they can recognize its virtues sooner, and be far ahead of the large U. S. companies. An opposite problem occurs when technology is developed by the larger U. S. companies that are so conservative and concerned with mergers that the developments are not utilized themselves, but licensed and left for foreign or smaller U. S. companies to commercialize, if at all.

A striking example of this is in the U. S. steel industry where company laboratories, along with university cooperative effort, developed over the years many major potential cost improving or higher profit technical innovations such as the basic oxygen injected furnace, electric arc furnaces, continuous casting and rolling, hydrogen reduction of ore, super alloys, and so on. However, no large steel company would commercialize any of these major developments (Ross 1987), so foreign companies did. This resulted in greatly increased competition, and when the big U. S. companies finally did start to slowly modernize it was much too little and perhaps too late (Szekely 1987). Steel company management also preferred to go the acquisition route rather than invest in new technology, with several weak companies merging with several others to form equally weak new companies. USX (U.S. Steel) appears to have merged itself partly out of the steel business rather than attempt to solve its industry's problems. On the other hand, many of the smaller steel companies who did modernize (mainly at first with small electric furnaces, continuous casting and reduced labor, production, and management overhead costs) have been very successful (*Fortune* 1987).

Whether the chemical industry will follow the major steel companies' nondevelopment pattern as well as drain much of their energies playing merger musical chair, or will be truly strengthened by the recent efficiency moves and mergers is not yet known. However, the substitution of mergers for sound new technical development appears to be quite common. As an example, one large firm in the field of electro- and chlorine chemistry was among the leaders in developing the revolutionary new dimensionally stabilized electrodes and polymer (cell) membranes. In fairly typical fashion, however, when the firm built a new chlorine-caustic plant it did not use this technology and stayed with improved, but old designs. The firm had also developed better vinyl chloride technology, but did not modernize or build a new plant. Later the firm acquired companies with both operations, stating the purchase of more modern plants as one of its main reasons for the acquisitions. The mergers will help the firm to catch up, but do not give much confidence that the firm will be ready with the next generation of improvements, or can even currently be competitive with more progressive companies. Mergers would appear to be a poor substitute for internal development if management pursues strictly one path or the other, or has no intention of capitalizing on new technical developments.

As a second factor, acquisition can often be a more risky route in reshaping a company than is first envisioned (Berney 1987). Frequently mismatches of operational methods (or "cultures") (Lefkoe 1987), losses of key personnel, a zeal for change, or a conservative, inattentive, or inept new management can destroy the anticipated profitability all too soon. A typical, hypothetical history of mergers is shown in Figure 7-18. In it a profitable company is acquired in year 0. After one year the new owner, confident now that he understands the business, reorganizes and installs a new general manager. Profits promptly begin to fall, but eventually bottom out around year 3, and remain low. Meanwhile the acquirer changes general managers about every 18 months. Finally, after five years and three general managers, one of two things occur: (1) the division is divested or even abandoned, or (2) after a second reorganization, profitability gradually recovers to an acceptable level, and the unit is retained as a division of the acquiring company. This later case only happened in from 13 to 83% (average about 50%) of the U. S. mergers during the 1970s according to a Harvard Business School study (Cory 1987). In a later study (*Fortune* 1987) it was noted that the profitability of most companies deteriorated significantly, and that 90% of mergers never live up to expectations.

A final example of potential problems with mergers or "raiding" is where the vigor of a dynamic company may be destroyed by the merger. An example of this may be the Borg-Warner's plastics division (Flanigan 1987). Building on technology learned in World War II when it made synthetic rubber insulation for radar wiring, it had developed into a technological and industry leader. It

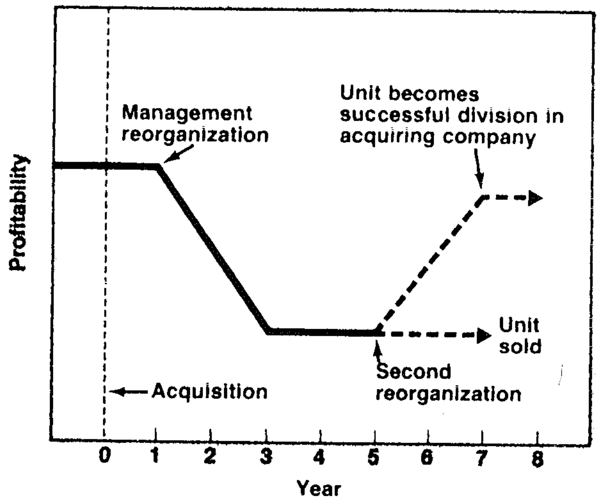


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Figure 7-18. Typical performance curve of mergered companies.

