CH402 Chemical Engineering Process Design

Class Notes L14

Cost Estimation & Capital Investments

WPR1 Corrections Due Thursday 24 Feb 2359

(Bonus, Point value = 40% of cut)

Download and open “Cost and Evaluation Spreadsheet”

L14 Learning Objectives

1. Use an I/O diagram to estimate total cash flow for a process.
2. Calculate the different types of cash flow in a chemical process (Figure 6-1).
3. Calculate equipment costs using capacity scaling factors.

Definitions:

Working capital, nonmanufacturing and manufacturing fixed costs, direct and indirect costs, total capital investment, gross profit, purchased equipment costs, operating labor costs, utility costs, depreciation, annual total product costs, cumulative cash position, cost capacity scaling factors

Known Vinyl Chloride Routes

5 processes

$C_2H_2 + HCl \longrightarrow C_2H_3Cl$ A

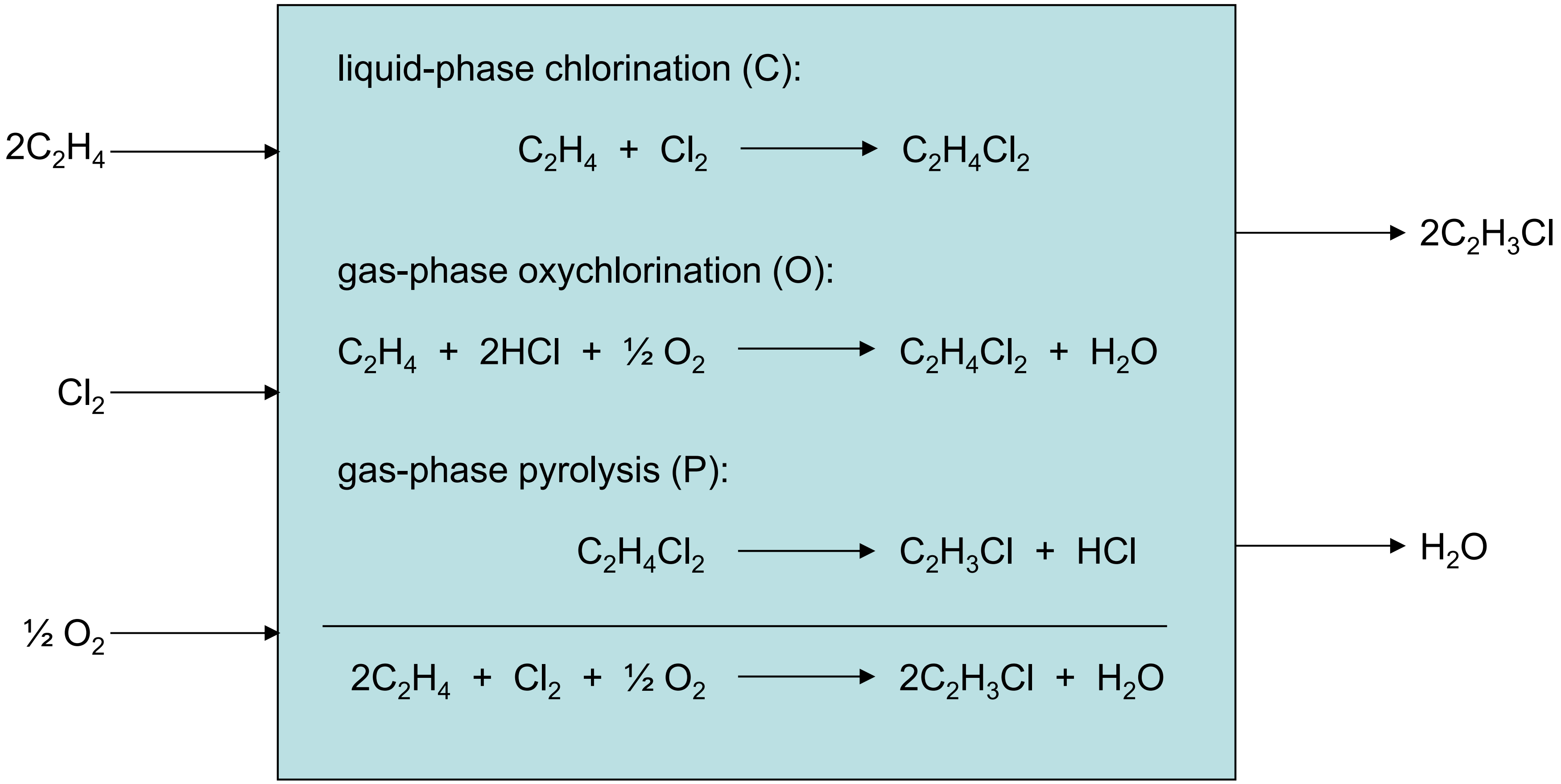
$C_2H_4 + Cl_2 \longrightarrow C_2H_3Cl + HCl$ C

$C_2H_4 + Cl_2 \longrightarrow C_2H_3Cl + HCl$ C-P

$C_2H_4 + HCl + \frac{1}{2} O_2 \longrightarrow C_2H_3Cl + H_2O$ O-P

$2C_2H_4 + Cl_2 + \frac{1}{2} O_2 \longrightarrow 2C_2H_3Cl + H_2O$ C-O-P

Input/Output Structure - Route 5 – “COP”



$2C_2H_4$

Cl_2

$\frac{1}{2}$ O_2

liquid-phase chlorination (C):

$$C_2H_4 + Cl_2 \longrightarrow C_2H_4Cl_2$$

gas-phase oxychlorination (O):

$$C_2H_4 + 2HCl + \tfrac{1}{2} O_2 \longrightarrow C_2H_4Cl_2 + H_2O$$

gas-phase pyrolysis (P):

$$C_2H_4Cl_2 \longrightarrow C_2H_3Cl + HCl$$

$$2C_2H_4 + Cl_2 + \tfrac{1}{2} O_2 \longrightarrow 2C_2H_3Cl + H_2O$$

$2C_2H_3Cl$

H_2O

The I/O diagram allows us to assessment the overall economics of the process.

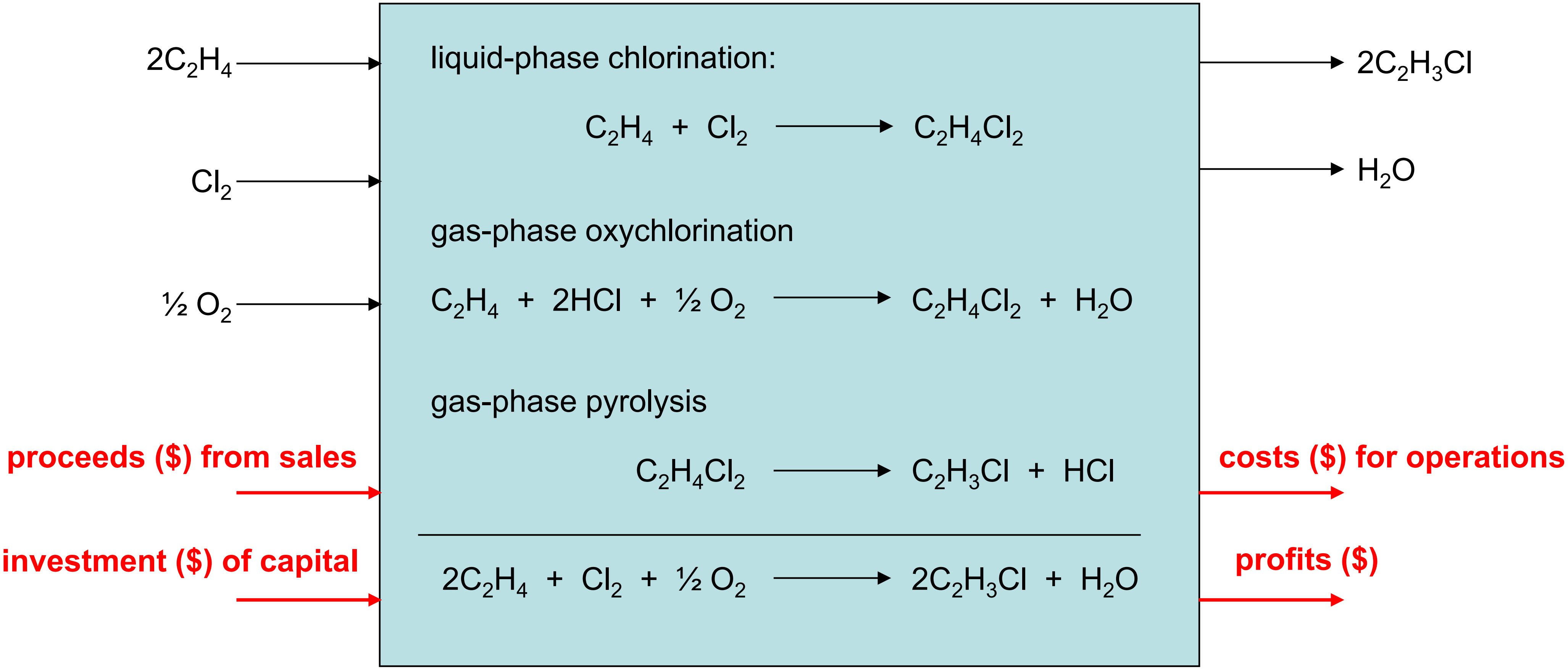
Economic Analysis Based on I/O Structure

			Reaction Path, kg/kg VC				
Species	MW, kg/kgmol	Price, $/kg	1	2	3	4	5
Cl_2	70.9	0.03	---	-1.13	-1.13		-0.57
HCl	36.5	0.22	-0.58	0.58	0.58	-0.58	---
C_2H_2	26.0	1.39	-0.42	---	---	---	---
C_2H_4	28.1	0.45	---	-0.45	-0.45	-0.45	-0.45
C_2H_3Cl	62.5	0.45	1.00	1.00	1.00	1.00	1.00
O_2	32.0	0.04	---	---	---	-0.26	-0.13
product value			$0.45	$0.58	$0.58	$0.45	$0.45
reactant cost			-$0.71	-$0.24	-$0.24	-$0.34	-$0.22
excess value			-$0.26	$0.34	$0.34	$0.11	$0.23
							I/O diagram
							for process
							5 is shown
							on previous
							slide

The bottom line represents $ per kg of product. If we know the kg/year, then we know the annual cash flow.

