Class notes for ChE 4N04
Engineering Economics section

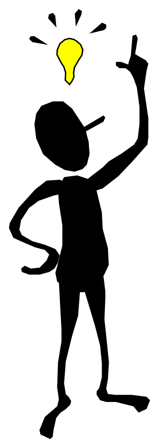
Ethics and Law

Safety and Environment

Engineering science

Process and Product Design

..



Economics

Risk and uncertainty

Chemistry and Biology

Project Management

..

We all must be able to apply basic concepts of economics because economics plays an important role in every engineering decision.

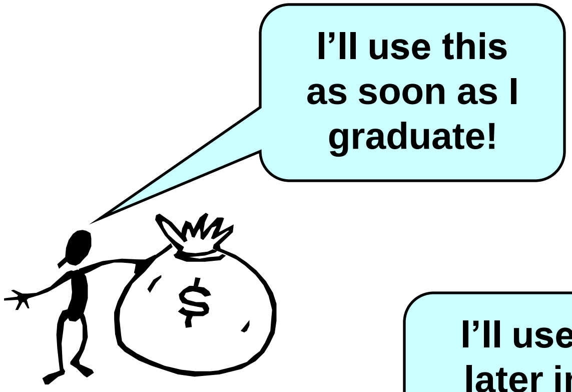
Course principles have many applications

Engineering Economics

- Evaluate profitability of alternative investments

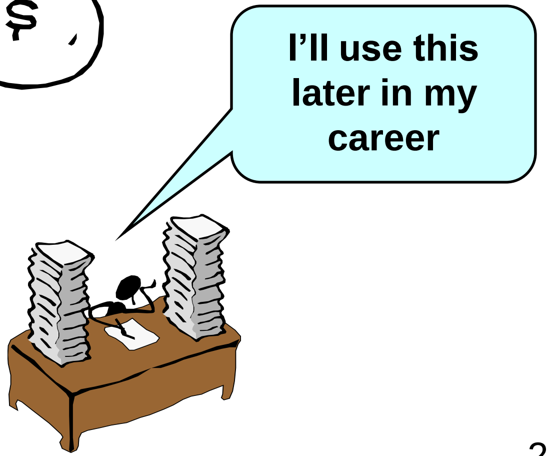
Personal Finance

- When to buy that new car!
- Determine proper level of borrowing and saving
- Calculate income taxes



Corporate Finance

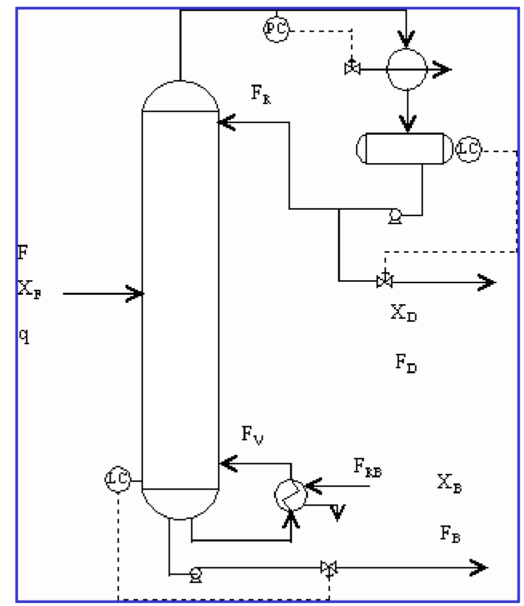
- Provide adequate cash reserves
- Determine minimum rate of return



Your first task at your new job

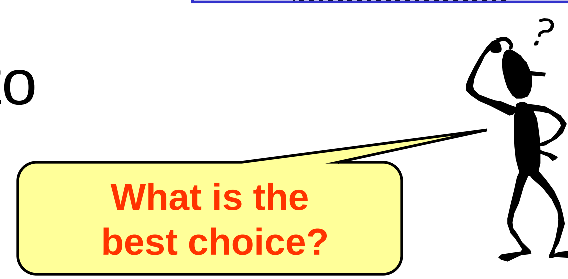
Supervisor to you: We want to increase our production rate by 35%, but the distillation tower is at its maximum capacity (liquid and vapour flows).

Evaluate the following feasible alternatives and determine the most financially attractive.



After some creative brainstorming …

1. Build a parallel distillation tower
2. Replace trays with packing
3. Increase the number of trays
4. Contract the extra production to another company
5. Change operating conditions



Roadmap for engineering economics topic

- **Four major topics**

  - Time value of money
  - Quantitative measures of profitability
  - Selecting from among alternatives
  - Cost estimating

  Able to evaluate potential projects and select the best

- **Lecture exercises and thought questions**
- **Class workshop**
- **Midterm (individual)**
- **Application in the SDL Project**

Four major topics in engineering economics

1. **Time value of money**

   - How do we compare $ at different times?

2. **Quantitative measures of profitability**

   - How do we determine the "profit" or "financial attractiveness" from an investment?

3. **Systematic comparison of alternatives**

   - How do we ensure that we select the "best" investment?

4. **Estimation of costs**

   - How do we determine the costs before we buy?

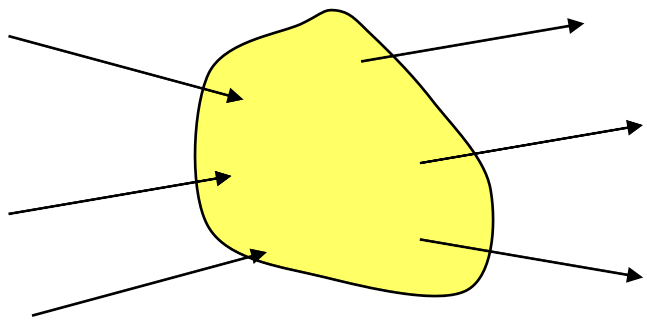
Time-value
Money

Time value of money

Let’s use our modeling skills to determine a “*money balance*”

Revenues or incomes flow into the system, e.g.

- **Product sales**
- **Equipment sales**
- **Licensing fees**



Expenditures or costs flow out of the system, e.g.,

- **Feed costs**
- **Fuel and electricity**
- **Employee salaries**

Important definition: Cash flows are transfers of money that cross the system boundary. The system is typically a “project”.

Time-value Money

Time value of money

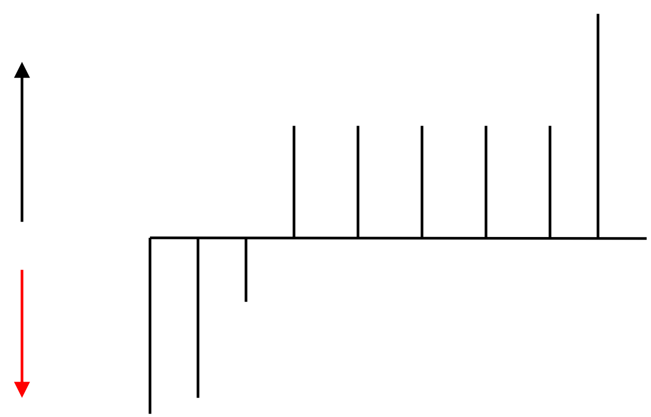
Cash flows occur over time.

We sum the revenues and expenditures within each time period to give the net cash flow at a time. We plot these in a cash flow diagram.

Cash flow diagram

Positive cash flow

Negative cash flow



time →

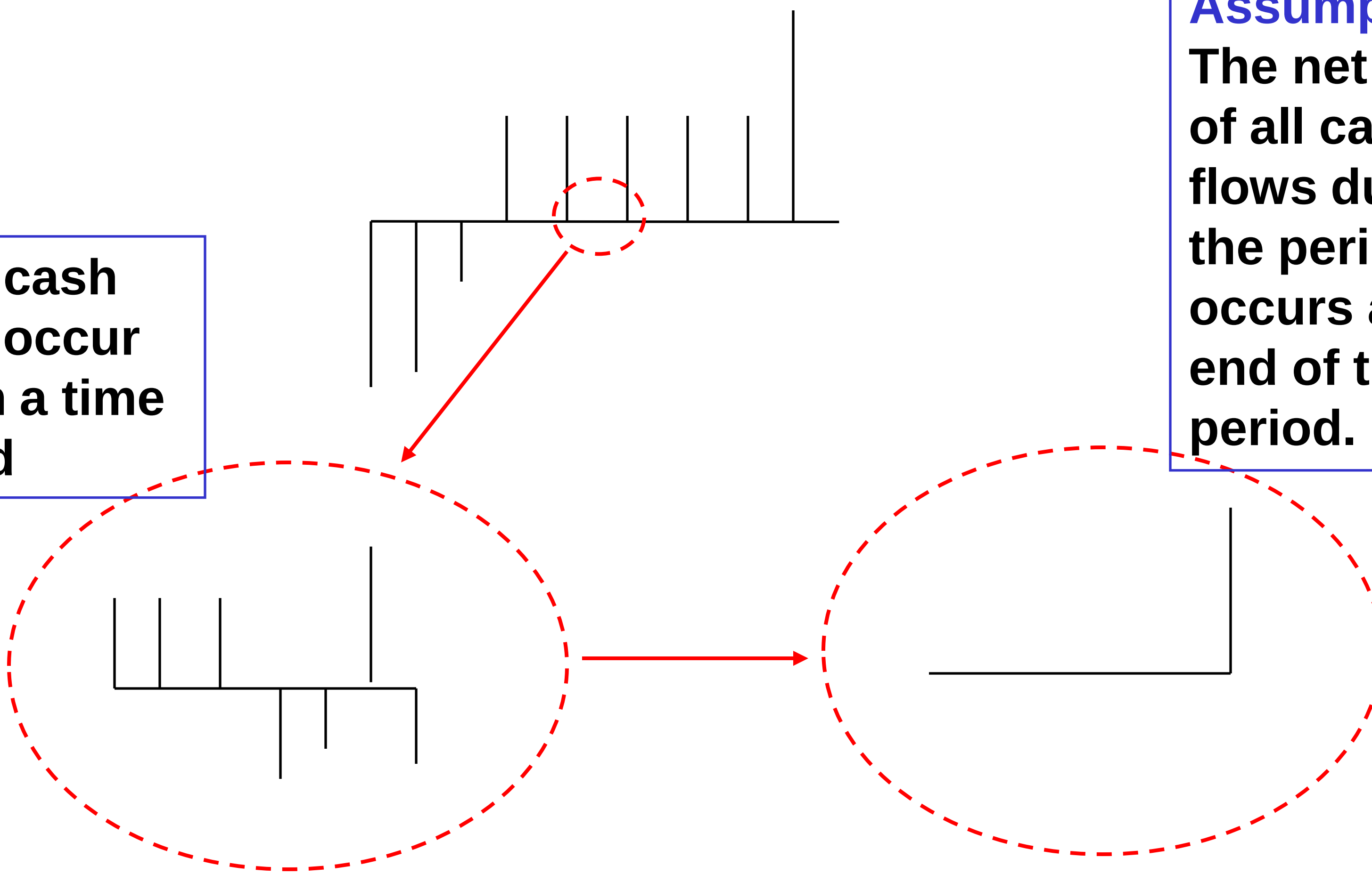
Periods are numbered from 0 to the end of analysis.

Period can be any time length; often one year for engineering projects

Cash flows in units of money ($)

Time value of money

Cash flow diagram and analysis



Many cash flows occur within a time period

Assumption: The net sum of all cash flows during the period occurs at the end of the period.

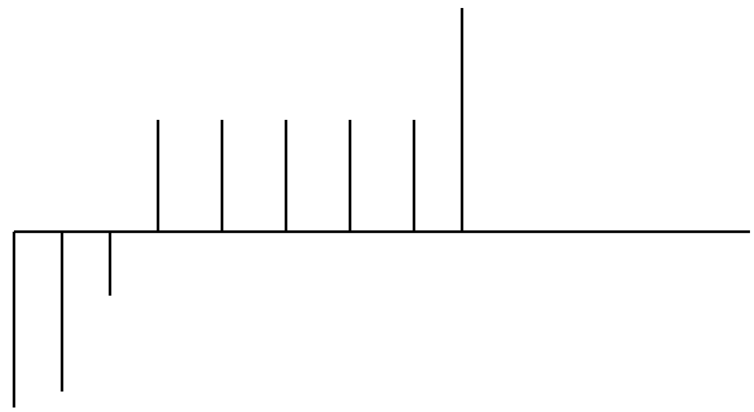
Time-value Money

Time value of money

We plot the end-of-period, or the cumulative cash flows

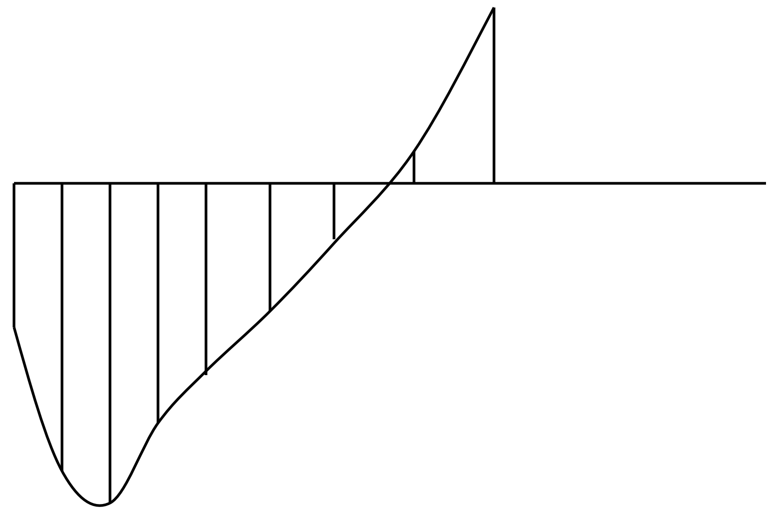
Cash flow diagram

(at each period)

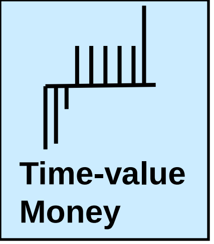


Cumulative cash flow diagram

(just the cumulative sum of the above plot)



We'll use both, with the top plot used more often.



Time value of money

Draw a cash flow diagram for your life from age 10 to age 40 with periods of 5 years

Time value of money

Key question: Why is there a "time value of money"?

Class exercise: A family member asks you to lend her $100. She promises to pay you exactly three years later. She will give you $100 then.

***Is this a good financial proposition?* Why?**

Time value of money

Why is there a "time value"?

- **The owner of money must defer its use**
- **The owner incurs risk**

Thus, money in the future is worth less than money now.

We must take this into account, as our employer's money will almost always be spent over a long period of time.

Time value of money

How do we characterize time value?

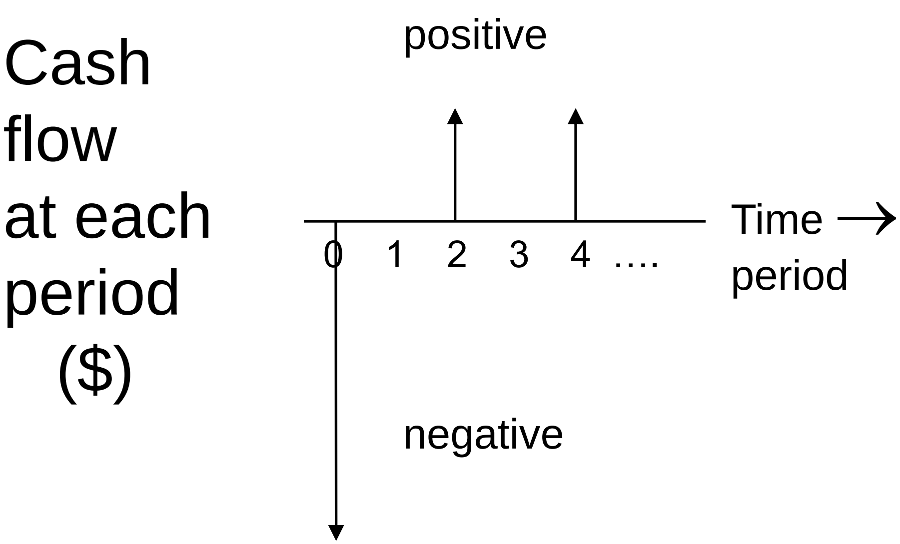
- **We use an interest rate, so that the effect of time is proportional to the total amount of money involved.**

Time-value Money

Time value of money

We will use cash flow diagrams to summarize the behaviour of the system.

We need to calculate the value of all cash flows at the same time to make economic analyses.



P = present value (period = 0)

F = future value (period > 0)

i = interest rate

n = number of periods between present and future

Time value of money

Example 1:

We would like a future amount F = \$1000

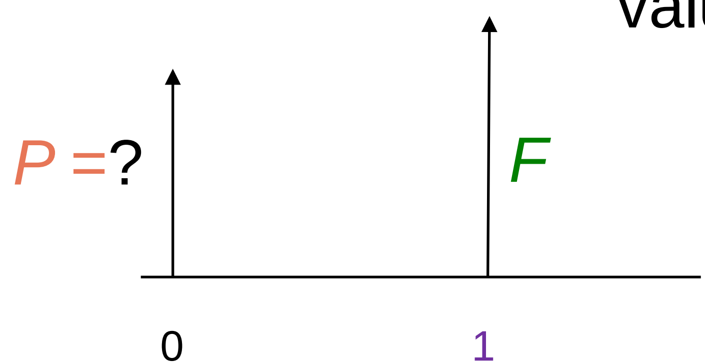
But we have only P = \$800 to invest now.

What interest rate is required to obtain F at $n = 1$ year from now?

Example 2:

We would like a future amount F = \$1000 at $n = 1$ year from now.

Given an interest rate i=0.04 [4%], how much should we invest today, called the present value, P ?



Time-value Money

Time value of money

Determine the relationships between ***P*** and ***F*** for

n time periods, with compound interest rate *i*

$$F_n = P\,(\,1 + i\,)^n$$

What is the present value of a revenue of F = \$1000 at time n for each year n = 1, 2 … 10 at 10% per year time value of money?

Asked another way …

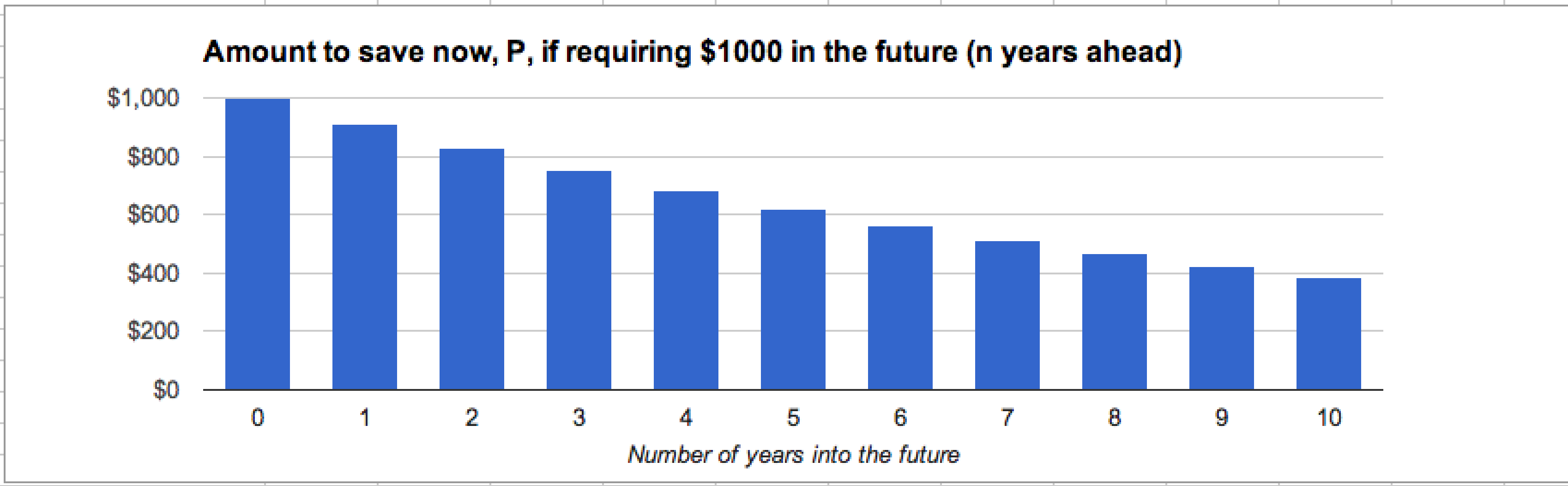
If you want to have F=\$1000 in n = 1, 2, …10 years from now, how much do you have to invest right now, if interest rates remain at 10% per year?

Time-value
Money

All these spreadsheets
are on the course website

Time value of money

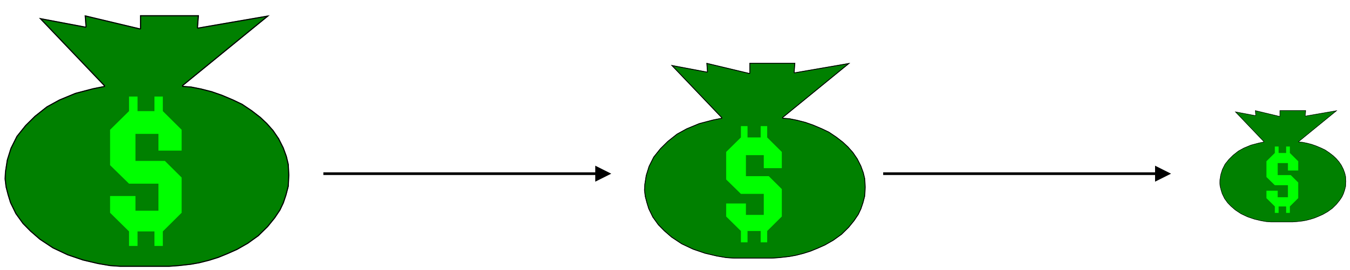
Amount in the future (F)	$1,000	(desired)									
Interest rate (i)	0.1										
Period, n	0	1	2	3	4	5	6	7	8	9	10
Present value required (P)	$1,000	$909	$826	$751	$683	$621	$564	$513	$467	$424	$386



Interpretation : $621 right now (*n*=0) has the equivalent worth of what $1000 will have 6 years (*n*=5) from now, at interest rates of 10%.

Time value of money

- Since money has a time value, money in the future has less value. We will characterize this decrease with the “time value of money”.
- For a worthwhile investment, the net income in the future must be greater than the original expense.

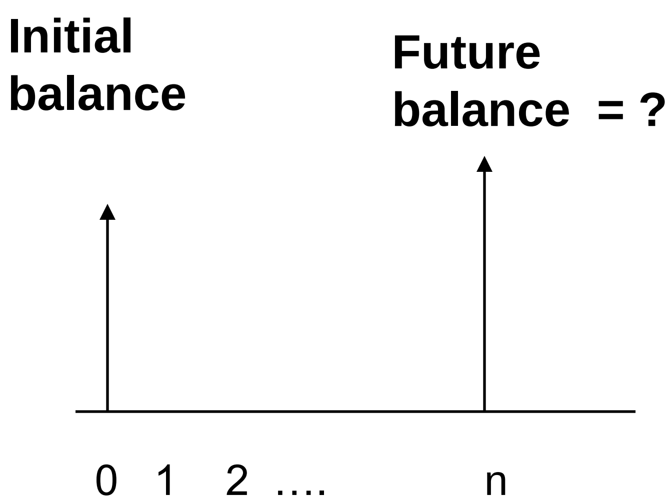


Time-value Money

Time value of money

Associated use of interest rates: When we place money in the bank, the bank increases the amount in our account according to an interest rate. This is payment for the bank using our money.

How do we calculate the future amount in our account?



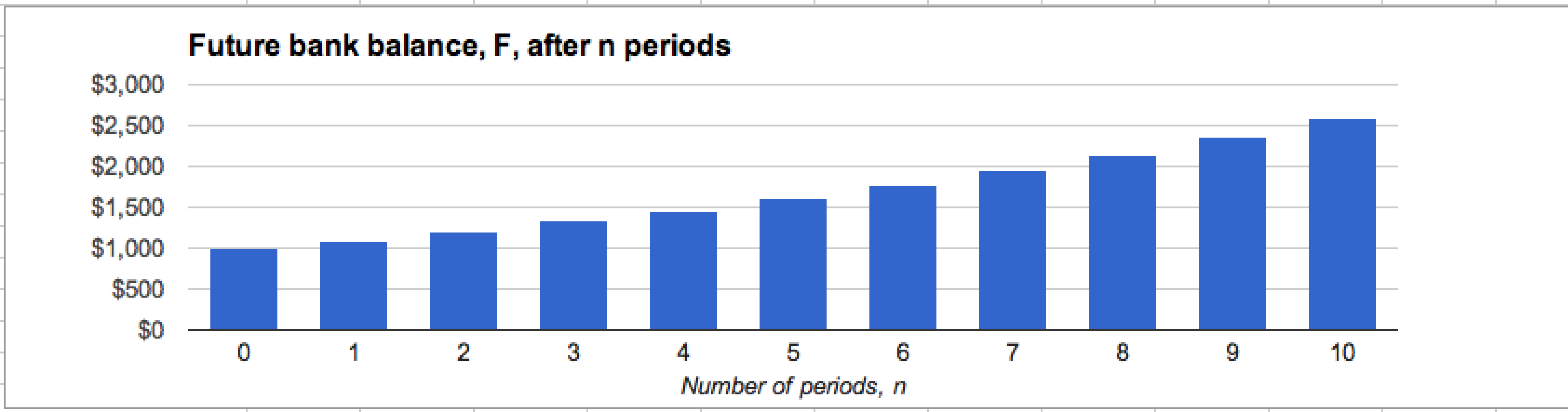
$$\boxed{\textbf{Future balance} = P\ (1 + i)^{n}}$$

What is the amount in your account ten years after depositing $1000 at 10% per year interest rate?

Time-value Money

Time value of money

Amount invested (P)	$1,000										
Interest rate (i)	0.1										
Period, n	0	1	2	3	4	5	6	7	8	9	10
Bank balance, F	$1,000	$1,100	$1,210	$1,331	$1,464	$1,611	$1,772	$1,949	$2,144	$2,358	$2,594

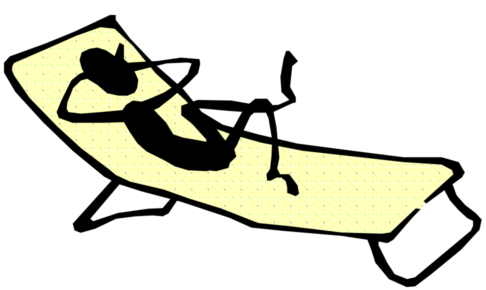


Time value of money

If you want to get rich, just invest and wait

Invest \$10,000/yr at 5% is worth after 35 years: \$ 948,000
after 40 years: \$ 1,268,000
after 45 years: \$ 1,677,000*

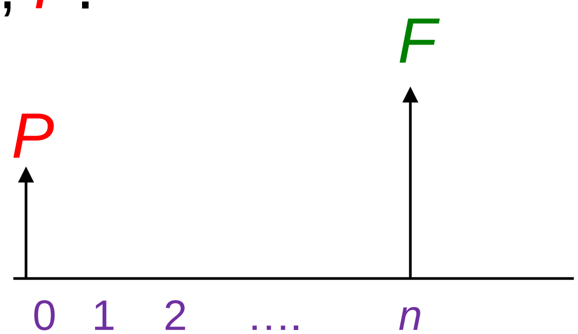
* This is close to the number we discussed at tutorial on Monday



*"Compound interest is the eighth wonder of the world. He who understands it, earns it ... he who doesn't ... **pays it**."* – Albert Einstein

Time value of money

We can consider inflation, i, in a similar way. An amount of money in the future (F), is worth less than in the present, P.



$$F_n = P\,(\,1 + i\,)^{n}$$

What is the present value of F=\$1000 at time = n

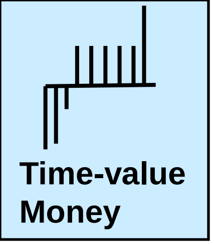
for each year (n= 1 to 10)

at 10% per year time value of money?