dominated the market for ABS plastics (acrylonitrile–butadiene–styrene) used for telephones, automobile bumpers, etc., was the world's largest producer, and had 30% of the market. It was a highly profitable business, accounting for less than one-third of Borg-Warner's $3.4 billion in revenue in 1986, but contributing about 60% of the total profit. The ABS resins accounted for $754 million of the plastics group's 1986 sales of $1.042 billion.

The company had also successfully developed a low-cost plastic that is capable of withstanding extreme heat or cold, and therefore was a candidate to replace steel in large parts of automobile bodies. If successful in preliminary tests in Detroit, the development could mean a big step forward for American plastics technology and for Borg-Warner. However, such breakthroughs don't come easily or cheaply. To get to this development, Borg-Warner started thinking about plastic cars in the 1960s, and built 10 prototypes. Years of expensive research chemistry stood behind the new product and an investment of $91 million in 1986, with much more ahead. The company would spend $200 million on a new plant if the car–plastic test was successful.

The question is can it do as much after being taken over in 1987, especially considering the $4 billion debt incurred to avoid the merger? When the debt burden is so high companies find ways to cut capital spending that are not immediately visible. The penalty for reduced spending today shows up in an uncompetitive business five years from now. The take-over action has probably resulted in such high fees, costs, and debt burden, plus probably an inferior (financial organization) management, that the company may never again be the dynamic force that it once was. This may remain the case even with GE's later purchase of the plastics division from the financial group.

In summary, the extensive merger activity of the mid-1980s would appear to have potentially offered some benefit to the U. S. CPI, but it has resulted in much more foreign control and financial company management, and all too often appears to have been done as the path of least resistance by management rather than face up to the uncertaintes of commercializing new technology and the difficulty of sound long-term cost improvement and growth policies. Merging is simple, easy to analyze, sometimes spectacular, and the results are instantly placed on the company books. Obviously it can do some companies a lot of good, but for the industry as a whole it would appear to provide far more publicity and short-term value than new developments, or basic and long-term strengthening against low profits or foreign competition. With the extensive new foreign ownership (23% in 1986; 26% in 1987) (Kiesche 1988; Reisch 1988) that has resulted the United States has lost ownership in a fair percentage of its chemical industry, and this segment has become the most research, development and growth (new capital addition) oriented part of the U. S. CPI. Perhaps this development will spur on the remaining U. S. companies (*Chemical Engineering and News* 1987*g*; *Chemical Week* 1987*b*; Allen 1988).

Strengthening Existing Production

Without question, the soundest method of improving costs and competitiveness is through the strengthening of existing business. This can be done in many ways, such as modernizing, developing new low-cost processes or product innovations, shifting to new and cheaper feedstocks, reducing energy costs, providing cheaper distribution, or acquiring the businesses of weaker suppliers, either to operate or to shut down and reduce industry capacity. The lowest cost producers should be able to make a profit even with heavy competition, but of course it requires efficient operation, reasonably priced raw materials, excellent technical capability, and the support of management to provide low overhead and the needed capital. It also requires that the needed new investments be economically justified, and this raises the question of whether management will accept a modest rate of return on a basic commodity rather than the very high rates that most companies aspire for on new investments. This is a general problem facing U. S. industry, in that almost all companies feel that they must obtain very high rates of return (which usually do not happen) on new capital spending even to the detriment of basic or core businesses where a secure, but lower return would still be considerably better than their present average.

A number of companies have or are using the merger route to strengthen their basic businesses by becoming larger, more modern, and integrating both backward to raw materials and forward to finished products. We have all ready mentioned Cain Chemical in the olefins business and Occidental Chemical building dominance in chlorine and vinyl chloride fields through mergers (Storck 1988). Obviously mergers can build size, which may improve strength and efficiency, but just as with the weak steel companies example, it will not provide benefits into the future unless there is also continued internal development, plant and product improvement, operating efficiency, management support, and wise selection among alternatives in this endeavor. This type of production strengthening implies that weaker operators drop out to leave probably only a handful of competitors for each product, and that capacity be adjusted to the amount that can be sold with high operating rates competitively in the United States and wherever else the pricing is favorable.

