# CHEMICAL ENGINEERING DESIGN & SAFETY

## CHE 4253

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## Process Engineering Economics

**1-Plant Cost Estimation**

# ECONOMIC DESIGN CRITERIA

## BASIC ECONOMIC TERMS

- Total Capital Investment, *TCI* or *I*

  Total Capital Investment=Fixed Capital Investment+ Working Capital

  $$TCI = FCI + WC$$

- Fixed Capital Investment, *FCI* or $I_F$

  FCI = (Direct Costs) + (Indirect Costs)

- Working Capital, *WC* or $I_W$

  Cash, raw materials, stock, etc. About 10-20% of *TCI*.

# BASIC ECONOMIC TERMS

- Product Cost $C$

$$C=C_I+C_Q+C_O+C_G$$

- Fixed Charges, $C_I$

  Do not depend on production level (insurance, property taxes, depreciation, rent etc.)

- Direct Production Cost, $C_Q$

  Labor, utilities, raw materials, maintenance, supplies, royalties etc.

- Plant Overhead, $C_O$

  Recreation, employee facilities, packaging etc.

- General Expenses, $C_G$

  Administration, marketing, R&D, distribution.

# BASIC ECONOMIC TERMS

- Income from Sales, $S$ in ($/yr)
- Gross Earnings, $R$ in ($/yr)

$$R = S - C$$

- Net Earnings, $P$ in ($/yr)