Input/Output Diagram - Route 5 - COP

Decision Makers (company, government, army, etc.)
are concerned with cash flows.



$2C_2H_4$

Cl_2

$\frac{1}{2}$ O_2

proceeds ($) from sales

investment ($) of capital

liquid-phase chlorination:

$$C_2H_4 + Cl_2 \longrightarrow C_2H_4Cl_2$$

gas-phase oxychlorination

$$C_2H_4 + 2HCl + \tfrac{1}{2}O_2 \longrightarrow C_2H_4Cl_2 + H_2O$$

gas-phase pyrolysis

$$C_2H_4Cl_2 \longrightarrow C_2H_3Cl + HCl$$

$$2C_2H_4 + Cl_2 + \tfrac{1}{2}O_2 \longrightarrow 2C_2H_3Cl + H_2O$$

$2C_2H_3Cl$

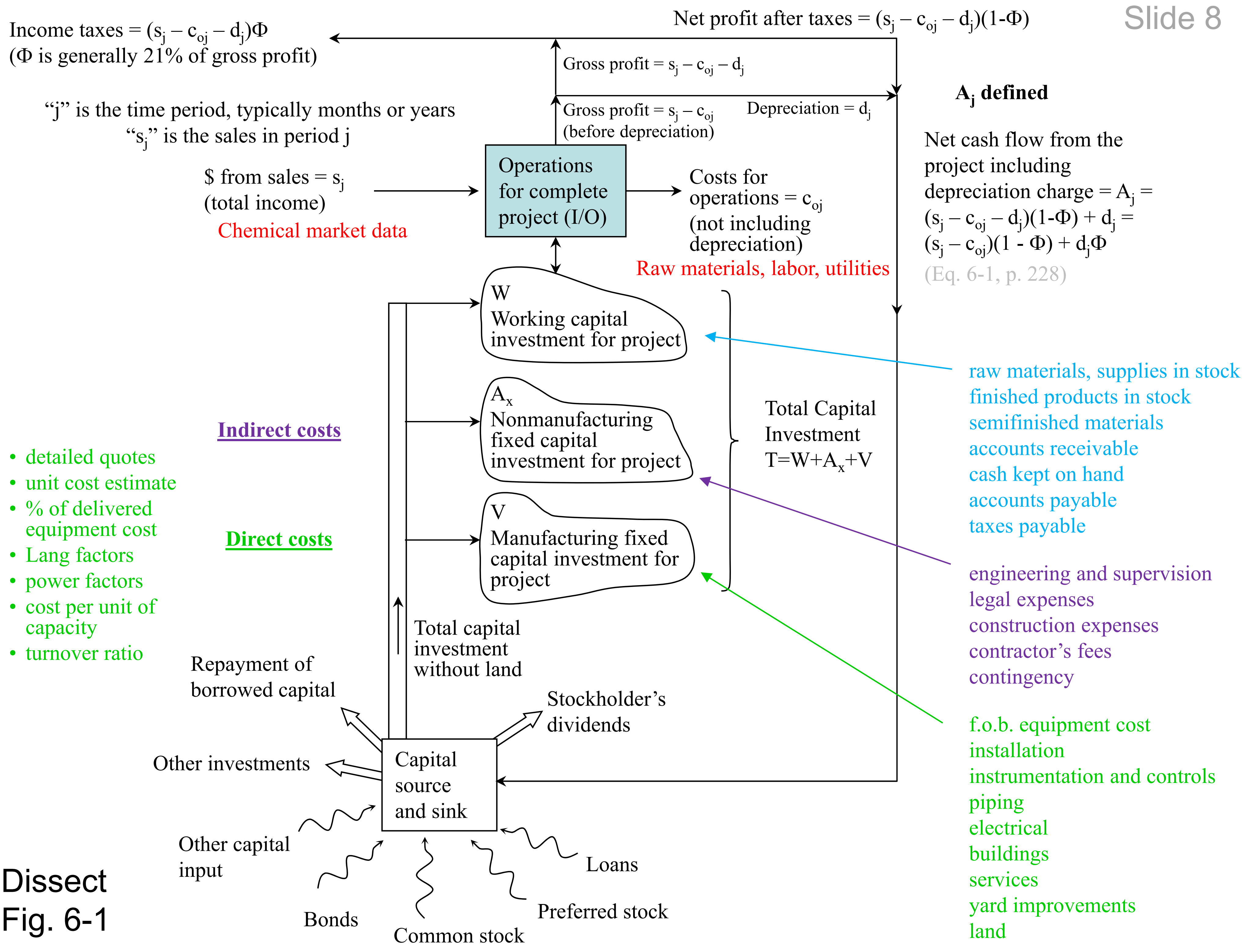
H_2O

costs ($) for operations

profits ($)

Evaluation of Industrial Processes

- Economic – depends on cost of process, cost of process flows, and cash flows to and from process.
- Equipment needs to be designed, sized, and costed.
- Preliminary cash flow patterns must be created from *future cash flows* and analyzed.
- *Future cash flows* are functionally related to chemical flow rates through market values.
- *Future* cash flows must account for (1) interest, (2) depreciation, and (3) taxes.



Income taxes = $(s_j - c_{oj} - d_j)\Phi$
(Φ is generally 21% of gross profit)

Net profit after taxes = $(s_j - c_{oj} - d_j)(1\text{-}\Phi)$

Gross profit = $s_j - c_{oj} - d_j$

Gross profit = $s_j - c_{oj}$
(before depreciation)

Depreciation = d_j

"j" is the time period, typically months or years
"s_j" is the sales in period j

$ from sales = s_j
(total income)
Chemical market data

Operations for complete project (I/O)

Costs for operations = c_{oj}
(not including depreciation)
Raw materials, labor, utilities

A_j defined

Net cash flow from the project including depreciation charge = A_j =
$(s_j - c_{oj} - d_j)(1\text{-}\Phi) + d_j$ =
$(s_j - c_{oj})(1 - \Phi) + d_j\Phi$
(Eq. 6-1, p. 228)

W
Working capital investment for project

A_x
Nonmanufacturing fixed capital investment for project

V
Manufacturing fixed capital investment for project

Total Capital Investment
$T=W+A_x+V$

raw materials, supplies in stock
finished products in stock
semifinished materials
accounts receivable
cash kept on hand
accounts payable
taxes payable

Indirect costs

engineering and supervision
legal expenses
construction expenses
contractor's fees
contingency

Direct costs

f.o.b. equipment cost
installation
instrumentation and controls
piping
electrical
buildings
services
yard improvements
land

- detailed quotes
- unit cost estimate
- % of delivered equipment cost
- Lang factors
- power factors
- cost per unit of capacity
- turnover ratio

