CH402 Chemical Engineering Process Design

Class Notes L14

Cost Estimation & Capital Investments

Download and open "Cost and Evaluation Spreadsheet"

L14 Learning Objectives

1. Relate the I/O analysis from Lesson 13 to the different cash flows in 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”

$2C_2H_4 \rightarrow$

$Cl_2 \rightarrow$

$\frac{1}{2}\,O_2 \rightarrow$

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):

$$C_2H_4Cl_2 \longrightarrow C_2H_3Cl + HCl$$

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

$\rightarrow 2C_2H_3Cl$

$\rightarrow H_2O$

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

Economic Analysis Based on I/O Structure

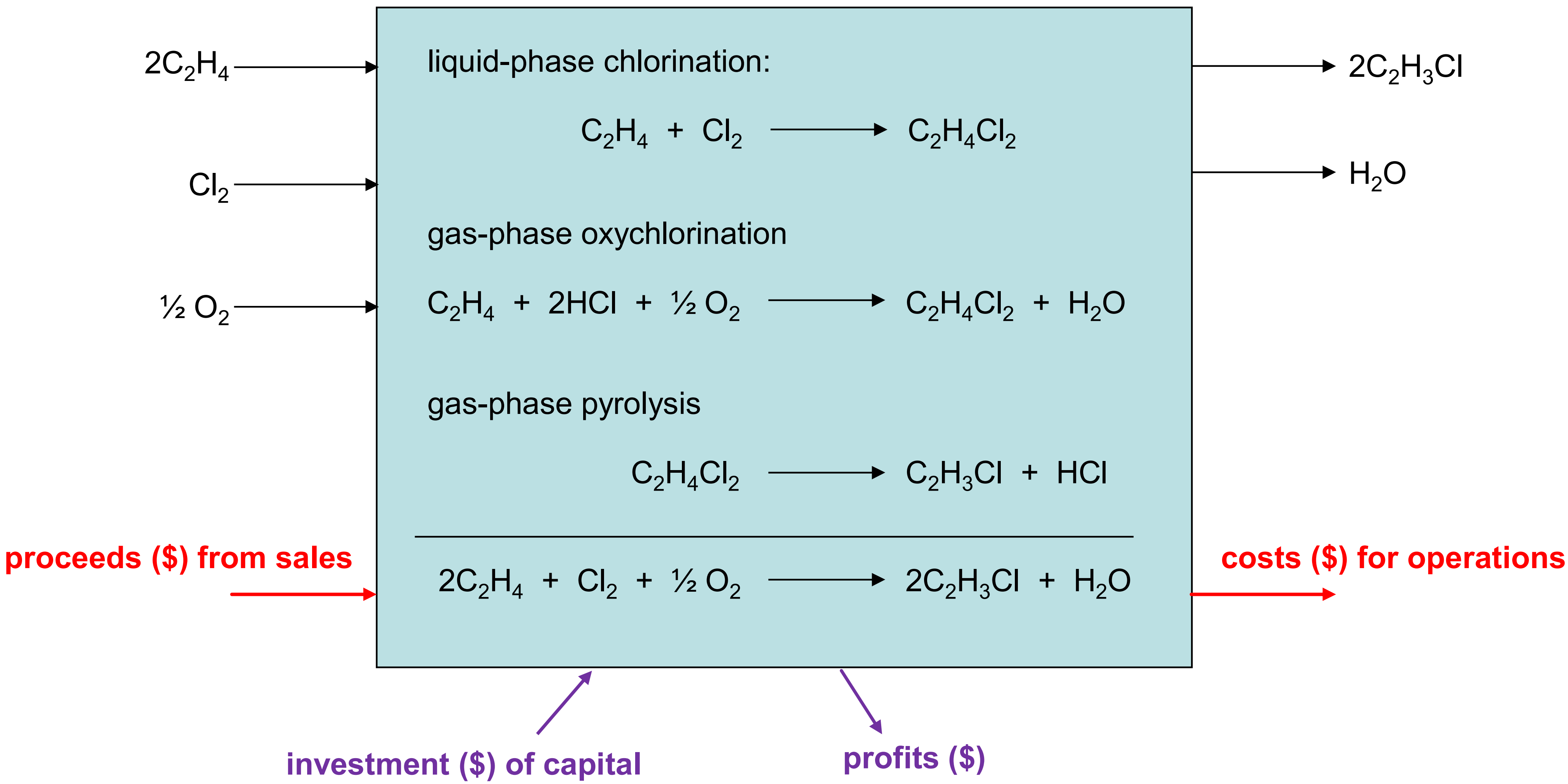
	A	B	C	D	E	F	G	H
1	Example 4-2. Compare product and raw material values based on 1kg of vinyl chloride							
2								
3						**Reaction Path, kg/kg VC**		
4	Species	MW, kg/kgmol	Price, $/kg	**1**	**2**	**3**	**4**	**5**
5	Cl_2	70.9	0.03	---	1.13	1.13	---	0.57
6	HCl	36.5	0.22	0.58	0.58	0.58	0.58	---
7	C_2H_2	26.0	1.39	0.42	---	---	---	---
8	C_2H_4	28.1	0.45	---	0.45	0.45	0.45	0.45
9	*C_2H_3Cl*	*62.5*	*0.45*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
10	O_2	32.0	0.04	---	---	---	0.26	0.13
11								
12	product value			$0.45	$0.58	$0.58	$0.45	$0.45
13	reactant cost			$0.71	$0.24	$0.24	$0.34	$0.22
14	excess value			-$0.26	$0.34	$0.34	$0.11	$0.23