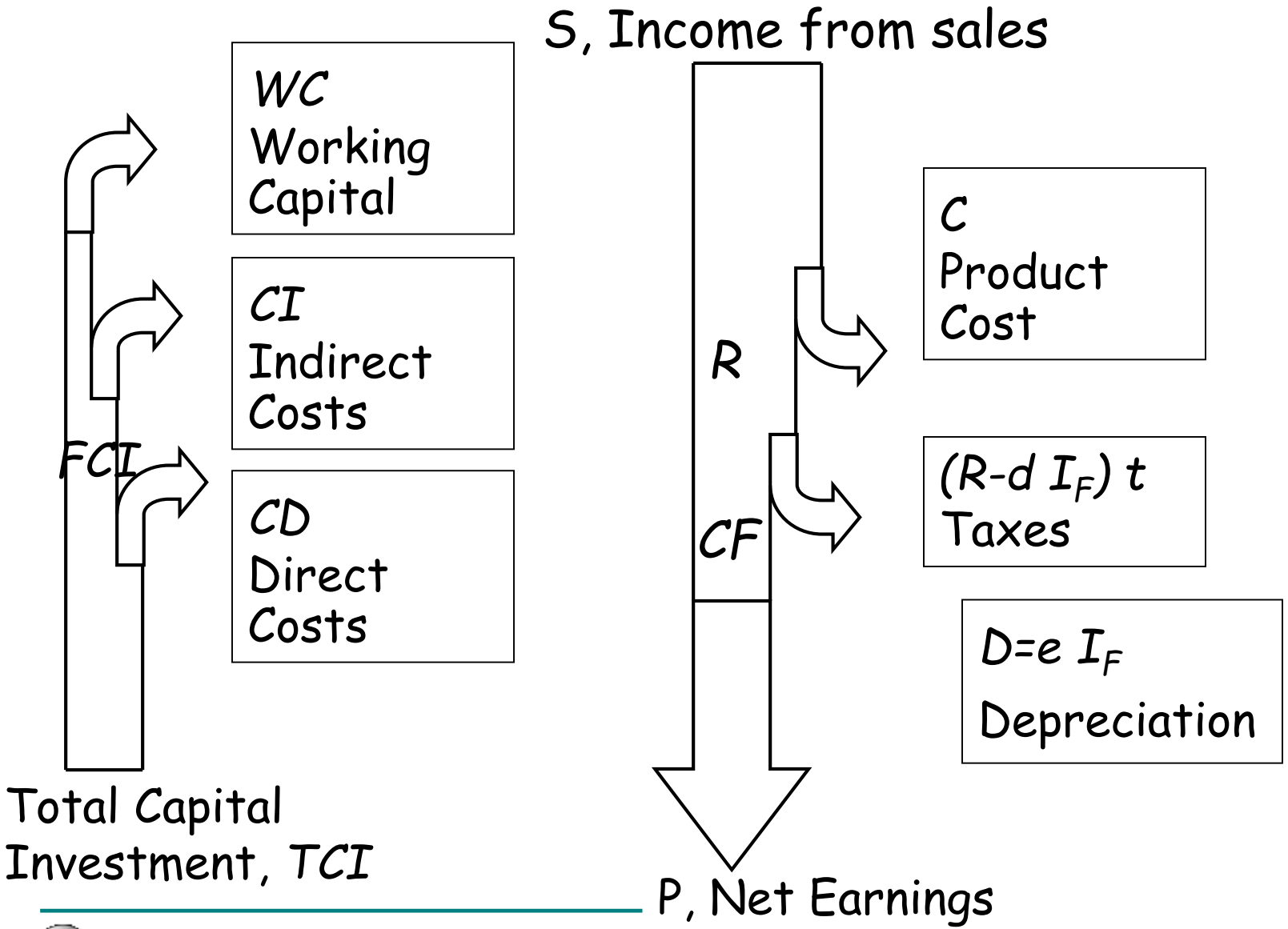
$$P = R - (R - d\,I_F)\,t$$

(Net Profit) = (Gross) - (Taxes)