The United States has always excelled in this type of technical improvement and product and process innovation, but as with the steel companies, CPI management has become very reluctant to commercialize new innovations or improvements. It is primarily in this area of management courage to utilize new technology (even though the U. S. CPI did spend an estimated \$15.6 billion in 1987 on research and development, with about 57% of this funding coming from the chemical industry—see Figure 4-4) that the U. S. CPI will either retain its position or continue to steadily decline.

Differentiation and Segmentation. Another method of improving profitability is to distinguish the company's total offering, product service, and image from those of its competition by finding a unique position through unusual product features, multiple grades tailored to specific uses, superior distribution, good technical service, and rapid response to new needs (Portnoy 1988). The company looks for new customer needs, and prices its products on their value in actual use. They attempt by continuous innovation and the maintenance of close customer ties to achieve higher sales and profits.

Alternatively, a company may find specific products, market segments, or special situations. Many low-volume fine chemicals and specialized grades of specialty and tonnage chemicals are examples of such product "niches" (see Table 7-10). An example of such a market area is water treating chemicals, where municipal and small facilities require a sales force and distribution network quite different from those of the industrial market. Regional segmentation is also common in chemical distribution, where a distributor may elect to serve only one area by specializing in that area's needs. Similar results can be obtained by innovative research and development, higher product purity and uniformity, customer service, and rapid response to customers' needs. These attributes generally allow pricing based upon the customer's need more so than on the basic material sold.

Move into Higher Value-Added Products

Just as with mergers, there is a real stampede in the CPI to diversify, or even change the entire business, into higher value-added products. The chemical industry has led the way to develop new materials and products in the past, and

Table 7-10
Specialty Chemical Niches, 1987

Category	*Recent Average Annual Increase, %*	*Niche*	*Recent Average Annual Increase, %*
Adhesives	7	Structural adhesives	10
Cosmetic additives	4	Ultraviolet absorbers	8
Diagnostics	10	Toxicology	15
Electronics	11	Polymer thick films	25
		Galium arsenide	30
		Specialty gases	20
Industrial coatings	5	High solids	8
		Powder	11
Specialty surfactants	5	Amphoterics	8
Synthetic lubricants	5	High-water-based hydraulics	10
Water management	4	Institutional	9
		Metalworking	8
		Food processing	8

Source: Portnoy 1988. Exerpted by special permission from *Chemical Week*, March 2, 1988. Copyright © 1988, by McGraw-Hill, Inc., New York.

certainly in the future many new products will also produce high profits and large-volume business. Consequently, this rush to value-added products is very sound, and hopefully will further strengthen the chemical industry for the future. However, the current rush into these fields would appear for many companies to be another case of management doing what is popular rather than what is sound, and merely following a "me too" path.

Some of the areas that are being investigated are (Kline 1986):

- Specialty chemicals, the oldest and best known downstream products, comprising some 50 categories, from dyestuffs to photoresists, and being sold to over 30 different industries;
- Pharmaceuticals, agricultural chemicals, and other life science products, also a familiar field to many old-line chemical companies but now in the forefront with biotechnology. This and the next two fields are considered to be "high technology";
- Advanced materials, a newer area, including composites, ceramics, specialty metals, surface-modified materials, super conductivity, and other products with new and special properties; and
- Instruments, systems, services, and devices based on chemical technology—for example, du Pont's automated clinical analyzer. Also, included is technical service, licensing, consulting, management, contract maintenance, and so on.

Entry into these new fields is not easy. All four are already served by established suppliers, companies such as Ciba-Geigy and Rohm & Haas in specialty chemicals; the drug and pesticide companies in the life sciences; Corning, Hercules, Norton, 3M, and aerospace companies in advanced materials; and electronic and mechanical goods companies in instruments, systems, and devices. A few examples of the merger entry route into these areas has previously been discussed; there were literally hundreds during the 1980s (Nordhoy 1987).

Several companies have already stumbled badly in these areas, such as National Lead (NL Industries) which changed so that much of its chemical business was specialty chemicals in the oil field area, just as oil prices dropped precipitously and the industry stayed depressed for many years. Others are entering fields where there is obviously great potential, but good profits are probably many, many years away, and very large research and development and market entry investments will be required. Based upon prior experience with similar highly popular fields (solar energy, fuel cells, insecticides, etc.), few companies have adequate staying power to remain with these new technologies until they are profitable.