Asked another way …

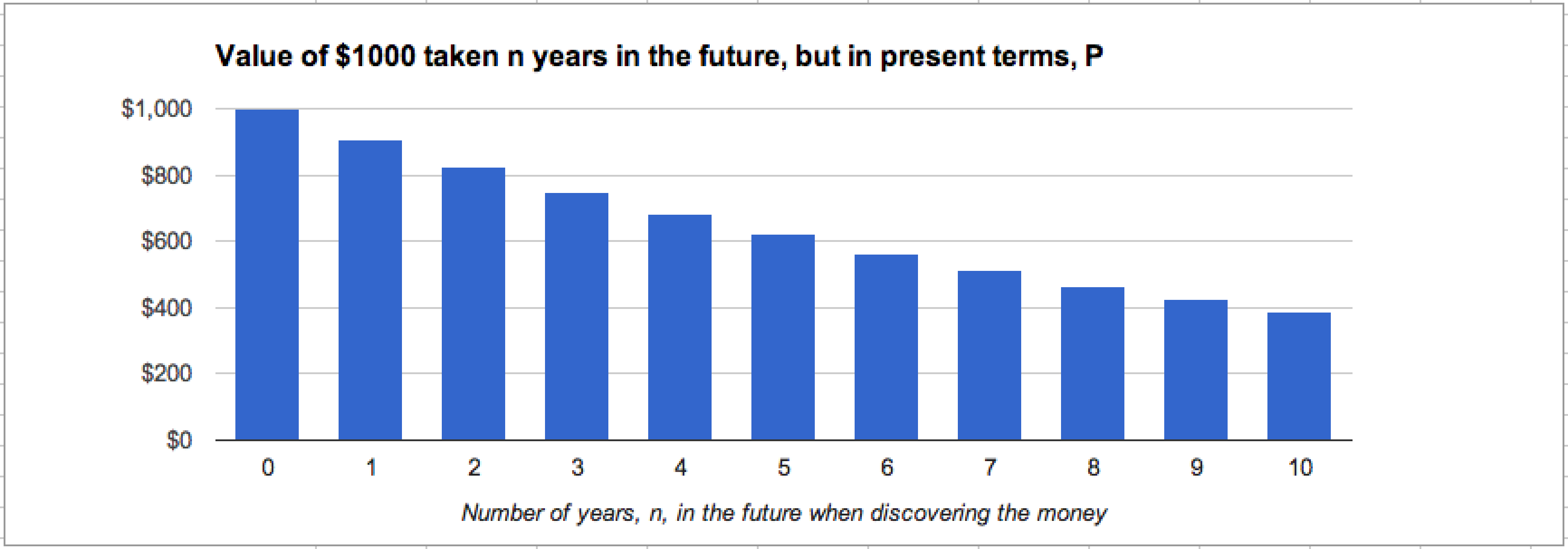
In n = 1, 2, …10 years from now you discover F = \$1000 under your mattress, and you can go buy goods with those dollars.

How much would those same goods have cost, in today's dollars if inflation was 10% per year?



Time value of money

Amount discovered later (F)	$1,000										
Inflation rate (i)	0.1										
Period, n	0	1	2	3	4	5	6	7	8	9	10
Value in present terms (P)	$1,000	$909	$826	$751	$683	$621	$564	$513	$467	$424	$386



Interpretation : If TVM (inflation) = 10%, then consider that something worth $424 now is what you'll have to pay $1000 for in 10 years (*n*=9) from now.

Time-value Money

Time value of money

Economic and financial indicators — **The Economist** September 7th 2013

Interest rates

Economic data (2)
% change on year ago

	Current-account balance: latest 12 months, $bn	Current-account balance: % of GDP 2013†	Budget balance % of GDP 2013†	Interest rates, % 10-year gov't bonds, latest	Currency units, per $: Sep 4th	Currency units, per $: year ago
United States	-425.7 Q1	-2.7	-4.0	2.89	-	-
China	+211.6 Q2	+2.1	-2.1	3.94§§	6.12	6.35
Japan	+54.1 Jun	+1.2	-8.3	0.78	99.5	78.4
Britain	-96.7 Q1	-2.7	-7.6	2.95	0.64	0.63
Canada	-59.6 Q2	-3.1	-2.8	2.72	1.05	0.99
Euro area	+247.1 Jun	+1.8	-3.3	1.94	0.76	0.80
Austria	+9.7 Q1	+2.4	-3.0	2.37	0.76	0.80
Belgium	-8.7 Mar	-0.7	-3.1	2.82	0.76	0.80
France	-46.4 Jun	-2.1	-4.2	2.53	0.76	0.80
Germany	+244.5 Jun	+6.6	+0.3	1.94	0.76	0.80
Greece	-3.4 Jun	-0.8	-4.7	10.46	0.76	0.80
Italy	+5.9 Jun	+0.6	-3.5	4.42	0.76	0.80
Netherlands	+85.1 Q1	+8.1	-3.8	2.35	0.76	0.80
Spain	+8.7 Jun	+0.7	-7.2	4.43	0.76	0.80
Czech Republic	-3.8 Q2	-1.9	-2.9	2.58	19.5	19.8
Denmark	+18.2 Jun	+5.2	-2.6	2.13	5.65	5.93
Hungary	+3.0 Q1	+1.7	-3.0	6.59	228	227
Norway	+64.6 Q2	+12.9	+13.0	3.15	6.07	5.79
Poland	-9.3 Jun	-2.4	-3.9	4.80	3.24	3.34
Russia	+47.9 Q2	+2.5	-0.6	7.94	33.3	32.3
Sweden	+32.0 Q2	+7.1	-1.4	2.57	6.60	6.71
Switzerland	+77.6 Q1	+11.6	+0.2	1.18	0.94	0.96
Turkey	-53.6 Jun	-6.8	-2.2	10.02	2.06	1.82
Australia	-49.4 Q2	-3.1	-1.3	4.02	1.09	0.98
Hong Kong	+5.2 Q1	+0.9	+2.0	2.47	7.76	7.76
India	-87.8 Q1	-4.5	-5.1	8.39†††	67.0	55.6
Indonesia	-28.8 Q2	-2.4	-2.9	na	11,065	9,571
Malaysia	+14.2 Q2	+5.8	-4.3	3.98	3.28	3.11
Pakistan	-2.3 Q2	-1.0	-8.8	12.10†††	105	94.8
Singapore	+49.9 Q2	+18.3	+0.7	2.65	1.27	1.25
South Korea	+59.8 Jul	+3.5	+0.5	3.64	1,095	1,133
Taiwan	+52.8 Q2	+11.7	-1.9	1.73	29.8	29.9

Time value of money

Class exercise: Your bank account is the "system". You have an initial revenue of $4,000 and the following monthly revenues and expenditures, and the bank pays 5% interest per month.

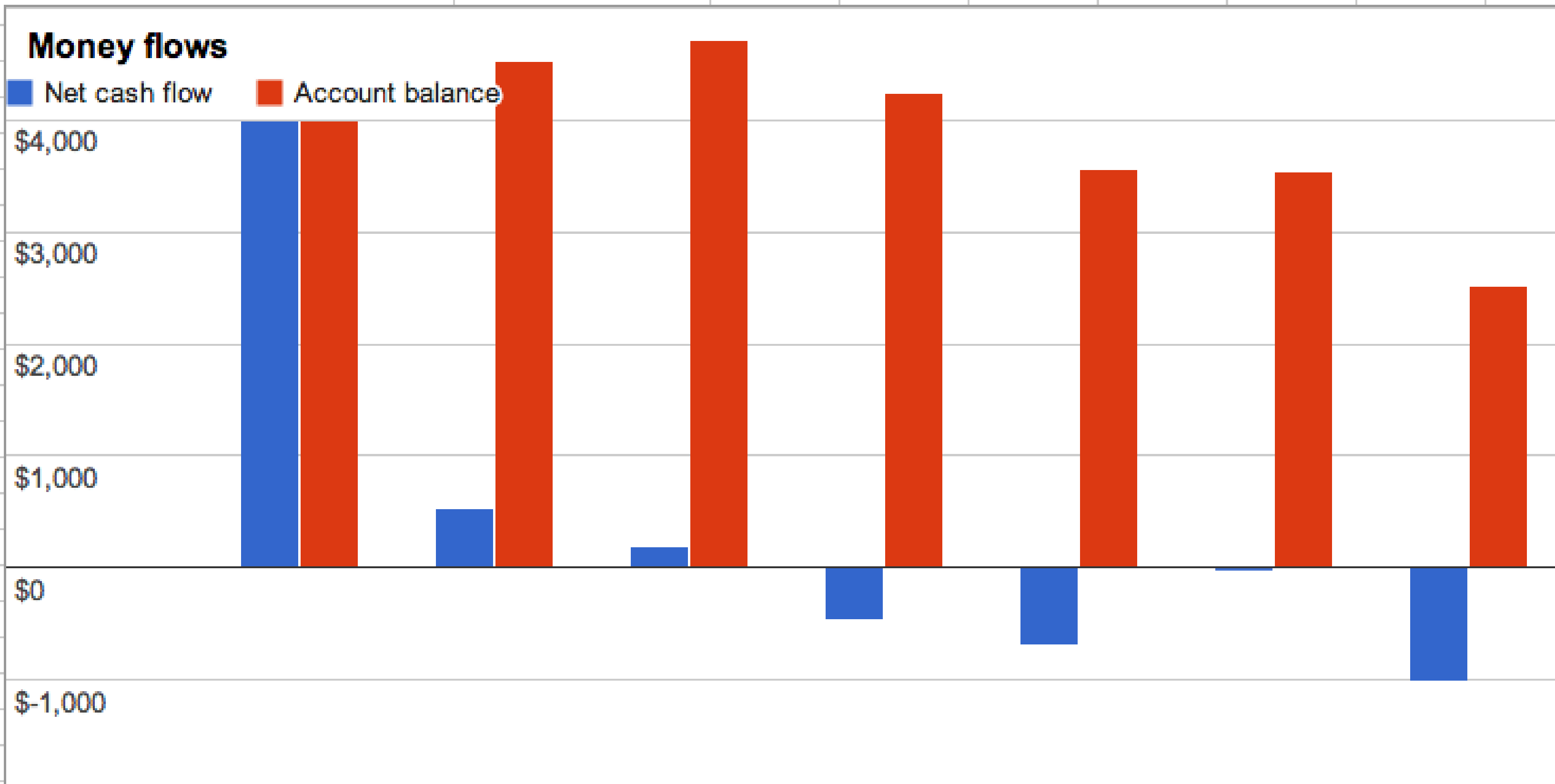
Plot the monthly balance *and* cash flow diagram for your bank account.

	Month	0	1	2	3	4	5	6
Revenues		$4,000	$530	$530	$0	$0	$0	$0
Expenses		$0	-$200	-$570	-$700	-$900	-$200	-$1,200

Time-value
Money

Time value of money

	Month	0	1	2	3	4	5	6
Revenues	A	\$4,000	\$530	\$530	\$0	\$0	\$0	\$0
Expenses	B	\$0	-\$200	-\$570	-\$700	-\$900	-\$200	-\$1,200
Interest earned at 5% per month	C = 0.05 x E(n-1)		\$200	\$227	\$236	\$213	\$178	\$177
Net cash flow	D = A + B + C	\$4,000	\$530	\$187	-\$464	-\$687	-\$22	-\$1,023
Account balance	E = D + E(n-1)	\$4,000	\$4,530	\$4,717	\$4,252	\$3,565	\$3,543	\$2,520



Time value of money

Now, let’s relate the banking interest to the time value of money

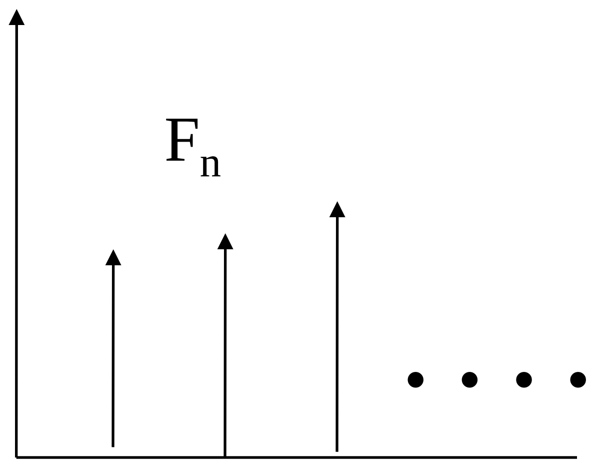
Class exercise: You deposit $5000 in a bank account with an annual compound interest rate i*****. The time value of money is described by an interest rate i' (inflation rate).

Calculate the present value of the bank account after n years.

Time-value Money

Time value of money

$C_0 = 5000$



$$F_n = C_0(1+i^*)^n$$

Interest earned on the investment

$$P = \frac{F_n}{(1+i')^n}$$

Present value of the investment

$$P = C_0 \frac{(1+i^*)^n}{(1+i')^n}$$

What is the result if $i^* = i'$?

How do we use this result to interpret the time-value of money?

Time value of money

Class exercise

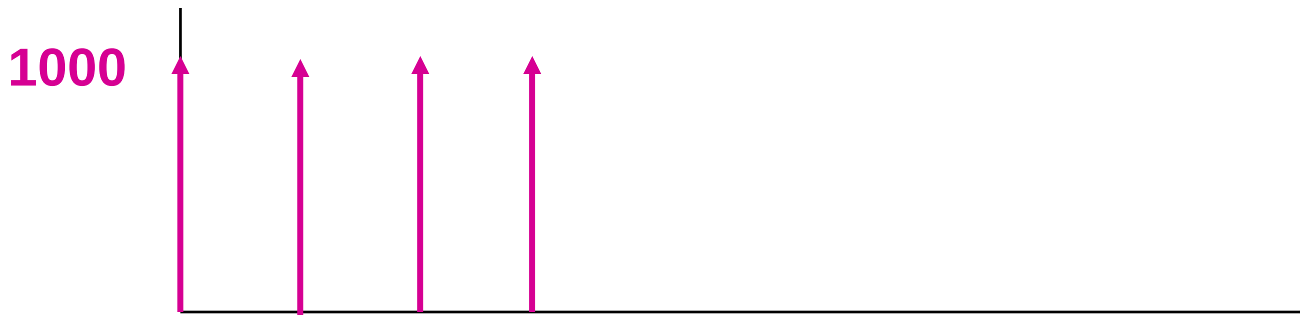
You have an income of $1000 per year for each of the 4 years of your undergraduate studies.

- Draw a cash flow diagram
- Determine the value for this income in the beginning of the first year when the inflation rate (time value of money) is 10%.

Time-value Money

Time value of money

Class exercise



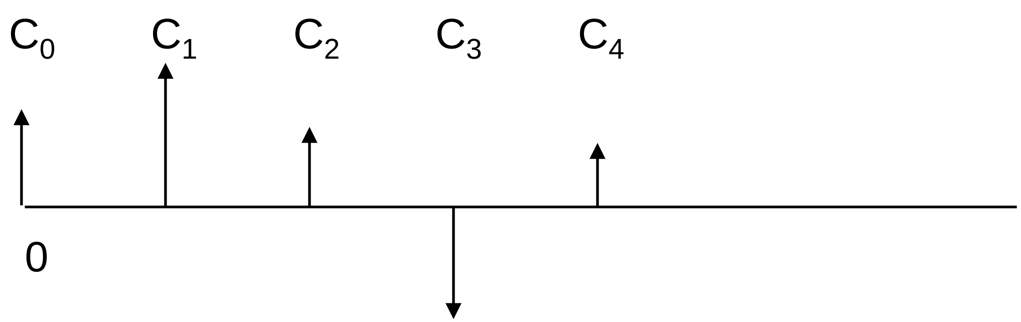
	Inflation rate, i =	0.1			
Period	n	**0**	**1**	**2**	**3**
Cash flow in the period	Fn	$1,000	$1,000	$1,000	$1,000
Cash flow in present value terms	P	$1,000	$909	$826	$751
Cumulate cash flow in present value terms		**$1,000**	**$1,909**	**$2,736**	**$3,487**

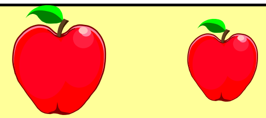
Interpretation: You could have replaced the cash flow with one revenue of $3487 at time period 0, that earned interest at 10%. Then make $1000 withdrawals in each year from the bank account. The balance will be $0 after the last withdrawal. Prove this interpretation for yourself in a spreadsheet.

Time-value
Money

Time value of money

Look ahead: We will be expressing values for different investments at the **same time** period for the purpose of comparison.





We need to compare apples and apples!

$$P = \frac{C_0}{(1+i)^0} + \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \frac{C_3}{(1+i)^3} + \frac{C_4}{(1+i)^4} + \cdots$$

with C_n = cash flow at period n with a TVM rate of i

Time value of money

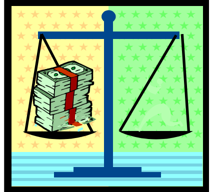
Some thoughts

- **Interest factor tables:** Many tables are provided for relationships among *P*, *F* and annuity values for specified interest rates and periods
- **Calculations:** Many projects have unequal cash flows. The time-value calculations are easily performed using spreadsheets like Excel.
- **Life-long applications:** These concepts are useful for personal finances (mortgage rate, credit card borrowing, and so forth).

Time value of money

Group learning / Self-directed learning

1. Determine the meanings of **simple**, **compound**, **nominal**, **effective** and **continuous** interest.
2. How would the equations used in this section be changed if the interest rate depended on the period?
3. You have a balance of \$4,000 on your credit card which has an interest rate of 24% (nominal, **compounded monthly**). How much do you have to pay per month to maintain your balance at \$4,000? How much do you have to pay per month to clear your debt in one year?
4. What is the meaning of the term "usury"? What is the history of charging interest for loans? Read up on Sharia compliant finance (finance without charging interest on loans).
5. Investigate the **`=PV( )`** and **`=FV( )`** functions in spreadsheet software



Profitability

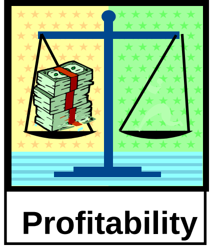
Measures of profitability

1. Time value of money
2. Quantitative measures of profitability
3. Systematic comparison of alternatives
4. Estimation of costs

- We need a systematic method for **comparing** expenses and incomes at different times using the time value of money
- We need to compare the project profitability with a **minimum acceptable performance**
- Many measures are in use; we'll look at four.

  - Two are useful and commonly used by engineers

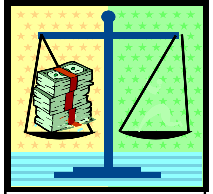
  - Two are not recommended, but are used in practice. We should know these as well.



Measures of profitability

The following organizations and decisions are not “profit based”; do they need measures of profitability?

- Universities
- Charities
- Governments
- For-profit companies when involved in
  - safety projects
  - environmental projects



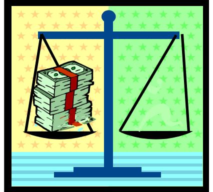
Profitability

Measures of profitability

Examples for each category

- Universities – e.g. rent or purchase computers
- Charities - Invest in fund raising
- Governments - In-house or outsource tasks
- For-profit companies when involved in
  - safety projects
  - environmental projects

  Find project that satisfies goals at the lowest cost



Profitability

Measures of profitability

Example

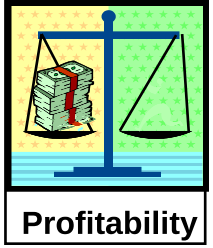
We can invest money yielding a 15% annually compounded return.

Compared to that, would the following project be financially attractive?

i.e. should we invest, or just park our money and earn the 15%?

Period	Cash Flow ($)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000

Don’t know how to estimate the costs? Don’t worry, we will cover the topic soon.



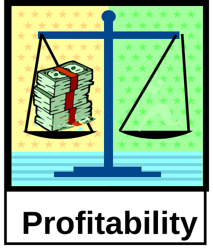
Measures of profitability

Payback time

- This measure is often used as a "quick and dirty" measure of profitability
- We use it in our daily lives: how long does it take to pay back for …(car, vacation, new cell phone, *etc*)
- Also called *Payout Time*
- Defined in units of time (e.g. months or years)

The time for the cumulative cash flow to achieve a value of $0

Usually (and in this course), payback time does not consider interest.

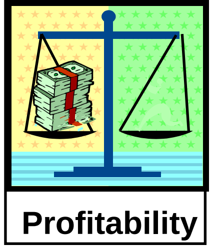


Measures of profitability

Class exercise: Payback time

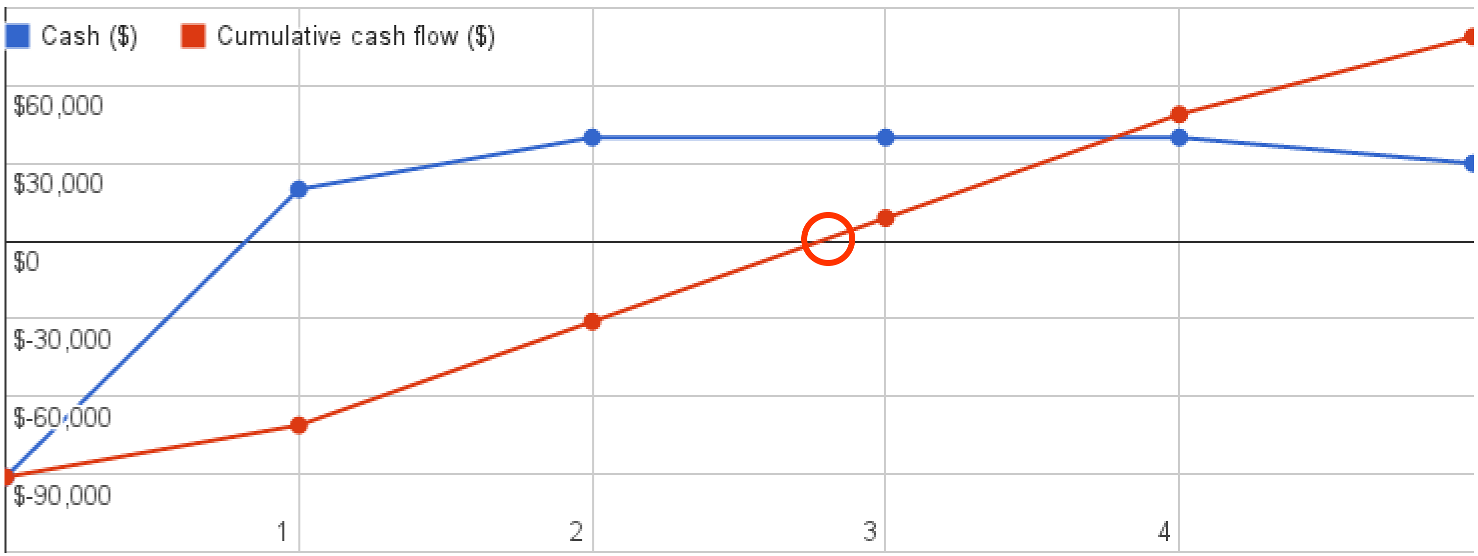
Determine the payback time for the cash flow defined in previous table

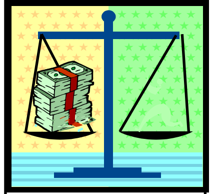
Period	Cash Flow ($)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000



Measures of profitability

A plot (visual interpolation) used to determine the payback time





Profitability

Measures of profitability

- What is the Payback time for a project that involves an original investment of $91,000 and provides an annual profit (positive cash flow) of $34,000 per year over the first three years and no depreciation.

  Payback time = 91/34 ≈ 2.7 years [rough calc.]

  Same payback time as previous example, but different cash flows

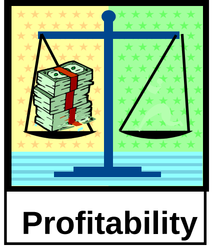
Notes

- No time value of money taken into account

- Doesn’t consider what happens after payback

Not recommended!

Can be an effective screening tool though



Measures of profitability

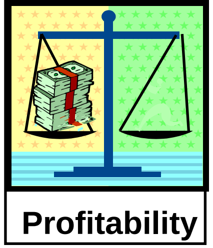
Return on original investment (ROI)

- Simple calculation

- ROI = $\dfrac{\text{average annual profit}}{\text{fixed capital} + \text{working capital}}$

- Expressed in units of percent per year

What is fixed capital?
What is working capital?

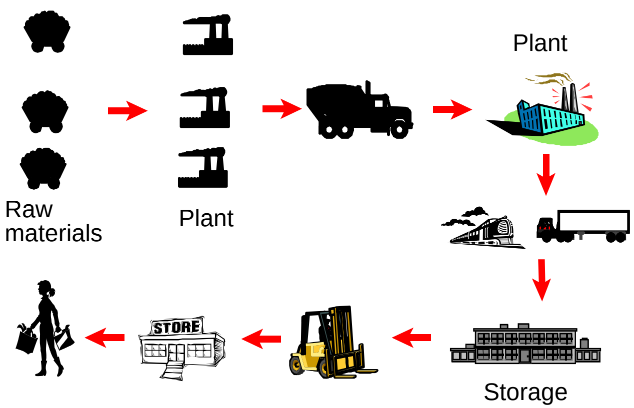


Measures of profitability

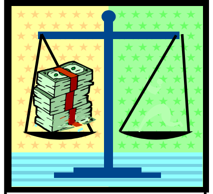
Working Capital

Working capital is the difference between current assets and current liabilities. (Estimation given later in course.) Examples include:

- Raw materials
- Work in progress (WIP), which is material part way through the production
- Supplies stored for manufacturing, e.g., catalyst
- Finished products in storage and transport that we still own
- Cash on hand to cover short-term expenses



A key feature of working capital is that it can be recovered when the plant is shutdown.



Profitability

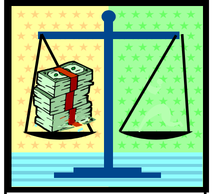
Measures of profitability

- Calculate the ROI for a project with fixed capital of $91,000, no working capital, and an average annual profit of $34,000.

$$ROI = 34/91 \times 100 \approx 34\%$$

Does not consider time value of money

Not recommended!



Profitability

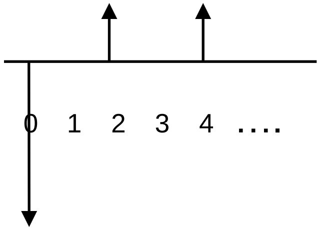
Measures of profitability

Net Present Value (NPV) (NP worth)

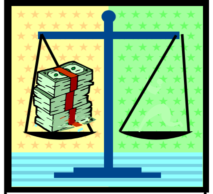
- Explicitly expressed as a **specific value of money**
- Defined as present value of all cash flows
- Sum up these present values (i.e. “net” them up)
- For N compounding periods in the life of the project, with a net cash flow in each period of C_n

recommended

$$\mathrm{NPV} = \sum_{n=0}^{N} C_n (1+i)^{-n}$$



What does NPV=$0 imply?



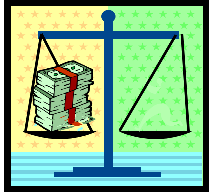
Profitability

Measures of profitability

Class exercise: Net Present Value (NPV)

Period	Cash Flow ($)	PV of cash flow ($)
0	-91,093	
1	20,000	
2	40,000	
3	40,000	
4	40,000	
5	30,000	

Calculate the NPV for this project at 15% time value of money


Profitability

Measures of profitability

Class exercise: Net Present Value (NPV)

See the calculations below and *on the course website*

Payback time	Period	Cash ($)	Present value ($)	Cumulative sum of PV ($)	Cumulative cash flow ($)
	0	-$91,093	-$91,093	-$91,093	-$91,093
	1	$20,000	$17,391	-$73,702	-$71,093
Interest rate	2	$40,000	$30,246	-$43,456	-$31,093
0.15	3	$40,000	$26,301	-$17,155	$8,907
	4	$40,000	$22,870	$5,715	$48,907
	5	$30,000	$14,915	$20,630	$78,907

What does this value mean?