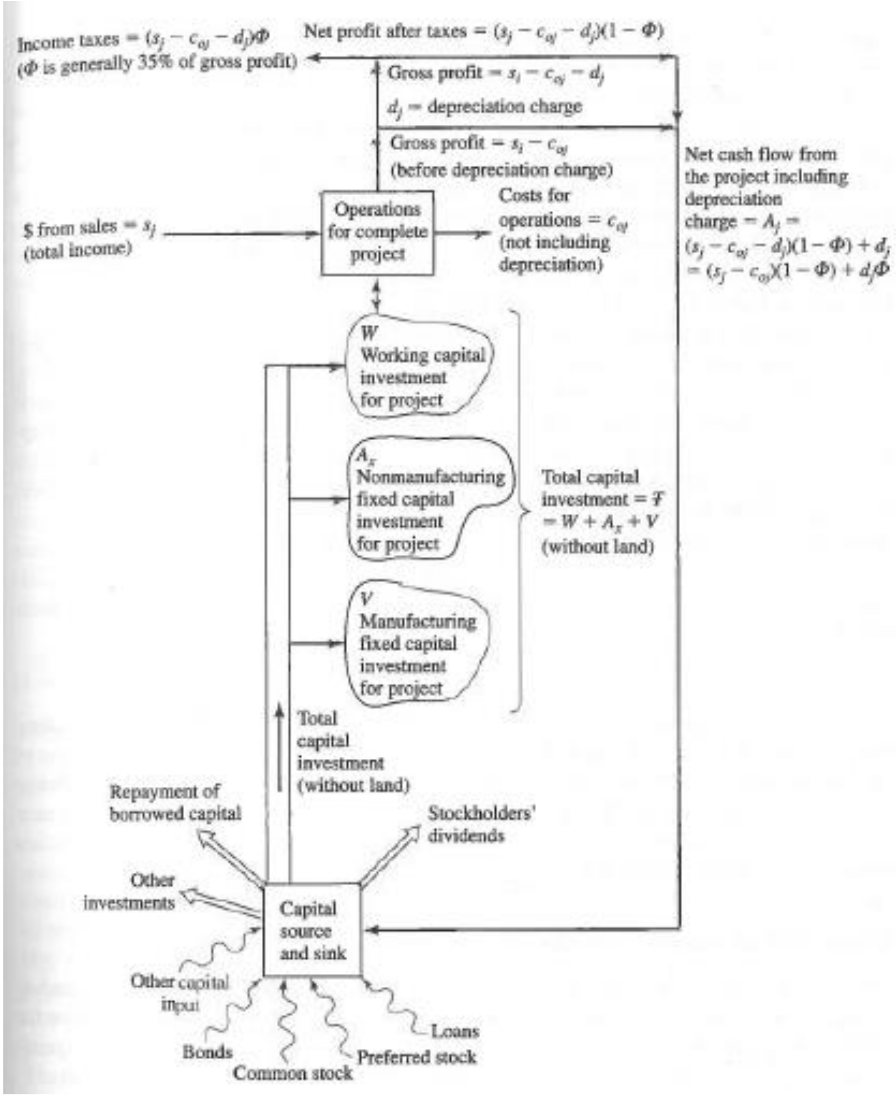
- Depreciation rate

Taxation purposes, $d\,I_F$

# BASIC ECONOMIC TERMS



# NET PROFIT


Income taxes = $(s_j - c_{oj} - d_j)\Phi$
($\Phi$ is generally 35% of gross profit)
Net profit after taxes = $(s_j - c_{oj} - d_j)(1 - \Phi)$
Gross profit = $s_j - c_{oj} - d_j$
$d_j$ = depreciation charge
Gross profit = $s_j - c_{oj}$
(before depreciation charge)
Net cash flow from the project including depreciation charge = $A_j$ = $(s_j - c_{oj} - d_j)(1 - \Phi) + d_j$ = $(s_j - c_{oj})(1 - \Phi) + d_j\Phi$
$ from sales = $s_j$
(total income)
Operations for complete project
Costs for operations = $c_{oj}$
(not including depreciation)
W
Working capital investment for project
$A_x$
Nonmanufacturing fixed capital investment for project
V
Manufacturing fixed capital investment for project
Total capital investment = $\mathcal{T} = W + A_x + V$
(without land)
Total capital investment (without land)
Repayment of borrowed capital
Stockholders' dividends
Other investments
Capital source and sink
Other capital input
Bonds
Common stock
Preferred stock
Loans

## DESIGN STAGES

1. Inception
2. Preliminary evaluation of economics and market
3. Data gathering
4. Basic Engineering & Final economic evaluation
5. Detailed engineering design
6. Procurement
7. Erection
8. Start-up
9. Production

# BASIC ECONOMIC TERMS

## Salvage Value

Net cash obtainable from the sale of used property (above charges for removal and sale)

*Scrap value*: Salvage value after dismantling a unit.

## Present Value

*Book Value* : (Total Capital Investment) - (All Depreciation)

*Market Value* : Cash obtainable from selling the unit.

*Replacement Value* : Cost of obtaining the same property.

# BASIC ECONOMIC TERMS

## Depreciation

Reduction in value due to any causes.

*Example*: Pump

Cost : $C_V$ = \$12,000

Scrap value : $V_S$ = \$2,000

Depreciation : $C_V - V_S$ = \$10,000

For engineers, depreciation is considered as a cost for using the equipment.

# DEPRECIATION

## Types Of Depreciation

Physical: Wear and Tear, corrosion, accidents, age deterioration.

Functional: All other causes.

Obsolescence: Due to technological advances.

Depletion: Loss due to materials consumed. Applicable to Natural Resources (timber, mineral, oil deposits)

**IRS:** "A reasonable allowance for the exhaustion, wear and tear of property used in the trade or business including a reasonable allowance for obsolescence"

# BASIC ECONOMIC TERMS

**Service Life**

The IRS has determined various values (See Peters et al., 2003, for complete list).