Total capital investment without land

Repayment of borrowed capital

Stockholder's dividends

Other investments

Capital source and sink

Other capital input

Bonds

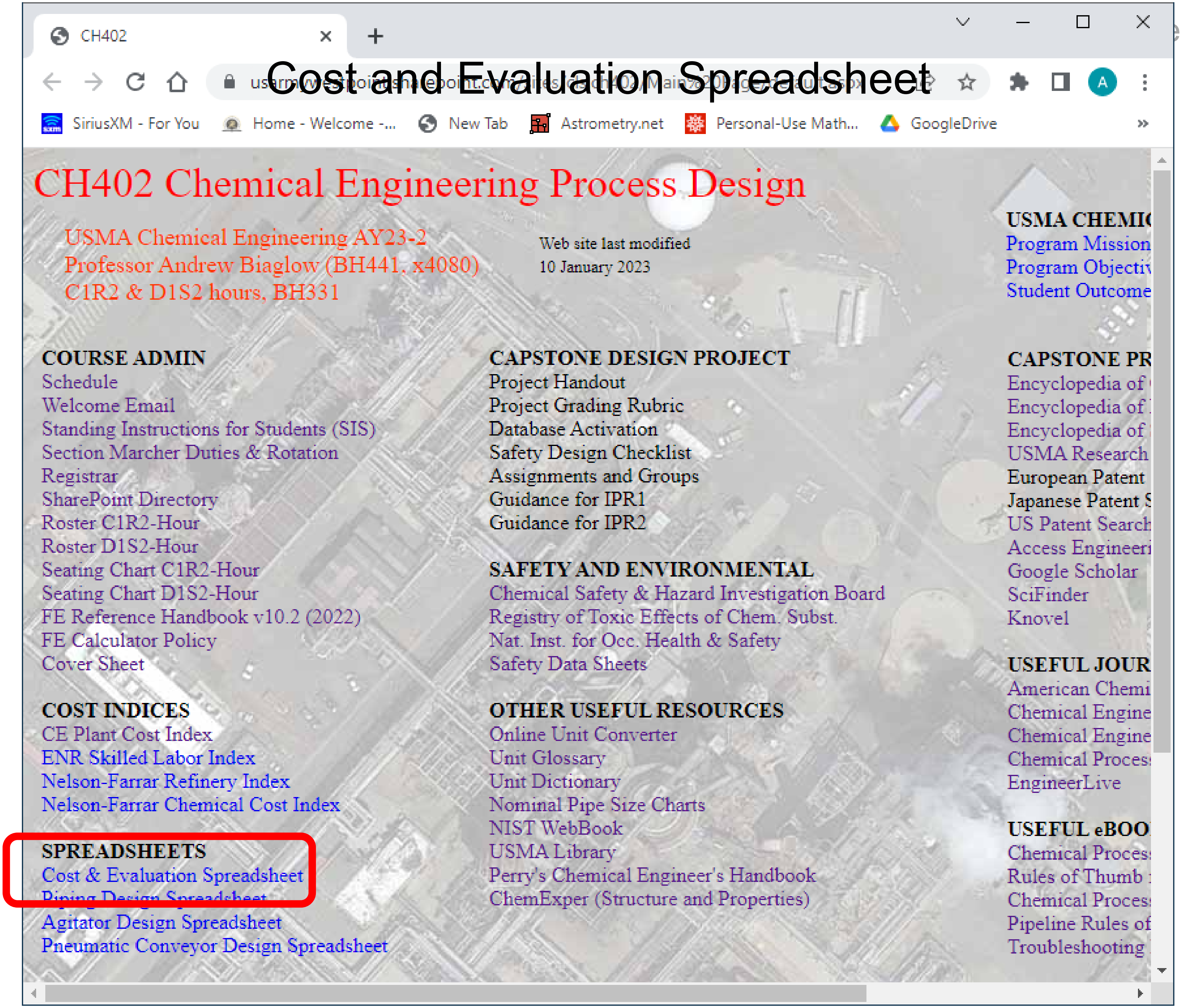
Common stock

Preferred stock

Loans

Dissect
Fig. 6-1

Cost and Evaluation Spreadsheet



CH402 Chemical Engineering Process Design

USMA Chemical Engineering AY23-2
Professor Andrew Biaglow (BH441, x4080)
C1R2 & D1S2 hours, BH331

Web site last modified
10 January 2023

USMA CHEMI
Program Mission
Program Objectiv
Student Outcome

COURSE ADMIN
- Schedule
- Welcome Email
- Standing Instructions for Students (SIS)
- Section Marcher Duties & Rotation
- Registrar
- SharePoint Directory
- Roster C1R2-Hour
- Roster D1S2-Hour
- Seating Chart C1R2-Hour
- Seating Chart D1S2-Hour
- FE Reference Handbook v10.2 (2022)
- FE Calculator Policy
- Cover Sheet

COST INDICES
- CE Plant Cost Index
- ENR Skilled Labor Index
- Nelson-Farrar Refinery Index
- Nelson-Farrar Chemical Cost Index

SPREADSHEETS
- Cost & Evaluation Spreadsheet
- Piping Design Spreadsheet
- Agitator Design Spreadsheet
- Pneumatic Conveyor Design Spreadsheet

CAPSTONE DESIGN PROJECT
- Project Handout
- Project Grading Rubric
- Database Activation
- Safety Design Checklist
- Assignments and Groups
- Guidance for IPR1
- Guidance for IPR2

SAFETY AND ENVIRONMENTAL
- Chemical Safety & Hazard Investigation Board
- Registry of Toxic Effects of Chem. Subst.
- Nat. Inst. for Occ. Health & Safety
- Safety Data Sheets

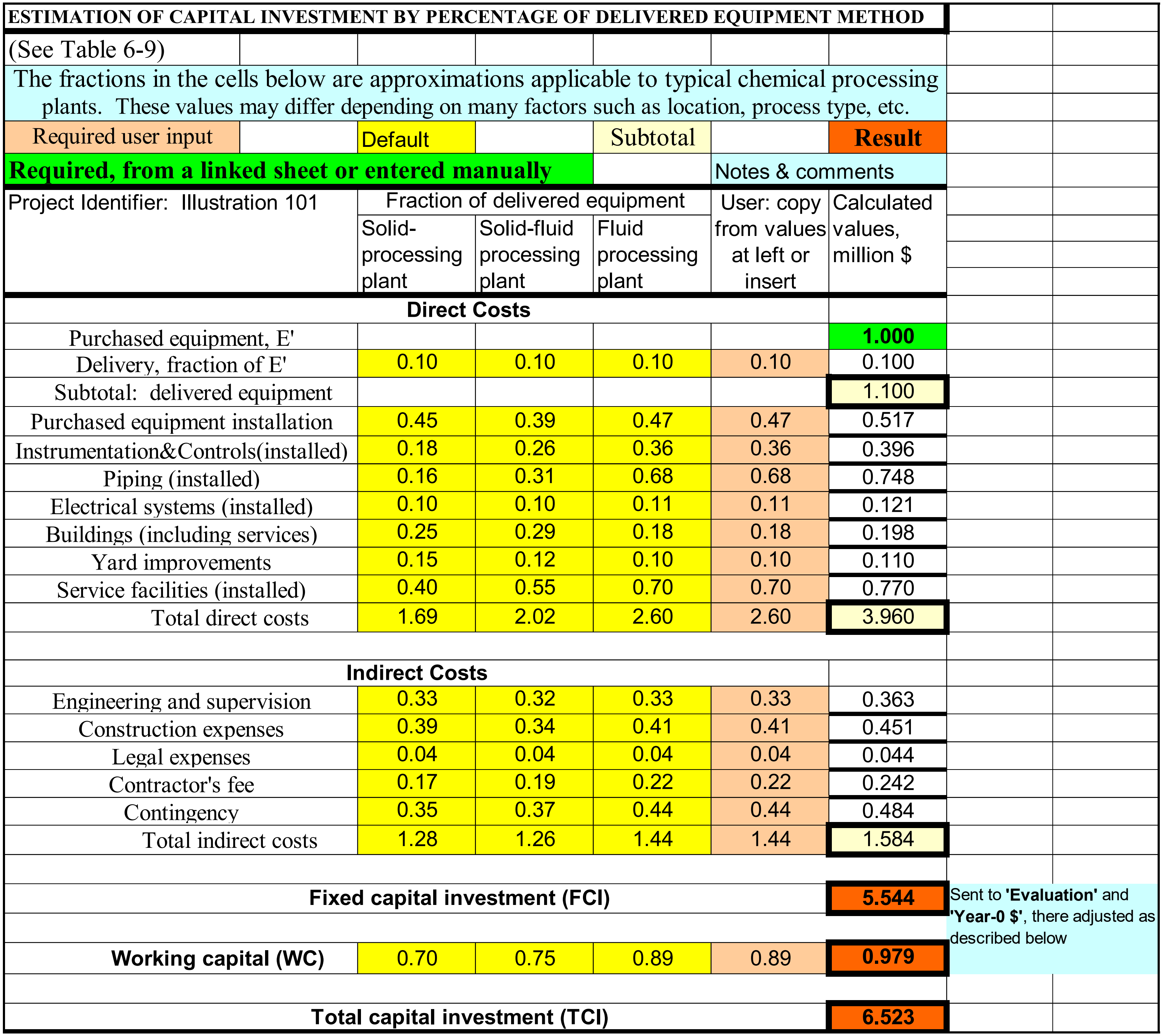
OTHER USEFUL RESOURCES
- Online Unit Converter
- Unit Glossary
- Unit Dictionary
- Nominal Pipe Size Charts
- NIST WebBook
- USMA Library
- Perry's Chemical Engineer's Handbook
- ChemExper (Structure and Properties)

CAPSTONE PR
- Encyclopedia of
- Encyclopedia of
- Encyclopedia of
- USMA Research
- European Patent
- Japanese Patent S
- US Patent Search
- Access Engineeri
- Google Scholar
- SciFinder
- Knovel

USEFUL JOUR
- American Chemi
- Chemical Engine
- Chemical Engine
- Chemical Proces
- EngineerLive

USEFUL eBOO
- Chemical Proces
- Rules of Thumb
- Chemical Proces
- Pipeline Rules of
- Troubleshooting

Cost Components of Capital Investments, FEE p. 257



ESTIMATION OF CAPITAL INVESTMENT BY PERCENTAGE OF DELIVERED EQUIPMENT METHOD

(See Table 6-9)

The fractions in the cells below are approximations applicable to typical chemical processing plants. These values may differ depending on many factors such as location, process type, etc.