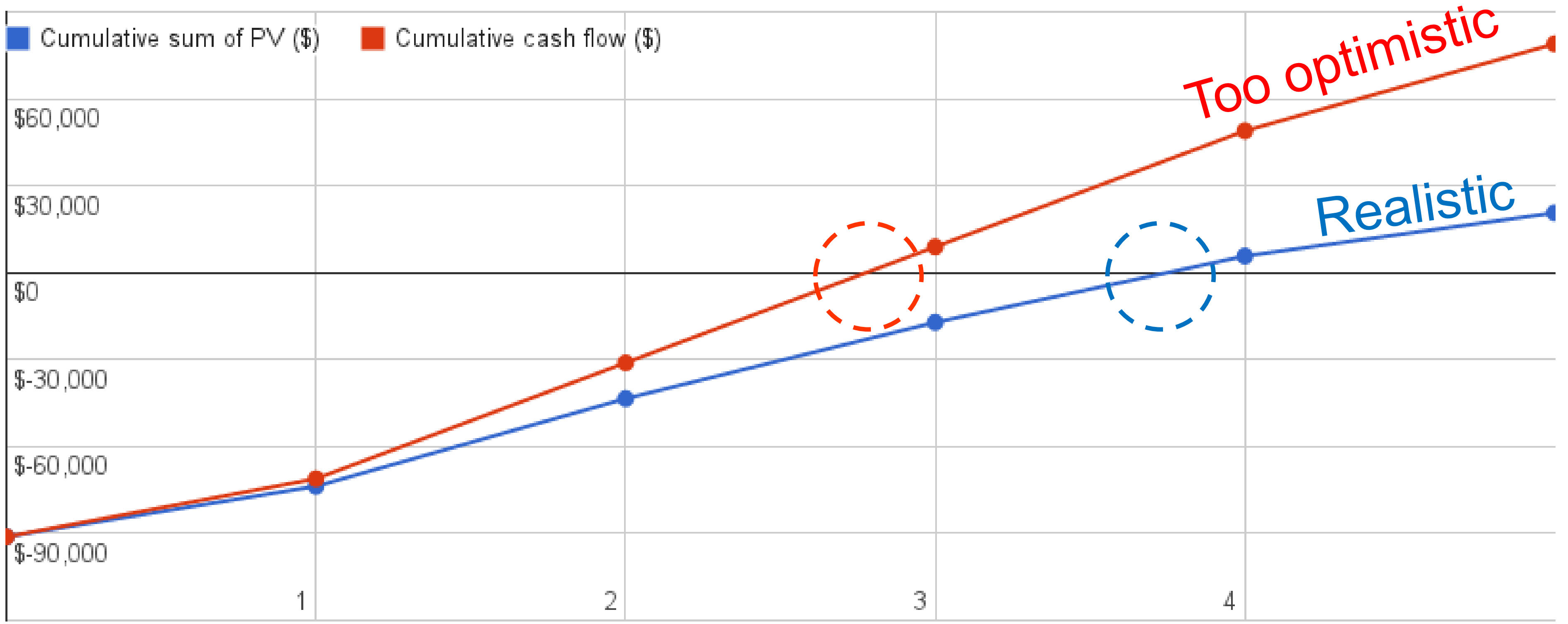
From prior exercise

This approach considers time value of money explicitly. Important for projects of long duration, and in high deflationary environments.

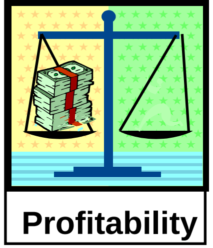
Measures of profitability

Profitability

Class exercise: Net Present Value (NPV)



Payback time **not** taking time value of money into account is too optimistic.

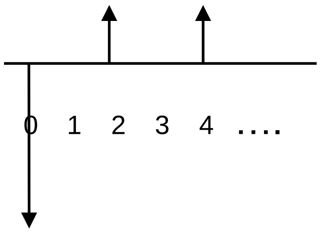


Measures of profitability

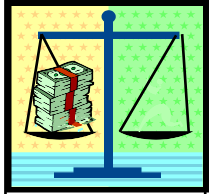
Discounted Cash Flow Rate Of Return (DCFRR)

- **Also called,** Discounted Cash Flow (DCF)
  Internal Rate of Return (IRR)
- Defined as **the interest rate** that results in a NPV of $0

$$NPV = \sum_{n=0}^{N} C_n (1+i)^{-n} = 0$$



recommended



Profitability

Measures of profitability

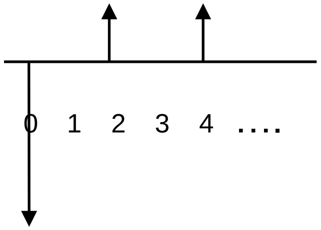
Internal Rate of Return (IRR)

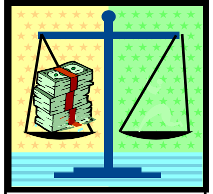
- Why *internal*? It is the NPV from this project's (internal) cash flows. NOT dependent on other project's.

- Simplest example: you invest \$100 now and wish to have \$108 next year. What is the rate of return, i.e. the IRR, required to achieve this?

Now use the equation below.

$$\text{NPV} = \sum_{n=0}^{N} C_n (1+i)^{-n} = 0$$





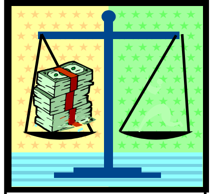
Profitability

Measures of profitability

Class exercise: Discounted cash flow rate of return (DCFRR)

Period	Cash Flow ($)
0	-91,093
1	20,000
2	40,000
3	40,000
4	40,000
5	30,000

Calculate the DCFRR for this project (you’ll need a computer for this)



Profitability

Measures of profitability

Calculate the DCFRR for this project

DCFRR = $i = 0.236$ **or 23.6% (By trial and error, use "goal seek")**

Payback time	Period	Cash ($)	Present value ($)	Cumulative sum of PV ($)
	0	-$91,093	-$91,093	-$91,093
	1	$20,000	$16,182	-$74,911
Interest rate	2	$40,000	$26,184	-$48,727
0.23597	3	$40,000	$21,185	-$27,542
Adjust this value to get cumulative	4	$40,000	$17,141	-$10,401
sum of PV, i.e. NPV = 0	5	$30,000	$10,401	$0

So the DCFRR is 23.6% in this example over the 6 periods of the project's life.

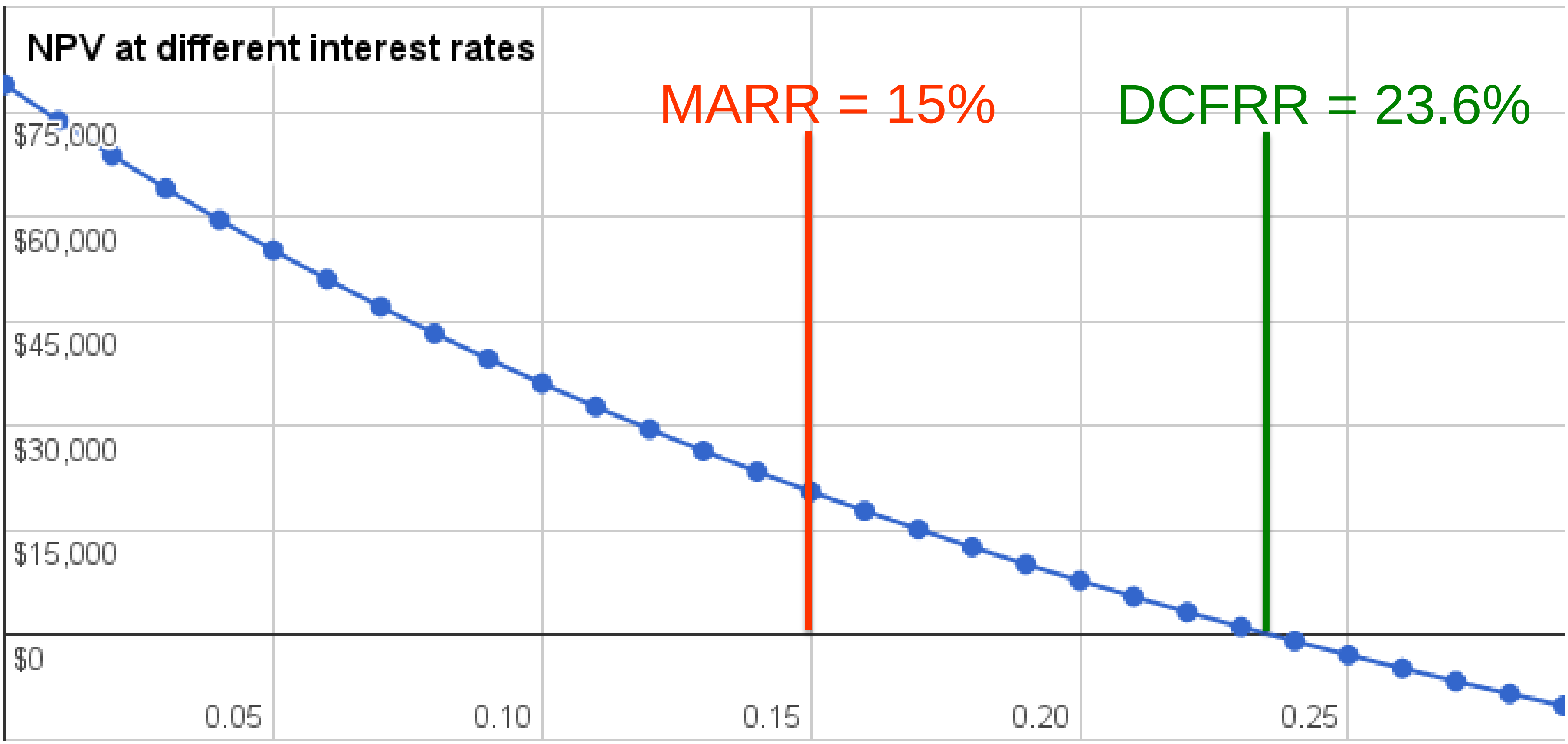
What does this value mean?

Considers time value of money explicitly

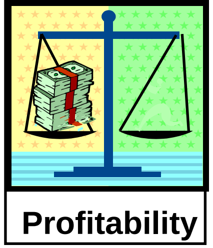
Measures of profitability

This is a fixed value that the company chooses

A profitable investment has DCFRR > MARR



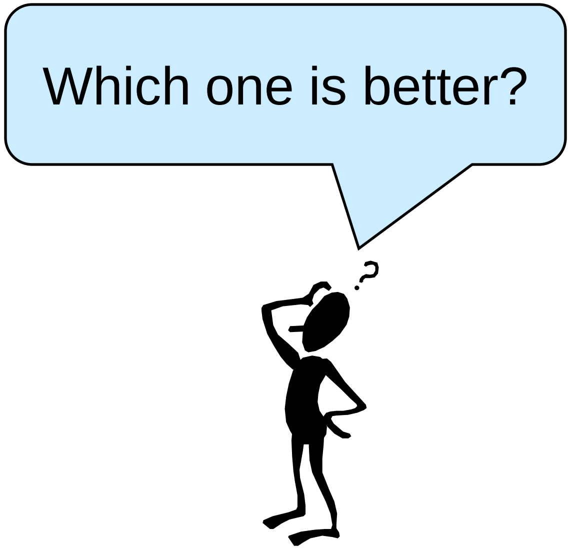
i **= interest rate**



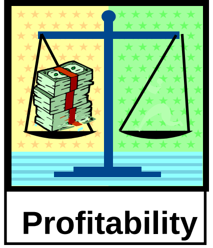
Measures of profitability

Calculate the DCFRR for the following cash flows

year		0	1	2	3
Cash flows	A	-1000	750	390	180
	B	-1000	350	470	660
	C	-1000	533	467	400



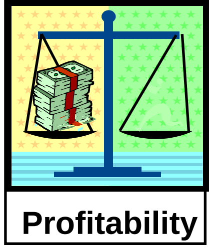
From Humphreys, Jelen's Cost and Optimization Engineering, page 117



Measures of profitability

Calculate the DCFRR for the following cash flows

Cash flow diagrams



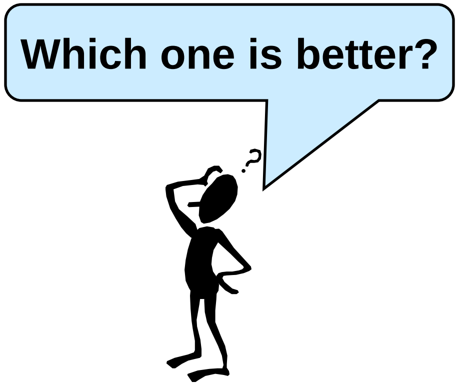
Measures of profitability

Calculate the DCFRR for the following cash flows

Period	Project A	Project B	Project C		Period	Cuml PV A	Cuml PV B	Cuml PV C
0	-$1,000	-$1,000	-$1,000		0	-$1,000	-$1,000	-$1,000
1	$750	$350	$533		1	-$375	-$708	-$556
2	$390	$470	$467		2	-$104	-$382	-$231
3	$180	$660	$400		3	$0	$0	$0
DCFRR	0.2000	0.2000	0.2000	*calculated with the =IRR(...) function*				

Different cash flows with the same DCFRR.

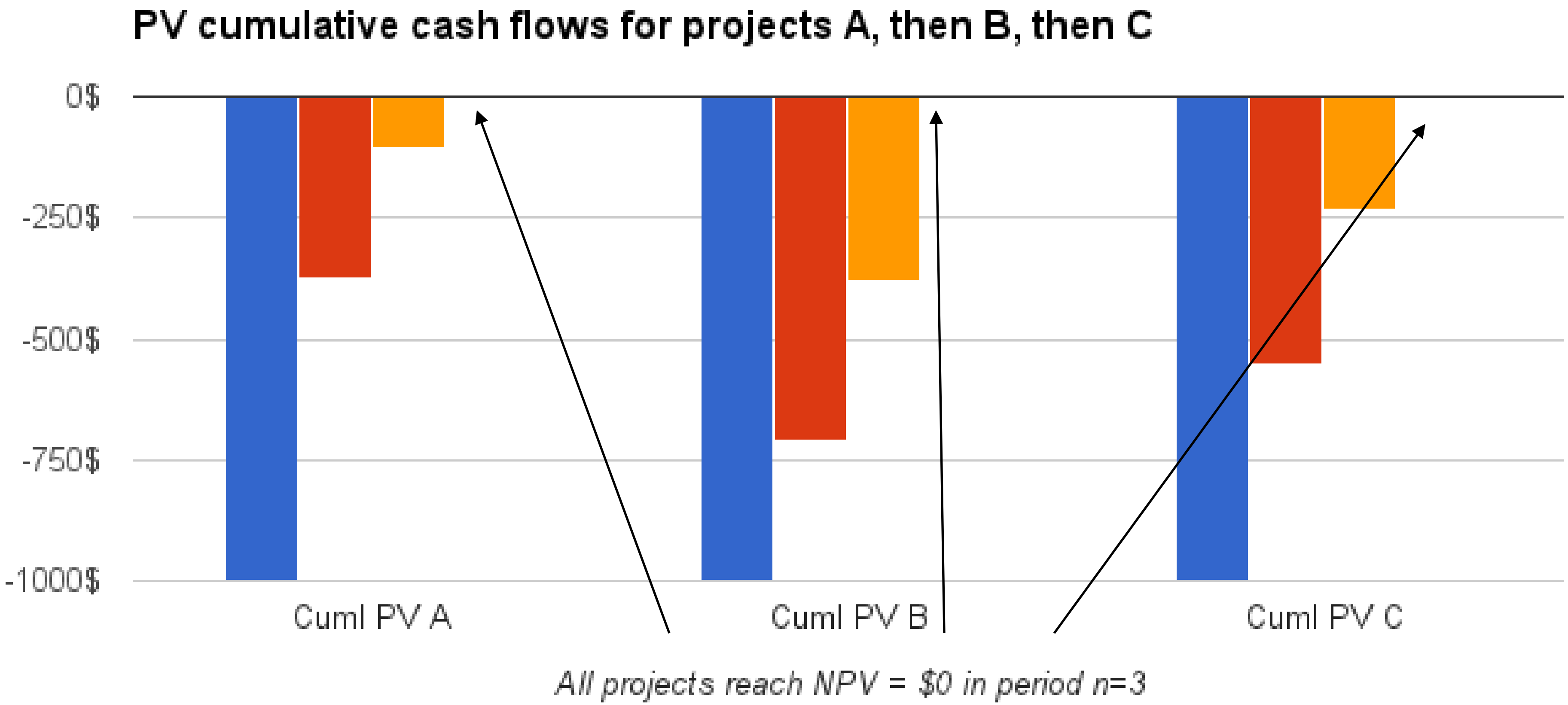
How do we interpret this?



Measures of profitability

Calculate the DCFRR for the following cash flows

Cumulative NPV using i_{TVM}=20%



Compare

We will come back to this topic again

Detour: Comparison of alternatives

We will need to know the following term

MARR = Minimum Acceptable (compound) Rate of Return

Desired return, considering risk

Weighted average cost of capital

Depends on debt and equity capital and percentage return to achieve breakeven.

MARR →

High risk

Venture capital

Historic return of investments

Bank loan interest

Bank deposit interest

0 Put money under your mattress

Compare

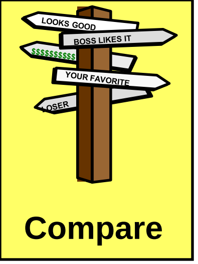
Detour: Comparison of alternatives

MARR = Minimum Acceptable Rate of Return

Sample values from Peters *et al*. Table 8-1.*

Description	Level of risk	Typical MARR (%)
Very low risk, hold capital short-term	Safe	4-8
New production capacity where company has established position in market	Low	8-16
New product or process technology, company has established market position	Medium	16-24
New process or product in new market	High	24-32
High R&D and marketing development	Very High	32-48

* Descriptions modified slightly



Detour: Comparison of alternatives

The analysis depends on the scenario

- Alternatives are: "project" *or* "do nothing"
- Independent alternatives

- Mutually exclusive alternatives
- Contingency dependent alternatives

We cover these later

Compare

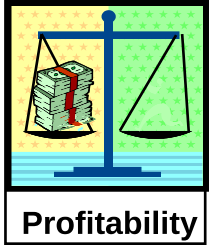
Detour: Comparison of alternatives

Comparing one alternative with "Do nothing"

- The "do nothing" alternative in a large company implies the that the money can be invested with a return rate = **MARR**.

- We always have the (***independent***) alternative of placing the money in an interest bearing bank account. This defines a lower limit on MARR.

- Therefore, we always compare alternatives.

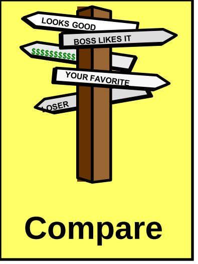


Measures of profitability

Can you have an investment with DCFRR **>** MARR, but NPV **<** $0 (calculating NPV with i_{TVM}=MARR)?

Can you have an investment with DCFRR **<** MARR, but NPV **>** $0 (calculating NPV with i_{TVM}=MARR)?

Can you have an investment with DCFRR **<** MARR, and NPV **<** $0 (calculating NPV with i_{TVM}=MARR)?

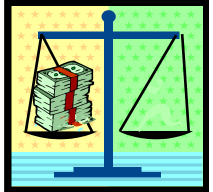


Detour: Comparison of alternatives

Independent alternatives

- Compare each alternative with the MARR
- Pick all combinations of investments for which:
  NPV > \$0 using i_{TVM} = MARR
  DCFRR > MARR
- Since they are independent, sufficient funds exist for all acceptable alternatives

Analysis for independent alternatives compares each project's DCFRR to the MARR



Profitability

Measures of profitability

We have learned four measures of profitability

- **Payback time**
- **ROI**

Not recommended!

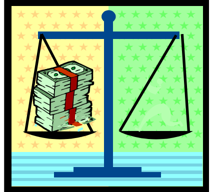
Unfortunately, both are used in everyday settings, so managers will often request these values. Just recognize their limitations.

- **NPV**
- **DCFRR**

Recommended

Note: both NPV and DCFRR require an estimate of *N* (project lifetime)

Which will you use in your course project and engineering practice?

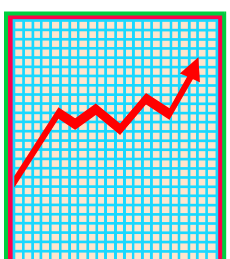


Profitability

Measures of profitability

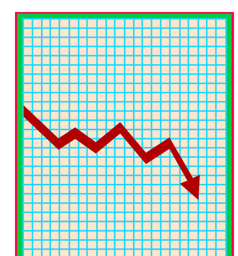
In summary, we have learned four methods

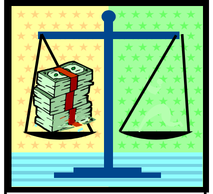
- What are they?
- Why did we learn more than one method?
- Which are recommended?
- Which will you use in your course projects?
- Which will you use in profession practice?



Is the project

profitable or unprofitable?





Profitability

Measures of profitability

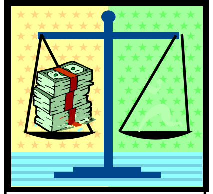
Self-directed learning: Covering the topic, extending beyond these visual aids.

1. For all four methods determine typical threshold values that define the boundary between attractive and unattractive projects Find the MARR for a company/sector you are interested in.

2. Investigate a fifth method, annual worth, define its threshold value, and explain when this method is most often used.

3. Determine how inflation affects the calculations of profitability measures.

4. Describe a mathematical method that you could use to calculate the DCFRR (IRR). How could you calculate the DCFRR (IRR) with the use of an Excel spreadsheet?



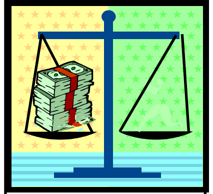
Profitability

Measures of profitability

Extending profitability coverage

Depreciation and Taxes

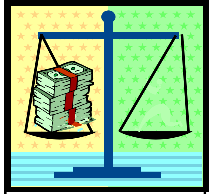
must be taken into account



Profitability

Corporate taxes and depreciation

- To this point, we have considered cash flows without tax. This is called Cash Flow Before Tax (CFBT). However, companies have to pay income taxes.
- Governments and non-profit organizations do not have to pay income tax.
- Tax rates generally depend on income level, but we will consider cases with high enough income that the tax rate will be considered constant.
- We will take a tax rate of 25% unless otherwise stated. Confirm that this is reasonable (CRA website).

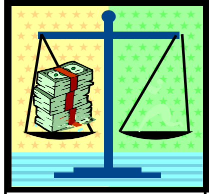


Profitability

Corporate taxes and depreciation

Drive that new car off the car agent's lot …

- Depreciation means a decrease in worth. This could be due to wear and tear, technology changes (obsolescence), depletion, inflation, or failures.
- Companies must replace capital. *The government allows companies to lower their taxes through depreciation allowances – this helps to provide resources for (re)investment*.
- Is this "fair"?
- Can you depreciate your personal car ?



Profitability

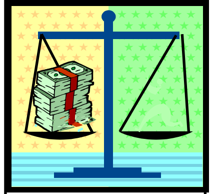
Corporate taxes and depreciation

Capital goods that can be depreciated are defined by the government. Typical properties of goods that can be depreciated are the following:

1. It must be used for the production of income.
2. It must have a determinable life longer than 1 year.
3. It must lose value over time.

Exercise: Which of the following can be depreciated by Suncor?

Laptop computers; printer paper; distillation columns; pumps; employee salaries; office buildings; land for the office buildings; company travel; CEO jet/vehicle; company travel; internet connection fees.

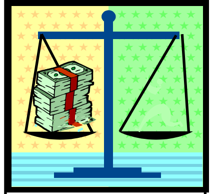


Profitability

Corporate taxes and depreciation

- The government defines what and how goods can be depreciated (Canada Revenue Agency, CRA). We will cover the basic concepts in this course, not the detailed tax laws of Canada or another country.
- The company can reduce its taxable income by a loss in value of its equipment, i.e., by the depreciation. This reduces the taxes, not the company’s actual income.

Tax paid = (tax rate) x (income – eligible expenses – depreciation)



Profitability

Corporate taxes and depreciation

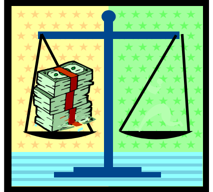
The following are "capital investments" and depreciated according to rules to be presented. **These are non-eligible expenses.** All non-eligible expenses are rolled up into the **"book value"**

- The equipment cost itself
- Improvements in equipment and processes
- Design engineering
- Equipment shipping and installation
- Land improvements*, site preparation (roads, sewers etc.)

The following are "expensed", i.e., the **full cost is deducted** from income in the year of the cash flow. These are "eligible expenses":

- All other expenses, e.g. salaries, utilities, raw materials, consumables, *etc*

* The value of land is never depreciated, but it is expensed.



Profitability

Corporate taxes and depreciation

Canada Revenue Agency, CRA term for **depreciation** is

Capital Cost Allowance (CCA)

Class 8 (20%)
Class 8 with a CCA **rate of 20%** includes certain property that is not included in another class. Examples include furniture, appliances, tools costing $500 or more per tool, some fixtures, machinery, outdoor advertising signs, refrigeration equipment, and other equipment you use in business.

Class 52 (100%)
Include in Class 52 with a CCA rate of 100% (with no half year rule) general-purpose electronic data processing equipment … …. if they were acquired after January 27, 2009, and before February 2011, but not including …

Class 10 (30%)
Include in Class 10 with a **CCA rate of 30%** general-purpose electronic data-processing equipment (commonly called computer hardware) and systems software for that equipment, including ancillary data-processing equipment, if you acquired them before March 23, 2004, or after March 22, 2004, and before 2005, and you made an election.

Also include in Class 10 motor vehicles as well as some passenger vehicles as defined in Type of vehicle

etc, etc

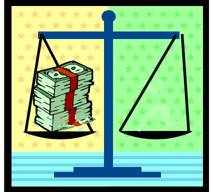
Check class 43: that usually applies.

Corporate taxes and depreciation

Depreciation in a time period is calculated as a ***percentage of the initial investment*** or remaining book value in that time period.

- Starts when equipment is “put in service”. The length of time that the depreciation will take place is defined by the government in some cases.
- The remaining value at the end of each period is termed the “book value”.
- The initial book value is the purchase (installed) price.

includes engineering, transportation, installation, and site preparation costs. We’ll see more in “Cost Estimation”.



Profitability

Corporate taxes and depreciation

Let’s look at ONE major depreciation method only.