I/O diagram for process 5 is shown in slides 4 and 6.

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.



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.

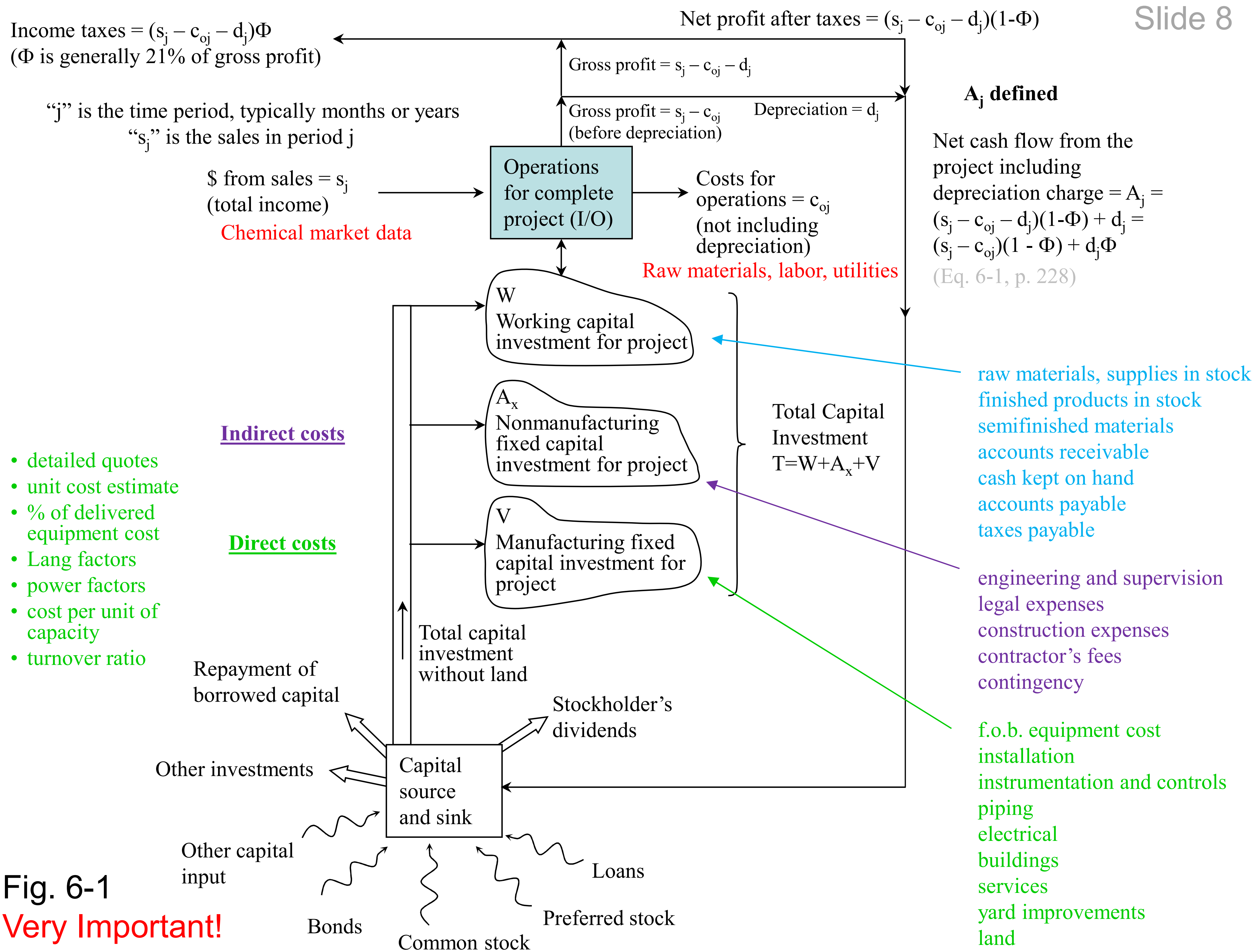
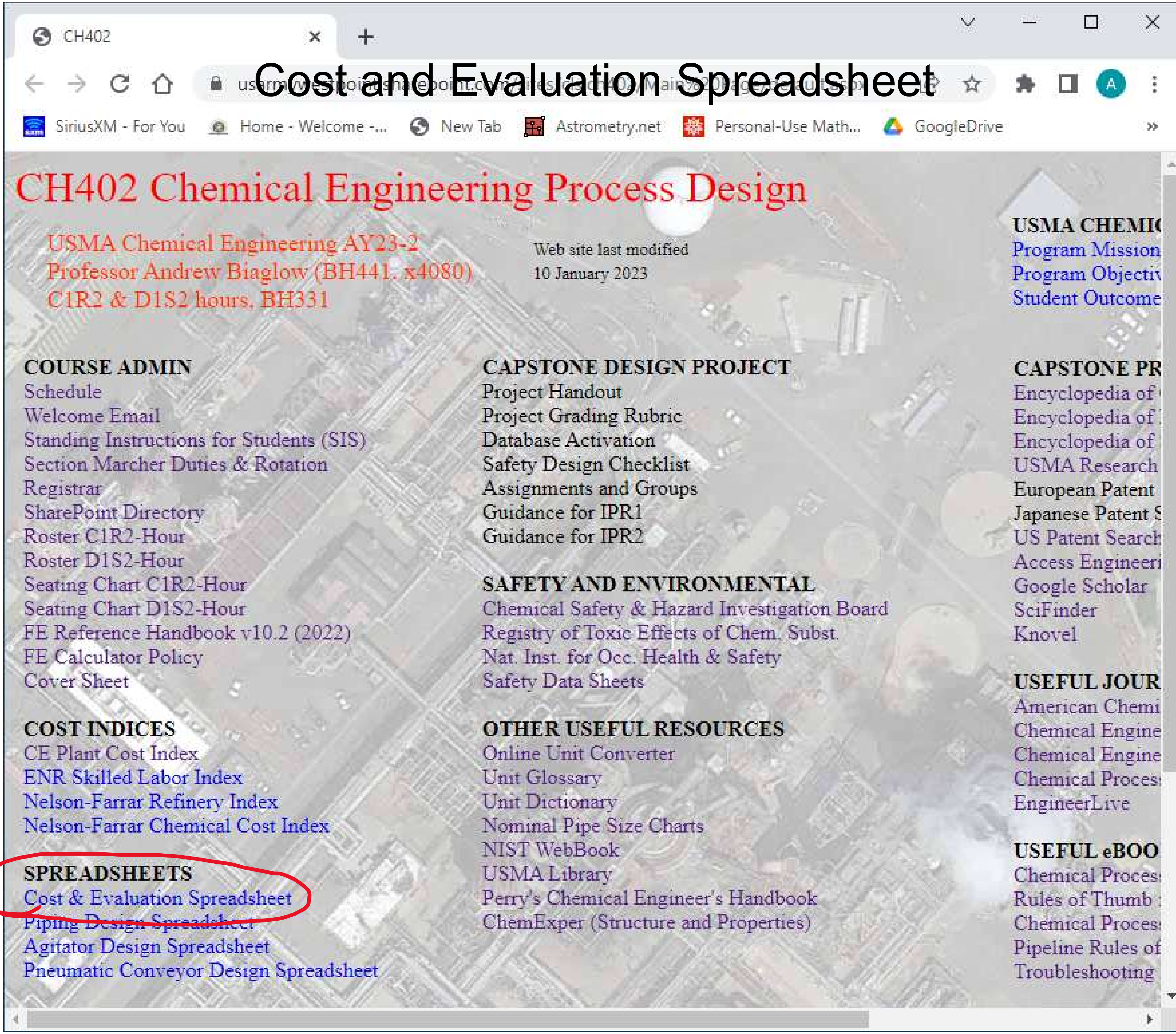


Fig. 6-1
Very Important!

