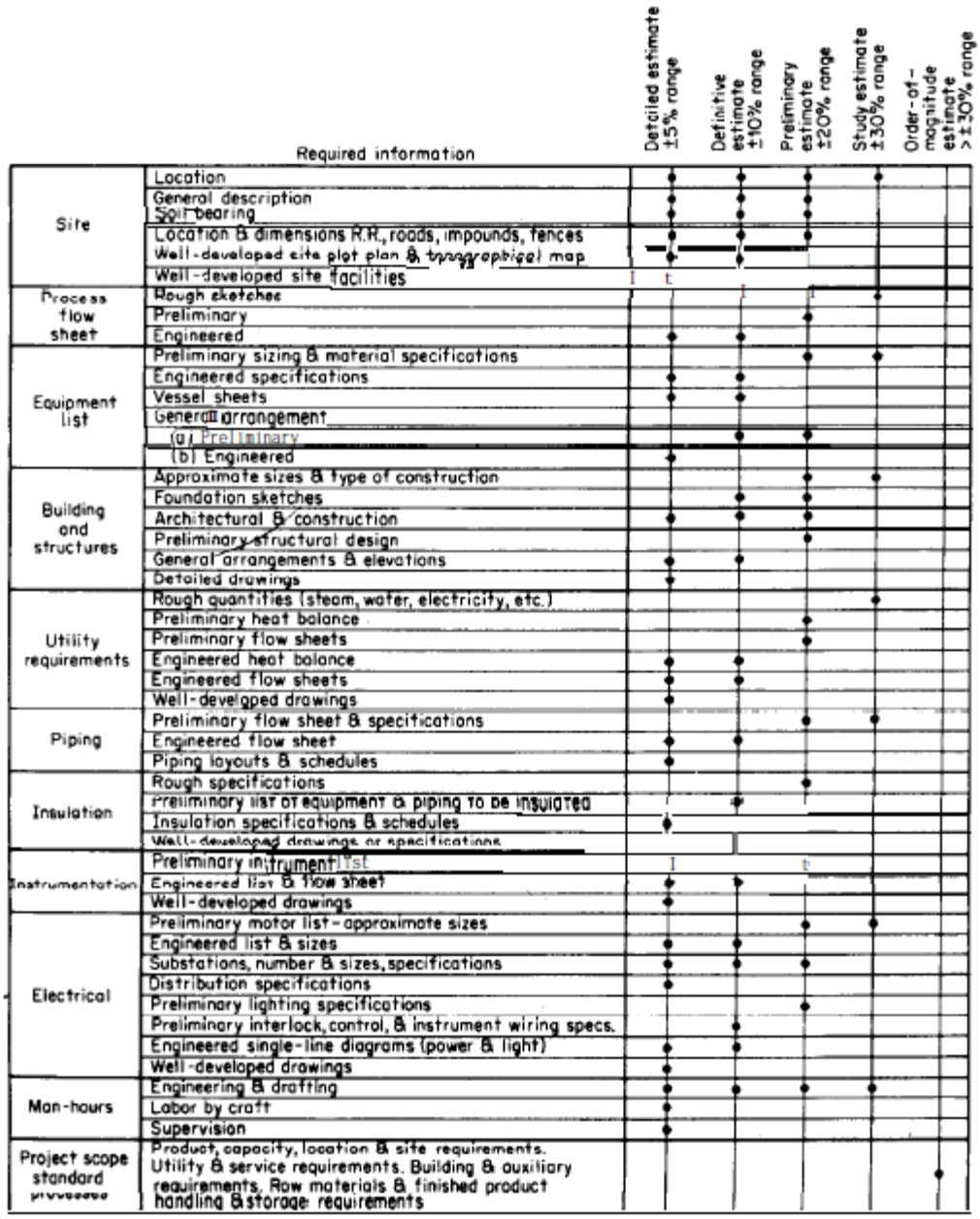

FIGURE 6-4
Cost-estimating information guide.