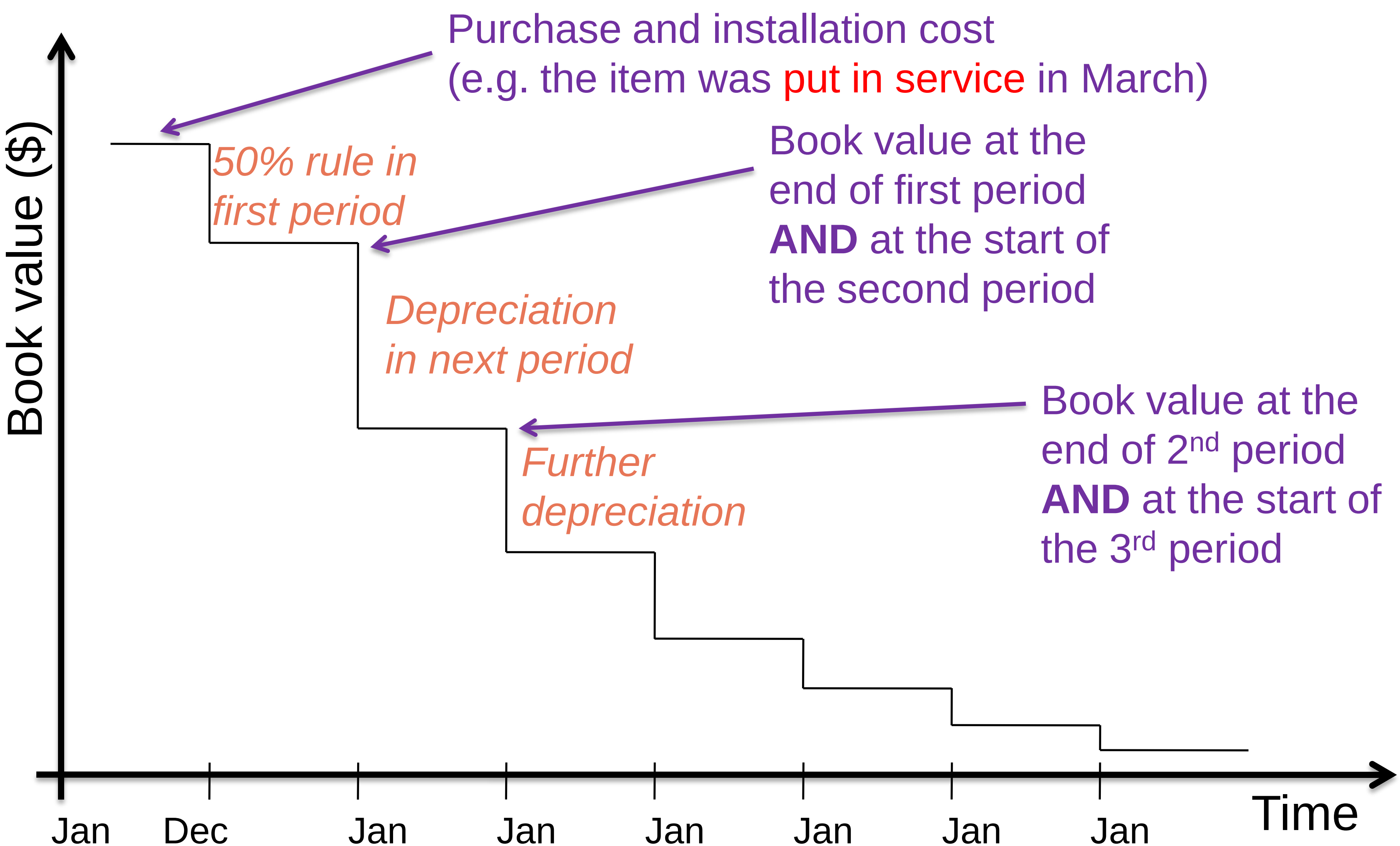
But first, we recall that the typical time period is one year. When in the year does the company invest, January 1 or December 31?

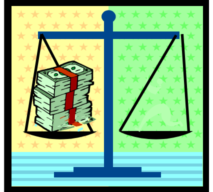
50% Rule : The government sets the rules. It assumes that the investment is made in the middle of the year, and it allows only 50% of the depreciation for the first year.

We must abide by this rule!

Profitability

Corporate taxes and depreciation





Profitability

Corporate taxes and depreciation

Declining balance depreciation

In this method, a percentage of the book value in each year is depreciated, so that the depreciated amount each year is not constant.

$$D_n = d \times B_n$$

$$B_n = B_{n-1} - D_{n-1}$$

$$D_0^{\text{actual}} = 0.5 D_0$$

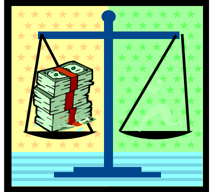
B_0 = initial cost (installed price) of equipment

B_n = book value at time t

d = depreciation rate (government class)

D_n = **amount** depreciated each year

50% rule applies in first period



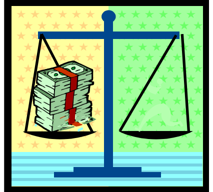
Profitability

Corporate taxes and depreciation

Example

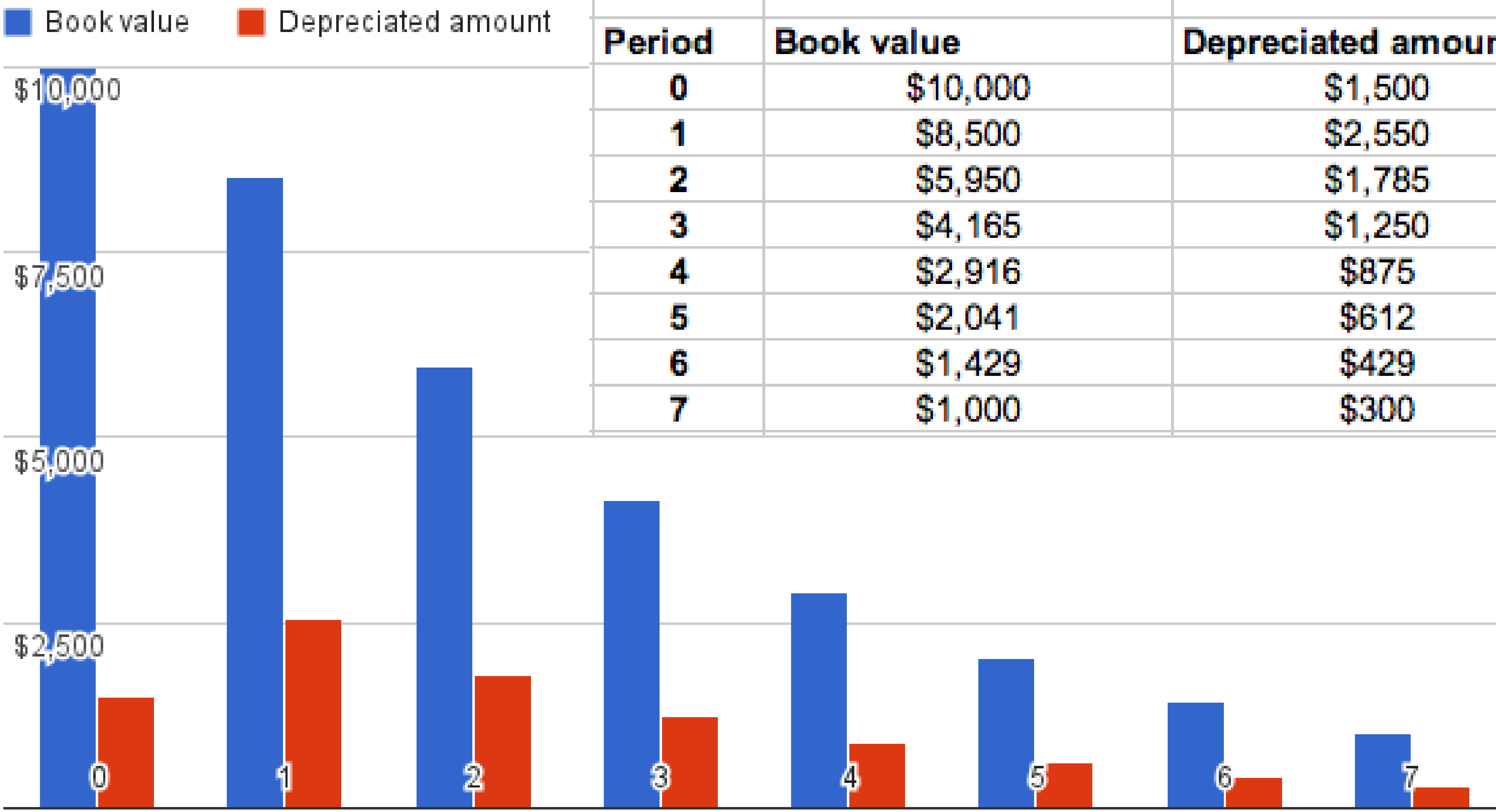
Suncor is purchasing a new reboiler for $10,000,000. The **CRA class is 43, with a rate of 30%**. Calculate and plot the book value (B_n) and depreciated amount (D_n) for 8 years.

Work in rounded $1000's.

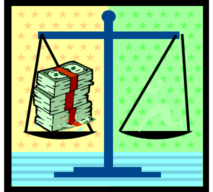


Profitability

Corporate taxes and depreciation



	Depreciation rate =	0.3
Period	**Book value**	**Depreciated amount**
0	$10,000	$1,500
1	$8,500	$2,550
2	$5,950	$1,785
3	$4,165	$1,250
4	$2,916	$875
5	$2,041	$612
6	$1,429	$429
7	$1,000	$300



Profitability

Corporate taxes and depreciation

	Depreciation rate =	0.3
Period	**Book value**	**Depreciated amount**
0	$10,000	$1,500
1	$8,500	$2,550
2	$5,950	$1,785
3	$4,165	$1,250
4	$2,916	$875
5	$2,041	$612
6	$1,429	$429
7	$1,000	$300

What happens with these depreciated amounts?
The total will eventually add up to the original book value.

Is it an income?
Is it an expense?
Does it exist as cash in the company's bank account?

Note: those depreciated amounts are not deflated for TVM, so their true value is actually less in PV terms.

Profitability

Corporate taxes and depreciation

What's the main advantage of depreciation for the company?

The company pays lower taxes! They can *reduce* their taxable income in a year by the amount of depreciation during the year. The company can, in **each** period:

A = sum all income and revenues

B = sum all ***eligible*** expenses (use –ve's for expenses)

C = all non-eligible expenses (use –ve's; equipment, shipping, installation, *etc*)

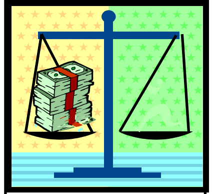
D = calculate the book value (at start of the period; update it from previous)

E = calculate the depreciation, and **sum all depreciations up** [always +ve]

F = taxable income = **A** + **B** *minus* **E** (note that **B** must have negative sign)

G = **tax paid** = (taxable income) * (tax rate) [can be a +ve or –ve result]

H = net cash flow for period = **A** + **B** + **C** *minus* **G**; then adjust **H** for TVM



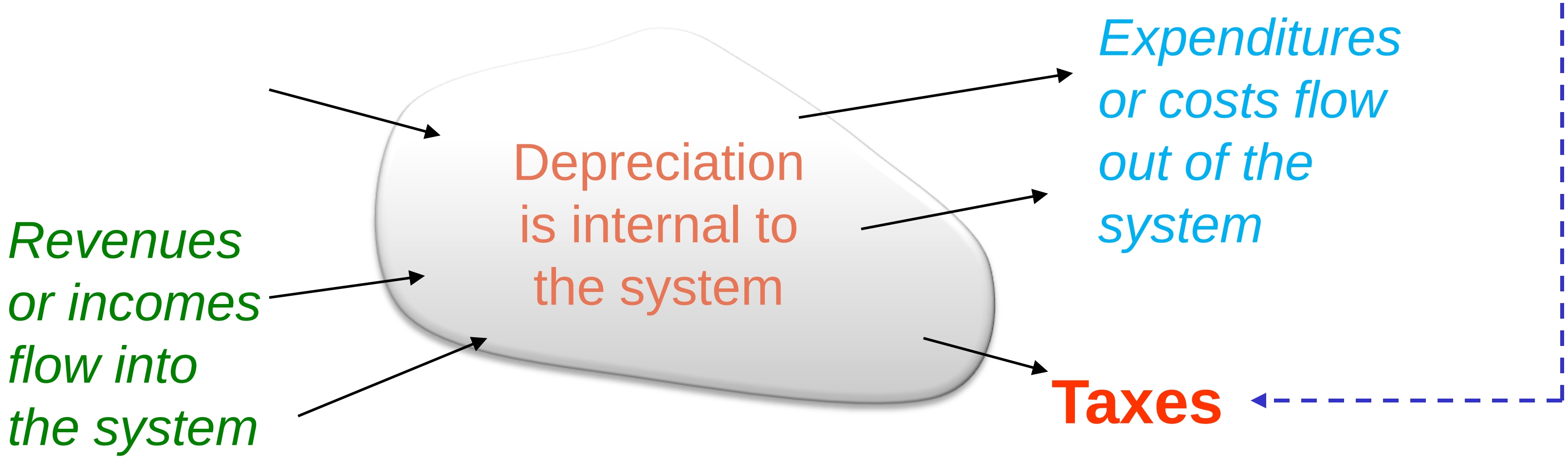
Profitability

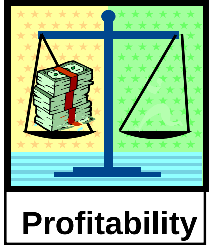
Corporate taxes and depreciation

Point of frequent misunderstanding:

Depreciation is not a cash flow!

However, it affects one cash flow: tax payments!





Corporate taxes and depreciation

Evaluate the **profitability** for installing an automated, online pulp quality analyzer (Kappa number) on a Kraft digester.

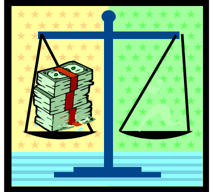
Analyzer capital cost including installation = $75,000
Analyzer maintenance cost = $5,000/year (except for first year)
Increased profit due to improved pulp quality = $20,000/year

Depreciate the analyzer using the declining balance method. The analyzer has an expected life of 5 years. The salvage value is $0.

Assume it is January 2014. Your company's year end is 31 December. Assume the equipment can be installed and put in service in January 2014.

Calculate the **payback time**, **cash flows** in each period, **NPV** (using a TVM of 8%), and **DCFRR**. The company’s MARR is 10%.

In class: set up the problem and calculate for *n=0*, *n=1*. Do the rest at home.



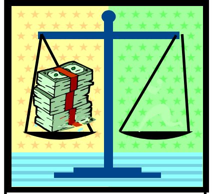
Profitability

Corporate taxes and depreciation

Depreciation rate =	**0.3**					
TVM rate =	**0.08**					
Corporate tax rate	**0.25**					
Period	**Revenue [A]**	**Eligible Exp [B]**	**Non-eligible exp [C]**	**Book value [D]**	**Depreciation [E]**	**Taxable income [F]**
0	$20,000	$0	-$75,000	$75,000	$11,250	$8,750
1	$20,000	-$5,000	$0	$63,750	$19,125	-$4,125
2	$20,000	-$5,000	$0	$44,625	$13,388	$1,613
3	$20,000	-$5,000	$0	$31,238	$9,371	$5,629
4	$20,000	-$5,000	$0	$21,866	$6,560	$8,440

Period	Tax paid [G]	Net cash flow [H]	Cumulative CF	TVM cash flow	Cuml TVM cash
0	$2,188	-$57,188	-$57,188	-$57,188	-$57,188
1	-$1,031	$16,031	-$41,156	$14,844	-$42,344
2	$403	$14,597	-$26,559	$12,514	-$29,829
3	$1,407	$13,593	-$12,967	$10,790	-$19,039
4	$2,110	$12,890	-$77	$9,475	-$9,564
			SUM	-$9,564	
			DCFRR	0.00	
			i.e.	0%	

Payback time is in period n=5 (around 5.1 years, although the life of the equipment is 5 years, we may never reach payback). Cash flows are shown above; NPV's are as shown; DCFRR=0% *in the 5 year period*.



Profitability

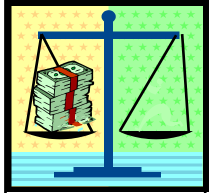
Corporate taxes and depreciation

Straight line depreciation

The CRA allows straight line depreciation in certain classes.

Example: \$10,000 over a 4 year (CRA specifies this) period, allows for

- \$2,500/2 in year 1 (BV = \$8,750)
- \$2,500 in year 2 (BV = \$6,250)
- \$2,500 in year 3 (BV = \$3,750)
- \$2,500 in year 4 (BV = \$1,250)
- \$1,250 in year 5 (BV = \$0)



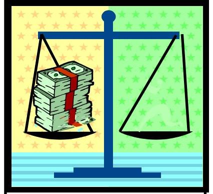
Profitability

Corporate taxes and depreciation

Group learning / Self-learning:

1. Determine the typical corporate tax rate in several countries.
2. What is the effect on cash flow after tax when a depreciated good is sold for a price different from its book value?
3. What is the (approximate) relationship between the MARR before and after taxes?
4. The company purchases and installs new equipment on January. How much can be depreciated during the first year?

   More generally, when can a company begin depreciating a capital expense?



Profitability

Corporate taxes and depreciation

Group learning / Self-learning:

5. What is more beneficial to a profitable company? Why?

   a. Rapid depreciation
   b. Slow depreciation

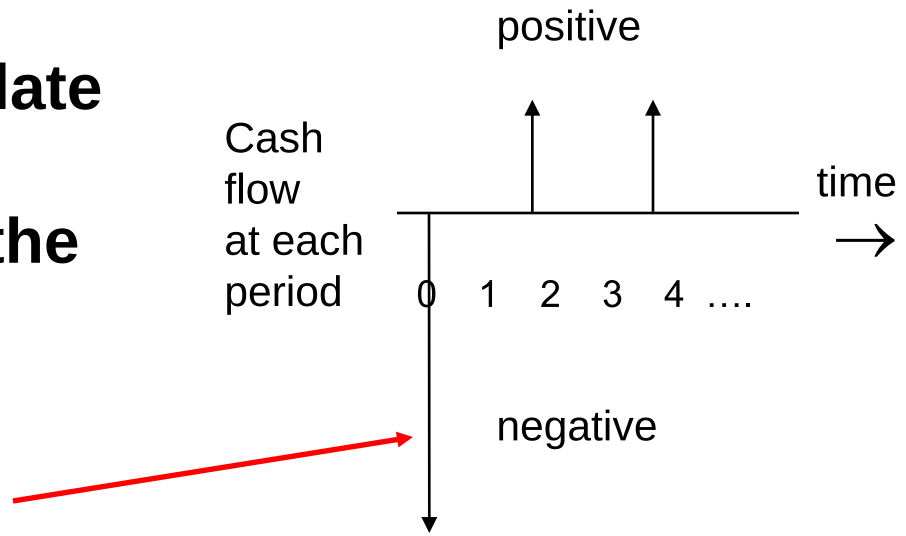
6. How can a government encourage investment in a specific technology via the tax laws? (for example, information technology, sustainability, or environmental protection)

7. What is the effect of a negative income taxes, which can occur when depreciation in greater in magnitude than net income?

Cost estimation

1. Time value of money
2. Quantitative measures of profitability
3. Systematic comparison of alternatives
4. Estimation of costs

We know how to calculate profitability; now, let's learn how to estimate the data, i.e., the costs.



Capital Cost Estimating

Cost estimation

Cost estimating is important to study.

What is Syncrude?

A. A company in Alberta, Canada.

B. The result of heavy oil being processed to form a synthetic crude oil of further processing.

C. A major source of crude oil for western Canada

D. The major employer in Fort McMurray, Alberta

Cost estimation

Syncrude has reported several changes to the cost estimate for its major expansion project that added 100,000 B/d of synthetic crude capacity.

Initial estimate:	3.6 Billion $
First correction:	4.6 Billion $
Second correction:	5.1 Billion $
"As built" cost:	8.4 Billion $

Don't let this happen to you!

As reported in the *Globe and Mail*, 14 September 2002 and 01 September 2007

Cost estimation

Suncor is another major oil-sands company

"Suncor Energy Inc. cancelled its $11.6-billion Voyageur upgrader project because of soaring capital costs – and the belief that better profits are to be found in shipping out unprocessed bitumen.

- Suncor will take a $140-million writedown that will erode its first-quarter profit
- In February, Suncor wrote off $1.5-billion of its investment in the upgrader.

Since 2010, market conditions have changed significantly, challenging the economics of the Voyageur upgrader project.

Suncor has already invested $3.5-billion in Voyageur, but decided to pull the plug after a detailed review… This decision is in line with our commitment to capital discipline and our stated plan to allocate capital with priority given to developing higher-return growth projects."

Consider the ripple effect across the industry this caused

As reported in the ***Globe and Mail*****, 27 March 2013**

Capital Cost Estimating

Cost estimation

We can always get someone else to tell us the costs.

Is this a good idea?

Class discussion

Equipment suppliers and technology licensors will give us estimates. We could call them and receive an estimate. This approach would involve little effort,

So, why is cost estimation a skill needed by all engineers?

Capital Cost Estimating

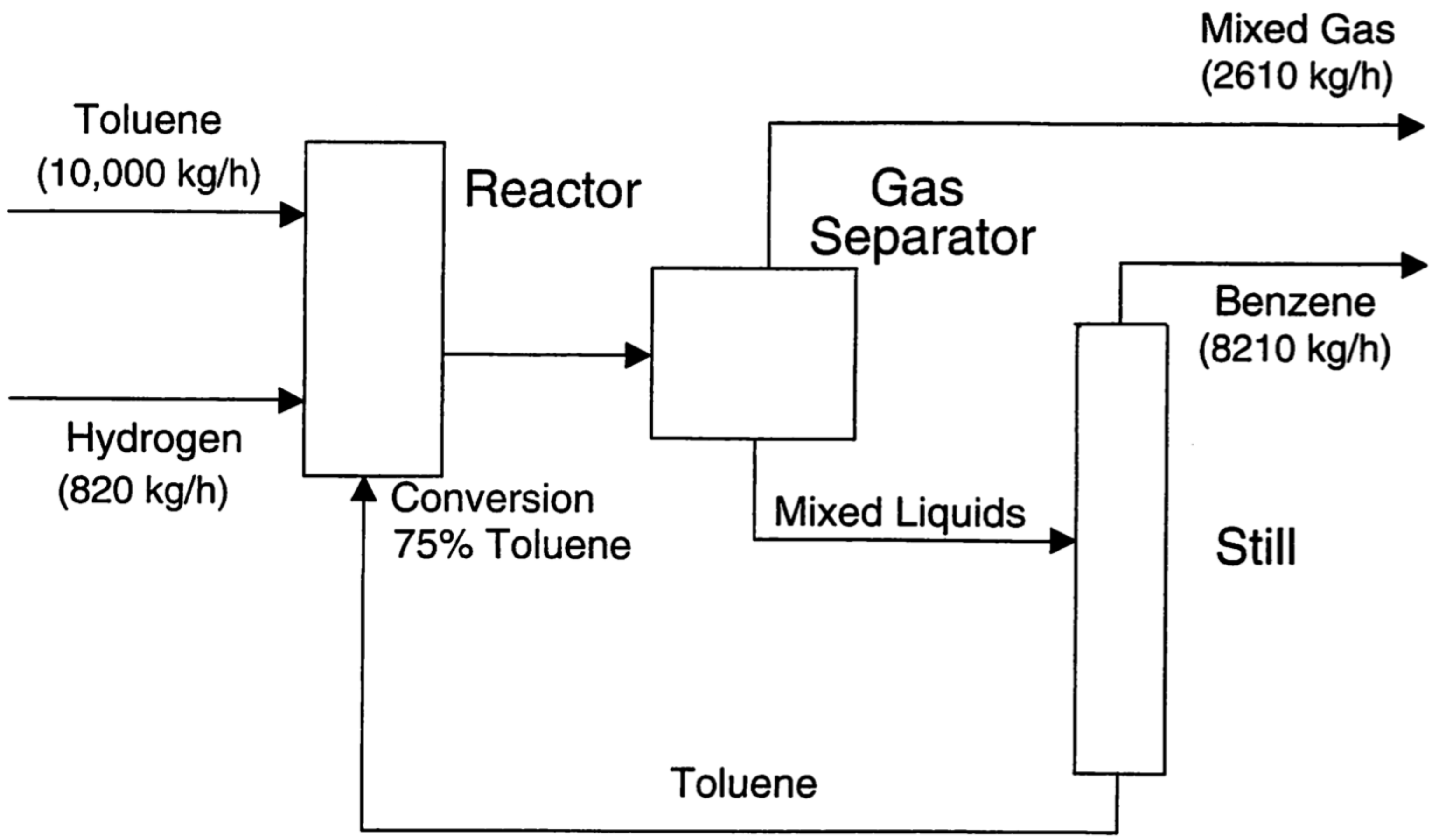
Cost estimation

Class question

- Timeliness - We need to screen many alternatives quickly
- Judgment - We need to evaluate the bids from equipment suppliers and technology licensors
- Confidentiality - We could be evaluating projects that are of interest to competitors
- Ethics - We should not mislead suppliers to think that we intend to purchase from them, just to have them perform our job
- Total cost - Project cost is much greater than equipment cost
- Other reasons perhaps?

Cost estimation

Order of magnitude for toluene + hydrogen → benzene

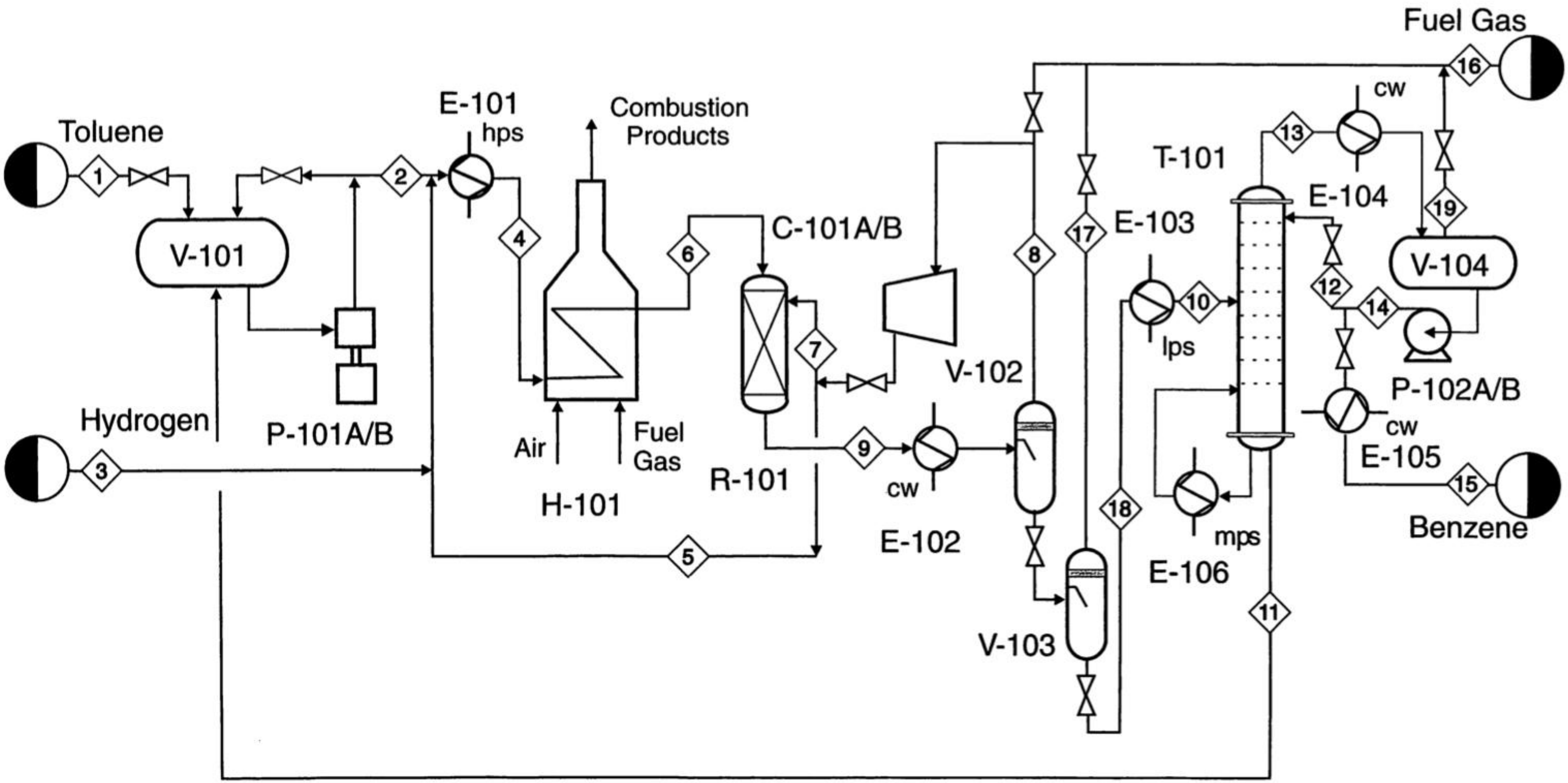


Block flow process diagram

Capital Cost Estimating

Cost estimation

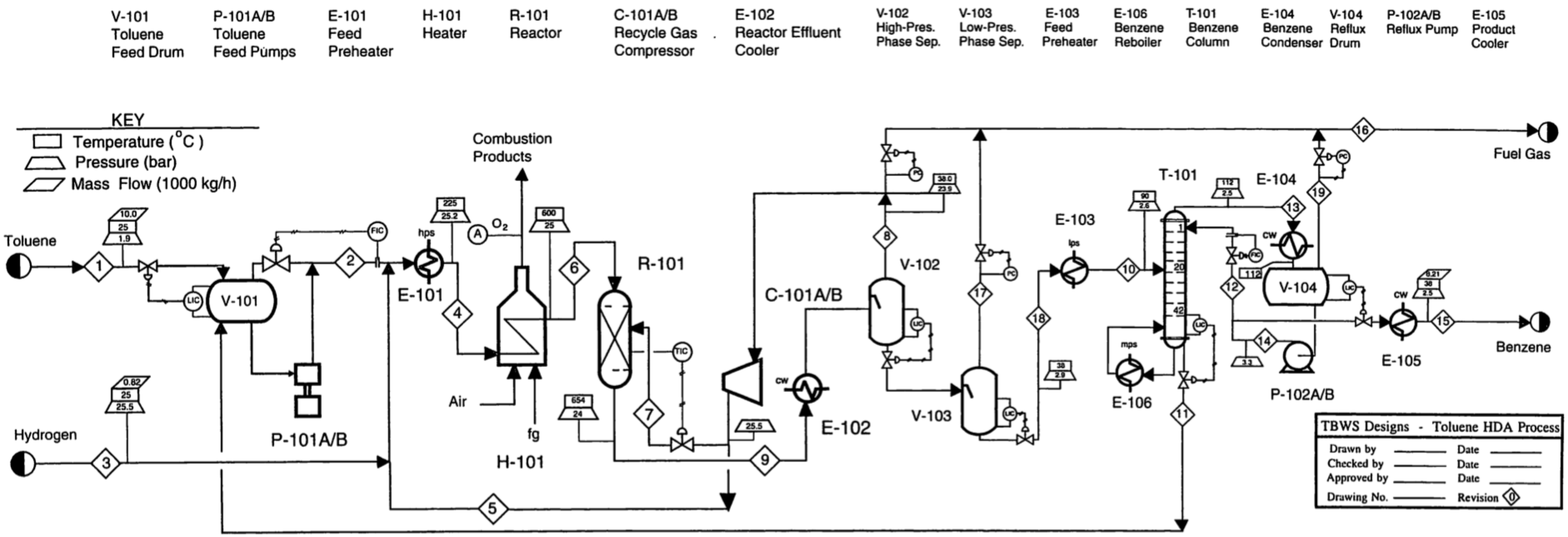
Order of magnitude: heading to more detailed