Required user input	Default	Subtotal	**Result**

Required, from a linked sheet or entered manually	Notes & comments

Project Identifier: Illustration 101	Fraction of delivered equipment			User: copy from values at left or insert	Calculated values, million $	
	Solid-processing plant	Solid-fluid processing plant	Fluid processing plant			
Direct Costs						
Purchased equipment, E'					**1.000**	
Delivery, fraction of E'	0.10	0.10	0.10	0.10	0.100	
Subtotal: delivered equipment					1.100	
Purchased equipment installation	0.45	0.39	0.47	0.47	0.517	
Instrumentation&Controls(installed)	0.18	0.26	0.36	0.36	0.396	
Piping (installed)	0.16	0.31	0.68	0.68	0.748	
Electrical systems (installed)	0.10	0.10	0.11	0.11	0.121	
Buildings (including services)	0.25	0.29	0.18	0.18	0.198	
Yard improvements	0.15	0.12	0.10	0.10	0.110	
Service facilities (installed)	0.40	0.55	0.70	0.70	0.770	
Total direct costs	1.69	2.02	2.60	2.60	3.960	
Indirect Costs						
Engineering and supervision	0.33	0.32	0.33	0.33	0.363	
Construction expenses	0.39	0.34	0.41	0.41	0.451	
Legal expenses	0.04	0.04	0.04	0.04	0.044	
Contractor's fee	0.17	0.19	0.22	0.22	0.242	
Contingency	0.35	0.37	0.44	0.44	0.484	
Total indirect costs	1.28	1.26	1.44	1.44	1.584	
Fixed capital investment (FCI)					**5.544**	Sent to **'Evaluation'** and **'Year-0 $'**, there adjusted as described below
Working capital (WC)	0.70	0.75	0.89	0.89	**0.979**	
Total capital investment (TCI)					**6.523**	

Raw Materials and Labor

ANNUAL RAW MATERIAL COSTS AND PRODUCTS VALUES

Process Identifier: Illustration 101	
Required user input	Notes & comments
Default, may be changed	
RESULT	

Products, Coproducts and Byproducts

Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual value of product, million $/y
Main	1.60	30.000	48.00
Byproduct	0.25	12.000	3.00
			0.00
			0.00
			0.00
			0.00
Total annual value of products =			**51.00**

Sent to **'Evaluation'** and **'Year-0 $'**

Raw Materials

Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual raw materials cost, million $/y
1	0.45	20.000	9.00
2	0.25	12.000	3.00
3	0.05	13.000	0.65
			0.00
			0.00
			0.00
Total annual cost of raw materials =			**12.65**

Sent to sheet **'Annual TPC'**

explained in slide 13

ANNUAL OPERATING LABOR COSTS

Process Identifier: Illustration 101	
Required user input	Notes & comments
Default, may be changed	
RESULT	

Operating Labor

Number of operators per shift*	Shifts per day**	Operator rate, $/h #	Annual operating labor cost, million $/y
3.0	3	33.67	**0.885**

Sent to **'Annual TPC'**

*See Tables 6-13 and Fig. 6-9.

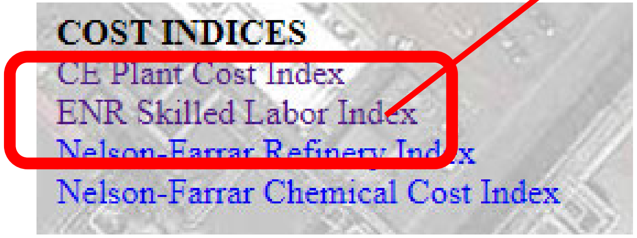
**Default = 3 for continuous process.

Enter appropriate value for batch operation.

#To obtain current, local value, enter (latest local ENR skilled labor index)/6067 = 1

Table 6-13 Typical Labor Reuirements for Process Equipment

Type of equipment	Workers/unit/shift		# units	
Blowers and Compressors	0.1-0.2	0.15	4	0.6
Centrifugal separator	0.25-0.50	0.37	0	0.0
Crystallizer, mechanical	0.16	0.16	0	0.0
Dryer, rotary	0.5	0.5	0	0.0
Dryer, spray	1.0	1	0	0.0
Dryer, tray	0.5	0.5	0	0.0
Evaporator	0.25	0.25	0	0.0
Filter, vacuum	0.125-0.25	0.131	0	0.0
Filter, plate and frame	1.0	1	0	0.0
Filter, rotary and belt	0.1	0.1	0	0.0
Heat exchangers	0.1	0.1	2	0.2
Process vessels, towers	0.2-0.5	0.35	2	0.7
Reactor, batch	1.0	1	1	1.0
Reactor, continuous	0.5	0.5	1	0.5
Total number of workers per shift =				3.0



COST INDICES

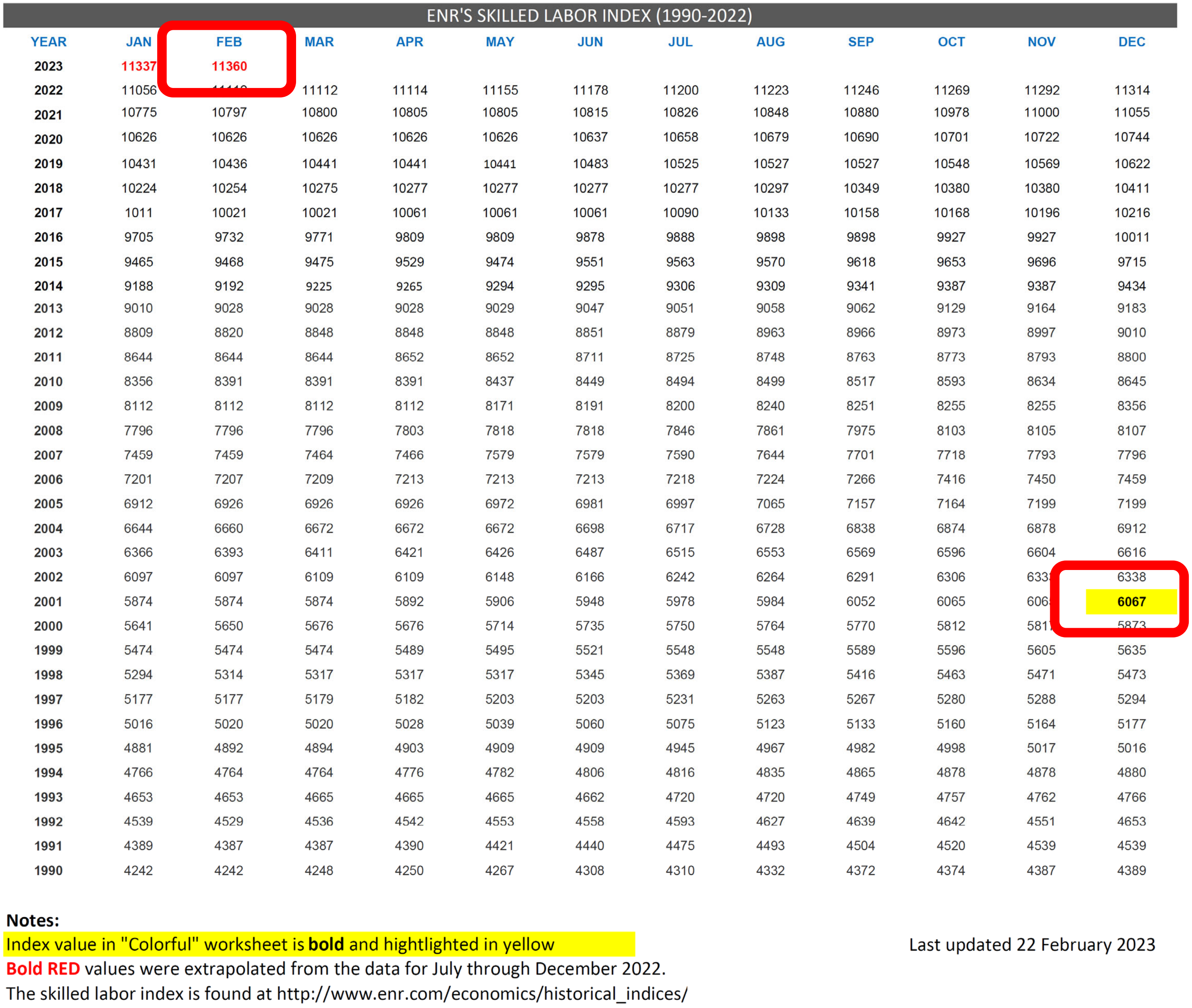
CE Plant Cost Index

ENR Skilled Labor Index

Nelson-Farrar Refinery Index

Nelson-Farrar Chemical Cost Index

ENR Skilled Labor Index



ENR'S SKILLED LABOR INDEX (1990-2022)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2023	**11337**	**11360**										
2022	11056	[illegible]	11112	11114	11155	11178	11200	11223	11246	11269	11292	11314
2021	10775	10797	10800	10805	10805	10815	10826	10848	10880	10978	11000	11055
2020	10626	10626	10626	10626	10626	10637	10658	10679	10690	10701	10722	10744
2019	10431	10436	10441	10441	10441	10483	10525	10527	10527	10548	10569	10622
2018	10224	10254	10275	10277	10277	10277	10277	10297	10349	10380	10380	10411
2017	1011	10021	10021	10061	10061	10061	10090	10133	10158	10168	10196	10216
2016	9705	9732	9771	9809	9809	9878	9888	9898	9898	9927	9927	10011
2015	9465	9468	9475	9529	9474	9551	9563	9570	9618	9653	9696	9715
2014	9188	9192	9225	9265	9294	9295	9306	9309	9341	9387	9387	9434
2013	9010	9028	9028	9028	9029	9047	9051	9058	9062	9129	9164	9183
2012	8809	8820	8848	8848	8848	8851	8879	8963	8966	8973	8997	9010
2011	8644	8644	8644	8652	8652	8711	8725	8748	8763	8773	8793	8800
2010	8356	8391	8391	8391	8437	8449	8494	8499	8517	8593	8634	8645
2009	8112	8112	8112	8112	8171	8191	8200	8240	8251	8255	8255	8356
2008	7796	7796	7796	7803	7818	7818	7846	7861	7975	8103	8105	8107
2007	7459	7459	7464	7466	7579	7579	7590	7644	7701	7718	7793	7796
2006	7201	7207	7209	7213	7213	7213	7218	7224	7266	7416	7450	7459
2005	6912	6926	6926	6926	6972	6981	6997	7065	7157	7164	7199	7199
2004	6644	6660	6672	6672	6672	6698	6717	6728	6838	6874	6878	6912
2003	6366	6393	6411	6421	6426	6487	6515	6553	6569	6596	6604	6616
2002	6097	6097	6109	6109	6148	6166	6242	6264	6291	6306	633	6338
2001	5874	5874	5874	5892	5906	5948	5978	5984	6052	6065	606	**6067**
2000	5641	5650	5676	5676	5714	5735	5750	5764	5770	5812	581	5873
1999	5474	5474	5474	5489	5495	5521	5548	5548	5589	5596	5605	5635
1998	5294	5314	5317	5317	5317	5345	5369	5387	5416	5463	5471	5473
1997	5177	5177	5179	5182	5203	5203	5231	5263	5267	5280	5288	5294
1996	5016	5020	5020	5028	5039	5060	5075	5123	5133	5160	5164	5177
1995	4881	4892	4894	4903	4909	4909	4945	4967	4982	4998	5017	5016
1994	4766	4764	4764	4776	4782	4806	4816	4835	4865	4878	4878	4880
1993	4653	4653	4665	4665	4665	4662	4720	4720	4749	4757	4762	4766
1992	4539	4529	4536	4542	4553	4558	4593	4627	4639	4642	4551	4653
1991	4389	4387	4387	4390	4421	4440	4475	4493	4504	4520	4539	4539
1990	4242	4242	4248	4250	4267	4308	4310	4332	4372	4374	4387	4389

Notes:

Index value in "Colorful" worksheet is **bold** and hightlighted in yellow

Bold RED values were extrapolated from the data for July through December 2022.