TABLE 3
Cost indexes as annual averages

Year	Marshall and Swift installed-equipment indexes, 1926 = 100		*Eng. News-Record* construction index			Nelson-Farrar refinery construction index, 1946 = 100	Chemical engineering plant cost index 1957-1959 = loo
	All-industry	Process-industry	1913 = 100	1949 = 100	1967 = 100		
1975	444	452	2412	464	207	576	182
1976	472	479	2401	503	224	616	192
1977	505	514	2576	540	241	653	204
1978	545	552	2776	582	259	701	219
1979	599	607	3003	630	281	757	239
1980	560	675	3237	679	303	823	261
1981	721	745	3535	741	330	904	297
1982	746	774	3825	802	357	977	314
1983	761	786	4066	852	380	1026	317
1984	780	806	4146	869	387	1061	323
1985	790	813	4195	879	392	1074	325
1986	798	817	4295	900	401	1090	318
1987	814	830	4406	924	412	1122	324
1988	852	870	4519	947	422	1165	343
1989	895	914	4606	965	429	1194	355
1990 (Jan.)	904†	924	4673	979	435	1203	356

† All costs presented in this text are based on this value of the Marshall and Swift index unless otherwise indicated.

TABLE 4
Typical percentages of fixed-capital investment values for direct and indirect cost segments for multipurpose plants or large additions to existing facilities

Component:	Range, %
Direct costs	
Purchased equipment	15-40
Purchased equipment installation	6-14
Instrumentation and controls (installed)	2-8
Piping (installed)	3-20
Electrical (installed)	2-10
Buildings (including services)	3-18
Yard improvements	2-5
Service facilities (installed)	8-20
Land	1-2
Total direct costs	
Indirect costs	
Engineering and supervision	4-21
Construction expense	4-16
Contractor's fee	2-6
Contingency	5-15
Total fixed-capital investment	

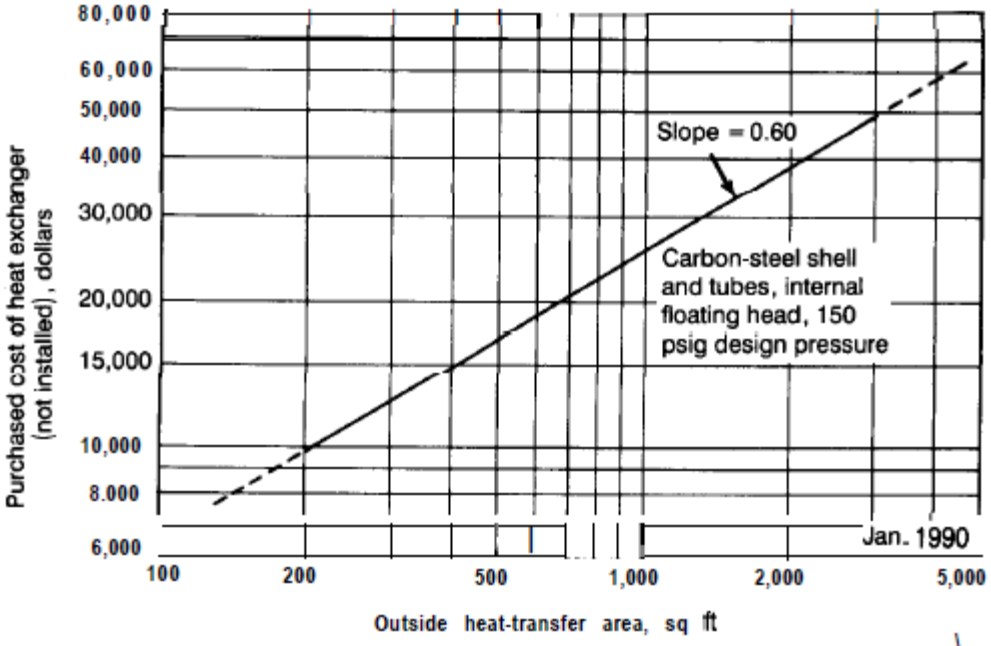

FIGURE 6-5
Application of "six-tenth-factor" rule to costs for shell-and-tube heat exchangers.