Cost and Evaluation Spreadsheet



Cost Components of Capital Investments

FEE Reference Handbook, v10.4, pp. 257 (263/502)

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**
Working capital (WC)		0.70	0.75	0.89	0.89	**0.979**
Total capital investment (TCI)						**6.523**

Sent to **'Evaluation'** and **'Year-0 $'**, there adjusted as described below

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'**

COST INDICES

CE Plant Cost Index

ENR Skilled Labor Index

Nelson-Farrar Refinery Index

Nelson-Farrar Chemical Cost Index

explained in further 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

explained further in slide 12

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

ENR Skilled Labor Index

ENR'S SKILLED LABOR INDEX (1990-2026)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2026	12490	12490	12534									
2025	11870	11997	12109	12191	12236	12267	12267	12327	12366	12450	12481	12481
2024	11709	11675	11675	11682	11687	11703	11703	11751	11805	11805	11805	11811
2023	11332	11332	11400	11445	11663	11674	11686	11686	11686	11698	11698	11698
2022	11056	11112	11112	11114	11869	11887	11905	11922	11940	11957	11975	11992
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		
2017	1011	10021	10021	10061	10061	10061	10090	10133	10158	10168		
2016	9705	9732	9771	9809	9809	9878	9888	9898	9898	9927	9927	10011
	9465	9468	9475	9529	9474	9551	9563	9570	9618	9653		
	9188	9192	9225	9265	9294	9295	9306	9309	9341	9387		
	9010	9028	9028	9028	9029	9047	9051	9058	9062	9129		
	8809	8820	8848	8848	8848	8851	8879	8963	8966	8973		
	8644	8644	8644	8652	8652	8711	8725	8748	8763	8773	8793	8800
	8356	8391	8391	8391	8437	8449	8494	8499	8517	8593	8634	8645
	8112	8112	8112	8112	8171	8191	8200	8240	8251	8255	8255	8356
	7796	7796	7796	7803	7818	7818	7846	7861	7975	8103	8105	8107
	7459	7459	7464	7466	7579	7579	7590	7644	7701	7718	7793	7796
	7201	7207	7209	7213	7213	7213	7218	7224	7266	7416	7450	7459
	6912	6926	6926	6926	6972	6981	6997	7065	7157	7164	7199	7199
	6644	6660	6672	6672	6672	6698	6717	6728	6838	6874	6878	6912
	6366	6393	6411	6421	6426	6487	6515	6553	6569	6596	6604	6616
	6097	6097	6109	6109	6148	6166	6242	6264	6291	6306	6333	6338
	5874	5874	5874	5892	5906	5948	5978	5984	6052	6065	6065	**6067**
	5641	5650	5676	5676	5714	5735	5750	5764	5770	5812	5817	5873

Last updated 13 February 2026

Entry for labor index:

$$\frac{12490}{6067} = 2.059$$

COURSE ADMIN
Schedule
Welcome Email
Standing Instructions for Students (SIS)
Section Marcher Duties & Rotation
Registrar
Canvas
Roster B1T2-Hour
Roster D1S2-Hour
Seating Chart B1T2-Hour
Seating Chart D1S2-Hour
FE Reference Handbook v10.4 (2024)
Cover Sheet
CHEMCAD License Server
CHEMCAD Installation Fix

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

...ue in "Colorful Worksheet" in December 2001 is **bold** and hightlighted in yellow.
...can be updated to the current month. Do the following:
...'Materials and Labor," cell J16, and enter the current value divided by 6067.
...ample, in February 2026, 12490/6067 = 2.059
The BOLD RED value in March of 2026 is extrapolated from the previous six months.