The skilled labor index is found at http://www.enr.com/economics/historical_indices/

Last updated 22 February 2023

Entry for labor index:

$$\frac{11360}{6067} = 1.87$$

Additional Info for Determining Operating Labor (Figure 6-9)

Example: A large automated plant produces 100,000 kg/day with 12 processing steps.

(34 employee hours per day / step) x 12 steps = 408 employee hours per day

408 employee hours per day / (8 hours / day) = 51 employees

51 employees / 3 shifts = 17 employees per shift

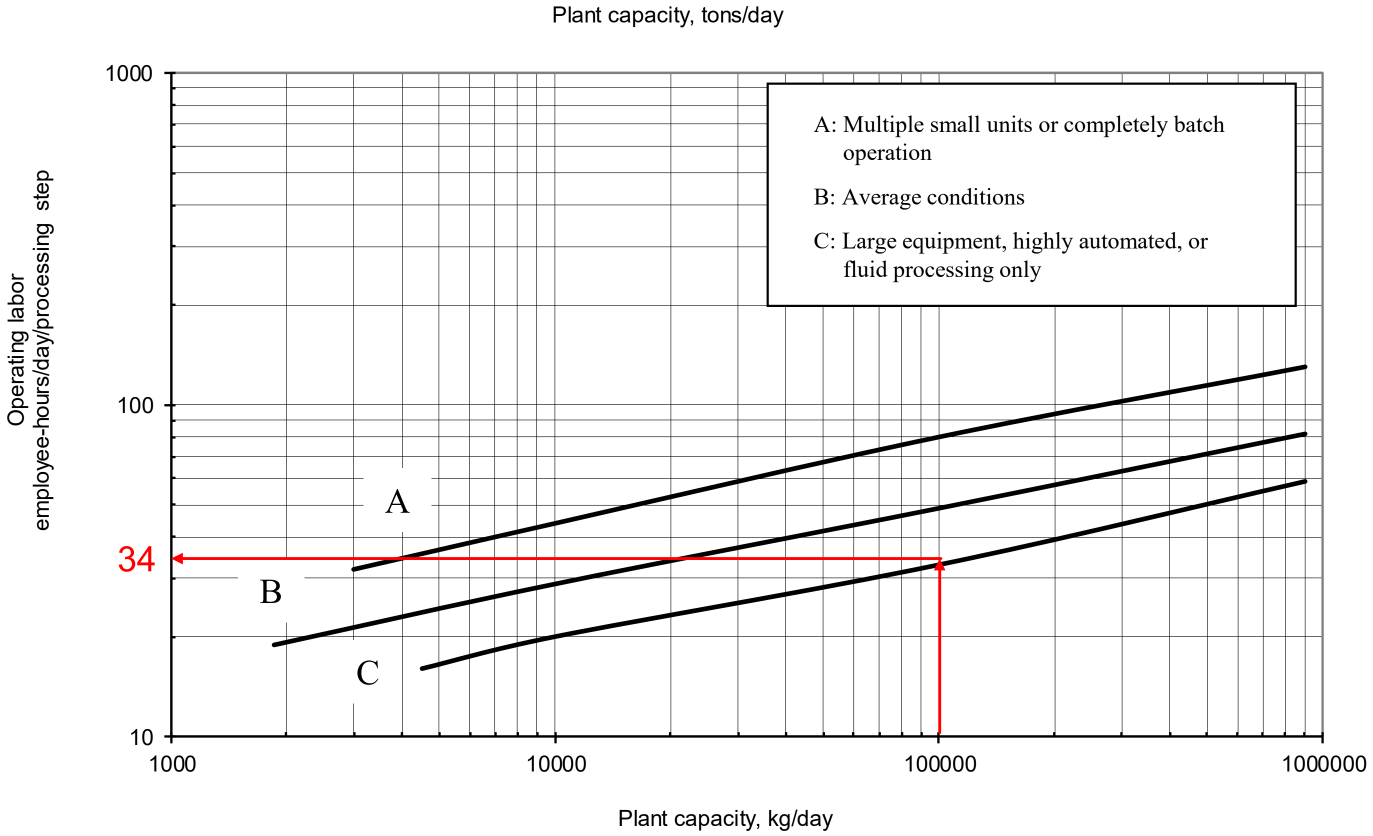


Figure 6-9 Operating Labor in the chemical process industries

UTILITY COSTS

See Table 6-14 and Table B-1 for ranges of utility unit costs and sources of information. Default values are rough averages and may be changed. Utility costs can differ widely with location.

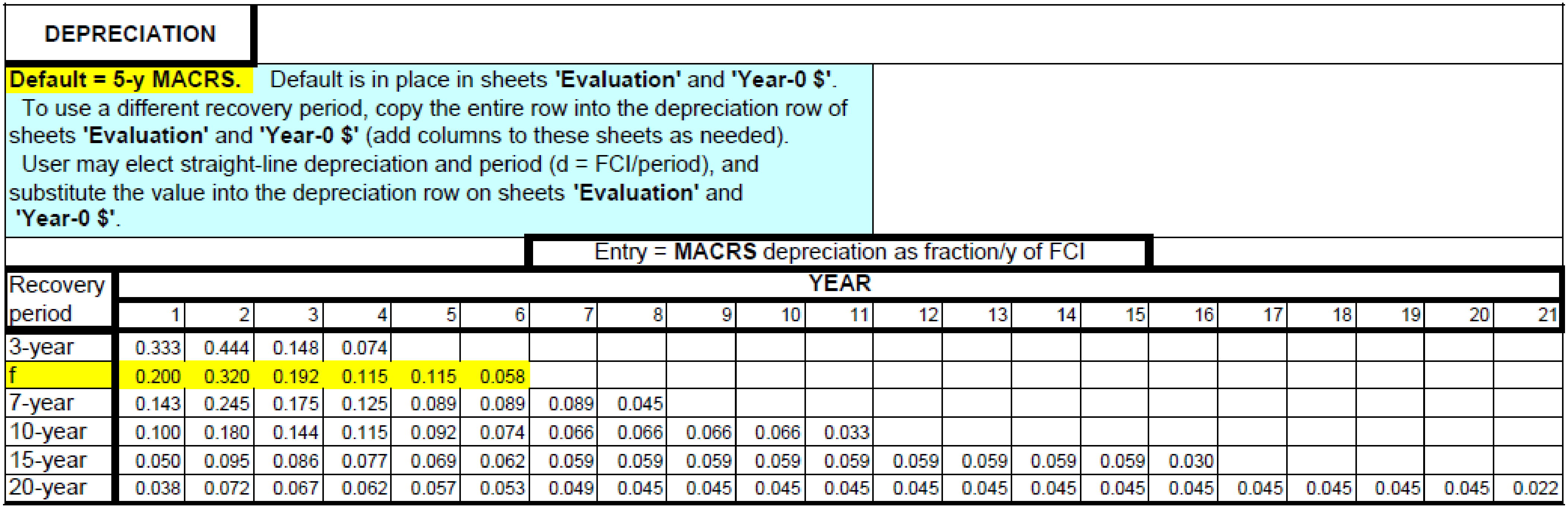
Process Identifier: Illustration 101

Required user input		Notes & comments
Result		Default, may be changed

TOTAL UTILITY COST =	**2.025**	million $/y
	Sent to sheet **'Annual TPC'**	

Utility	Default unit cost	Default cost units	Annual utility requirement, in appropriate units	Default units of utility requirement	Annual utility cost, million $/y
Air, compressed					
Process air	0.45	$\$/100\text{m}^{3\#}$		$100\ \text{m}^{3\#}/\text{y}$	
Instrument air	0.90	$\$/100\text{m}^{3\#}$		$100\ \text{m}^{3\#}/\text{y}$	
Electricity					
Purchased, U.S. average	0.045	$/kWh	1800000	kWh/y	0.081
Self-generated	0.05	$/kWh		kWh/y	
Fuel					
Coal	1.66	$/GJ		GJ/y	
Fuel oil	3.30	$/GJ		GJ/y	
Natural gas	3.00	$/GJ	360000	GJ/y	1.080
Manufactured gas	12.00	$/GJ		GJ/y	
Refrigeration, to temperature					
15 °C	4.00	$/GJ		GJ/y	
5 °C	5.00	$/GJ		GJ/y	
-20 °C	8.00	$/GJ		GJ/y	
-50 °C	14.00	$/GJ		GJ/y	
Steam, saturated					
3550 kPa	8.00	$/1000 kg		1000 kg/y	
790 kPa	6.00	$/1000 kg	40000	1000 kg/y	0.240
Exhaust (150 kPa)	2.00	$/1000 kg		1000 kg/y	
Waste water					
Disposal	0.53	$\$/\text{m}^3$		m^3/y	
Treatment	0.53	$\$/\text{m}^3$	400000	m^3/y	0.212
Waste disposal					
Hazardous	145.00	$/1000 kg		1000 kg/y	
Non-hazardous	36.00	$/1000 kg		1000 kg/y	
Water					
Cooling	0.08	$\$/\ \text{m}^3$	2500000	m^3/y	0.200
Process					
General	0.53	$\$/\text{m}^3$	400000	m^3/y	0.212
Distilled	0.90	$\$/\text{m}^3$		m^3/y	