TABLE 5
Typical exponents for equipment cost vs. capacity

Equipment	Siie range	Exponent
Blender, double cone rotary, c.s.	SO-250 ft^3	0.49
Blower, centrifugal	10^3–10^4 ft^3/min	0.59
Centrifuge, solid bowl, c.s.	10–10^2 hp drive	0.67
Crystallizer, vacuum batch, c.s.	500-7000 ft^3	0.37
Compressor, reciprocating, air cooled, two-stage, 150 psi discharge	10–400 ft^3/min	0.69
Compressor, rotary, single-stage, sliding vane, 150 psi discharge	10^2–10^3 ft^3/min	0.79
Dryer, drum, single vacuum	10–10^2 ft^2	0.76
Dryer, drum, single atmospheric	10–10^2 ft^2	0.40
Evaporator (installed), horizontal tank	10^2–10^4 ft^2	0.54
Fan, centrifugal	10^3–10^4 ft^3/min	0.44
Fan, centrifugal	2×10^4–7×10^4 ft^3/min	1.17
Heat exchanger, shell and tube, floating head, c.s.	100-400 ft^2	0.60
Heat exchanger, shell and tube, fixed sheet, c.s.	100-400 ft^2	0.44
Kettle, cast iron, jacketed	250-800 gal	0.27
Kettle, glass lined, jacketed	200-800 gal	0.31
Motor, squirrel cage, induction, 440 volts, explosion proof	5-20 hp	0.69
Motor, squirrel cage, induction, 440 volts, explosion proof	20-200 hp	0.99
Pump, reciprocating, horizontal cast iron (includes motor)	2–100 gpm	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	10^4–10^5 gpm × psi	0.33
Reactor, glass lined, jacketed (without drive)	50–600 gal	0.54
Reactor, s.s., 300 psi	10^2–10^3 gal	0.56
Separator, centrifugal, c.s.	50-250 ft^3	0.49
Tank, flat head, c.s.	10^2–10^4 gal	0.57
Tank, c.s., glass lined	10^2–10^3 gal	0.49
Tower, c.s.	10^3–2 x 10^6 lb	0.62
Tray, bubble cup, c.s.	3-10 ft diameter	1.20
Tray, sieve, c.s.	3-10 ft diameter	0.86

TABLE 6
Installation cost for equipment as a percentage of the purchased-equipment cost†

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

† Adapted from K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, California, 1974.

TABLE 7
Typical exponents for equipment installation labor vs. size

Equipment	Size range	Exponent
Conduit, aluminum	0.5-2-in. diam.	0.49
Conduit, aluminum	2-4-in. diam.	1.11
Motor, squirrel cage, induction, 440 volts	1-10 hp	0.19
Motor, squirrel cage, induction, 440 volts	10-50 hp	0.50
Pump, centrifugal, horizontal	0.5-1.5 hp	0.63
Pump, centrifugal, horizontal	1.5-40 hp	0.09
Tower, c.s.	Constant diam.	0.88
Tower, c.s.	Constant height,	1.56
Transformer, single phase, dry	9-225 kva	0.58
Transformer, single phase, oil, class A	15-225 kva	0.34
Tubular heat exchanger	Any size	0.00

TABLE 8
Estimated cost of piping

Type of process plant	Percent of purchased-equipment			Percent of fixed-capital investment
	Material	Labor	Total	Total
Solid †	9	7	16	4
Solid-fluid ‡	17	14	31	7
Fluid §	36	30	66	13

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

TABLE 9
Component electrical costs as percent of total electrical cost

Component	Range, %	Typical value, %
Power wiring	25-50	40
Lighting	1-25	12
Transformation and service	9-65	40
Instrument control wiring	3-8	5

The lower range is generally applicable to grass-roots single-product plants; the higher percentages apply to complex chemical plants and expansions to major chemical plants.

TABLE 10
Cost of buildings including services based on purchased-equipment cost

Type of process plant†	Percentage of purchased-equipment cost: New plant at new site (Grass roots)	New unit at existing site (Battery limit)	Expansion at an existing site
Solid	68	25	15
Solid-fluid	47	29	7
Fluid	45	5–18‡	6

† See Table 8 for definition of types of process plants.
‡ The lower figure is applicable to petroleum refining and related industries.