Skeleton Process Flow Diagram

Cost estimation

More detailed estimate (study phase)

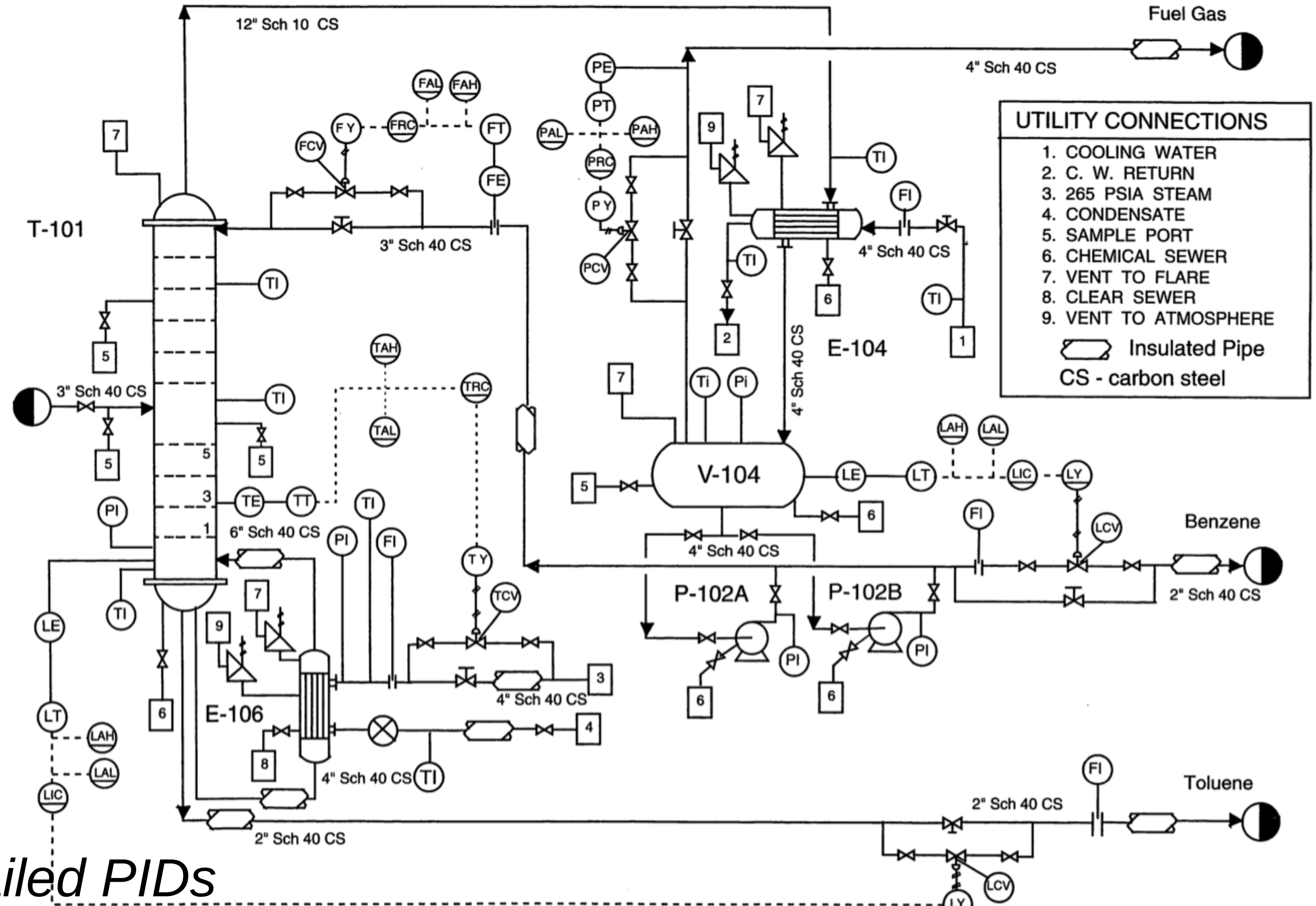


Detailed Process Flow Diagram

Capital Cost Estimating

Cost estimation

Definitive estimates



Detailed PIDs

Cost estimation

We must balance the needed accuracy with the cost to perform.

(See Peters and Timmerhaus, Pg 160-162)

Name	Accuracy	Application	Process detail
Order of magnitude	-30 to +50%	Screen investments	Block flow diagram
Study	-15 to +30%	Finalize major choices	PFD + rough design of major equipment
Definitive	-5 to +15%	Control costs	P&I Drawing, detailed M&E balances, equipment specifications

Takes time and effort: Total cost to prepare an estimate could be several $100k, but the same effort would be required later in the design phase, part of cost is really just pre-investment.

Cost estimation

We must balance the needed accuracy with the cost to perform.

(See Peters and Timmerhaus, Pg 160-162)

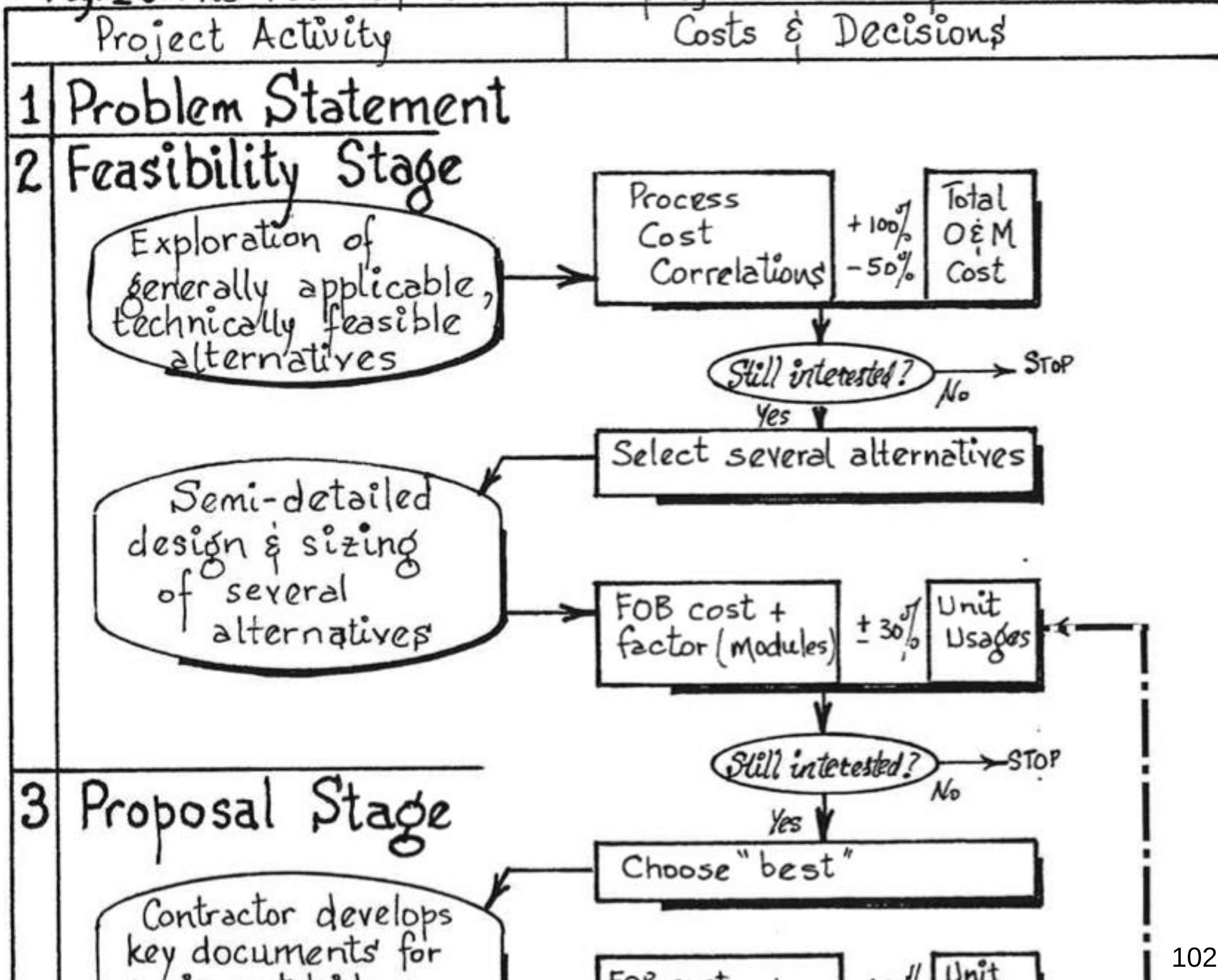
Name	Accuracy	Application	Process detail
Order of magnitude	-30 to +50%	Screen investments	Block flow diagram
Study	-15 to +30%	Finalize major choices	PFD + rough design of major equipment
Definitive	-5 to +15%	Control costs	P&I Drawing, detailed M&E balances, equipment specifications

No shortcut: A flow sheet simulation (e.g., HYSIS/PRO II/ASPEN) is required when developing a definitive cost estimation. The information is required for accurate estimates of both capital and manufacturing costs.

Capital Cost Estimating

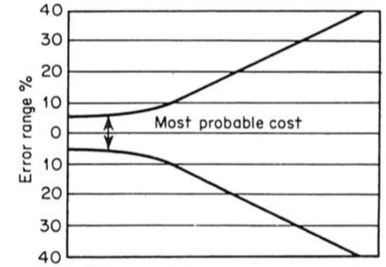
1-21

Fig. 1-6: The role of costs in project development



Capital Cost Estimating

Cost estimation



This useful table is available in Peters and Timmerhaus [Fig 6.4] and in Perry's Handbook [link on course website]

It gives a summary of the type of information needed for each level of estimate.

	Required information	Detailed estimate ±5% range	Definitive estimate ±10% range	Preliminary estimate ±20% range	Study estimate ±30% range	Order-of-magnitude estimate >±30% range
Site	Location	•	•	•	•	
	General description	•	•	•		
	Soil bearing	•	•	•		
	Location & dimensions R.R., roads, impounds, fences	•	•	•		
	Well-developed site plot plan & topographical map	•	•			
	Well-developed site facilities	•				
Process flow sheet	Rough sketches				•	
	Preliminary			•		
	Engineered	•	•			
Equipment list	Preliminary sizing & material specifications			•	•	
	Engineered specifications	•	•			
	Vessel sheets	•	•			
	General arrangement					
	(a) Preliminary		•	•		
	(b) Engineered	•				
Building and structures	Approximate sizes & type of construction			•	•	
	Foundation sketches		•	•		
	Architectural & construction	•	•	•		
	Preliminary structural design			•		
	General arrangements & elevations	•	•			
	Detailed drawings	•				
Utility requirements	Rough quantities (steam, water, electricity, etc.)				•	
	Preliminary heat balance			•		
	Preliminary flow sheets			•		
	Engineered heat balance	•	•			
	Engineered flow sheets	•	•			
	Well-developed drawings	•				
Piping	Preliminary flow sheet & specifications			•	•	
	Engineered flow sheet	•	•			
	Piping layouts & schedules	•				
Insulation	Rough specifications			•		
	Preliminary list of equipment & piping to be insulated		•			
	Insulation specifications & schedules	•	•			
	Well-developed drawings or specifications	•				
Instrumentation	Preliminary instrument list			•		
	Engineered list & flow sheet	•	•			
	Well-developed drawings	•				
Electrical	Preliminary motor list – approximate sizes			•	•	
	Engineered list & sizes	•	•			
	Substations, number & sizes, specifications	•	•	•		
	Distribution specifications	•				
	Preliminary lighting specifications			•		
	Preliminary interlock, control, & instrument wiring specs.		•			
	Engineered single-line diagrams (power & light)	•	•			
	Well-developed drawings	•				
Man-hours	Engineering & drafting	•	•	•	•	
	Labor by craft	•				
	Supervision	•				
Project scope standard processes	Product, capacity, location & site requirements. Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements					•

Cost estimation

Capital costs

- Fixed equipment
- Working capital

Manufacturing costs

- Direct (materials and labour that scale in proportion to throughput)
- Fixed costs (utilities, labour, *etc*, that are required no matter what the production rate is)

Evaluating capital equipment cost estimates:

Use historical data to develop correlations, and apply corrections for unique factors in specific situations.

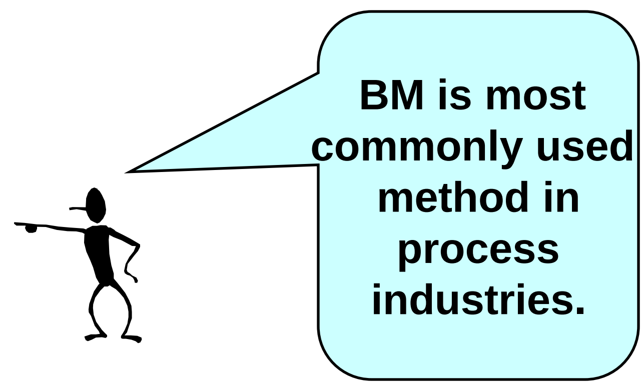
Cost estimation

Capital cost estimation

Methods covered in this course

- A couple of very rough methods (initial screening)
  - Turnover ratio
  - Lang’s Factor

- Bare Module (BM) method
  - Concept and items included
  - Factor tables with corrections
  - Inflation
  - Examples



Cost estimation

Very rough capital cost estimation (*use with caution!*)

Turnover ratio: values of 0.2 to 4.0;
usually 0.5 in the process industries

(Fixed capital cost)(TR) = gross annual sales

errors are between –50% to +100%

We can use this to estimate the fixed capital costs for a plant making a known quantity for sales. The *number of times we turn around* our capital cost into sales.

Reference: Perry's Ch 9.3; Peters Ch 6

Capital Cost Estimating

Cost estimation

Very rough capital cost estimation (*use with caution!*)

Lang's factor is used to estimate fixed capital cost given the delivered cost of the equipment:

(Σ delivered cost of major equipment)(LF) = Fixed capital cost

Type of plant	Fixed capital
solids processing (cement)	**4.0**
solid/fluids processing (alumina)	**4.3**
fluids processing	**5.0**

1. Uses only delivered cost (no L+M for installation)
2. Estimated fixed capital cost includes land plus contractors fees

Reference: Perry's Ch 9.3; Peters Ch 6

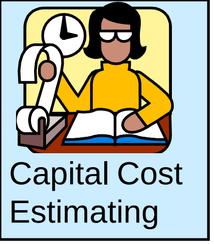
Cost estimation

Delivered cost

Cost estimation

Fixed capital cost

flickr-6343899995_e9ecd80533



Cost estimation

Bare module method most commonly used for capital cost estimation. Here's the general approach:

1. Historical cost for equipment (common material, low pressure, ambient temperature)

   + correct for capacity, material, P, T, and inflation

2. FOB (free on board)

   + labour and materials for installation
   + shipping

3. Bare module cost

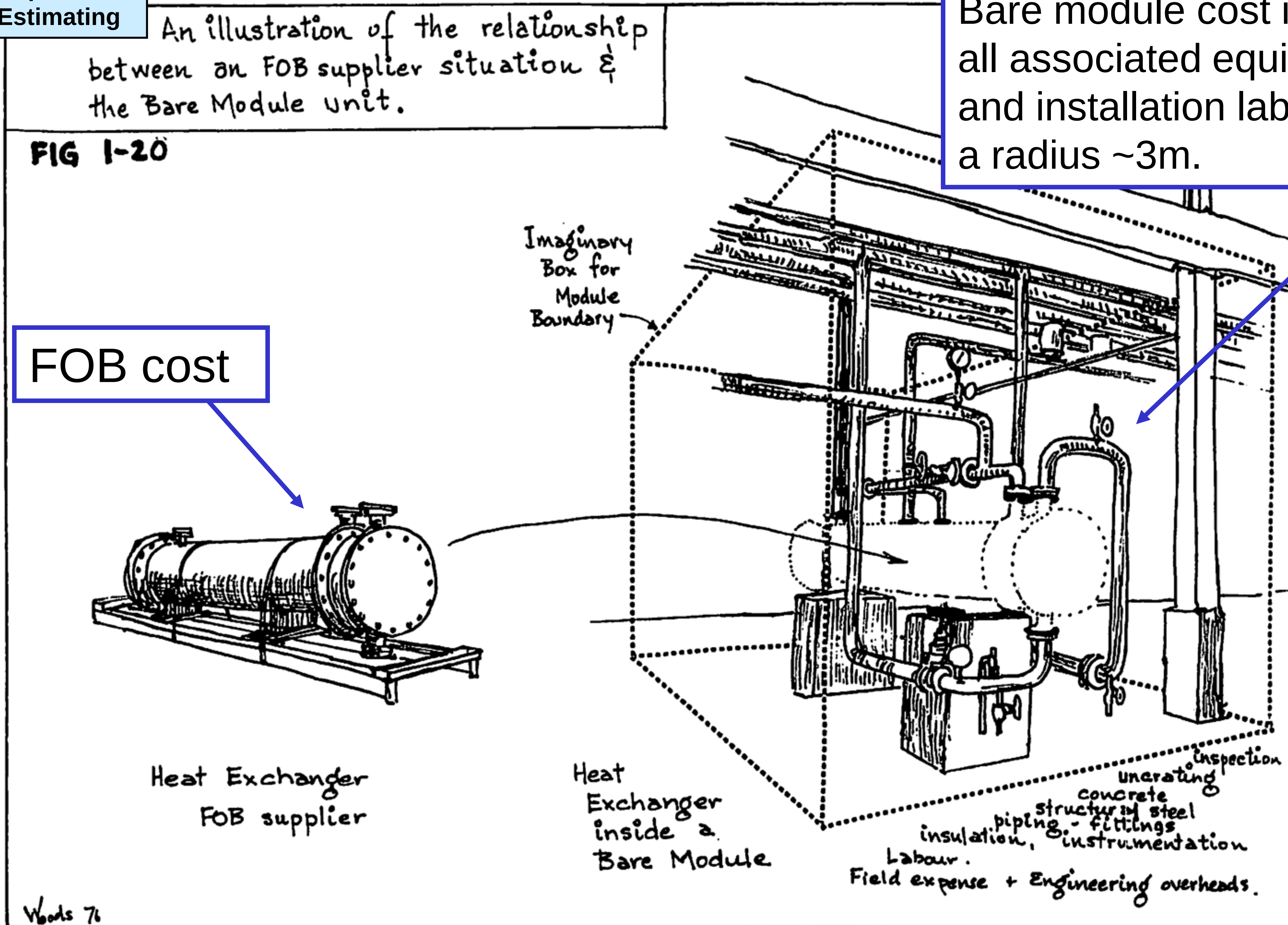
   + contractors fees, contingencies, etc.

4. Total module cost

Cost estimation

Bare module cost is for all associated equipment and installation labour in a radius ~3m.

FOB cost



Cost estimation

Bare module cost includes the following:

- labour and materials
- Uncrating
- Inspection
- Structure (foundation, etc.)
- Piping
- Instrumentation
- Painting and insulation
- Utility hookup (electrical, water, steam, sewer, etc.)
- Engineering supervision

Cost estimation

Summary of the Bare Module method

FOB	free on board, cost of equipment ready for shipment from supplier
Installed = FOB + shipping + uncrate, inspect, and hook up	
L+M = (installed-shipping) + piping + instruments + electrical + insulation + foundation + structure + offsites	L+M = FOB * (L+M Factor)
Physical plant cost = L+M + shipping	Note that shipping cannot be correlated
BM = above + home engineering + field expense	BM = Bare module Home off = 9% of L+M Field = 10 to 15% L+M BM = FOB*(BM Factor) Rough esimate BM factor = (L+M)*1.4
TM = Total fixed capital investment = BM + contractors fees + contingencies	TM = total module Contr = 3 to 5% of BM Conting = 10 to 15% of BM
Total investment = above + royalty + land + spare parts + legal + working capital + interest during construction	Working capital = 10+% of fixed capital invest. This could vary greatly. Note: This is for isolated module, not grassroots plant.
Turnkey cost = total invest + Startup expenses	

Notes: 1. Total module (TM) does not account for site development, off-sites, utilities, etc. These costs would vary depending upon the equipment considered. Turton (pg. 68) suggests 35% of BM costs for this factor.

Cost estimation

Method and Data for Bare Module method

We have data from the past on a limited number of designs

The labour and materials depends on the equipment design

FOB	free on board, cost of equipment ready for shipment from supplier
Installed = FOB + shipping + uncrate, inspect, and hook up	
L+M = (installed-shipping) + piping + instruments + electrical + insulation + foundation + structure + offsites	L+M = FOB * (L+M Factor)
Physical plant cost = L+M + shipping	Note that shipping cannot be correlated
BM = above + home engineering + field expense	BM = Bare module Home off = 9% of L+M Field = 10 to 15% L+M BM = FOB*(BM Factor) Rough esimate BM factor = (L+M)*1.4
TM = Total fixed capital investment = BM + contractors fees + contingencies	TM = total module Contr = 3 to 5% of BM Conting = 10 to 15% of BM
Total investment = above + royalty + land + spare parts + legal + working capital + interest during construction	Working capital = 10+% of fixed capital invest. This could vary greatly. Note: This is for isolated module, not grassroots plant.
Turnkey cost = total invest + Startup expenses	

Notes: 1. Total module (TM) does not account for site development, off-sites, utilities, etc. These costs would vary depending upon the equipment considered. Turton (pg. 68) suggests 35% of BM costs for this factor.

Cost estimation

Method and data for Bare Module method

We will now cover the various “factors” that are used to enable us to estimate the cost of equipment with various capacities, pressures, etc. from a limited set of data.

Limited number of specific equipment designs and times

Correction for the “capacity”

Correction for the inflation from the database year

$$\text{BM cost} = [\text{Database}] \times [\text{capacity factor}] \times [\text{inflation factor}]$$
$$\times [\text{installation factor}] \times [\text{operating condition correction}]$$

Additional cost for equipment and labour to connect to the process

Correction for process conditions that affect the capital cost, e.g., pressure, and for materials of construction

Capital Cost Estimating

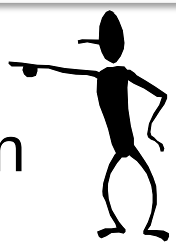
Cost estimation

Capacity factor - Converting the historical capital cost data to FOB using the power law.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[\frac{\text{Factor}_A}{\text{Factor}_B}\right]^n$$

1. What is a typical value for "n"?
2. Why does a power-law work?

Usually set B = known and A = new design

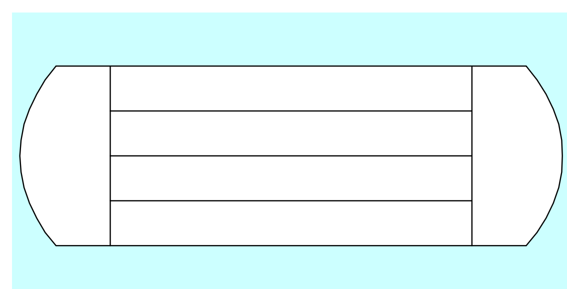


The "factor" is selected to be the feature of the design that correlates best with the capital cost item.

Cost estimation

Capacity factor - Converting the historical capital cost data to FOB using the power law.

$$\frac{Cost_A}{Cost_B} = \left[\frac{Factor_A}{Factor_B}\right]^n$$

What is the correct factor for a shell and tube heat exchanger?	What is the exponent for a shell and tube heat exchanger?
• Heat duty • area • number of tubes • flow rate	

Capital Cost Estimating

Cost estimation

Capacity factor - Converting the historical capital cost data to FOB using the power law.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[\frac{\text{Factor}_A}{\text{Factor}_B}\right]^n$$

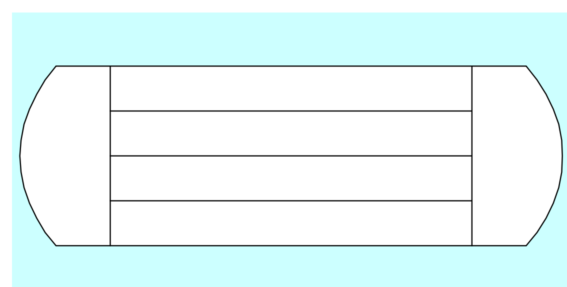
Area has the dominant effect on manufacturing cost.