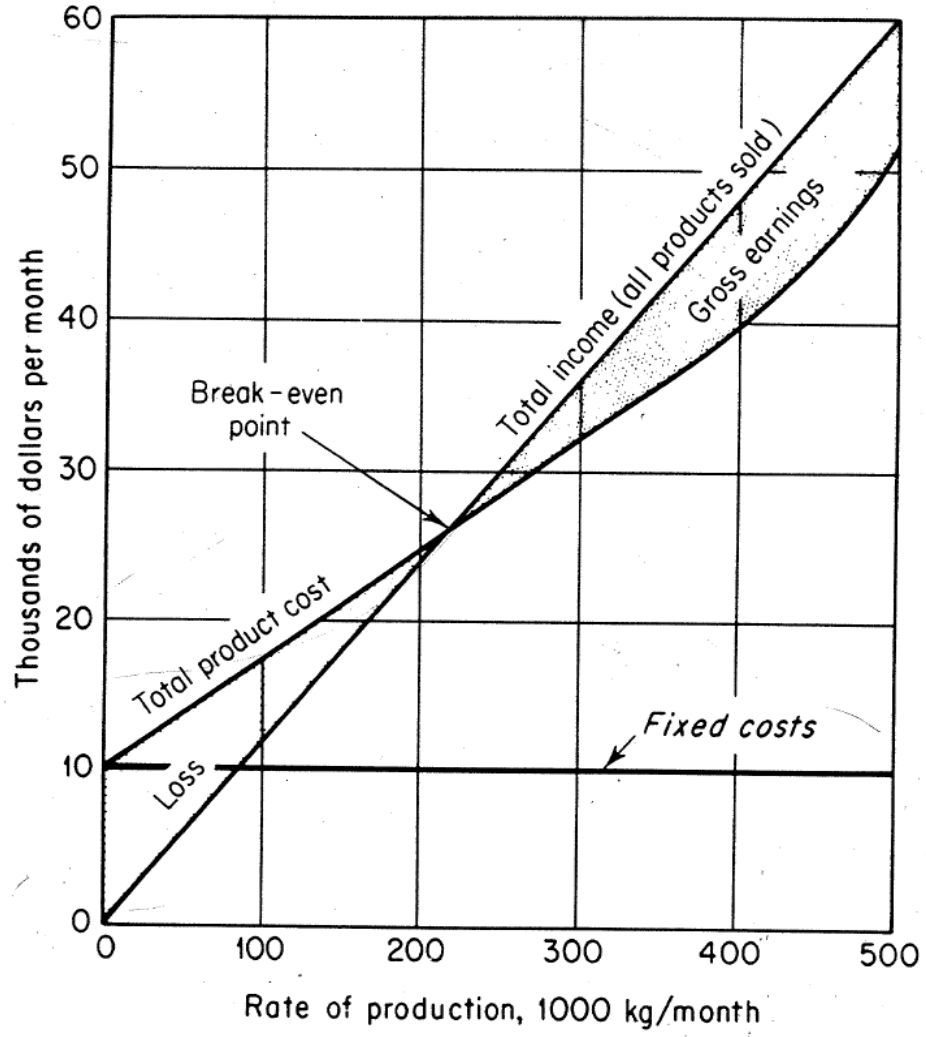
*Group 1*: General Business Assets. (Office furniture, Land, Buildings, etc)

*Group 2:* Non-manufacturing activities: (Agriculture, Fishing, Mining, etc.)

*Group 3*: Manufacturing, e.g. Petroleum Refining: 16 years. Chemicals 11 years.