TABLE 11
Cost of buildings and services as a percentage of fixed-capital investment for various types of process plants

Type of process plant†	New plant at new site	New unit at existing site	Expansion at an existing site
Solid	18	1	4
Solid-fluid	12	7	2
Fluid	10	2–4‡	2

TABLE 12
Typical variation in percent of fixed-capital investment for yard improvements

Yard improvement	Range, %	Typical value, %
Site clearing	0.4-1.2	0.8
Roads and walks	0.2–1.2	0.6
Railroads	0.3–0.9	0.6
Fences	0.1-0.3	0.2
Yard and fence lighting	0.1-0.3	0.2
Parking areas	0.1-0.3	0.2
Landscaping	0.1-0.2	0.1
Other improvements	0.2-0.6	0.3

TABLE 13

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

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

TABLE 14

Typical variation in percent of fixed-capital investment for engineering and services

Component	Range, %	Typical value, %
Engineering	1.5–6.0	2.2
Drafting	2.0-12.0	4.8
Purchasing	0.2-0.5	0.3
Accounting, construction, and cost **engineering**	0.2-1.0	0.3
Travel and living	0.1-1.0	0.3
Reproductions and **communications**	0.2–0.5	0.2
Total **engineering** and **supervision** (including overhead)	4.0-21.0	8.1

TABLE 15
Typical variation in percent of fixed-capital investment for construction expenses

Component	Range, %	Typical value, %
Temporary construction and operations	1.0-3.0	1.7
Construction tools and rental	1.0-3.0	1.5
Home office personnel in field	0.2-2.0	0.4
Field payroll	0.4–4.0	1.0
Travel and living	0.1-0.8	0.3
Taxes and insurance	1.0-2.0	1.2
Startup materials and labor	0.2–1.0	0.4
overhead	0.3-0.8	0.5
Total construction expanses	4.2-16.6	7.0

TABLE 16
Correction factors for operating pressure, operating temperature, and material of construction to apply for fixed-capital investment of major plant items†‡

Operating pressure, psia (atm)	Correction factor
0.08 (0.005)	1.3
0.2 (0.014)	1.2
0.7 (0.048)	1.1
700 (48) 100 (6.8)	1.0 (base)
3000 (204)	1.21.1
6000 (408)	1.3

Operating temperature, °C	Correction factor
-80	1.3
0	1 .0 (base)
100	1.05
600	1.1
5,000	1.2
10,000	1.4

Material of construction	Correction factor
Carbon steel-mild	1 .0 (base)
Bronze	1.05
Carbon/molybdenum steel	1.065
Aluminum	1.075
Cast steel	1.11
Stainless steel	1.28 to 1.5
Worthite alloy	1.41
Hastelloy C alloy	1.54
Monel alloy	1.65
Nickel/inconel alloy	1.71
Titanium	2.0

† Adapted from D. H. Allen and R. C. Page, Revised Techniques for Predesign Cost Estimating, *Chem. Eng.*, 82(5): 142 (March 3, 1975).

‡ It should be noted that these factors are to be used *only* for complete, main-plant items and serve to correct from the base case to the indicated conditions based on pressure or temperature extremes that may be involved or special materials of construction that may be required. For the case of small or single pieces of equipment which are completely dedicated to the extreme conditions, the factors given in this table may be far too low and factors or methods given in other parts of this book must be used.

TABLE 17

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

Values presented are applicable for major process plant additions to an existing site where the necessary land is available through purchase or present ownership.† The values are based on fixed-capital investments ranging from under $1 million to over $20 million.

Item	Percent of deliveredequipment cost for Solid-processing plant‡	Solid-fluid-processing plant ‡	Fluid-processing plant ‡
Direct costs			
Purchased equipment-delivered (including fabricated equipment and process machinery) §	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	9	13	18
Piping (installed)	16	31	66
Electrical (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	13	10	10
Service facilities (installed)	40	55	70
Land (if purchase is required)	6	6	6
Total direct plant cost	264	293	346
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Total direct and indirect plant costs	336	359	420
Contractor's fee (about 5% of direct and indirect plant costs)	17	18	21
Contingency (about 10% of direct and indirect plant costs)	34	36	42
Fixed-capital investment	387	413	483
Working capital (about 15% of total capital investment)	68	74	86
Total capital investment	455	487	569

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

‡ See Table 8 for definition of types of process plants.