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

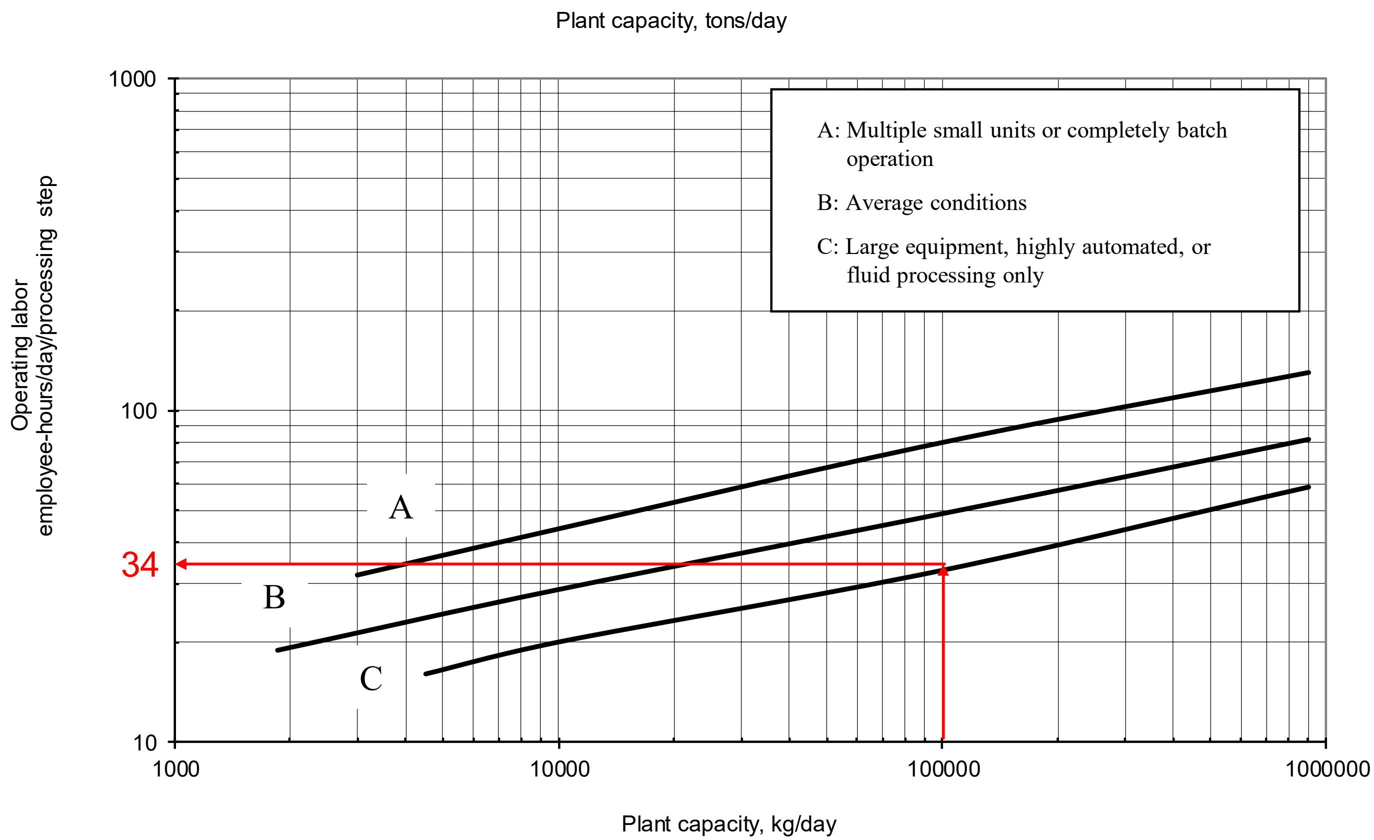


Figure 6-9 Operating Labor in the chemical process industries

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	$/100m^{3*}		100 m^{3*}/y	
Instrument air	0.90	$/100m^{3*}		100 m^{3*}/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	$/m^3		m^3/y	
Treatment	0.53	$/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	$/ m^3	2500000	m^3/y	0.200
Process					
General	0.53	$/m^3	400000	m^3/y	0.212
Distilled	0.90	$/m^3		m^3/y	

Modified Accelerated Cost Recovery System (MACRS)

FEE Reference Handbook, v10.5, pp. 230-231

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	
Taxes (property)	0.02	of FCI	50.114	1.002		'Year-0 $'
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