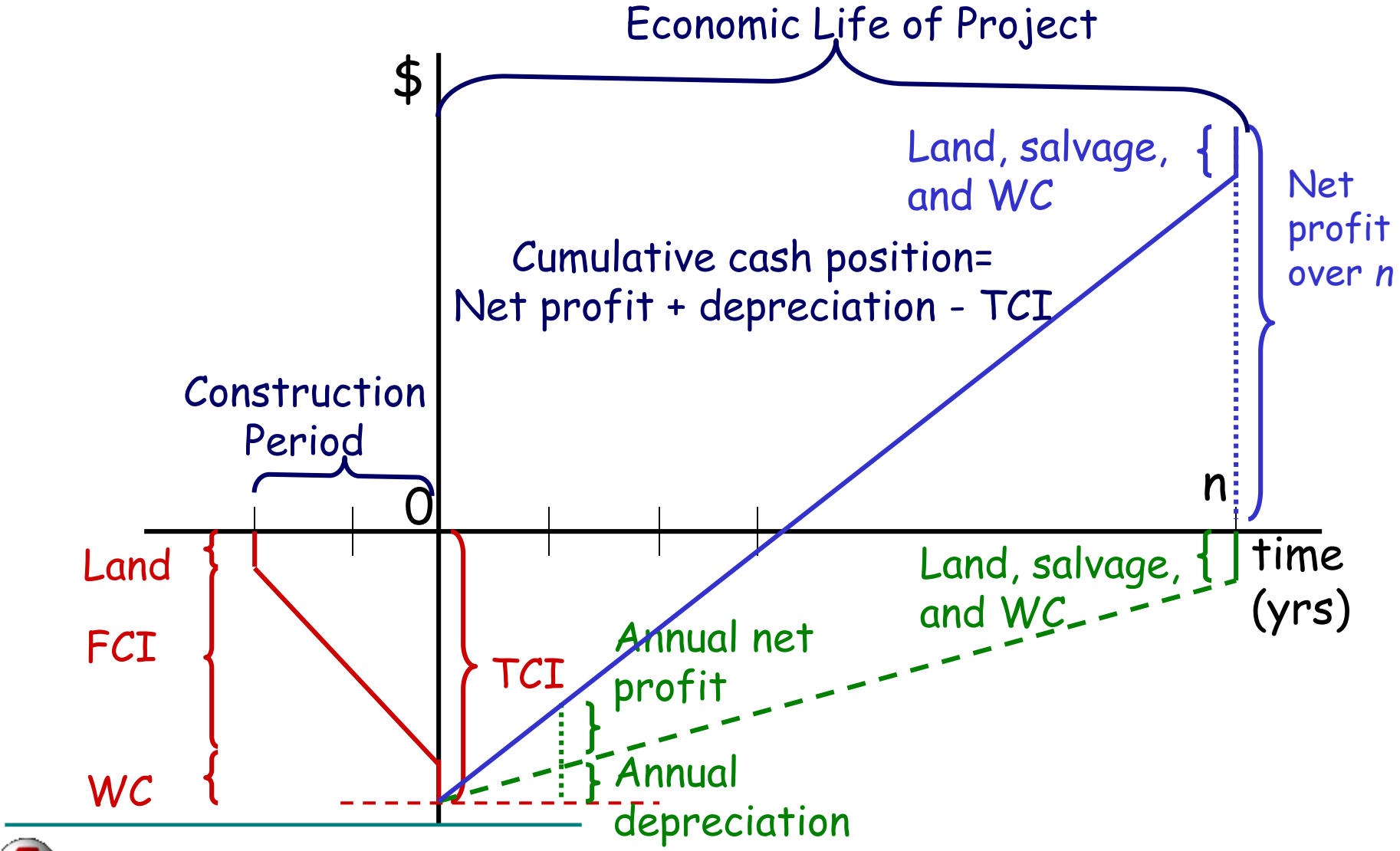
*Group 4:* Transportation, Communication and Public Utilities: (Electrical, Gas, Motor transport, Radio and TV broadcasting, railroad, etc.)

# BASIC ECONOMIC TERMS (break-even chart)



# BASIC ECONOMIC TERMS

## Cumulative Cash Position



# COST ESTIMATION

***Fixed Capital Investment***: Cost of equipment and facilities

$$FCI = \text{Direct Costs} + \text{Indirect Costs}$$

***Direct Costs***:

1. Purchased equipment: Columns, Heat Exchangers, pumps, tanks, etc.
2. Equipment Installation
3. Piping (includes insulation)
4. Instruments and Control
5. Electrical Equipment.
6. Buildings: Process, Administration, Maintenance shops, etc.
7. Site Preparation
8. Service Facilities: steam, water, air, fuel, etc. Waste treatment, fire control, offices, etc.
9. Land

# COST ESTIMATION

***Indirect Costs*:**

1. Engineering and Supervision: Administrative and Design. Supervision and Inspection.
2. Construction Expenses
3. Contractor's fee
4. Contingency.
5. Start up expenses (sometimes in WC)

# COST ESTIMATION

***Types Of Cost Estimates***

1. Order of Magnitude estimate. Extrapolate similar plant cost
   Accuracy: over 30%
2. Study Estimate. Knowledge of major pieces of equipment
   Accuracy: ± 30%
3. Preliminary Estimate. Enough for budget authorization.
   Accuracy: ± 10-20%
4. Definitive Estimate. Based on basic Engineering and quotes from suppliers and contractors.
   Accuracy: ± 10%
5. Detailed Estimate.Based on Detailed Engineering.
   Accuracy: ± 5%

# COST ESTIMATION

***Cost Indexes***

*Present Cost=(original cost at time t)** $\left( \frac{index\ value\ now}{index\ value\ at\ time\ t} \right)$

- Marshall and Swift.