Pumps:	m^3/s or power
Agitators:	power
Distillation:	height*diameter

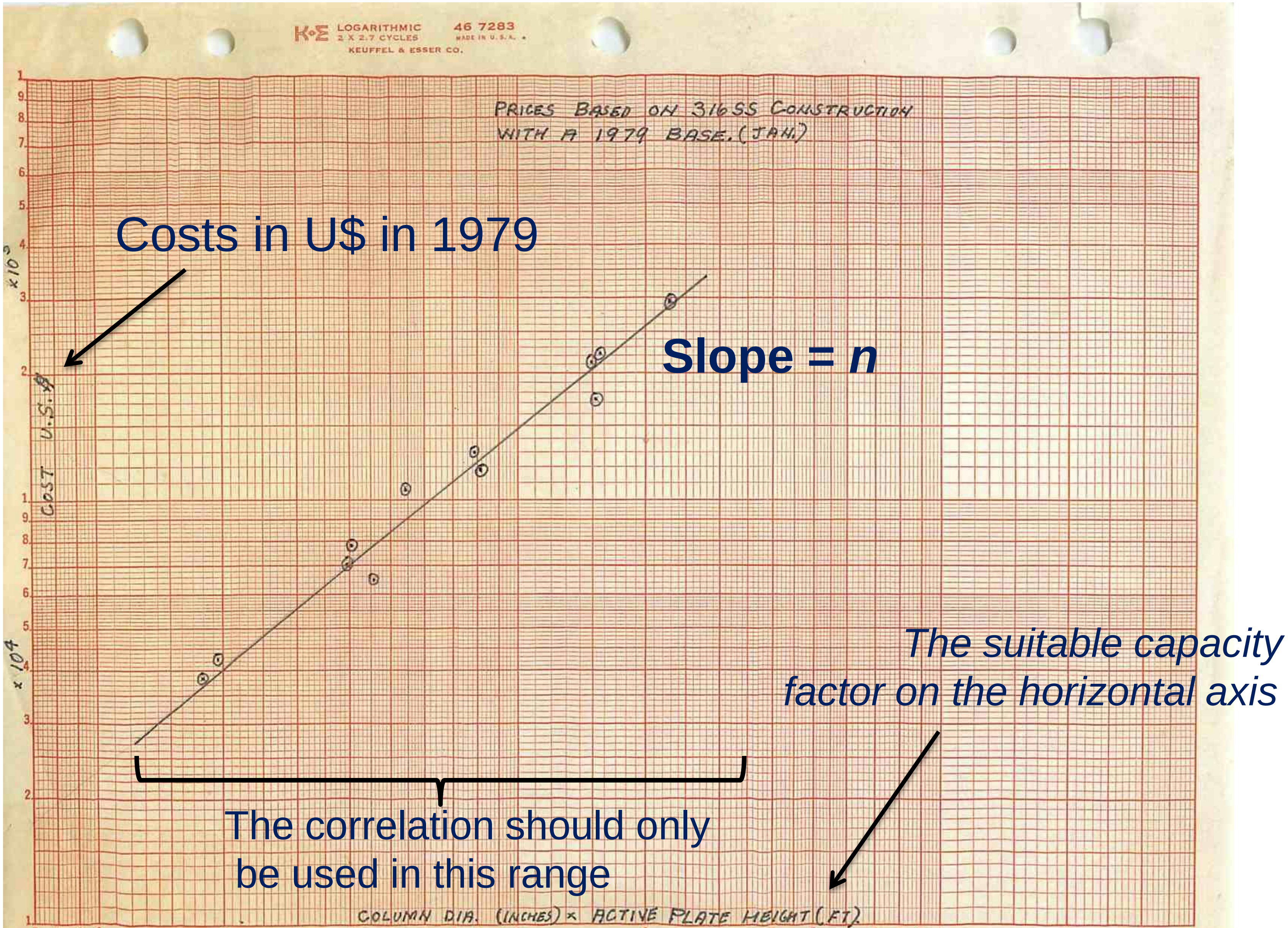
What is the correct factor for a shell and tube heat exchanger?

- Heat duty
- area
- number of tubes
- flow rate

What is the exponent for a shell and tube heat exchanger?



Capacity factor: the power $n < 1.0$ (usually) !



Cost estimation

Capacity factor: the power n < 1.0 (usually) !

$$\frac{\mathrm{Cost}_A}{\mathrm{Cost}_B} = \left[\frac{\mathrm{Factor}_A}{\mathrm{Factor}_B}\right]^n$$

Rough guideline, n = 0.6

What could limit the use of the power law?

Materials of construction
Temperature and pressure ranges

Key point: always look up the value of n

Capital Cost Estimating

Cost estimation

Example

A certain electric motor with capacity of 100 hp cost $4 500. What is the estimated cost of a motor with capacity of 175 hp?

Electric motors of this type have a capacity factor of *n*=0.81.

$$\frac{\text{Cost}_A}{\text{Cost}_B} = \left[\frac{\text{Factor}_A}{\text{Factor}_B}\right]^n$$

$$\frac{\text{Cost}_A}{\$4,500} = \left[\frac{180}{100}\right]^{0.81}$$

$$\text{Cost}_A = \$4,500\left[\frac{175}{100}\right]^{0.81} = \$7,080$$

Advantage of the correlations:

You can estimate prices of larger or smaller units at any point in time from another unit's cost. Does not only apply in 1970, but at any time!


Capital Cost Estimating

Has gone private now; use CEPCI instead

Cost estimation

Inflation factor - Converting the historical capital cost data to the time when the equipment is purchased.

Year	Marshall & Swift	Eng-News	Nelson-Farrar	Chem Eng Plant Cost Index (CEPCI)
1970	301	133	365	123
1980	675	300	900	261
1990	915	400	1200	358
2000	1089	510	1500	394
2000/1970	3.6	3.8	4.1	3.2
	Chem. Engr.(US)	Engr-News Record	Oil & Gas J	Chem. Engr.(US)

Why don't we use the consumer's price index (CPI), which is reported frequently in the news?

Cost estimation

Plot of inflation data

(from: Edgar, Himmelblau and Lasdon, Optimization for Chemical Processes 2nd Ed., McGraw Hill, 2001)

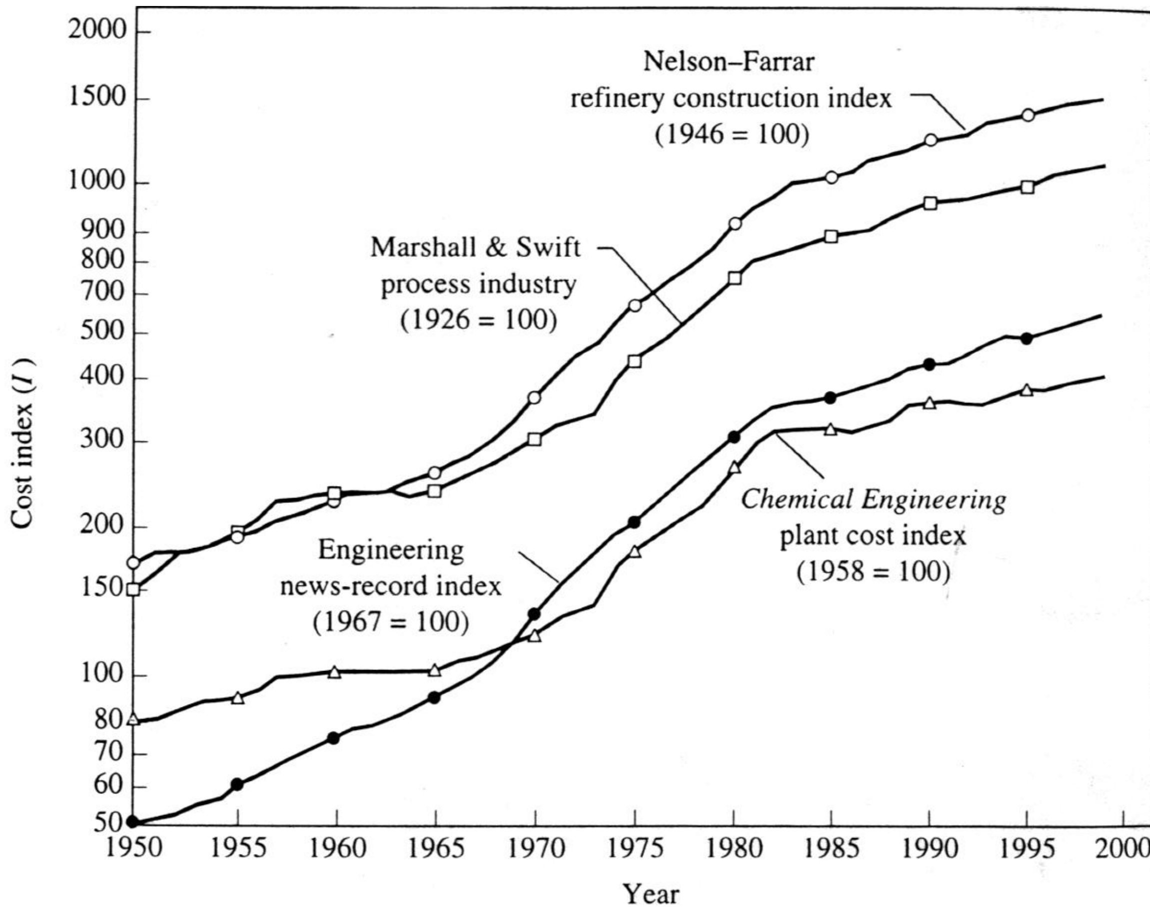


FIGURE B.4
History of selected cost indexes pertinent to chemical process construction (1950–1998)

Capital Cost Estimating

Cost estimation

Example

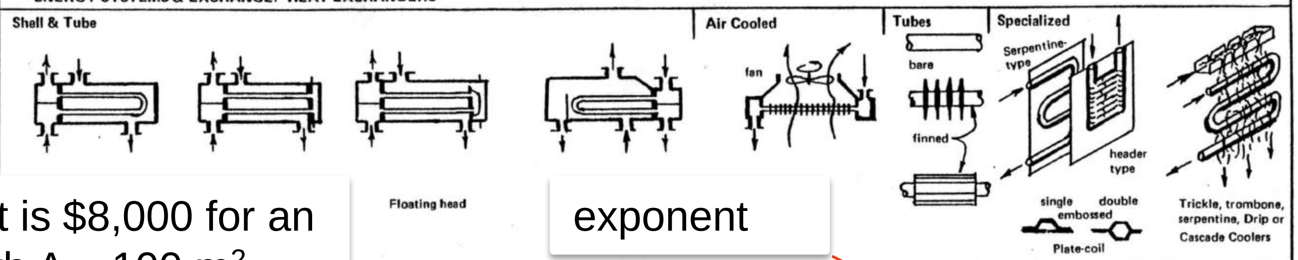
In 1979, a distillation column cost $65 690. What is the cost of the unit in 2011?

Marshall and Swift index in 1979 was 607 and in 2011 is was 1490.

Sample cost estimation data

Costs are for mid-1970

ENERGY SYSTEMS & EXCHANGE: HEAT EXCHANGERS — MS = 300



The base cost is \$8,000 for an exchanger with A = 100 m^2

exponent

	Size	Unit	Cost 10^3\$	Range	n	Error %	L+M	L/M	BM	Comments
SHELL AND TUBE Floating head, 1140 kPa, c/s in c/s shell, bare tube Delivered cost: standard 4.85 m length, with either 2.5 or 1.9 cm O.D. tubes on square or triangular pitch. Pressure, MPa 2.2 : x 1.15 — 7.0 : x 1.55 2.9 : x 1.25 — 22. : x ~2.5 4.2 : x 1.45 — 28. : x ~2.8 5.6 : x 1.52 — 35. : x ~3.1 tubes in c/s shell: Al x 1.2 — s/s 316 x 2.4 Cu x 1.35 — s/s 304 x 2.0 Brass x 1.3 — Monel x 3.0 Admiralty x 1.5 — Ti x 9.0 70-30 Cu-Ni x 1.7 — Inconel x 2.4 Ni x 2.8 — Hastalloy C x 8.5 tubes and shell: s/s 316 x 3.0 — Monel x 4.0 s/s 304 x 2.8 — Ti x 13.0	1	Heat Tranfer Area 10^2 m^2 (1076 ft^2)	8	0.02 to 20	0.71	40	2.30	0.36	3.14	Fixed tube x 0.85 U-tube x 0.87 Kettle reboiler x1.35 Tubes only x 0.3 Expansion joint on fixed tube x 1.25 23,70,91 123,126,127 128,145,150 170,201,203 212,314,318 344,403,494 498,506,531
After cooler for compressor, c/s with water on shell side. excl: separator, integral piping, support stand and instrumentation.	0.1	m^3/s	0.38	0.03 to 0.3	0.58					
Cross bore in c/s shell. Karbate. Delivered.	10 108	Heat Transfer Area m^2 (ft^2)	4	0.7 to 70	0.69					

5-2 Heat Exchange

5-5

Define basic shell and tube

Corrections for pressure and material

The correlation is valid for A = 2 to 2000 m^2

Estimate uncertainty in ± %

$$0.02 \le \frac{\text{factor}_B}{\text{factor}_A} \le 20$$

$$0.02 \le \frac{\text{Area of desired heat exchanger}}{100\,\text{m}^2} \le 20$$

$$2\,\text{m}^2 \le \text{Area of desired heat exchanger} \le 2000\,\text{m}^2$$

Reference: Woods, 1993

Cost estimation

Uncertainty in the tables is large; why?

- Covers times of economic stagnation and growth
- Covers all locations (at least in North America)
- Covers range of equipment suppliers with various technologies and efficiencies

For a specific location and equipment, a company would likely have data with less uncertainty.

Capital Cost Estimating

Cost estimation

Shell and tube, water cooled condenser

Cost estimation

Condenser in Bartek Plant

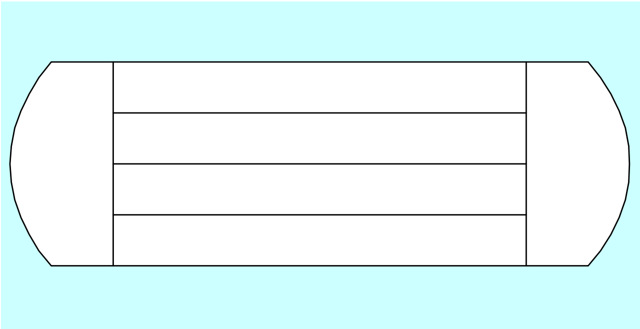
Courtesy Bartek

Capital Cost Estimating

Cost estimation

Class exercise: Estimate the Bare Module cost in 2000 for the following equipment.

- Shell and tube heat exchanger #1
- Floating head
- Carbon steel for shell and tubes
- P = 1.0 MPa
- Area = 70 m^2



Cost estimation

Class exercise: Solution for heat exchanger #1

From page 5-5 in Woods (1993)

FOB = \$8000 x $(70/100)^{0.71}$ = \$6210

Capacity factor

Bare Module = \$6210 x 3.14 = \$19,500

Bare module, F_{BM}

No corrections for pressure (P < 1.1 MPa) or material (carbon steel) are required

Cost from 1970 to 2000 by
Marshall Swift = (1089/301) x 19,500
= \$ 70,500 $\pm$ 40%

Inflation factor

Cost estimation

Systematic approach:

1. Look up the correlation. Does the equipment match ours?
2. Check the range. Does out capacity factor fall in the range?
   - Use the same units as the given factor. Another range (even in a different set of units) might apply.
3. Read base cost ($) and base year = $\$FOB_{1970}$ (usually)
4. Inflate for capacity using exponent *n*
5. Adjust price for materials, pressure, and temperature
6. Calculate bare module cost, using bare module factor, F_{BM}
7. Inflate the price into today's dollars, using an index
8. Report the value as a range, rather than a point estimate.

Capital Cost Estimating

Cost estimation

Distillation reflux drum

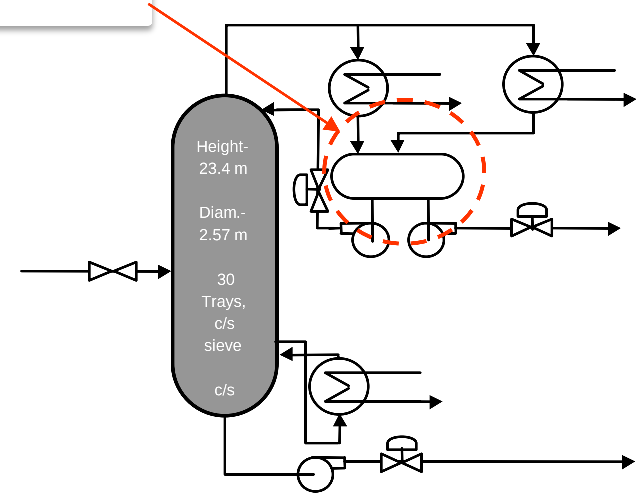
University of New South Wales, Austalia, http://www.cse.unsw.edu.au/~lambert/vrml/kumip/docs/reflux.html

Cost estimation

Class example: Estimate the Bare Module cost in year **2000** for the following equipment.

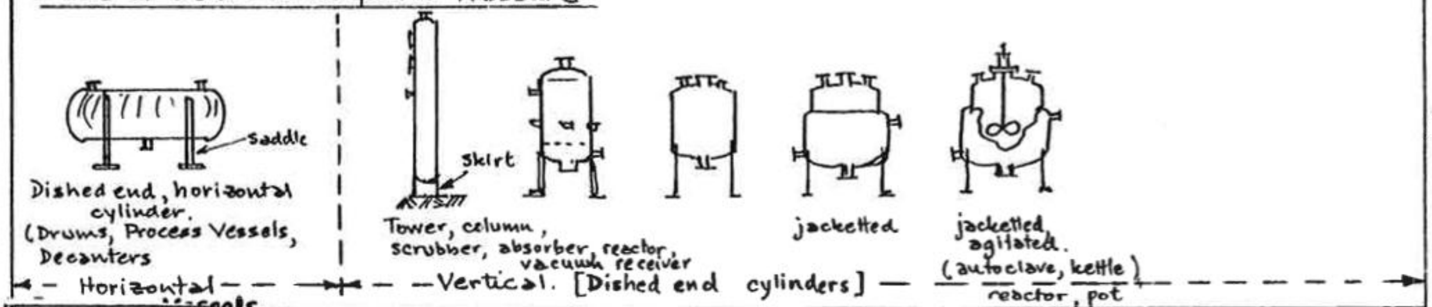
- 57m^3
- horizontal, cylindrical, dished ends
- P = 0.30 MPa
- T = 290 K
- Material = carbon steel (c/s)

Reflux drum



VESSELS (for Liquids &/or Gas) MS = 300

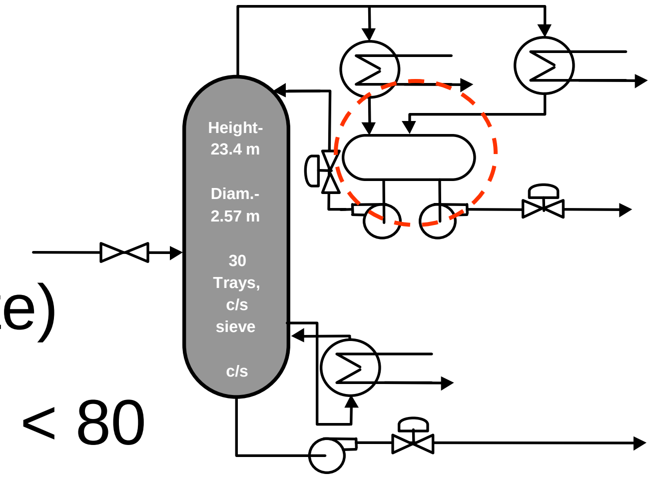
Above or Below Atmospheric Pressure



	Size	Unit	Cost 10^3\$	Range	n	Error %	L+M	L/M	BM	Comments
PRESSURE VESSELS										
Horizontal, cylindrical, dished ends, c/s, 150 psig, unfired.	1 (3.8)	volume 10^3USgal. (m^3)	1.9	0.1 to 80	0.62		2.2	0.35	3.0	7,18,23,91, 201,318,321, 357,506.
FOB incl: manhole, usual nozzles, support saddle.	{1 10}	bare weight 10^3lb	{0.6 3.3}	0.1 to 2 2 to 100	0.57 0.79					
excl: stress relieving, foundations.	3	(length,ft) $\times$(diam,ft)$^{1.5}$	11	12 to 100	0.84					
factors: 316 s/s x 4.0 clad x 2.25 Titanium x 8 clad x 4.25 Monel x 6.3 clad x 3.9										
Pressure: 200 x 1.15 700 x 1.70 300 x 1.25 800 x 1.90 500 x 1.45 900 x 2.3 600 x 1.60 1000 x 2.5										
Complexity: Ave. complexity x 1.00 no accessories x 0.80 complex accessories x 1.3										
Vertical cylinders, dished ends, c/s, 150 psig unfired	100 (5.2)	(length,ft) $\times$(diam,ft)$^{1.5}$ (m)(m)$^{1.5}$	4.8	8 to 350	0.81	50	3	0.50	4.0	7,23,33,109, 112,143,186, 201,318,344, 357,506.
FOB incl: manhole, usual nozzles, support skirt	{0.1 10}	nominal vol. 10^3US gal.	{0.6 12}	0.01 to 2.5 2.5 to 28	0.53 0.89	40 40				
excl: foundations	10	bareweight 10^3lb	4.7	0.1 to 300	0.70					

2-2

Cost estimation



Class example: Solution for vessel

1. Use Wood's page 2-2 (it is appropriate)
2. Range: $57 m^3 \times 264 \text{ gal/m}^3 / 1000 = 15 < 80$
3. $FOB_{1970, A} = \$1900$
4. $FOB_{1970, B} = 1900 \times (57/3.8)^{0.62} = \$10,180$
5. Not required
6. $BM_{1970} = \$10,180 \times 3.0 = \$30,550$
7. $BM_{2000} = \$30,500 \times (1089/301)$
8. $BM_{2000} = \$110,500 \pm 40\%$ error

Capacity factor, **volume**

Bare module, F_{BM}

Inflation factor, MSwift

Not reported for table entry, use from vertical drum. Why?

Cost estimation

The Bare Module factor is the sum of many costs. We can find the factor for each element for specific equipment.

Table 1-11: Guthrie's FACTORS FOR INDIVIDUAL PIECES OF EQUIPMENT BASED ON FOB COST OF EQUIPMENT = 1.00 (BASED ON CARBON STEEL)*

	Furnaces	Exchangers Shell-tube
FOB Equipment		1.00
Piping		0.46
Concrete		0.05
Steel		0.03
Instruments		0.10
Electrical		0.02
Insulation		0.05
Paint		—
Total materials ($E + m$) = M =		1.71
Erection and setting (L)		0.63
X, excluding site preparation and auxiliaries ($L + M$)		2.34
Freight, insurance, and taxes		0.08
Engineering and home office, construction overhead, or field expense		0.95
Bare Module Factor (BM)		3.37

f_{piping}

From Woods (1993), page 1-58

HEx example from before

$BM_{1970} = C_0 \quad \times F_{BM} = BM$

$BM_{1970} = \$6{,}210 \times 3.14 = \$19{,}500$

This includes the cost of the original unit!

FOB cost	= \$ 6,210	x 1.00
All BM costs (left)	= <u>\$ 13,290</u>	<u>x 2.14</u>
Total bill, BM_{1970}	= **\$ 19,500**	x 3.14 factor

So …

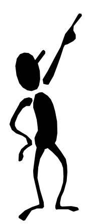
All BM costs $= C_0 F_{BM} - C_0 = C_0(F_{BM} - 1)$

Cost estimation

Pressure and materials factors

Example: a shell and tube heat exchanger (see next slide also)

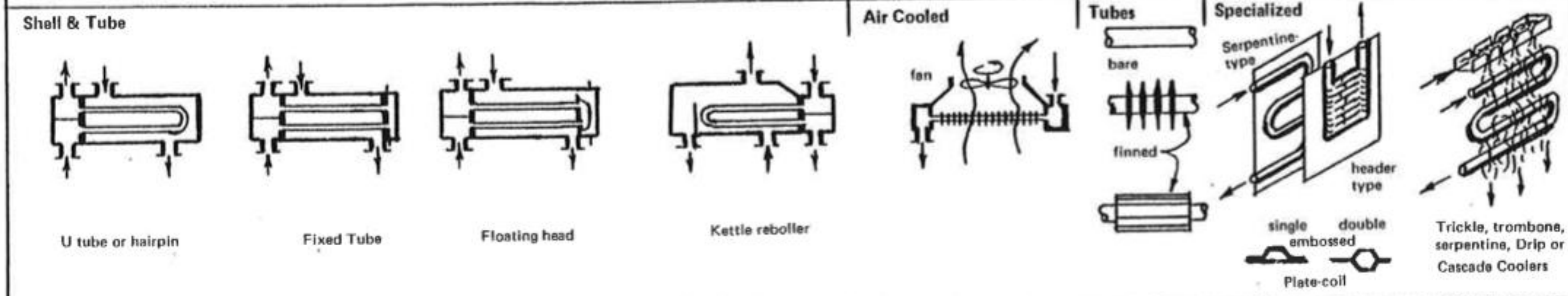
- F_P = 1.25 for the case of pressure = 3 MPa
- F_M = 3.0 for the case of 316 stainless steel



How are BM costs affected by this?

ENERGY SYSTEMS & EXCHANGE: HEAT EXCHANGERS

MS = 300



	Size	Unit	Cost $10^3\$$	Range	n	Error %	L+M	L/M	BM	Comments
SHELL AND TUBE Floating head, 1140kPa, c/s in c/s shell, bare tube Delivered cost: standard 4.85m length, with either 2.5 or 1.9 cm O.D. tubes on square or triangular pitch. Pressure, MPa 2.2 : x 1.15 ; 7.0 : x 1.55 2.9 : x 1.25 ; 22. : x ~2.5 4.2 : x 1.45 ; 28. : x ~2.8 5.6 : x 1.52 ; 35. : x ~3.1 tubes in c/s shell: Al x 1.2 ; s/s 316 x 2.4 Cu x 1.35 ; s/s 304 x 2.0 Brass x 1.3 ; Monel x 3.0 Admiralty x 1.5 ; Ti x 9.0 70-30 Cu-Ni x 1.7 ; Inconel x 2.4 Ni x 2.8 ; Hastalloy C x 8.5 tubes and shell: s/s 316 x 3.0 ; Monel x 4.0 s/s 304 x 2.8 ; Ti x 13.0	1	Heat Tranfer Area 10^2 m^2 (1076 ft^2)	8	0.02 to 20	0.71	40	2.30	0.36	3.14	Fixed tube x 0.85 U-tube x 0.87 Kettle reboiler x1.35 Tubes only x 0.3 Expansion joint on fixed tube x 1.25 23,70,91 123,126,127 128,145,150 170,201,203 212,314,318 344,403,494 498,506,531
After cooler for compressor, c/s with water on shell side. excl: separator, integral piping, support stand and instrumentation.	0.1	m^3/s	0.38	0.03 to 0.3	0.58					
Cross bore in c/s shell. Karbate. Delivered.	10 108	Heat Transfer Area m^2 (ft^2)	4	0.7 to 70	0.69					

5-2 Heat Exchange

5-5

Capital Cost Estimating

Cost estimation

Which Bare Module contributors change when pressure and material are significantly different from the base FOB?

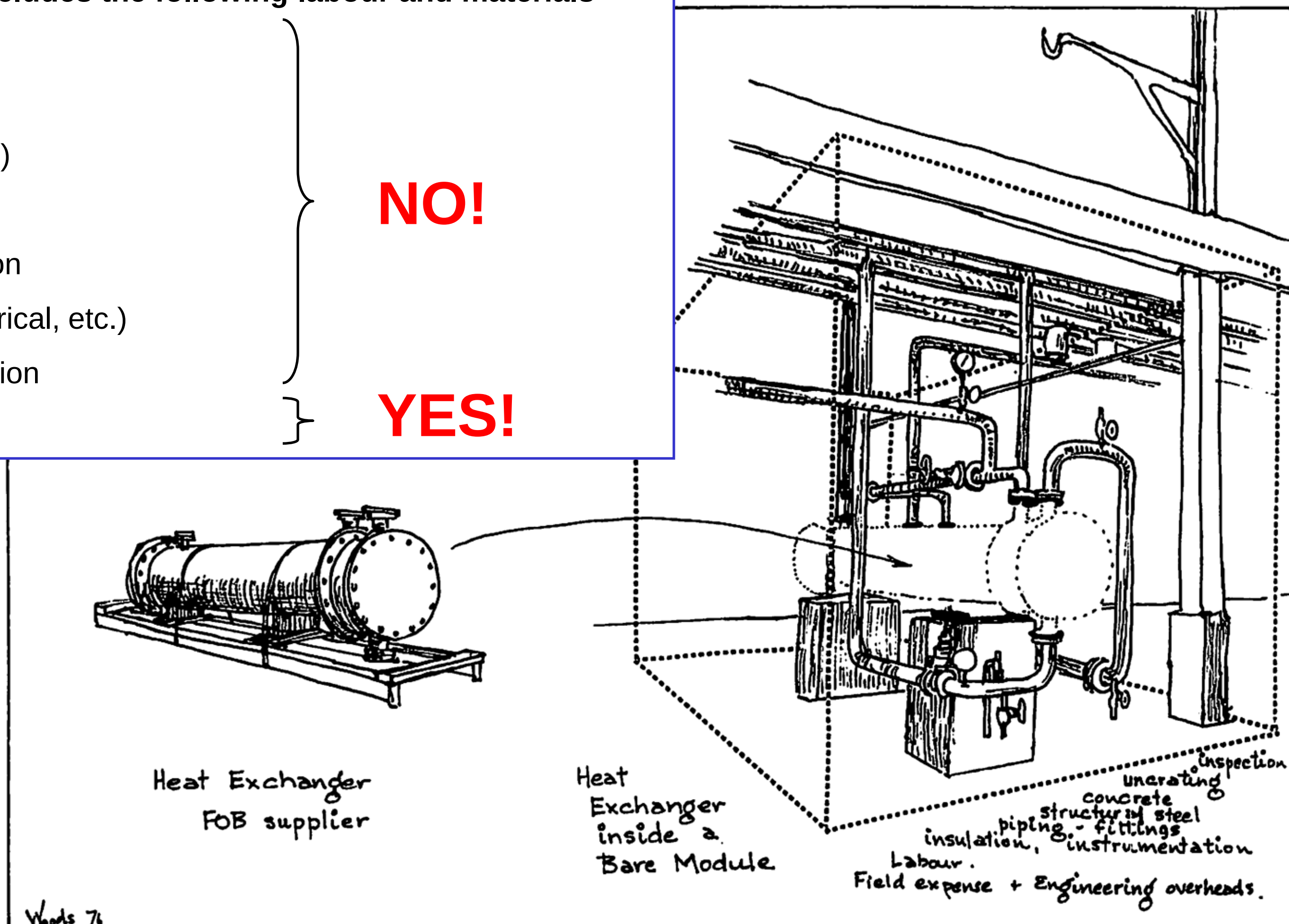
Bare module cost includes the following labour and materials

- •Uncrating
- •Inspection
- •Structure (foundation)
- •Instrumentation
- •Painting and insulation
- •Utility hookups (electrical, etc.)
- •Engineering supervision

NO!