§ Includes pumps and compressors.

TABLE 18

Lang multiplication factors for estimation of fixed-capital investment or total capital investment

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

Type of plant	Factor for: Fixed-capital investment	Factor for: Total capital investment
Solid-processing plant	3.9	4.6
Solid-fluid-processing plant	4.1	4.9
Fluid-processing plant	4.8	5.7

TABLE 19

Capital-cost data for processing plants (1990)†

Product or process	Process remarks	Typical plant size, 1000 tons / yr	Fixed-capital investment, million $	$ of fixed-capital investment per annual ton of product	Power factor (x)‡ for plant-capacity ratio
	Chemical plants				
Acetic acid	CH_3OH and CO-catalytic	10	6	650	0.68
Acetone	Propylene-copper chloride catalyst	100	32	320	0.45
Ammonia	Steam reforming	100	24	240	0.53
Ammonium nitrate	Ammonia and nitric acid	100	5	50	0.65
Butanol	Propylene, CO, and H_2O—catalytic	50	40	800	0.40
Chlorine	Electrolysis of NaCl	50	28	550	0.45
Ethylene	Refinery gases	50	13	260	0.83
Ethylene oxide	Ethylene-catalytic	50	50	1000	0.78
Formaldehyde (37%)	Methanol-catalytic	10	16	1600	0.55
Glycol	Ethylene and chlorine	5	15	2900	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	10	8	800	0.68
Methanol	CO_2, natural gas, and steam	60	13	200	0.60
Nitric acid (high strength)	Ammonia-catalytic	100	6	65	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	5	3	650	0.60
Polyethylene (high density)	Ethylene-catalytic	5	16	3200	0.65
Propylene	Refinery gases	10	3	320	0.70
Sulfuric acid	Sulfur-catalytic	100	3	32	0.65
Urea	Ammonia and CO_2	60	8	130	0.70

TABLE 19
Capital-cost data for processing plants (1990) (*Continued*)

Product or process	Process remarks	Typical plant size, 1000 bbl / day	Fixed-capital investment, million $	$ of fixed-capital investment per bbl / day	Power factor (x)‡ for plant-capacity ratio
		Refinery units			
Alkylation (H_2SO_4)	Catalytic	10	19	1900	0.60
Coking (delayed)	Thermal	10	26	2600	0.38
Coking (fluid)	Thermal	10	16	1600	0.42
Cracking (fluid)	Catalytic	10	16	1600	0.70
Cracking	Thermal	10	5	500	0.70
Distillation (atm.)	65% vaporized	100	32	3m	0.90
Distillation (vac.)	65% vaporized	100	19	200	0.70
Hydrotreating	Catalytic desulfurization	10	3	320	0.65
Reforming	Catalytic	10	29	2900	0.60
Polymerization	Catalytic	10	5	500	0.58

† Adapted from K. M. Guthrie, Capital and Operating Costs for 54 Chemical Processes, *Chem. Eng.*, 77(13):140 (June 15, 1970) and K. M. Guthrie, "Process Plant Estimating, Evaluation, and Control," Craftsman Book Company of America, Solana Beach, California. 1974. See also J. E. Haselbarth, Updated Investment Costs for 60 Chemical Plants, *Chem. Eng.*, 74(25):214 (Dec. 4, 1967) and D. Drayer, How to Estimate Plant Cost-Capacity Relationship, *Petro/Chem Engr.*, 42(5):10 (1970).
‡ These power factors apply within roughly a three-fold ratio extending either way from the plant size as given.

TABLE 20
Relative labor rate and productivity indexes in the chemical and allied products industries for the United States (1989)†