1. *All industry-equipment index*. Arithmetic average of 47 equipment types.
2. *Process-industry equipment index*. Weighted average of 8 of these:

| | | | |
|---|---|---|---|
| cement | 2% | paint | 5% |
| chemicals | 48% | paper | 10% |
| clay products | 2% | petroleum | 22% |
| glass | 3% | rubber | 8% |

M&S was 100 in 1926. Published in "Chemical Engineering".

# COST INDEXES

- Engineering News-Record Construction Cost index.
  - Steel, lumber, labor, concrete.
  - Published in "Engineering News-record".
  - ENR value reported based on 100 in 1913, 1949 or 1967.
- Nelson-Farrar Refinery Construction Cost index.
  - Skilled and common labor, iron and steel, building materials, miscellaneous equipment.
  - Published in "Oil and Gas Journal".
  - N-R value of 100 in 1946.
- Chemical Engineering Plant Cost Index. Chemical Plants.

| | | | |
|---|---|---|---|
| Equipment, machinery supports | 61% | Engineering and supervision | 10% |
| Installation labor | 22% | Buildings, material, labor | 7% |

Published in "Chemical Engineering".
PCI value of 100 in 1957-59.

# COST INDICES (as inflation indicators)



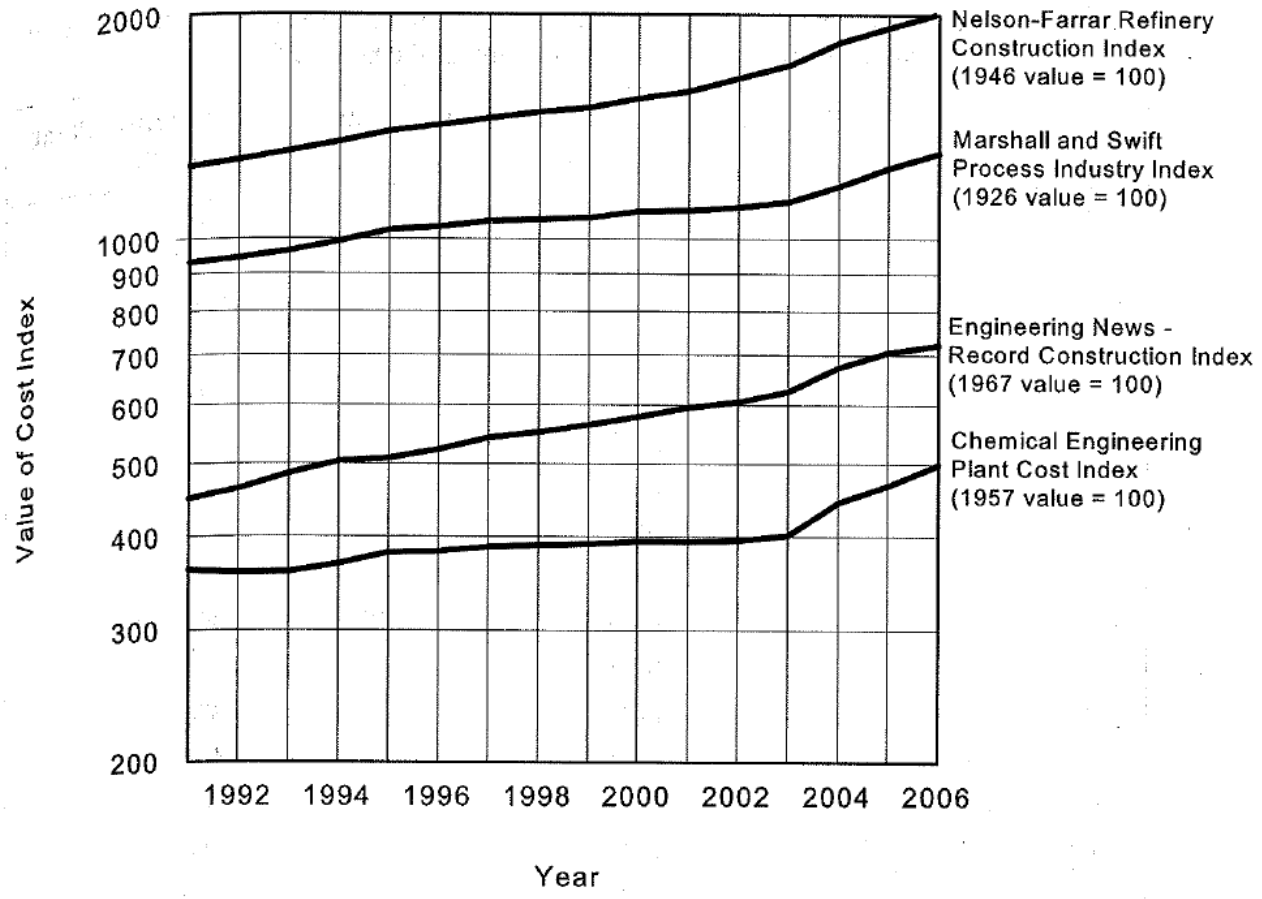



**Figure 7.3** The Variations in Several Commonly Used Cost Indexes Over 15 Years (1992–2006)

From Turton et al., 2009

# Methods For Estimating Capital Investment

## *Detailed-Item Estimate*

All items in the direct and indirect cost are evaluated with as much detail as possible. All specs are known.
(± 5% accuracy, contractor's estimate)

***PRIOR LIST***

1. Order of Magnitude estimate. Extrapolate similar plant cost
2. Study Estimate. Knowledge of major pieces of equipment.
3. Preliminary Estimate. Enough for budget authorization.
4. Definitive Estimate. Based on basic Engineering and quotes from suppliers and contractors.
5. Detailed Estimate. Based on Detailed Engineering.

# Methods For Estimating Capital Investment

## *Percentage of Delivered-Equipment Cost.*

All items in the direct and indirect cost are evaluated as a percentage of the delivered-equipment cost. Usually ± 30% (definitive estimate in certain cases, ± 10% )

$$C = \left[\sum E + \sum \left( f_1 E + f_2 E + f_3 E + \ldots \right)\right] f_I$$

***PRIOR LIST***

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# Methods For Estimating Capital Investment