- •Piping

YES!



Cost estimation

Cost estimation with pressure (F_P) and materials of construction (F_M) corrections.

FOB Cost for equipment at base pressure and material	$C^0 = FOB_{unit} \times \text{Capacity factor}$
Cost for installation of base case equipment without P and M corrections	$C^0(F_{BM} - 1)$
Additional FOB cost for pressure and materials correction (the 1.0 is for base case)	$C^0(F_P F_M - 1)$
Additional cost for bare module piping (due to P and M)	$C^0(F_P F_M - 1)(f_{piping})(\psi)$

Data on f_{piping} in Woods' page 1-58, Table 1-11. Timmerhaus et. al. give a value of 0.68 for fluid. Value of ψ is from 1.0 (Turton) to 0.70 (Woods).

Cost estimation

The piping factor is different for each equipment.

Table 1-11: Guthrie's FACTORS FOR INDIVIDUAL PIECES OF EQUIPMENT BASED ON FOB COST OF EQUIPMENT = 1.00 (BASED ON CARBON STEEL)*

		Exchangers		Vessels		Pump and driver	Compressors and driver	Tanks
	Furnaces	Shell-tube	Air-cooled	Vertical	Horizontal			
FOB Equipment	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Piping	0.18	0.46	0.18	0.61	0.42	0.30	0.21	
Concrete	0.10	0.05	0.02	0.10	0.06	0.04	0.12	
Steel	—	0.03	—	0.08	—	—	—	
Instruments	0.04	0.10	0.05	0.12	0.06	0.03	0.08	
Electrical	0.02	0.02	0.12	0.05	0.05	0.31	0.16	
Insulation	—	0.05	—	0.08	0.05	0.03	0.03	
Paint	—	—	0.01	0.01	0.01	0.01	0.01	
Total materials $(E + m) = M =$	1.34	1.71	1.38	2.05	1.65	1.72	1.61	1.20
Erection and setting (L)	0.30	0.63	0.38	0.95	0.59	0.70	0.58	0.13
X, excluding site preparation and auxiliaries $(L + M)$	1.64	2.34	1.76	3.00	2.22	2.42	2.19	1.33
Freight, insurance, and taxes	—	0.08	—	0.08	0.08	0.08	0.08	0.08
Engineering and home office, construction overhead, or field expense	0.60	0.95	0.70	0.22	[illegible]	0.97	0.89	
Bare Module Factor (BM)	2.24	3.37	2.46	4.30	3.22	3.47	3.16	

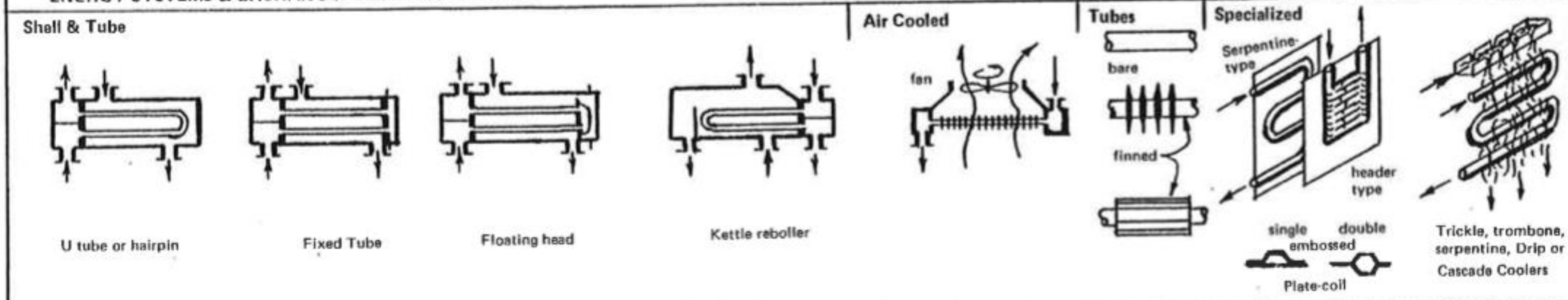
f_{piping}

From Woods (1993), page 1-58

Cost estimation

Class exercise: Estimate the Bare Module cost in 1970 for the following equipment.

- Shell and tube heat exchanger
- Floating head
- 316 stainless steel for shell and tubes
- P = 5.6 MPa
- Area = 70 m^2



	Size	Unit	Cost 10^3\$	Range	n	Error %	L+M	L/M	BM	Comments
SHELL AND TUBE Floating head, 1140 kPa, c/s in c/s shell, bare tube Delivered cost: standard 4.85 m length, with either 2.5 or 1.9 cm O.D. tubes on square or triangular pitch. Pressure, MPa 2.2 : x 1.15 7.0 : x 1.55 2.9 : x 1.25 22 : x ~2.5 4.2 : x 1.45 28. : x ~2.8 5.6 : x 1.52 35. : x ~3.1 tubes in c/s shell: Al x 1.2 s/s 316 x 2.4 Cu x 1.35 s/s 304 x 2.0 Brass x 1.3 Monel x 3.0 Admiralty x 1.5 Ti x 9.0 70-30 Cu-Ni x 1.7 Inconel x 2.4 Ni x 2.8 Hastalloy C x 8.5 tubes and shell: s/s 316 x 3.0 Monel x 4.0 s/s 304 x 2.8 Ti x 13.0	1	Heat Tranfer Area 10^2 m^2 (1076 ft^2)	8	0.02 to 20	0.71	40	2.30	0.36	3.14	Fixed tube x 0.85 U-tube x 0.87 Kettle reboiler x1.35 Tubes only x 0.3 Expansion joint on fixed tube x 1.25 23,70,91 123,126,127 128,145,150 170,201,203 212,314,318 344,403,494 498,506,531
After cooler for compressor, c/s with water on shell side. excl: separator, integral piping, support stand and instrumentation.	0.1	m^3/s	0.38	0.03 to 0.3	0.58					
Cross bore in c/s shell. Karbate. Delivered.	10 108	Heat Transfer Area m^2 (ft^2)	4	0.7 to 70	0.69					

5-2 Heat Exchange

5-5

Capital Cost Estimating

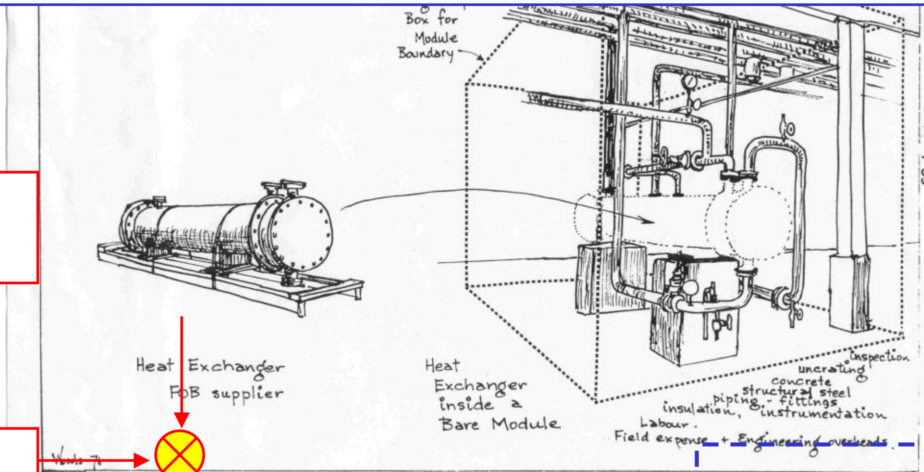
Cost estimation

Class exercise: Solution for heat exchanger

FOB Cost for equipment at base pressure and material	FOB = \$8000 x $(70/100)^{0.71}$ = \$6210
Cost for installation (unchanged from base)	$C^0 (F_{BM} - 1)$ = \$6210 (3.14 – 1) = \$13290
Additional cost in FOB for pressure temperature and materials	$C^0 (F_P F_M - 1)$ = \$6210(1.52 x 3.0 – 1) = \$22110
Additional cost for bare module piping (due to P & M)	$C^0 (F_P F_M - 1) (f_{piping}) (\psi)$ = (\$22110)(0.46)(0.70) = \$ 7120

Total BM cost in 1970 = \$ 6210 + \$13290 + \$22110 + \$7120 = \$48,730

Schematic of cost estimation with pressure and material corrections



Base condition FOB

Capacity factor

Inflation factor

C^0

$(F_{BM} - 1)$

FOB w/o corrections

Installation w/o corrections

Purchase & installation w/o corrections

Corrections to FOB, $(F_P{*}F_M - 1)$

Piping correction, $f_{pipe}(\psi)$

FOB correction

Installation correction

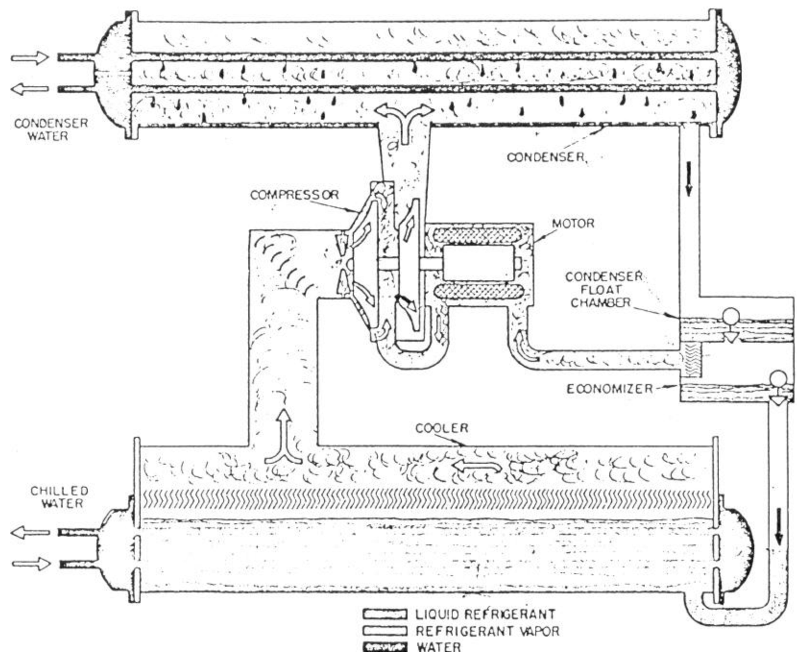
Purchase & installation corrections

Capital Cost Estimating

Cost estimation

Class exercise: Estimate the Bare Module cost in 2000 for the following equipment.

- Packaged vapor recompression refrigeration unit
- 7040 kW
- Evaporator T = 275 K
- Includes compressor, condenser, evaporator, motor, insulation, and instrumentation, delivery, installed
- Material c/s



Capital Cost Estimating

Cost estimation

McMaster University Boiler House

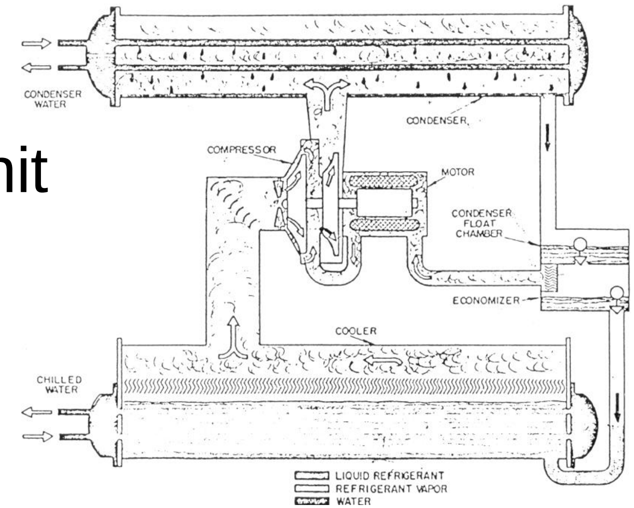
	Size	Unit	Cost $10^3\$$	Range	n	Error %	L+M	L/M	BM	Comments
TRANSFORMER STATION (Cont)		Rated capacity								
Transformers - 1-phase, oil type.	0.3	10^2kW	0.36	0.1 to 0.7	0.64					
dry type for <250 kW ∿ ×1.5	1		0.83	0.7 to 5	0.78					
ELECTRICAL DISTRIBUTION SYSTEM		Capacity								
Labour plus material costs		10^4kW	900		0.90					23,205,530,535, 561
REFRIGERATION										
Mechanical Vapor Recompression, evaporator temp. 4.4°C, c/s. Packaged unit. Delivered and field erected. incl: centrifugal compressor, condensers, instrumentation, insulation, field erection, subcontractors indirects, single transformer substation for starting motor driven units >600 hp. excl: cooling tower.	1	Refrigeration capacity 10^3kW	100	0.02 to 5	0.77	30	1.3	0.82	1.4	1,13,23,91,199, 201,318,366, 500,516,530, 561.
Factors: Evap. temp. 9.9°C × 0.94 -29°C × 3.0 4.4°C × 1.00 -40°C × 4.0 -1.1°C × 1.08 -51°C × 7.0 -6.6°C × 1.4 -62°C × 15.0 -17.7°C × 1.8 incl. cooling tower × 5.5										
Steam Vacuum, 20°C. Installed Unit. Factors: 10°C × 0.80	1	Refrigeration capacity 10^3kW	78	0.05 to 2.8	0.61					91,435,530,535
Low temperature Dewar plus mechanical energy extraction & heat exchange, Helium 4.2°K. Installed package unit	1	W	60	1 to 9	0.31					517,530,535, 561
closed loop	100	W	400	9 to 1000	0.50					
open loop	10	W	82	3 to 350	0.32					

Capital Cost Estimating

Cost estimation

Class exercise: Solution for refrigeration unit

(Note: this solution puts step 7 earlier, but the answer is still the same)



From Wood's page 9-7, (we are extrapolating!!)

$FOB_{1970} = 100{,}000\ (7040/1000)^{0.77} = \$450{,}000$

$FOB_{2000} = 450{,}000 \times (1089/301) = \$1{,}626{,}000$

$\Delta FOB_{temperature} = (1.02\text{-}1) \times 1{,}626{,}000 = \$33{,}000$

Slightly below 4.4 C, assume no effect on installation (BM) costs

$BM_{2000} = 1{,}626{,}000 \times 1.4 = 2{,}276{,}000$ (for base unit)

$BM_{2000} = \$\ 2{,}276{,}000 + 33{,}000 = 2{,}310{,}000 \pm 30\%$

Note the low F_{BM} for a packaged unit. Does this make sense?

Cost estimation

Class exercise: Solution for refrigeration unit.

From Wood's page 9-7,

$FOB_{1970} = 100{,}000\ (7040/1000)^{0.77} = 450{,}000$

$FOB_{2000} = 450{,}000 * (1089/301) = 1{,}626{,}000$

$\Delta FOB_{temperature} = (1.02\text{-}1) * 1{,}626{,}000 = 33{,}000$

$BM_{2000} = 1{,}626{,}000 * 1.4 = 2{,}276{,}000$ (for base unit)

$BM_{2000} = \$\ 2{,}276{,}000 + 33{,}000$ $\boxed{= \mathbf{\$2{,}310{,}000 \pm 30\%}}$ **Correct!**

If we had used the *average BM factor* of 3.6 from Peters et.al., the **incorrect** estimate would be **$5,900,000!**

Cost estimation

Class exercise: Estimate the Bare Module cost in 2011 for a 20 kW centrifugal pump, made from 316 S/S clad, and a suction pressure of 7000 kPa.

$F_M = 1.45$

$F_P = 1.90$

http://www.lowara.com/products/photo.php/2670

	Size	Unit	Cost 10^3\$	Range	n	Error ±	L+M	L/M	BM	Comments
CENTRIFUGAL PUMPS (Cont)										
FOB. incl: impeller, mechanical seal, base-plate coupling, THFC motor. excl: duties and sales tax.		**Power**								
	10 (13.4)	kW (hp)	0.92	1 to 23	0.39		2.40	0.40	3.3	143,201,344, 355,357
factors:	10^2 (134)	kW (hp)	2.8	23 to 250	0.58					B + M = 1.70
cast iron × 1.00; Titanium × 9.0										
carbon steel × 1.3; nickel × 3.5										
bronze × 1.28; monel × 3.2										
s/s 316 alloy × 1.93; Alloy 20 × 2.3		**Capacity**								
clad × 1.45; Hast alloy C × 2.95	1	m^3/min	1.6	0.04 to 30	0.59					
suction pressure:										
1135 kPa × 1.0										
3550 × 1.5										
7000 × 1.9										

Capital Cost Estimating

Cost estimation

1. **Correlation:** use Woods, p8-8, since it applies

2. **Range check:** Base unit is in kW, our unit is 20 kW, so

$$1 \leq \frac{20\text{kW}}{\text{kW}} \leq 23$$

which means n = 0.39

3. **Base unit cost:** $\$FOB_{1970,B}$ of 10 kW was \$920

4. **Capacity inflation:** $\$FOB_{1970,A} = 920 \times \left(\frac{20}{10}\right)^{0.39}$ = \$1205

5. **Materials inflation:**

$F_{BM} = 3.3$, $F_M = 1.45$ and $F_P = 1.90$

Bare module cost (no corrections) = $C^0(F_{BM})$ = 1205 x 3.3 = \$3980

Module installation, etc =$C^0(F_{BM} - 1)$ =3980 – 1205= \$2775

So \$2775 = incremental cost of getting unit in the bare module area

Cost estimation

5. Materials inflation:

$$F_{BM} = 3.3, \qquad F_M = 1.45 \qquad \text{and} \qquad F_P = 1.90$$

Charge to upgrade the equipment = 1205 x 1.45 x 1.90 – 1205 = $2115

This is what the vendor adds to our bill = $C^0(F_M F_P - 1)$ = $2115

Reasonable to expect **OUR** cost to upgrade piping in the BM is some fraction of this $2115. Naïve estimate would be ($2115)($F_{BM}$) = $ 6980.

But, we don’t need to upgrade all BM costs, just the piping portion. For pumps: f_{pipe} =0.3 This indicates 0.3/3.3 = 9% of the cost of upgrading the BM is due to piping.

Further, we don’t need to upgrade every pipe in the BM, some factor ψ of the total only, where $0.7 < \psi < 1$. We will assume 70%.

So piping upgrade = (2115)(0.30)(0.7) = **$444**.

Now let’s add up our estimates.

Cost estimation

5. Materials inflation:

Cost of the equipment	\$ 1205
Cost of installation into BM	\$ 2775
Cost of the vendor's upgrades	\$ 2115
Cost of **our** upgrades in BM piping:	<u>\$ 444</u>

6. Bare module cost: **\$ 6540**

So the fully installed price was multiplied 6540/1205 = 5.4 times

7. Price inflation: $\$BM_{2011} = 6540\left(\frac{586}{126}\right)$ = \$30,420 using CEPCI

8. Error bounds: assuming 40%

$$\$18,250 \quad < \quad \$BM_{2011} \quad < \quad \$42,600$$

Capital Cost Estimating

Cost estimation

Homework problem:

Capital cost of a 316 stainless steel distillation column

21.3 m high, 2.3 m diameter

26 trays at standard spacing of 0.6m

3.2 MPa operation

Capital Cost Estimating

Cost estimation

	Size	Unit	Cost 10^3 $	Range	n	Error %	L+M	L/M	BM	Comments
Tray columns; c/s tower with c/s sieve plates on 0.6 m spacing. [standard plate spacing] FOB unit with trays, shop installed. Column has no manholes	100	$(\text{tower ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	65	4 to 150	0.57	20				Use slope 0.57 if column has no manholes, few small nozzles and no tooling charge for making trays. Otherwise use 0.53.
-as above but with manholes, more nozzles and incl. tooling up charge.	100	$(\text{tower ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	65	4 to 150	0.53	20	3.00	0.43 to 0.58	4.16	
Tray columns; 316 s/s tower with 316 s/s sieve plates on 0.6 m spacing. FOB unit with trays shop installed in tower. Column has no manholes and tooling up charge for trays is neglected.	14	$(\text{tower ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	42	5 to 14	0.78	40		0.43 to 0.58		
				14 to 100	0.93	40				
-as above but with manholes, more nozzles and incl. tooling up charge.	22	$(\text{tower ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	65	5 to 22	0.52	40				
				22 to 100	0.96	40				
Factors For 0.3 m spacing × 0.67										
For other combinations of tray and column, cost column as a pressure vessell and add the appropriate internals from the following costs:										
Tray internal units, incl. trays, supports, fittings, shop fabrication and installation c/s sieve trays on 0.6 m spacing. Installed in column. excl. tooling up fee but accounting for penalty charge based on number of trays ordered, column shell	100	$(\text{stack ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	16	1.5 to 250	0.78	48				
-as above. incl. tooling up fee Factors: tray spacing 0.6 m : × 1.0 0.45 m : × 1.4	66	$(\text{stack ht., m})\left[\frac{\text{diam}}{\text{m}}\right]^{1.5}$	20	(1.5 to 66	0.39	40				
				(66 to 250	0.78	40	incl			

9-9

Capital Cost Estimating

Cost estimation

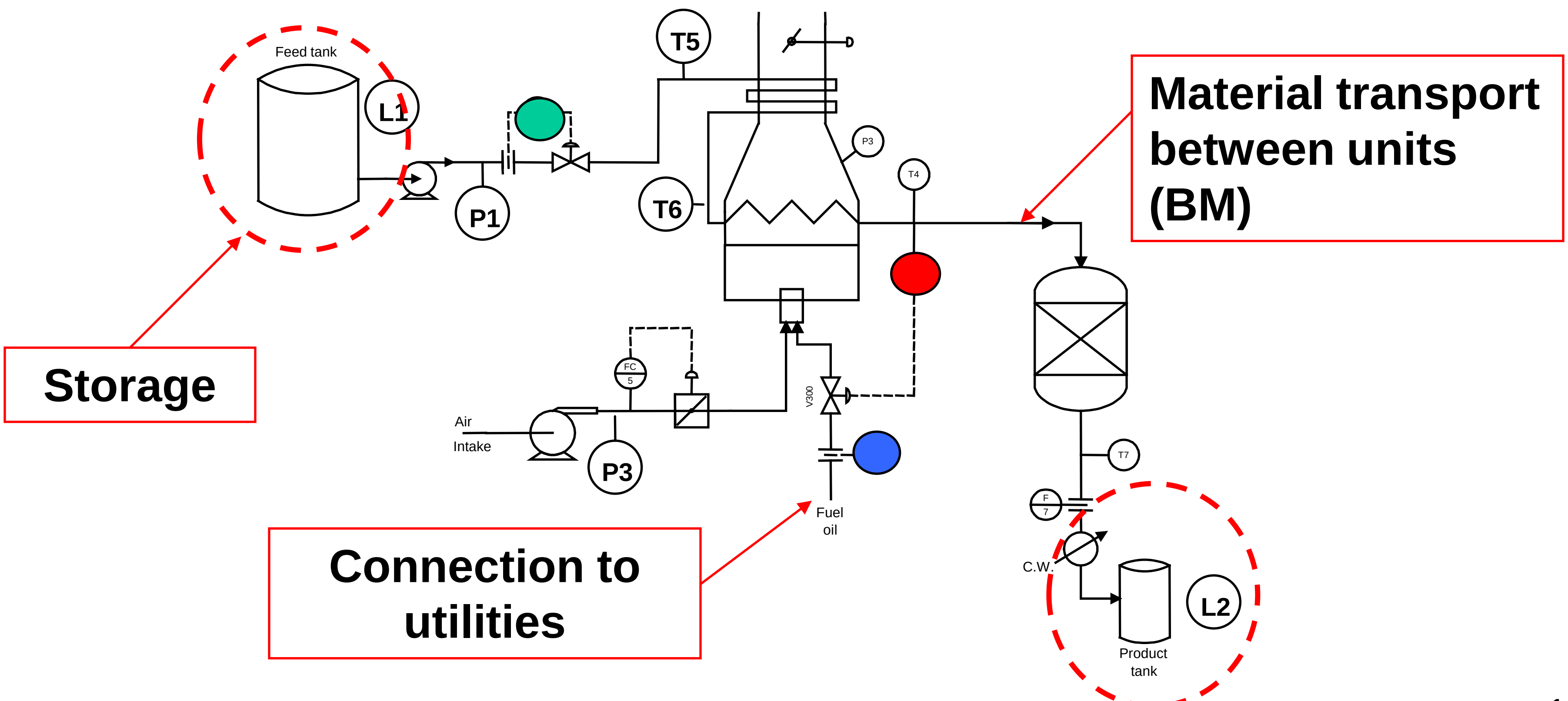
Comparison of Bare Module (installed) cost estimates in US Dollars for 2000

Equipment	Woods (Individual BM Factor for each equipment)	Peters, Timmerhaus, West*	Matches Internet Site*
Heat Exchanger	70,500	39,100	100,000
Horizontal Drum	110,000	107,000	89,100 (15,048 gallons)
Refrigeration	2.31 M$ [1.3 to 3.2 M$] (extrapolation)	5.33 M$ (extrapolation)	4.51 M$ (interpolate 20 and 40F)

* Bare module factor of 3.6 from Peters et. al. table 6-9.

Cost estimation

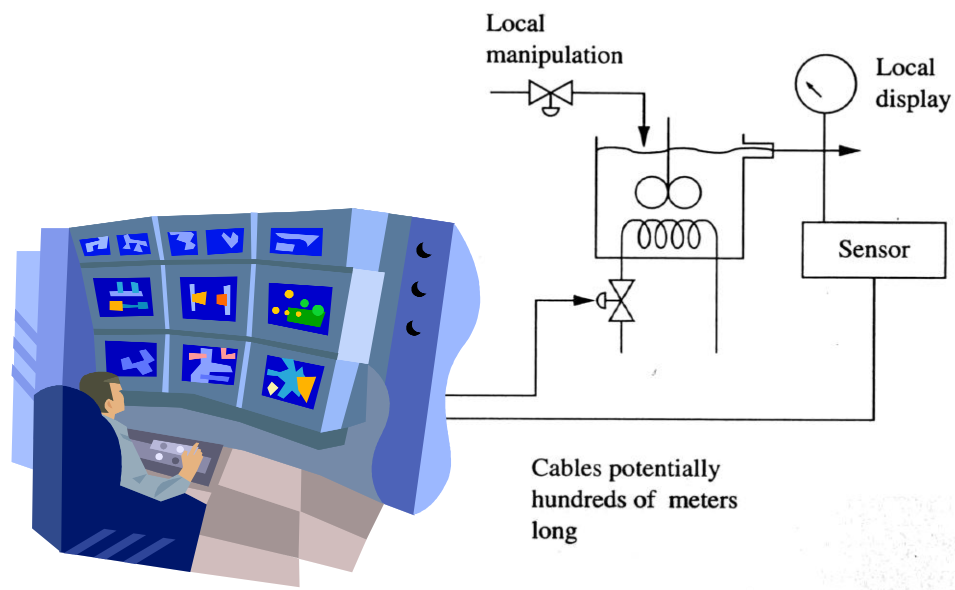
The Bare Module method provides equipment costs for units considered. These units must be connected into an integrated plant. What additional equipment is required?