Specialty chemicals also represent somewhat of a mixed opportunity. The classic specialty chemical company is now seeing quite heavy competition and

reduced opportunity for growth, as shown in Tables 7-11 and 7-12. There is also considerable consolidation among these companies with 1986 alone seeing 47 mergers. However, the old definition that specialty chemicals are sold on the basis of what they do, not what they are, generally low-volume chemicals with a degree of "uniqueness," is changing from "niche," "effect," or "performance" chemicals to more generally, "highly profitable chemicals."

As an example of this trend, Dow Chemical targeted a change in 1978 to have 50% of its business in 1987 be in specialty chemicals. Dow began realigning business, and by 1986 the specialties contributed 49% of sales revenue and 54% of operating income. Included in Dow's rather liberal definition of specialty chemicals are pharmaceuticals, electronics chemicals, high-performance ABS and polycarbonate resins (for automotive uses), polyolefin and polystyrene polymers (for food packaging), styrofoam and chlorinated polyethylene products (for the construction industry), mining chemicals, adhesives and sealants, chemicals for the oil and gas industries, specialized

Table 7-11
Current Growth Prospects for Specialties, 1986

Slow Growers	*Medium Growers*	*Fast Growers*
Ag chemicals (3%)	Specialty polymers (8%)	Advanced polymer composites (13%)
Cosmetic chemicals (3%)	Specialty adhesives and sealants (7%)	Electronic chemicals (12%)
Foundry chemicals (3%)	Specialty surfactants (6%)	High-performance ceramics (11%)
Industrial chemicals (3%)	Plastic additives (5%)	Diagnostics chemicals (10%)
Industrial institutional chemicals (3%)	Reagents (5%)	
Petroleum additives (3%)	Refinery chemicals (5%)	
Metal finishing chemicals (3%)	Biocides (4%)	
Paint and coating additives (3%)	Catalysts (4%)	
Printing ink additives (3%)	Food additives (4%)	
Textile chemicals (3%)	Oil field chemicals (4%)	
Explosives (2%)	Paper chemicals (4%)	
Mining chemicals (−3%)	Photo chemicals (4%)	
	Rubber processing chemicals (4%)	
	Specialty lubricants (4%)	
	Water management chemicals (4%)	

Source: Horiszny 1987. Courtesy of *Chemical Business*.

Table 7-12
Estimated Future U. S. Specialty Chemicals Sales Growth

Segment	Sales, Million dollars 1985[a]	Sales, Million dollars 1991[b]	Estimated Average Annual Growth, %/yr
Adhesives and sealants	$1,415	$2,245	8
Advanced polymer composites	1,370	4,090	20
Agricultural chemicals	5,840	6,975	3
Biocides	560	710	4
Catalysts	1,520	1,925	4
Cosmetics	555	665	3
Diagnostic chemicals	1,815	3,216	10
Electronic chemicals	3,930	8,625	14
Explosives	430	485	2
Food additives	1,300	1,645	4
Foundry chemicals	135	160	3
Fuel additives	230	290	4
Industrial coatings	4,245	5,070	3
Industrial and institutional cleaners	3,080	3,680	3
Metal finishing chemicals	610	730	3
Mining chemicals	340	285	−3
Oil field chemicals	4,285	5,420	4
Paint and coating additives	895	1,070	3
Paper chemicals	365	460	4
Petroleum additives	1,595	1,905	3
Photographic chemicals	1,165	1,475	4
Plastic additives	1,765	2,365	5
Printing inks	185	220	3
Reagents	410	550	5
Refinery chemicals	285	380	5
Rubber processing chemicals	510	645	4
Specialty lubricants	630	795	4
Specialty polymers	2,115	3,545	9
Specialty surfactants	475	675	6
Textile chemicals	1,320	1,575	3
Water treatment chemicals	1,600	2,025	3
Total	$44,975	$63,900	

Source: Wilson 1987. Excerpted by special permission from *Chemical Week*, May 13, 1987. Copyright © 1987, by McGraw-Hill, Inc., New York.
a. Actual. b. Estimated.

ceramics and epoxy resins (for aircraft and aerospace applications), powder metallurgy, and a number of household consumer specialties.