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

# Methods For Estimating Capital Investment

## *Estimation based on "Lang" factors .*

Named after Lang (1947). The Fixed Capital Investment is found by multiplying equipment cost by a factor (± 30% accuracy, order of magnitude estimate)

$$C = \left[E\left(1 + f_F + f_p + f_m\right) + E_i + A\right] f_I$$

$f_F$: cost factor for field labor
$f_p$: cost factor for piping materials
$f_m$: cost factor for miscellaneous (insulation, foundations etc.)
$E$: cost of installing equipment
$A$: incremental cost for corrosion resistant materials
$f_I$: indirect cost factor=**4.74**
(fluid processing plants)

***PRIOR LIST***

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# Methods For Estimating Capital Investment

## *Power factor applied to plant-capacity .*

Order of magnitude estimates based on the fixed capital investment for a similar plant.

$$C = C_{old} \left(R\right)^{x} f$$

*x*: between 0.6 and 0.7
*R*: Capacity ratio, (new facility)/(old facility)

If the direct, *D*, and indirect, *I*, costs are known, then: $C = \left[D\left(R\right)^{x} + I\right] f$

***PRIOR LIST***

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# Methods For Estimating Capital Investment

## *Power factor applied to plant-capacity .*

Order of magnitude estimates based on the fixed capital investment for a similar plant.

$$C = C_{old}\left(R\right)^{x} f$$

*x*: between 0.6 and 0.7

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

***PRIOR LIST***

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# Methods For Estimating Capital Investment

## *Power factor applied to plant-capacity .*

The factor *f* is a composite of geographical labor cost index, the area productivity index and a material and equipment index.

***Example:***

Plant in Dallas. What is the cost for a similar plant in Los Angeles?
LA labor rate=0.88, TX labor rate=1.22
LA productivity=0.89, TX productivity=1.04

(Tab. 6-12 in Peters et al., 2003)

Relative Labor=(TX/LA)=1.22/0.88 = 1.3864
Relative Productivity=(TX/LA)=1.04/0.89=1.17

$$f = \left(\frac{Rate(TX)}{Rate(LA)}\right)_{labor}\left(\frac{Rate(TX)}{Rate(LA)}\right)_{productivity} = \left(\frac{1.22}{0.88}\right)\left(\frac{1.04}{0.89}\right) = 1.62$$

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