CURRENT, i.e. INFLATED, DOLLARS

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

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

Year ending at time	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	Row Sum	COMMENTS & NOTES
																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	13.8															Compare with ROI = 15.0 %/y
19. Payback period, y	3.8															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

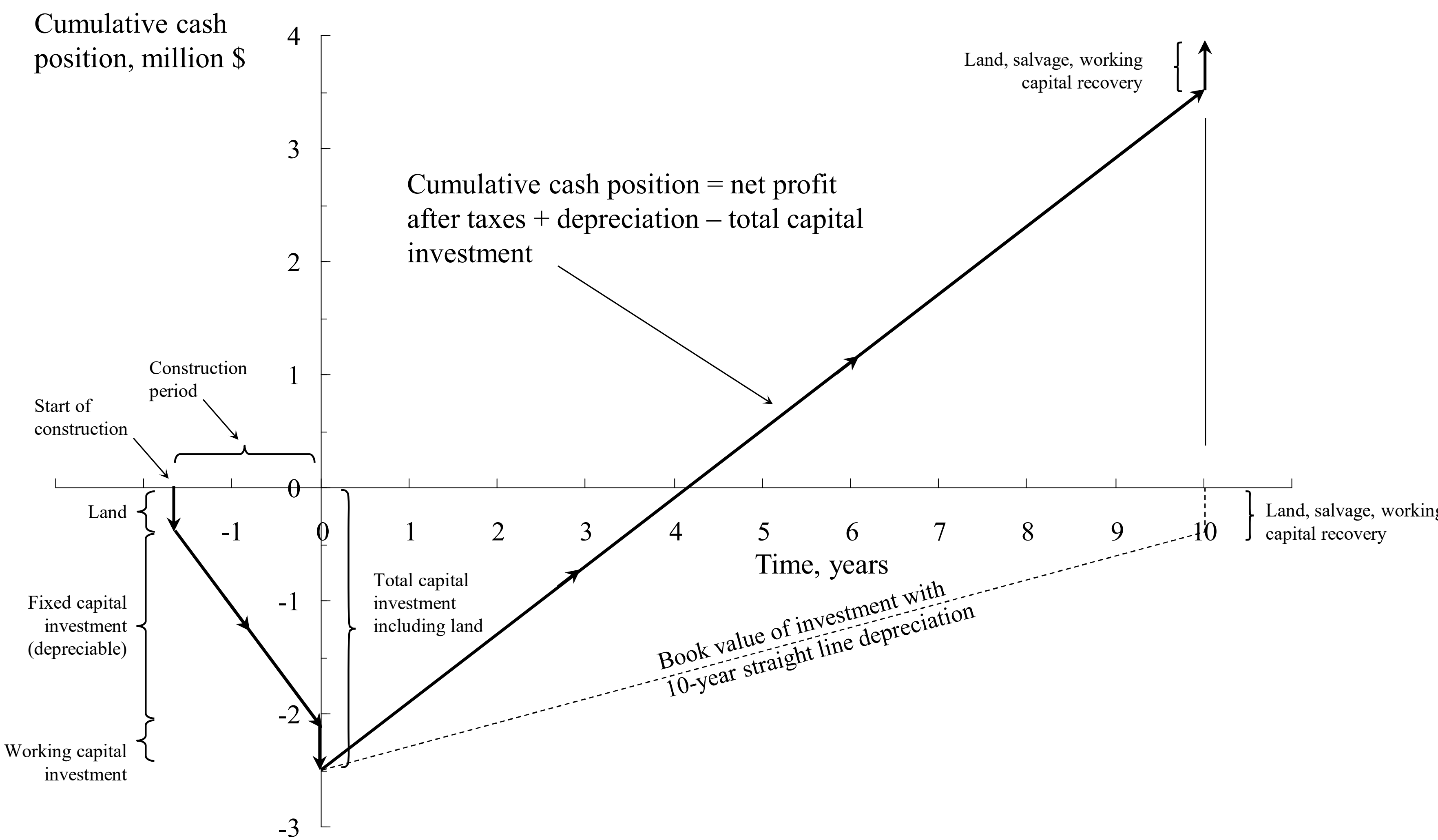


Figure 6.2 Graph of cumulative cash position showing effects of cash flow over full life cycle for a 10-year industrial operation, neglecting the time value of money

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.

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

FEE Reference Handbook, v10.5, pp. 257-258

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?