In concentrating on certain markets, Dow added special qualities to what others call commodity chemicals, thereby blurring the traditional line between specialty and commodity. They do not plan on abandoning their basic chemicals and plastics business, believing that the largest profit increase over the late 1980s and early 1990s will come in basic chemicals and plastics since restructuring may have removed much of the overcapacity that plagued the industry during the 1970s. It takes about three years to build a basic chemical plant, and in the mid-1980s there were few plans by anybody to build these large chemical plants around the world.

One of the new areas that would appear to offer very large potential rewards is biotechnology, but it can be seen already that legal (even moral), political, and sales problems on top of the technical demands make this a difficult and long-range field. Small companies have prospered on a speculative basis to date, but by the time technical, marketing, permitting (with the government), and environmental pressure group problems are solved, it is quite possible that only large companies and perhaps even consortiums with very large resources and long-term commitment will prosper. As with computer chips and pharmaceuticals, this gives foreign competitors such as Japan with its major governmental sponsorship, consortium action, and willingness to invest heavily in long-term projects before a payout is expected, or other countries where governmental permitting is much easier and faster, a considerable advantage. U. S. companies are leading in this technology and first applications race at present, but the future must be considered as quite uncertain. Hopefully the U. S. government will not be too harsh with their restrictions, costs and time delays, and the U. S. companies involved will be correspondingly more resourceful and persistent.

Other higher value-added fields also offer considerable promise, but they are in production areas that already are well supplied by a number of strong producers. There is always room for new more efficient operators and for new commercial developments, so some of the new entries will prosper. However, for many it will be the "grass being greener on the other side of the fence" situation, and it is doubtful that this is a major panacea for the U. S. chemical industry. This is especially true considering the foreign competition that is also developing in this area. It does not mean that it is not deserving of a major effort, for in many cases it represents the essence of innovation and skillful marketing, but this movement should be balanced with efficiency and excellence in the companies' basic commodities.

Foreign Trade and Production

Many CPI executives feel that U. S. companies will have to undergo a striking change toward a more international outlook (Shamel 1986; Mullen 1987). To profit in the late 1980s and 1990s, some claim that more will have to become lean, global competitors. The modern manager feels the effects of decisions made in other countries very quickly. The CPI is no longer a regional or even a national business, as chemical products are now made all over the world. The new global industry is very competitive, fast moving, and changing.

The U. S. chemical industry has for many years been a world trader, with large export sales, considerable import purchasing, and a steadily growing manufacturing presence overseas. This has considerably added to its strength and vigor, but even this situation is changing. Europe and Japan have seen a decline in the growth rates of their markets and greatly increased competition. A high percentage of their chemical production (i.e., 50% or more) is exported, so they must react. Many of their companies have also announced a change from commodities to high-technology products like biotechnology and specialty chemicals. In Italy, Montedison announced a shift from 20% specialties to 80%. Japan announced an annual investment of $200 million per year in biotechnology, the "next major frontier of the century." Most European and Japanese companies also rely heavily on new technical development, such as West Germany's Bayer, which invested one-third more for research (as a percentage of sales) than did du Pont in 1984. This kind of investment has marked Bayer for decades, and as a result, "40% of its roughly $16 billion in worldwide sales comes from products that didn't exist 15 years ago." The results are a global market, and Bayer's 1984 North American sales were larger than its West German sales. Foreign companies were also issued 46% of all U. S. patents in 1986.

Developing countries, on the other hand, have rushed into commodity or basic chemicals, and mostly for export (*Chemical and Engineering News* 1987*b*). Taiwan, for example, has moved into petrochemicals, South Korea into fertilizers, polypropylene, and so on, and South America into "oil field" chemicals, particularly plastics. Saudi Arabia now produces 4% of the world's ethylene, 3% of the world's ammonia, 6% of the world's methanol, and many other basic commodities (*Chemical Week* 1987). Most of this new production is accomplished with very low-cost raw materials, low-cost labor, and large, modern, and efficient plants.