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

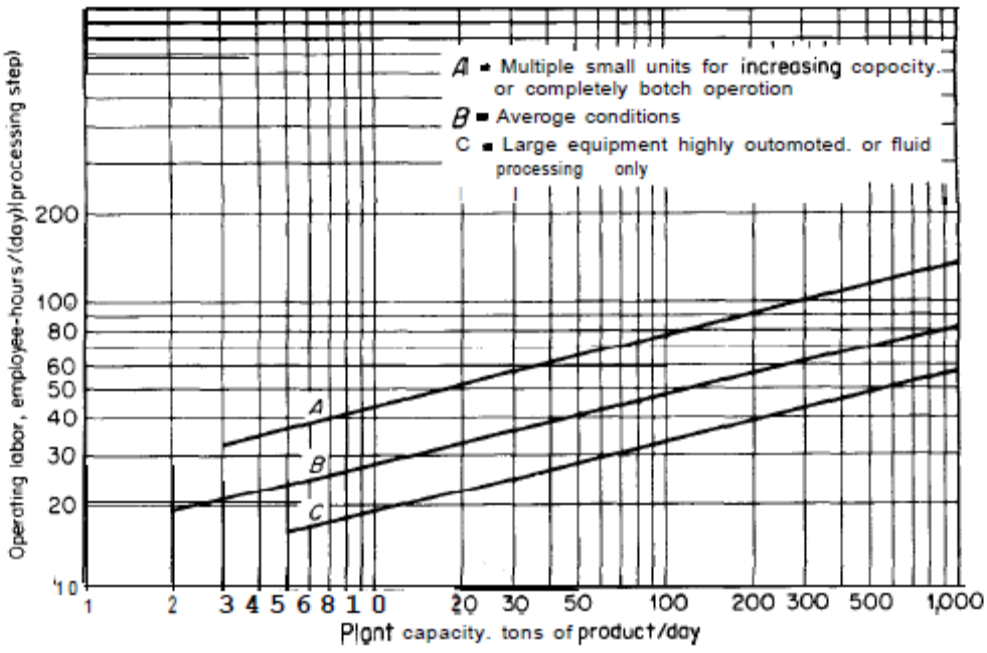

FIGURE 6-8
Operating labor requirements for chemical process industries.

TABLE 22
Operating labor, fuel, steam, power, and water requirements for various processes†

	Capacity thousand ton/yr	Operating labor and supervision workhours/ ton	Maintenance labor and supervision workhours/ ton	Power and utilities, per ton/yr or bbl/day capacity			
				Fuel MM Btu/h	Steam lb/h	Power kWh	Water gph
Chemical plants							
Acetone	100	0.518	0.315		1.73	310	5.18
Acetic acid	10	1.483	0.984			180	0.58
Butadiene	100	0.345	0.285		0.012	130	0.73
Ethylene oxide	100	0.232	0.104		4.88	140	0.148
Formaldehyde	100	0.259	0.328		34.6	200	0.029
Hydrogen peroxide	100	0.288	0.352		2.62	160	0.186
Isoprene	100	0.230	0.325		0.81	710	0.001
Phosphoric acid	10	1.85	0.442		0.18	40	0.03
Polyethylene	100	0.259	0.295		0.23	450	0.0004
Urea	100	0.238	0.215		0.33	135	0.0002
Vinyl acetate	100	0.432	0.528		1.34	275	0.27
Refinery units							
	Thousand bbl/day	Workhours/ bbl	Workhours/ bbl				
Alkylation	10	0.007	0.0895		10.83	0.07	1.48
Coking (delayed)	10	0.011‡	0.0096	0.007	1.85	0.07	
Coking (fluid)	10	0.0096	0.0058	0.012	2.55	0.06	0.64
Cracking (fluid)	10	0.0122	0.0115		(4.73)§	0.02	0.33
Cracking (thermal)	10	0.0096	0.0025	0.012	(2.55)§	0.06	0.64
Distillation (atm)	10	0.0048	0.0042	0.004	0.25	0.03	0.16
Distillation (vac)	10	0.0024	0.0154	0.003	0.95	0.04	0.18
Hydrotreating	10	0.0048	0.0028	0.006	0.92	0.01	0.14
Reforming, catalyt.	10	0.0048	0.0078	0.002	1.38	0.23	0.28
Polymerization	10	0.0024	0.0158		4.85	0.07	0.43

† Based on information from K. M. Guthrie, Capital and Operating Costs for 54 Chemical Processes, *Chem. Eng.*, **77(13)**: 140 (June 15, 1970).

‡ Includes two coke cutters (1 shift/day).

§ Net steam generated.

TABLE 25
Estimation of costs for maintenance and repairs

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