Modified Accelerated Cost Recovery System (MACRS)
FEE Reference Handbook, v10.3, pp. 231-232



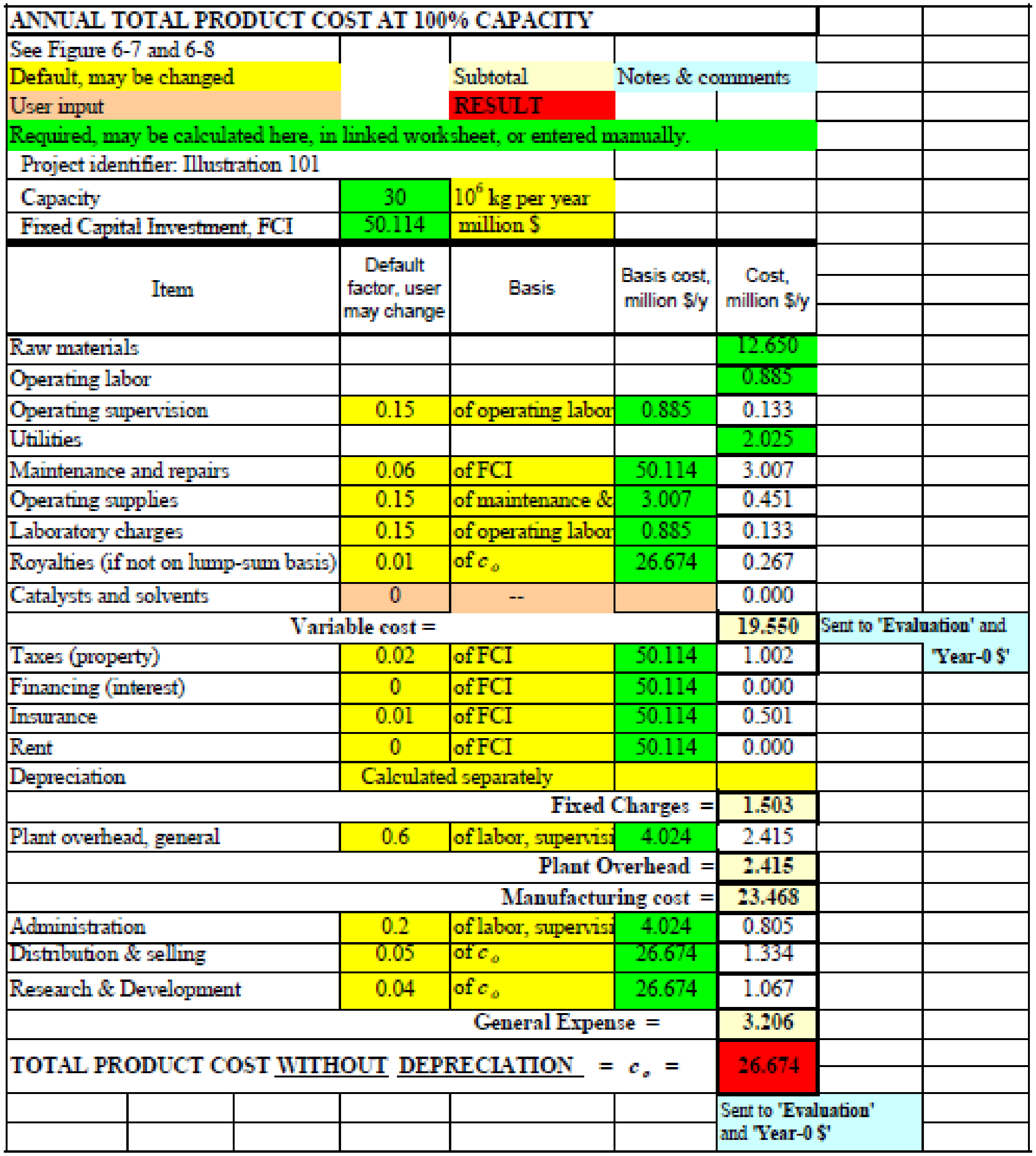
DEPRECIATION

Default = 5-y MACRS. Default is in place in sheets **'Evaluation'** and **'Year-0 $'**.
To use a different recovery period, copy the entire row into the depreciation row of sheets **'Evaluation'** and **'Year-0 $'** (add columns to these sheets as needed).
User may elect straight-line depreciation and period (d = FCI/period), and substitute the value into the depreciation row on sheets **'Evaluation'** and **'Year-0 $'**.

Entry = **MACRS** depreciation as fraction/y of FCI

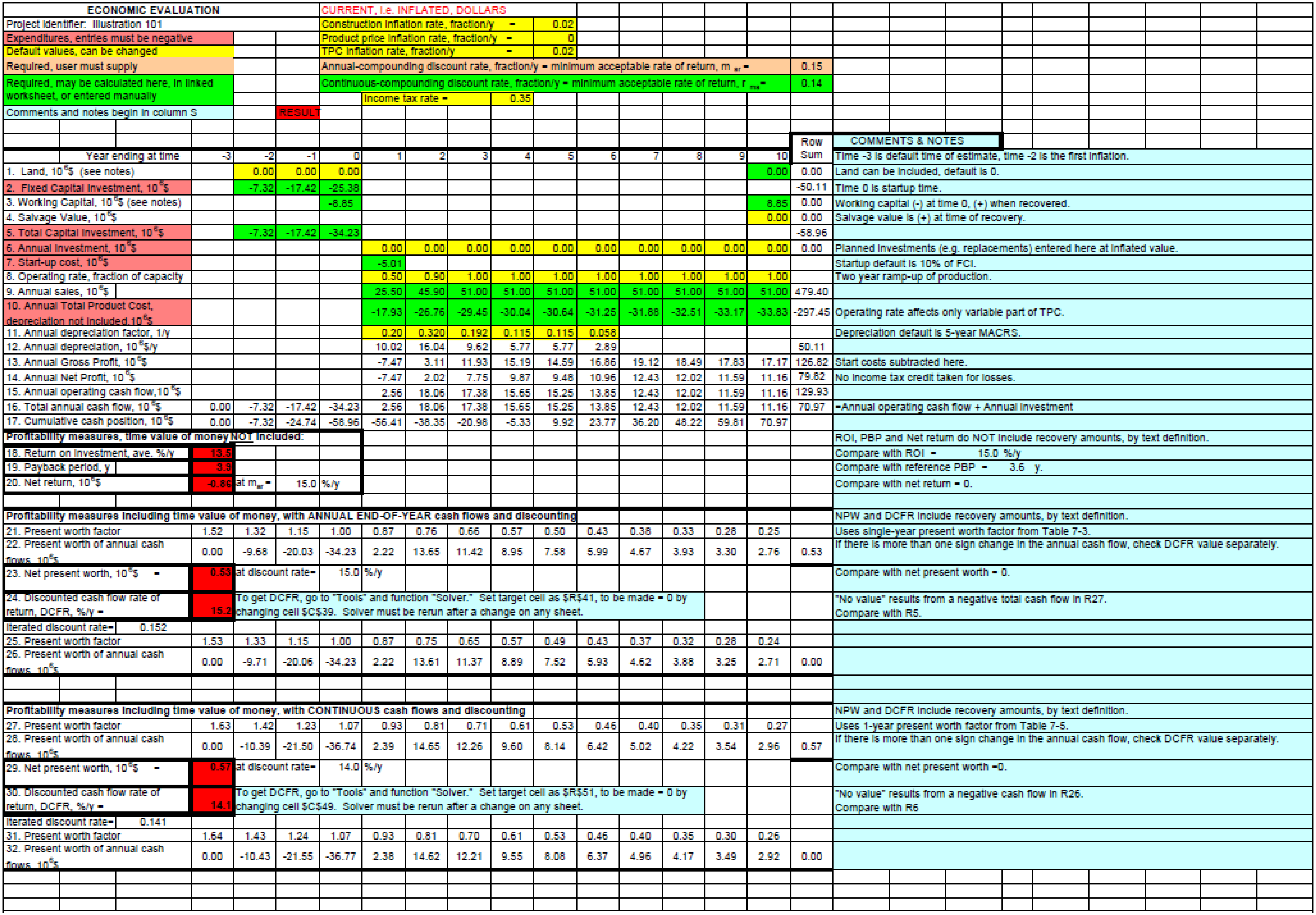
Recovery period	YEAR																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3-year	0.333	0.444	0.148	0.074																	
f	0.200	0.320	0.192	0.115	0.115	0.058															
7-year	0.143	0.245	0.175	0.125	0.089	0.089	0.089	0.045													
10-year	0.100	0.180	0.144	0.115	0.092	0.074	0.066	0.066	0.066	0.066	0.033										
15-year	0.050	0.095	0.086	0.077	0.069	0.062	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.030					
20-year	0.038	0.072	0.067	0.062	0.057	0.053	0.049	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.022