All of these factors point toward the U. S. CPI needing to develop an even greater global outlook. There are still many new markets in both developed and developing countries that the United States can profitably operate in with intelligent and aggressive salesmanship. This may require more knowledgeable multilingual local representation, perhaps more barter (trade one commodity for another) arrangements, and so forth. It will also definitely require more foreign plants and joint venture relationships to take advantage of highly favorable raw material, labor, energy, or sales opportunities. Care must be taken, however, not to rush excessively into foreign operations for cheaper labor or raw materials when equivalent modern plants in the United States with improved innovations would result in a much sounder long-term position. It will finally require an even closer knowledge of what is happening with foreign chemical production, and an improved product quality and service. The chemical industry has indeed become global in its nature, and the U. S. companies, if they are to compete, must emphasize its most unique skills (that it at least once had): technical

innovations, quality products and service, venturesome and skillful management, and an ability to react reasonably quickly to the changing world situation. Some U. S. chemical companies already are very skillful world traders, and hopefully many others will be able to develop these skills.

Diversification

It was noted earlier in this section that very few of the major chemical producers manufacture chemicals alone. Among the top 50 chemical operators in Table 7-2 there are 11 different industry categories, with the average of the 50 only having about 54% of their business in chemicals. Many of the companies in other industries became chemical manufacturers for any of a wide range of reasons including increased profitability, diversification, their use of the products, or because they had inexpensive raw materials. The chemical companies added their nonchemical products for similar reasons such as diversification or because they controlled or needed raw materials, were in related businesses, or in some cases, just to grow in a hurry. The du Pont white knight take-over of Conoco was probably an example of the later cause, more than doubling its size, and making du Pont more of an oil than a chemical company. Only 10 of the top 50 chemical manufacturers were listed in 1986 as being pure chemical companies, and this number has been reduced since that time. The trend for U. S. chemical companies is strongly toward having a diversity of products, and pure U. S. chemical producers will probably be a rarity in the future.

There is a very positive management rational for this diversification movement. For many products a period of depressed sales for one product may not be the same for another. This occurs within the chemical industry itself, for example, since a period when fibers and their raw materials are selling poorly or at depressed prices might very well be a period when some of the inorganic commodities are selling well. For this reason most chemical companies are reasonably well diversified with respect to different types of chemicals, but the current trend is far more than that. Companies are also branching into nonchemical products in their desire to smooth out economic cycles of product demand and profits. For instance, when du Pont's oil business has experienced profit declines, its chemicals have carried the company, and vice versa.

Diversification, however, has many other advantages such as providing an opportunity to enhance profits through the control of business areas throughout their entire cycle. Petrochemical companies are large consumers of hydrocarbon feed stocks, so the acquisitions of an oil company would not only provide another business area for profits, but also guarantee feed stocks at a reasonable price. Several chemical companies have done this. Other chemical companies have diversified into mining, such as soda ash (Na_2CO_3) production by Allied, FMC, Stauffer, and Tenneco; potash by PPG and International Minerals; and agriculture by Quaker Oats (corn cobs to produce furfural). There are many such examples of raw materials processing in a different industry to produce chemicals.

A similar branching out can result from companies that produce intermediate materials to carry them one step or more to the ultimate consumer. Examples were Union Carbide's production of carbon for electrodes, and electrolyte chemicals, and then combining them into the final consumer product, batteries in their former Eveready division. In a similar manner they marketed some of their glycols directly to the consumer as Prestone antifreeze liquids. Until the early 1980s not too many companies did such marketing directly with the public other than Union Carbide as just noted, and du Pont with paints and lacquers. However, this tendency is being strongly reversed with the industries' new interest in higher value-added products, and many more companies are diversifying in this manner.

A general case study of this combined with innovative marketing and excellent management is Monsanto's current production of acrylic fibers (Reisch 1987c). This activity had made up one-fourth of its chemical revenues, and was in trouble. The company had more capacity than business, having build megaplants with high capacity and little flexibility, so that while there were increasing economies of scale, far eastern competitors were cutting into their sales. In addition, Monsanto was relying heavily on commodity fibers sales, half the volume being derived from low-margin exports.

The company was forced to change its strategy, and businesses totaling \$2 billion in sales have been dropped since 1979. In 1986 Monsanto was a \$4.7 billion chemicals company with returns three times what they were in 1979. They have attempted to emphasize increased profitability more than sales alone (*Chemical and Engineering News* 1987*f*). The changes include more distribution points for their fibers, and major investments in flatbed knitting machines that can manufacture many styles more quickly than older methods. When a market survey indicated customers were unhappy with the amount of wear they were receiving from their socks, Monsanto increased its "Acrilan" socks' lifetime by 50% in less than 18 months, and its market share climbed 50%. The company also initiated a "Wear-Dated" apparel warranty program that has proven to be very popular. Finally, Monsanto has now invested in "the plant of the '90s". It has electronic networks linking Monsanto to its customers, ensuring the quick response time so crucial in competing with foreign suppliers.

This type of diversification and management response to changes, competition, and opportunities is obviously very beneficial to the individual companies and the entire industry, but it is not without its potential problems. The entire chemical industry owes its past success to technical innovation, and managements' ability to commercialize the resultant new processes and developments. But this is a very difficult job, since even with extensive pilot plant testing, comprehensive market research, and detailed staff reports there are always major uncertaintes and some failures. Also, there is invariably competition among different projects for the company's limited capital resources. Consequently, for a company to truly succeed and prosper over the long period, management must have outstanding knowledge and experience to make these difficult technical decisions, which means expertise in the fields involved. If a company diversifies into fields too different from its general area of corporate skill and knowledge, the chances for success become very poor and many of the new ventures will ultimately fail or falter.

As noted previously, 85–95% of most companies' top management time is taken up with financial matters, government relations, management or legal problems, and public relations or employee concerns, all of which are generally similar from one company to another. Many chief executives are selected on the basis of these skills, and are felt to be readily transferable from one industry or business area to another. Of course these functions are important and can greatly contribute to a company's short-term success, but without the deep technical knowledge of the industry involved, such an executive has to be very conservative and in the majority of cases will essentially stop all new development projects, and thus the long-term growth and vigor of the company.

As an example of this, there is little doubt that the executives of the steel industry were excellent administrators, and probably performed well by "Harvard Business School" standards. However, their conservatism, lack of perception of the industry changing around them, and refusal to sponsor any new technical developments essentially destroyed their industry (Ross 1987). Of course, foreign government subsidized imports, out-of-control union pensions, wages, and work rules, competition with plastics and other metals, and a slowed U. S. economy and minirecessions caused a great deal of the problem the industry now faces, but basically a nontechnical, noninnovative, very bureaucratic and high-overhead management must take most of the blame.

The lesson to be learned by the CPI in its diversification program is that new ventures in other industries should be as closely related in some aspects of the business as possible so that there will still be management expertise, or the management of the new companies must be allowed to operate on an independent "cost center" basis so that they can make the important decisions and have their own capital investment budgets. Otherwise, as an extreme example, with an oil producing division competing for capital with a basic chemical division, no matter how attractive a new project for the later group may look, the oil group can always claim the possibility of finding a new Prudho Bay oil field, and a conservative or nonthinking management will make everything (except perhaps the thrill of mergers) stop in favor of oil drilling. On an independent profit center basis both divisions would have their own business objectives, profits, and capital decisions to be responsible for, and thus presumably would be better managed. This is the only possible way that basic commodities, new technology, or new venture groups have a chance of growing or prospering in a large organization, but it is very hard for most managements to let them operate semiindependently with their own divisional objectives for long-term programs.

In summary, diversification is rapidly giving the chemical industry a totally different appearance than it has ever had before. It should help it to be more profitable and active, and if done well should assist in chemical production remaining the innovative major industry that it has always been.

REFERENCES

Allen, Deborah, and John Rutledge. 1988. We should love the trade deficit. *Fortune* (Feb. 29):125.

Anderson, Earl V. 1987. U.S. surpluss in chemical trade. *Chemical and Engineering News* (Dec. 4):29–31.

Berney, Karen. 1987. Just merged. *Nations Business* (Dec.):30–36.

Block, Paul M. 1987. Saudi petrochemicals. *Chemical Week* (Dec. 9):30–36.

Brockington, Langdon C. 1987. OxyChem's investment in PVC pays off. *Chemical Week* (Sept. 2):30–33.

Chemical and Engineering News. 1987*a*. Companies spend more to curb pollution. (Feb. 16):9.

Chemical and Engineering News. 1987*b*. Third world leads in chemical growth. (March 16).

Chemical and Engineering News. 1987*c*. U. S. chemical trade hurt by developing country debt. (April 13):25–26.

Chemical and Engineering News. 1987*d*. Cain chemical (May 11):4.

Chemical and Engineering News. 1987*e*. Facts and figures. (June 8):24–76; (April 13):22–24.

Chemical and Engineering News. 1987*f*. Monsanto stresses profitability over sales. (Aug. 10).

Chemical and Engineering News. 1987*g*. Foreign ownership of U.S. patents still rising. (Aug. 17).