Annual Total Product Cost



ANNUAL TOTAL PRODUCT COST AT 100% CAPACITY					
See Figure 6-7 and 6-8					
Default, may be changed		Subtotal	Notes & comments		
User input		RESULT			
Required, may be calculated here, in linked worksheet, or entered manually.					
Project identifier: Illustration 101					
Capacity	30	10^6 kg per year			
Fixed Capital Investment, FCI	50.114	million $			
Item	Default factor, user may change	Basis	Basis cost, million $/y	Cost, million $/y	
Raw materials				12.650	
Operating labor				0.885	
Operating supervision	0.15	of operating labor	0.885	0.133	
Utilities				2.025	
Maintenance and repairs	0.06	of FCI	50.114	3.007	
Operating supplies	0.15	of maintenance &	3.007	0.451	
Laboratory charges	0.15	of operating labor	0.885	0.133	
Royalties (if not on lump-sum basis)	0.01	of c_o	26.674	0.267	
Catalysts and solvents	0	--		0.000	
Variable cost =				**19.550**	Sent to 'Evaluation' and 'Year-0 $'
Taxes (property)	0.02	of FCI	50.114	1.002	
Financing (interest)	0	of FCI	50.114	0.000	
Insurance	0.01	of FCI	50.114	0.501	
Rent	0	of FCI	50.114	0.000	
Depreciation	Calculated separately				
			Fixed Charges =	**1.503**	
Plant overhead, general	0.6	of labor, supervisi	4.024	2.415	
			Plant Overhead =	**2.415**	
			Manufacturing cost =	**23.468**	
Administration	0.2	of labor, supervisi	4.024	0.805	
Distribution & selling	0.05	of c_o	26.674	1.334	
Research & Development	0.04	of c_o	26.674	1.067	
			General Expense =	**3.206**	
TOTAL PRODUCT COST WITHOUT DEPRECIATION = c_o =				**26.674**	
				Sent to 'Evaluation' and 'Year-0 $'	

Economic Evaluation



ECONOMIC EVALUATION

Project identifier: Illustration 101

Expenditures, entries must be negative

Default values, can be changed

Required, user must supply

Required, may be calculated here, in linked worksheet, or entered manually

Comments and notes begin in column S

RESULT

CURRENT, i.e. INFLATED, DOLLARS

Construction inflation rate, fraction/y = 0.02

Product price inflation rate, fraction/y = 0

TPC inflation rate, fraction/y = 0.02

Annual-compounding discount rate, fraction/y = minimum acceptable rate of return, m_{ar} = 0.15

Continuous-compounding discount rate, fraction/y = minimum acceptable rate of return, r_{ma} = 0.14

Income tax rate = 0.35

															Row	COMMENTS & NOTES
Year ending at time	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Sum	Time -3 is default time of estimate, time -2 is the first inflation.
1. Land, $10^6\,\$$ (see notes)		0.00	0.00	0.00										0.00	0.00	Land can be included, default is 0.
2. Fixed Capital Investment, $10^6\,\$$		-7.32	-17.42	-25.38											-50.11	Time 0 is startup time.
3. Working Capital, $10^6\,\$$ (see notes)				-8.85										8.85	0.00	Working capital (-) at time 0, (+) when recovered.
4. Salvage Value, $10^6\,\$$														0.00	0.00	Salvage value is (+) at time of recovery.
5. Total Capital Investment, $10^6\,\$$		-7.32	-17.42	-34.23											-58.96	
6. Annual Investment, $10^6\,\$$					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Planned investments (e.g. replacements) entered here at inflated value.
7. Start-up cost, $10^6\,\$$					-5.01											Startup default is 10% of FCI.
8. Operating rate, fraction of capacity					0.50	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		Two year ramp-up of production.
9. Annual sales, $10^6\,\$$					25.50	45.90	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00	479.40	
10. Annual Total Product Cost, depreciation not included, $10^6\,\$$					-17.93	-26.76	-29.45	-30.04	-30.64	-31.25	-31.88	-32.51	-33.17	-33.83	-297.45	Operating rate affects only variable part of TPC.
11. Annual depreciation factor, 1/y					0.20	0.320	0.192	0.115	0.115	0.058						Depreciation default is 5-year MACRS.
12. Annual depreciation, $10^6\,\$$/y					10.02	16.04	9.62	5.77	5.77	2.89					50.11	
13. Annual Gross Profit, $10^6\,\$$					-7.47	3.11	11.93	15.19	14.59	16.86	19.12	18.49	17.83	17.17	126.82	Start costs subtracted here.
14. Annual Net Profit, $10^6\,\$$					-7.47	2.02	7.75	9.87	9.48	10.96	12.43	12.02	11.59	11.16	79.82	No income tax credit taken for losses.
15. Annual operating cash flow, $10^6\,\$$					2.56	18.06	17.38	15.65	15.25	13.85	12.43	12.02	11.59	11.16	129.93	
16. Total annual cash flow, $10^6\,\$$	0.00	-7.32	-17.42	-34.23	2.56	18.06	17.38	15.65	15.25	13.85	12.43	12.02	11.59	11.16	70.97	=Annual operating cash flow + Annual investment
17. Cumulative cash position, $10^6\,\$$	0.00	-7.32	-24.74	-58.96	-56.41	-38.35	-20.98	-5.33	9.92	23.77	36.20	48.22	59.81	70.97		
Profitability measures, time value of money NOT included:																ROI, PBP and Net return do NOT include recovery amounts, by text definition.
18. Return on investment, ave. %/y	13.5															Compare with ROI = 15.0 %/y
19. Payback period, y	3.9															Compare with reference PBP = 3.6 y.
20. Net return, $10^6\,\$$	-0.86	at m_{ar} =	15.0	%/y												Compare with net return = 0.
Profitability measures including time value of money, with ANNUAL END-OF-YEAR cash flows and discounting																NPW and DCFR include recovery amounts, by text definition.
21. Present worth factor	1.52	1.32	1.15	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25		Uses single-year present worth factor from Table 7-3.
22. Present worth of annual cash flows, $10^6\,\$$	0.00	-9.68	-20.03	-34.23	2.22	13.65	11.42	8.95	7.58	5.99	4.67	3.93	3.30	2.76	0.53	If there is more than one sign change in the annual cash flow, check DCFR value separately.
23. Net present worth, $10^6\,\$$ =	0.53	at discount rate=		15.0	%/y											Compare with net present worth = 0.
24. Discounted cash flow rate of return, DCFR, %/y =	15.2	To get DCFR, go to "Tools" and function "Solver." Set target cell as \$R\$41, to be made = 0 by changing cell \$C\$39. Solver must be rerun after a change on any sheet.														"No value" results from a negative total cash flow in R27. Compare with R5.
Iterated discount rate= 0.152																
25. Present worth factor	1.53	1.33	1.15	1.00	0.87	0.75	0.65	0.57	0.49	0.43	0.37	0.32	0.28	0.24		
26. Present worth of annual cash flows, $10^6\,\$$	0.00	-9.71	-20.06	-34.23	2.22	13.61	11.37	8.89	7.52	5.93	4.62	3.88	3.25	2.71	0.00	
Profitability measures including time value of money, with CONTINUOUS cash flows and discounting																NPW and DCFR include recovery amounts, by text definition.
27. Present worth factor	1.63	1.42	1.23	1.07	0.93	0.81	0.71	0.61	0.53	0.46	0.40	0.35	0.31	0.27		Uses 1-year present worth factor from Table 7-5.
28. Present worth of annual cash flows, $10^6\,\$$	0.00	-10.39	-21.50	-36.74	2.39	14.65	12.26	9.60	8.14	6.42	5.02	4.22	3.54	2.96	0.57	If there is more than one sign change in the annual cash flow, check DCFR value separately.
29. Net present worth, $10^6\,\$$ =	0.57	at discount rate=		14.0	%/y											Compare with net present worth =0.
30. Discounted cash flow rate of return, DCFR, %/y =	14.1	To get DCFR, go to "Tools" and function "Solver." Set target cell as \$R\$51, to be made = 0 by changing cell \$C\$49. Solver must be rerun after a change on any sheet.														"No value" results from a negative cash flow in R26. Compare with R6
Iterated discount rate= 0.141																
31. Present worth factor	1.64	1.43	1.24	1.07	0.93	0.81	0.70	0.61	0.53	0.46	0.40	0.35	0.30	0.26		
32. Present worth of annual cash flows, $10^6\,\$$	0.00	-10.43	-21.55	-36.77	2.38	14.62	12.21	9.55	8.08	6.37	4.96	4.17	3.49	2.92	0.00	