Chemical and Engineering News. 1987*h*. Foreign investment in U.S. chemicals soars. (Oct. 5):11.

Chemical Processing. 1987. Acquisitions in chemicals. (Aug. 12):12.

Chemical Week. 1987*a*. Mergers and acquisitions. (Jan. 7–14):51–53.

Chemical Week. 1987*b*. Foreign takeovers: Boost or bane. (April 29):19.

Chemical Week. 1987*c*. Cain chemical. (June 10):7–9.

Chemical Week. 1987*d*. Saudi petrochemicals. (Dec. 9):30–36.

Chemical Week. 1988. Forecast, 1988. (Jan. 6–13):34–48; 1987 (Jan. 7–14):32.

Cory, Peter. 1987. Diversity spells failure. *Fresno Bee* (May 7):D-1,3.

Dressler, O., and R. Shinar. 1986. Return on investments. *Chemtech* (Jan.):30–41.

Flanigan, James. 1987. Parasites may drain health of U. S. industries. *L.A. Times* (April 21).

Fortune. 1987. 500 largest companies. (April 27):355–414.

Goldbaum, Ellen. 1988. 1987 calms the CPI acquisition pace. *Chemical Week* (Jan. 20):61–62.

Goldbaum, Ellen, and Meyer G. Lurie 1987. Another LBO goes public. *Chemical Week* (June 24):8.

Horiszny, Jean. 1987. Specialty chemicals. *Chemical Business* (April):10–13.

Kiefer, David M. 1987. World chemical outlook. *Chemical and Engineering News* (Dec. 14):25–48.

Kiesche, Elizabeth S. 1988. Non-U.S. bids-benefit or risk? *Chemical Week* (March 16):10–13.

Kline, Charles H. 1986. Reshaping the chemical industries. *Chemtech* (Aug.):478–483.

L.A. Times. 1987. Mergers fall But value rises. (Oct. 19).

Lefkoe, Morty. 1987. Why so many mergers fail. *Fortune* (July 20):113–114.

— 1988. The new J.P. Morgans. *Fortune* (Feb. 29):44–58.

Loomis, Carol J. 1987. LBO's are taking their lumps. *Fortune* (Dec. 7):63–68.

McGuire, Jane. 1987. Life among the LBO's. *Chemical Business* (June):38–39.

Mullen, Theo. 1987. How to thrive in a global market. *Chemical Week* (Feb. 25):16–17.

Nordhoy, Frode. 1987. Acquisitions. *Chemical Engineering Progress* (Feb.):9–13.

Portnoy, Kristine. 1988. Realizing specialties' potential. *Chemical Week* (March 2):9–12.

Reisch, Marc. 1987*a*. Chemicals key to ICI's Stauffer plans. *Chemical and Engineering News* (July 6):17–18.

— 1987*b*. Chemical capital spending to jump 20% in 1988.*Chemical and Engineering News* (Dec. 21):9–11.

— 1987*c*. Monsanto stresses profitability over sales. (Aug. 10):17; *Chem. Mkt. Reptr.* (Apr. 20):3.

— 1988. Occidental acquires Cain Chemical. *Chemical and Engineering News* (Apr. 25):4.

Ross, Irwin. 1987. Is steel's revival for real. *Fortune* (Oct. 26):94–99.

Savage, Peter 1988. Cain Chemical builds a name in basic chemicals. *Chemical Week* (March 23):22–26.

Schwartz, Irvin. 1987. Cain: Countin on an ethylen upturn. *Chemical Business* (Aug.):18–21.

Shamel, R. E. 1986. Strategies for the global chemical industry. *Chemical Engineering Progress* (Aug.):8–12.

Storck, William J. 1988. Chemical earnings. *Chemical and Engineering News* (Feb. 22):10–14.

— 1988. Occidental Petroleum is still building by acquisition. *Chemical and Engineering News* (May 2):19–22.

— 1987. Chemical industry productivity continued to rise in 1986, *Chemical and Engineering News* (March 9):9–10.

Szekely, Julian. 1987. Can advanced technology save the U.S. steel industry? *Scientific American* (July):34–41.

Wilson, Linda J. 1987. Specialty chemicals. *Chemical Week* (May 13):12.

— 1988. Foreign investment in U.S. chemical industry continues steady climb. *Chemical and Engineering News* (April 25):7–10.