Cumulative Cash Flow Position

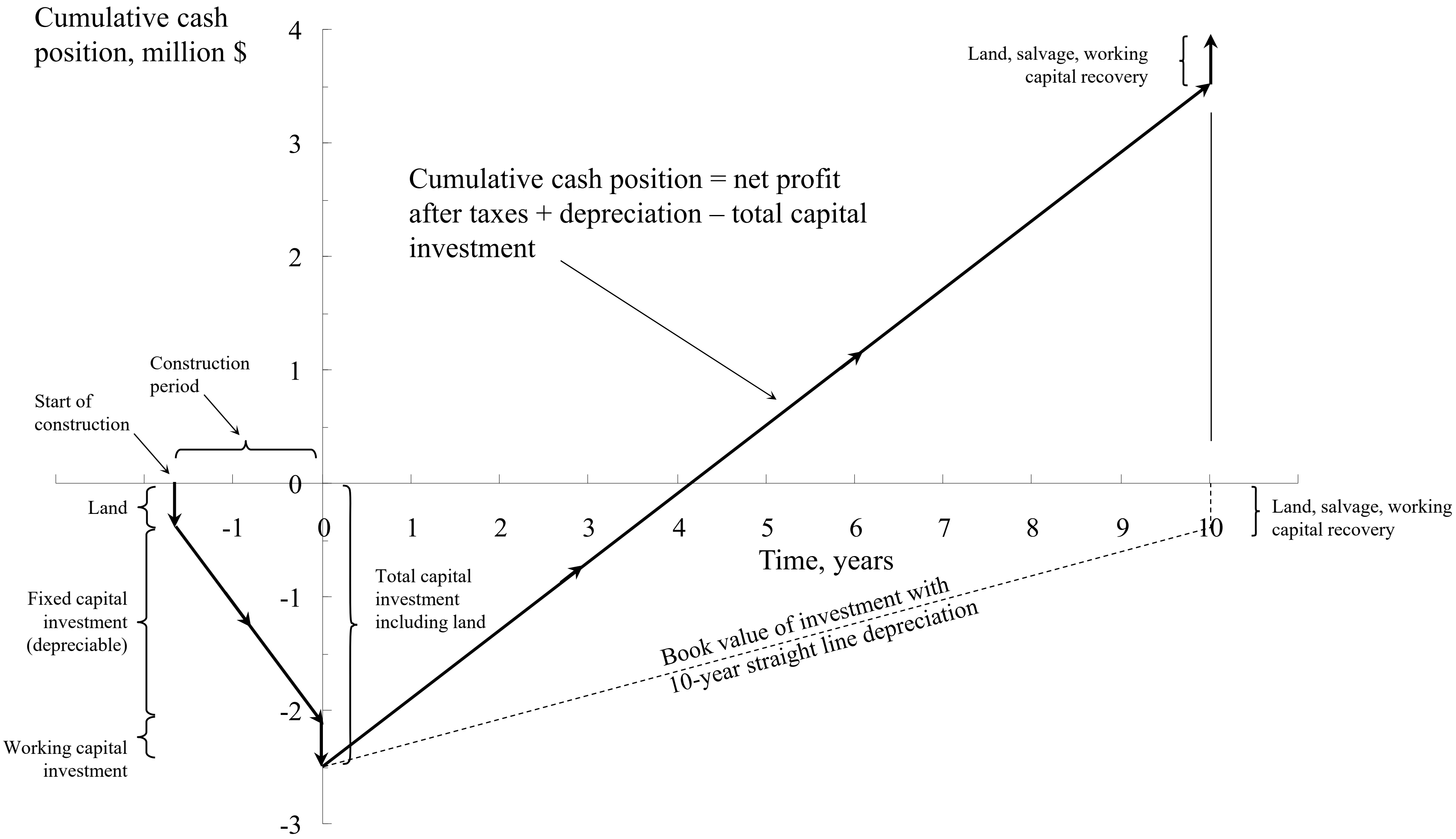


Figure 6.2 Graph of cumulative cash position showing effects of cash flow over full life cycle for a 10-year industrial operation, neglecting the time value of money

Problem 6-1

The purchased cost of a shell-and-tube heat exchanger (floating head and carbon steel tubes) with 10 m^2 (not 100 m^2) of heating surface was \$4200 in 1990. What was the 1990 purchased cost of a similar heat exchanger with 20 m^2 of heating surface if the purchased cost capacity exponent is 0.60 for surface areas ranging from 10 to 40 m^2? If the purchased cost capacity exponent is 0.81 for surface areas ranging from 40 to 200 m^2, what was the purchased cost of a heat exchanger with 100 m^2 of heating surface in 2000?

This problem jumps ahead to lesson 15.

Scaling of Equipment Costs

$$\text{Cost of equipment a} = (\text{Cost of equipment b}) \cdot X^{0.6}$$

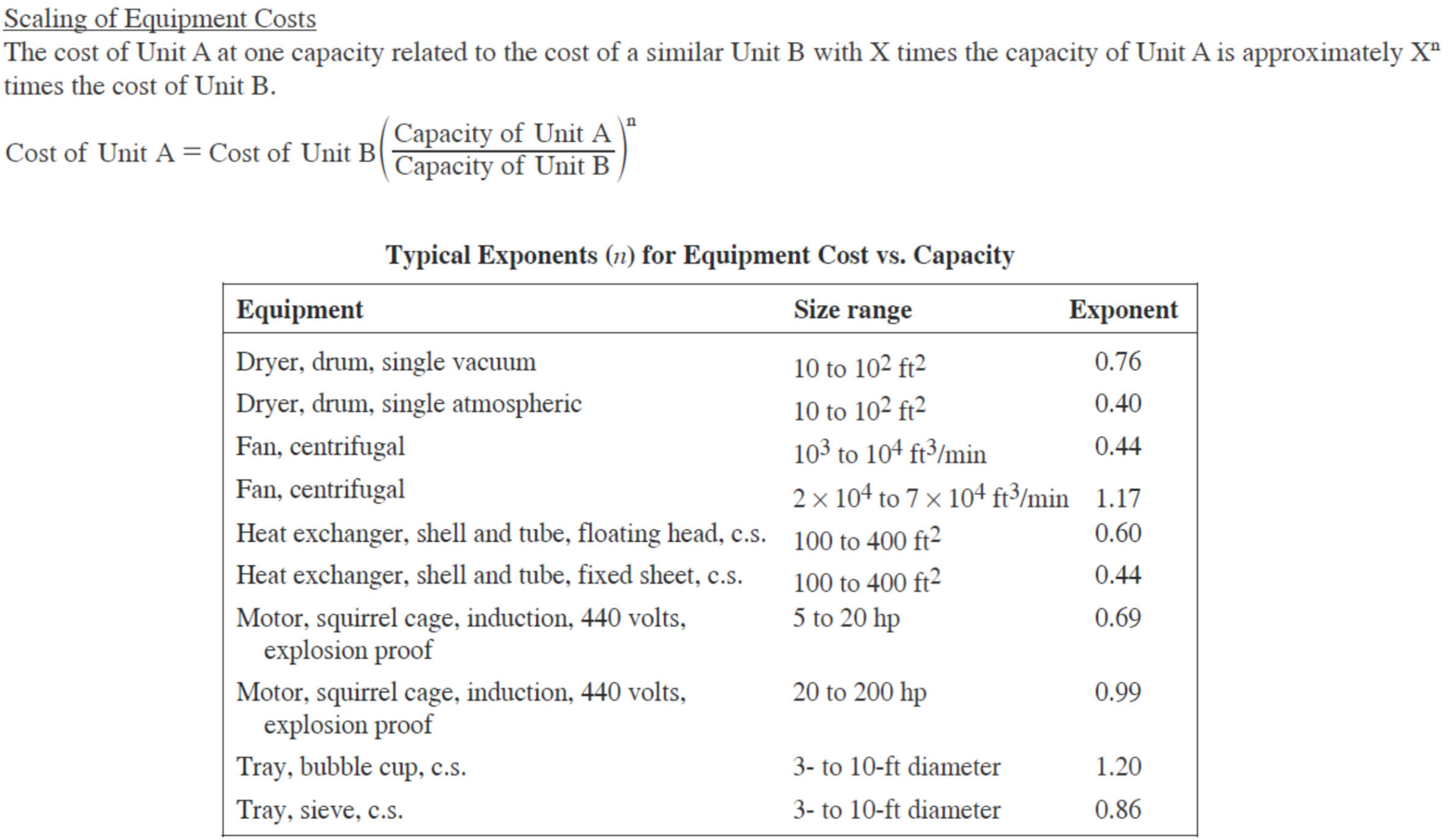
X is the “capacity ratio”

Equipment	Size Range	Exponent
Heat exchanger, shell-and-tube, floating head, (c.s.)	10 - 40 m^2	0.60
Heat exchanger, shell-and-tube, fixed sheet, (c.s.)	10 - 40 m^2	0.44
Pump, centrifugal, horizontal, cast steel (with motor)	4 - 40 $(m^3/s)\cdot(kPa)$	0.33
Reactor, glass-lined, jacketed (without drive)	0.2 - 2.2 m^3	0.54
Tower (c.s.)	500 – 5,000,000 kg	0.62
Tray, sieve	1 - 3 m	0.86

Selected entries from Table 6-4, page 243

Lesson 15

FE Ref. Manual page 258



Scaling of Equipment Costs

The cost of Unit A at one capacity related to the cost of a similar Unit B with X times the capacity of Unit A is approximately X^n times the cost of Unit B.

$$\text{Cost of Unit A} = \text{Cost of Unit B}\left(\frac{\text{Capacity of Unit A}}{\text{Capacity of Unit B}}\right)^n$$

Typical Exponents (n) for Equipment Cost vs. Capacity

Equipment	Size range	Exponent
Dryer, drum, single vacuum	10 to 10^2 ft^2	0.76
Dryer, drum, single atmospheric	10 to 10^2 ft^2	0.40
Fan, centrifugal	10^3 to 10^4 ft^3/min	0.44
Fan, centrifugal	2×10^4 to 7×10^4 ft^3/min	1.17
Heat exchanger, shell and tube, floating head, c.s.	100 to 400 ft^2	0.60
Heat exchanger, shell and tube, fixed sheet, c.s.	100 to 400 ft^2	0.44
Motor, squirrel cage, induction, 440 volts, explosion proof	5 to 20 hp	0.69
Motor, squirrel cage, induction, 440 volts, explosion proof	20 to 200 hp	0.99
Tray, bubble cup, c.s.	3- to 10-ft diameter	1.20
Tray, sieve, c.s.	3- to 10-ft diameter	0.86

average, this table = .76

average, all equipment = .60

Problem 6-2

Plot the 2000 purchased cost of the shell-and-tube heat exchanger outlined in Problem 6-1 as a function of surface area from 10 to 200 m^2. Note that the purchased cost capacity exponent is not constant over the range of surface areas requested.

This problem also jumps ahead to lesson 15.

Questions?