Cost estimation

The Bare Module method provides equipment costs for units considered. The cost of basic instrumentation is included in the bare module factor; however the cost for “additional” sensors, e.g., analyzers must be added if they exist.

Also, the cost for the control system, including computing, consoles, power supply, wiring and control house must be estimated separately.



Capital Cost Estimating

Cost estimation

The Bare Module method provides equipment costs for units considered. Please do not forget that all other equipment must be estimated. For new facilities and large changes to existing facilities, much new equipment is required

Battery Limits, the process, roads, etc.

Administration, offices, labs, machine shops, etc.

Offsites, storage, waste treatment, etc

Outside battery limits

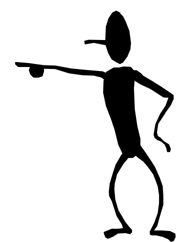
Utilities, steam, cooling water, air, fuel, etc.

Cost estimation

Manufacturing costs - These are incurred with every unit of production and do not include capital items.

- **Direct** – raw materials, labour, labs, utilities, consumable supplies, waste treatment, packaging and shipping, utilities = (water, electricity, steam, cooling, compressed air, inert gas)
- **Fixed (indirect)** - Land taxes, insurance, maintenance, licensing fees, plant administration, etc.
- **General** - Corporation, marketing & sales, finance, R&D, etc.

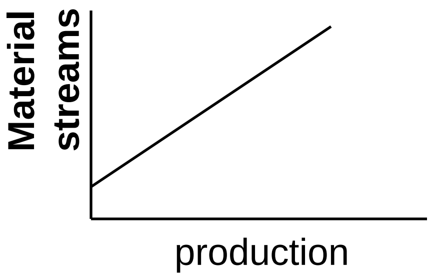
How do these costs depend on the plant production rate?

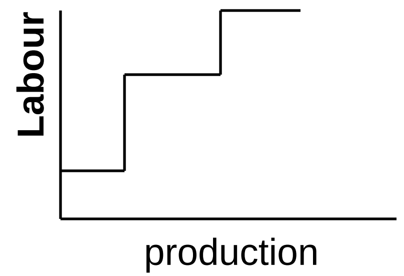


Cost estimation

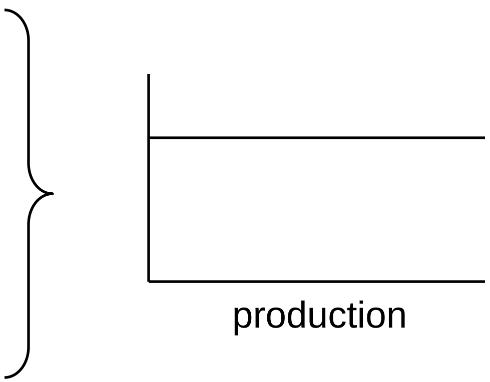
Manufacturing costs - These are incurred with every unit of production and do not include capital items.

- **Direct** - materials, labour, utilities, supplies, waste treatment, etc.





- **Fixed (indirect)** - Land taxes, insurance, plant administration, etc.
- **General** - Corporation, sales, finance, R&D, etc.



Capital Cost Estimating

Cost estimation

Capital costs

- Very rough - Total unit/plant estimates; see Woods, 1993 and other databases.
- Good accuracy - Combine flow sheet (e.g., HYSYS, Aspen, Pro II) results with equipment-specific information, e.g., pump efficiency, fired heater efficiency, etc. In addition to process, utilities systems (plant fuel, steam, and electric power balances) can be modelled.

How does Aspen calculate equipment costs? See Seider et al. textbook for additional insight, as well as on-line research.

Capital Cost Estimating

Cost estimation

COST OF MANUFACTURE

Cost Item	Factor	Estimate based on Flowsheet & preliminary design		Annual Cost ($/year)
		Quantity/ year	Cost/ quantity	
Variable costs				
Raw Materials		kg/year	$/kg	
- itemize all				
Products				
- itemize all				
By-products				
- itemize value, waste treatment costs, etc.				
Consumables				
- catalyst, solvents, etc.				
Fixed costs			**($/person)**	
a. Operating personnel (1 post = 4.4 people)			70,000	
b. Supervision and engineering	0.25*a		100,000	
c. Maintenance personnel	0.03*FC		75,000	
d. Engineering & Management	0.5*(a)		100,000	
Overhead on personnel	0.4* (a+b+c+d)			
Maintenance materials	0.03*FC			
Insurance	0.01*FC			
Taxes (property)	0.02*FC			
Laboratory personnel and consumables	0.15*(a+b+c)			
Royalties				
Operating overhead (business and employee relations, etc.)	.25*(a+b+c+d) *1.4			
Cost of Manufacture				
Sum of all items				

Notes:

1. Profitability analysis will integrate the Cost of Manufacture with capital cost, taxes, depreciation, and contingency. (General costs could be added depending on the basis of the study.)
2. All costs for project accounted for, including onsites, offsites, and utilities, including steam, electricity, fuel, water, oxygen, nitrogen, refrigeration, etc.
3. Factors based on tables in Peters et. al., Towler and Sinnott, and Sieder et. al. All are approximate and should be replaced by process –specific information, where available.

Manufacturing cost estimate should consider every major cost and give the basis of the value, e.g.,

- Flowsheet
- Experience (staffing)
- Factors for other costs

The result of this analysis becomes one element of the profitability calculation.

For sensitivity analysis, variable and fixed costs should be identified individually in the profitability analysis

(FC = fixed capital cost)

Capital Cost Estimating

Cost estimation

Manufacturing costs:

- **Utilities**
  - Seider, Seader, Lewin, Widagdo, table 23.1
  - Turton, *et al.*, Chapter 8
- **Cost of personnel**
  - $ 60,000 to $70,000 per operator-shift, or $35/hr
  - One “post” or shift = 4.4 x annual salary
  - $100,000 for managers and engineers
  - Overhead is about 40% of salary
  - Personnel do not scale with production when equipment size can be increased.

Capital Cost Estimating

Cost estimation

Manufacturing costs - some cautions:

- Do not use standard inflation for energy or raw materials costs. Show/research Crude Oil price over the last 100 years.

  These can change rapidly up and down due to international incidents.

Cost estimation

Manufacturing costs - some cautions:

- Equipment selected strongly affects maintenance and waste treatment.
- Remember costs for operating outside battery limits, e.g., the laboratory.

  See Haseltime, 1996
- Operating costs depend on total operation time.
- Incremental cost of steam changes significantly from summer (excess steam available, cost = $0) to winter (when extra fuel is required to produce steam)

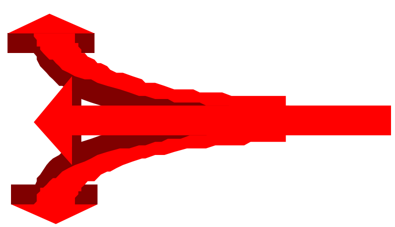
compare

Comparison of alternatives

1. Time value of money
2. Quantitative measures of profitability
3. Systematic comparison of alternatives
4. Estimation of costs

Is there a systematic way to make choices among alternatives?

Success !!



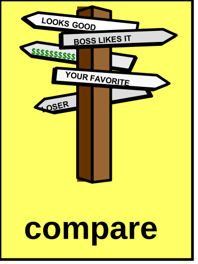
Oops !!

Compare

Comparison of alternatives

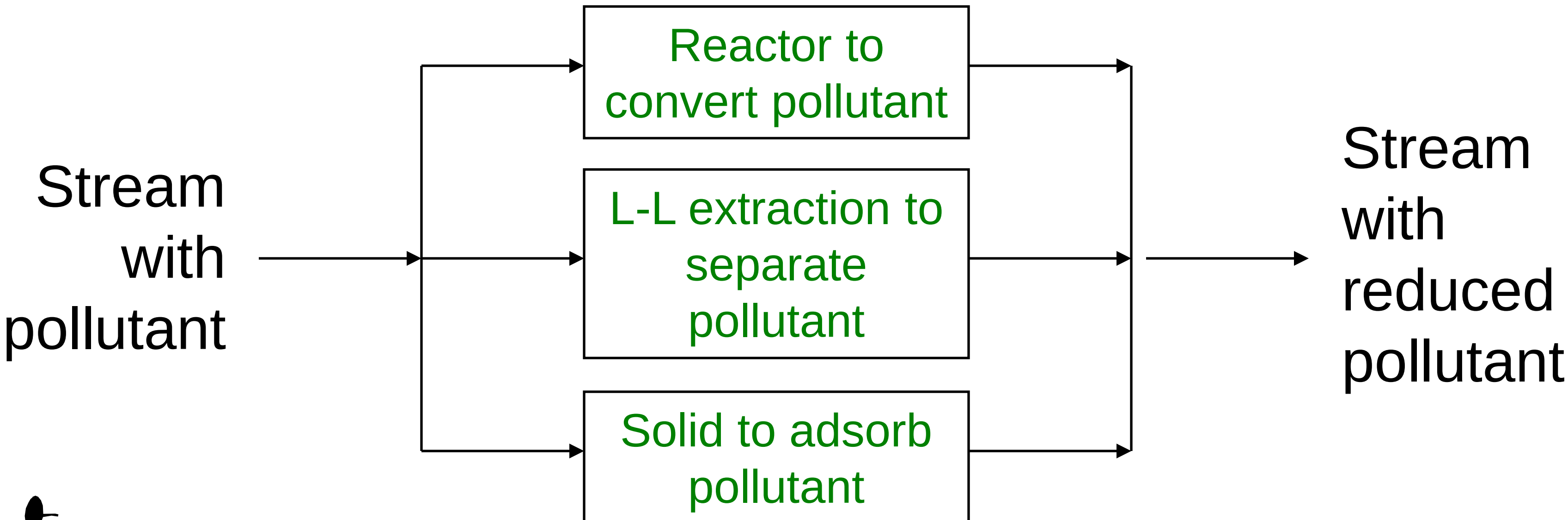
Some assumptions of the quantitative comparison methods

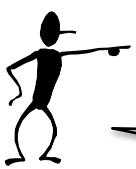
- All viable candidates must satisfy minimum needs of company, e.g., safety, legal restrictions, ethics, product quality, production rate, etc.
- All costs and benefits can be quantified in dollars
- We begin by assuming that no uncertainty exists



Comparison of alternatives

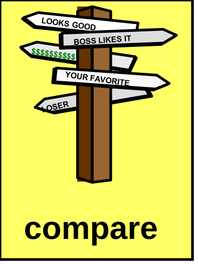
Mutually exclusive alternatives





What do we mean by mutually exclusive?

Only one of the alternatives will be selected. Any one will satisfy all technical requirements for the project.



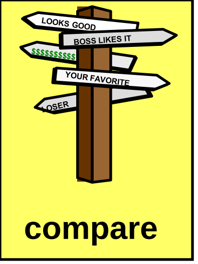
Comparison of alternatives

Mutually exclusive alternatives

Which is/are the correct approach(es)?

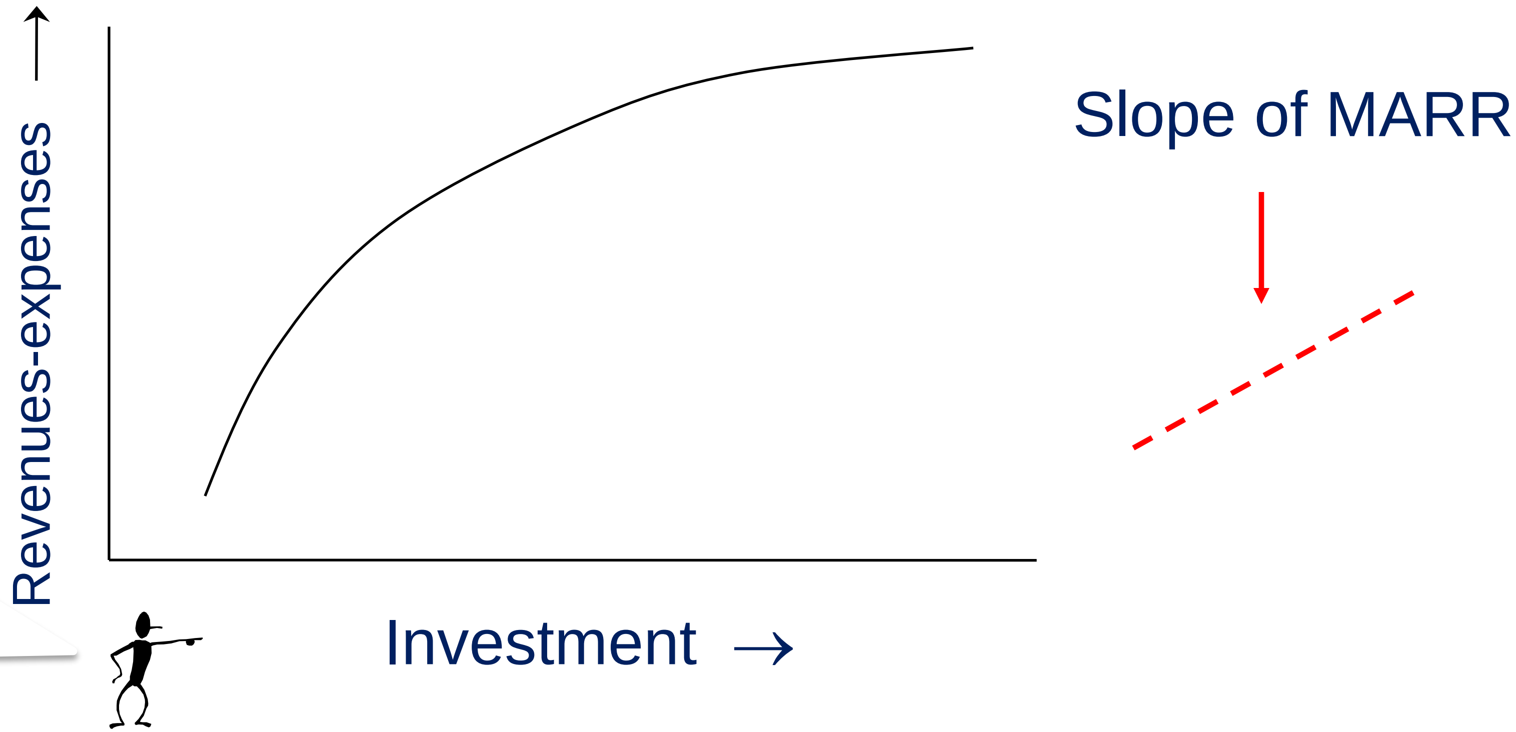
- Largest *investment* with DCFRR > MARR
- Largest *investment* with NPV > 0
- *Investment* with highest DCFRR
- *Investment* with lowest DCFRR

The first three seem reasonable, but all four are wrong!



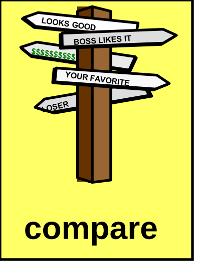
Comparison of alternatives

What is the best value for the investment?



For this thought exercise, we'll assume continuous.

Key concept: We want the return > MARR for every dollar invested!!



Comparison of alternatives

We'll come back to these two columns

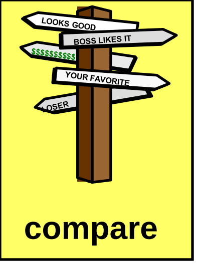
What is the best value for the investment?

MARR = 10%

Period, n	Project A	Project B	Project (B-A)	Invest in MARR
0	-$1000	-$5000	-$4000	-$4000
1	+$2000	+$7000	$5000	$4400
DCFRR	**100%**	40%	25%	10%
NPV at *i*=10%	$818	**$1364**	$545	**$0**

Problem: NPV is an absolute measure

DCFRR is a relative measure

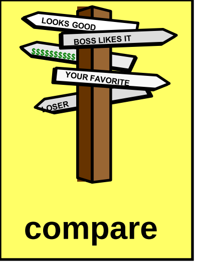


Comparison of alternatives

Mutually exclusive alternatives

A. Using net present value as the basis:

- Calculate the NPV for every alternative
- Select the largest **positive** NPV
- If no positive NPV exists, reject **all unless required** to accept the least economic loss for compelling reasons, e.g., safety, environmental regulations, etc.

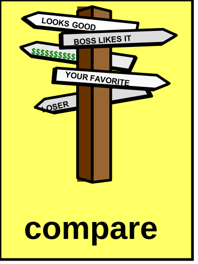


Comparison of alternatives

Mutually exclusive alternatives

B. Using discounted cash flow as the basis:

- Calculate the DCFRR for the **lowest investment**; accept if DCFRR > MARR. If not, take next largest investment. Continue until one has been accepted.
- Calculate the DCFRR on the **incremental investment** for the next largest investment, accept only if **incremental DCFRR > MARR**
- Continue until all investments have been considered.



Comparison of alternatives

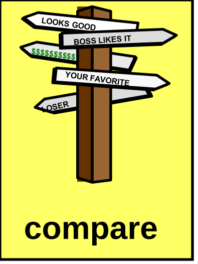
Example: Do you select Project A, B or None?

Mutually exclusive project selection example

(Data from Park et. al (2001) Contempary Engineering Economics, pg. 298)

MARR = 10%

year	Project A	Project B	B-A
0	-3000	-12000	-9000
1	1350	4200	2850
2	1800	6225	4425
3	1500	6330	4830
DCFRR	25%	17%	15%
NPV (10%)	$841.85	$1,718.63	$876.78



Comparison of alternatives

Example: Do you select Project A, B or None?

Mutually exclusive project selection example

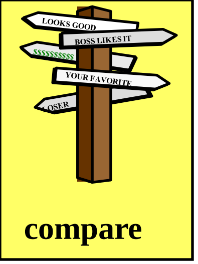
(Data from Park et. al (2001) Contempary Engineering Economics, pg. 298)

MARR = 10%

year	Project A	Project B	B-A
0	-3000	-12000	-9000
1	1350	4200	2850
2	1800	6225	4425
3	1500	6330	4830
DCFRR	25%	17%	15%
NPV (10%)	$841.85	$1,718.63	$876.78

Using the DCFRR on the incremental change, select Project B

Using NPV criterion, select Project B



Comparison of alternatives

Another example for a company with MARR = 12%

A = do nothing

B = Purchase a plate and frame filter press (separates solids from liquid)

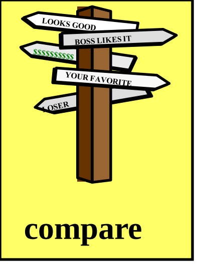
C = Same filter press, but with the automatic cleaning option

Projected costs (in first year) and savings (same amount saved for period n=1,2, ….8) after that.

	Costs	Savings	DCFRR	NPV
A = Do nothing	$0	$0	0%	$0
B = Plate & frame	-$50,000	$11,000	14.6%	$4,644
C = B, plus auto clean	-$68,000	**$14,000**	12.6%	$1,547
C – B (incremental)	-$18,000	$ 3,000	6.9%	-$3,097

Pick project ___________

Engineering Economics, Fraser and Jewkes, p 132



Comparison of alternatives

Another example for a company with MARR = 12%

A = do nothing

B = Purchase a plate and frame filter press (separates solids from liquid)

C = Same filter press, but with the automatic cleaning option

Projected costs (in first year) and savings (same amount saved for period n=1,2, ….8) after that.

	Costs	Savings	DCFRR	NPV
A = Do nothing	$0	$0	0%	$0
B = Plate & frame	-$50,000	$11,000	14.6%	$4,644
C = B, plus auto clean	-$68,000	**$15,500**	15.7%	$9,000
C – B (incremental)	-$18,000	**$ 4,500**	**18.6%**	**$4,354**

Pick project __________

Engineering Economics, Fraser and Jewkes, p 132

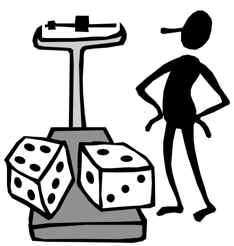
compare

Comparison of alternatives

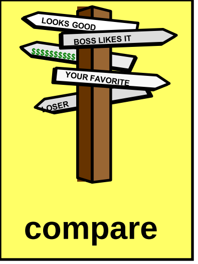
When making a recommendation: “Are we sure?”

We want to answer, “what if?”

- The product (sales) rate or price changes
- The energy costs change
- The project life changes (new technology)
- Feed material costs change


Dealing with uncertainty

We perform a sensitivity analysis

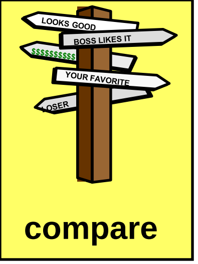


Comparison of alternatives

Sensitivity analysis

Some parameters in the analysis involve considerable uncertainty

- Concentrate on parameters with greatest uncertainty and impact on key decisions
- Determine likely range of variation
- Evaluate profitability over the range
- Determine if key conclusions change: profitability, payback
- If conclusions change, select decisions that give the highest profit considering probabilities.

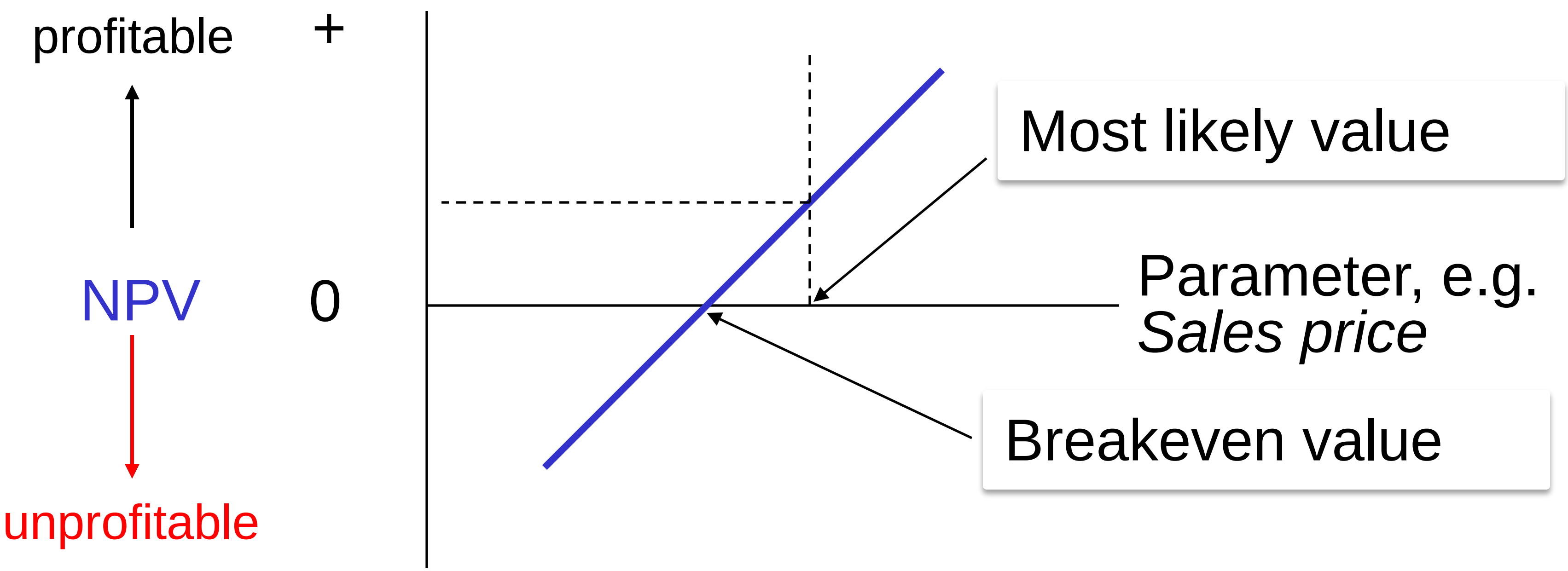


Comparison of alternatives

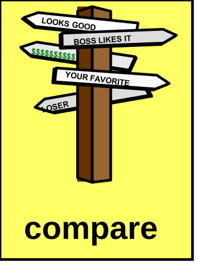
Sensitivity analysis

Results are often presented graphically

For one parameter (with other parameters constant)



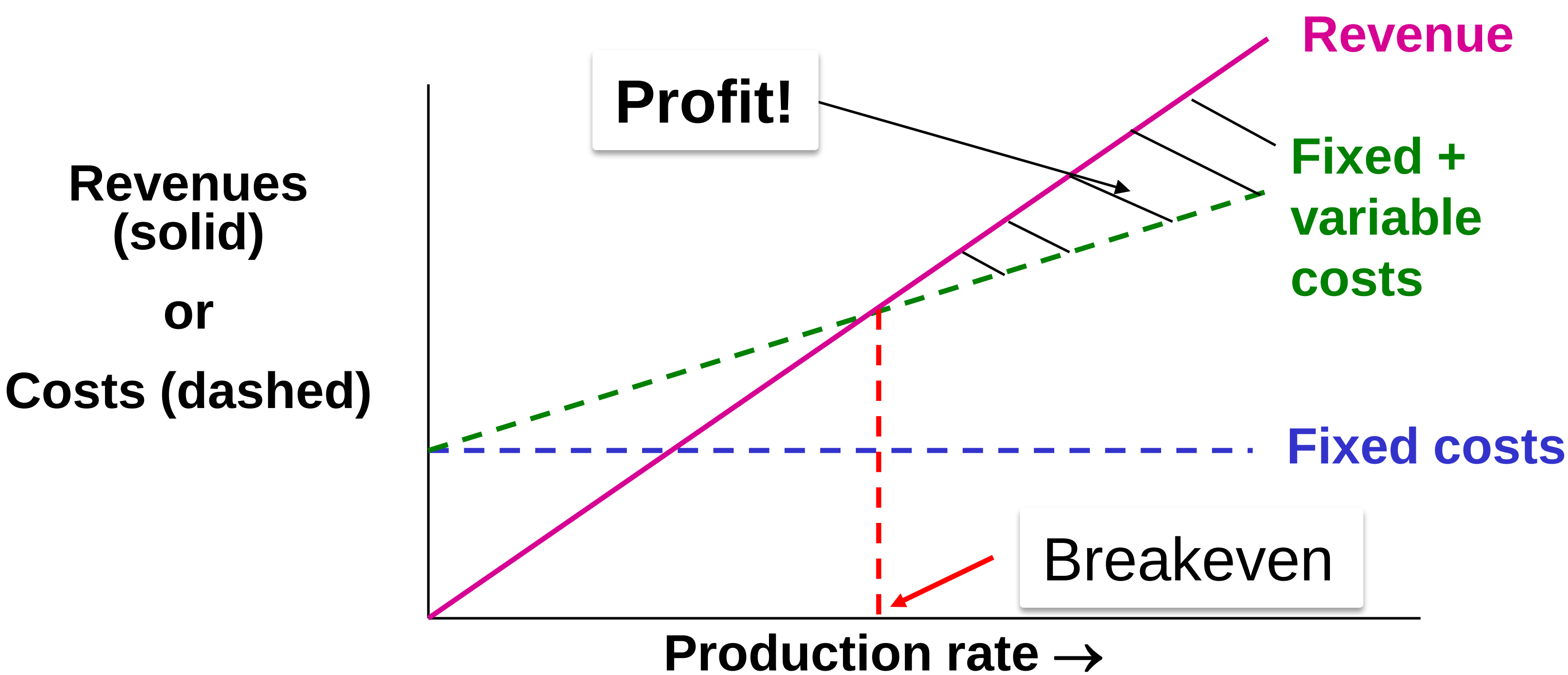
Very important for management to know when evaluating risk!



Comparison of alternatives

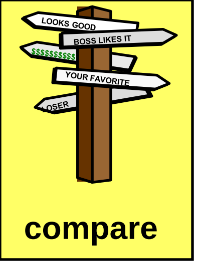
Sensitivity analysis

Key parameter: production (sales) rate



What are each of these costs?

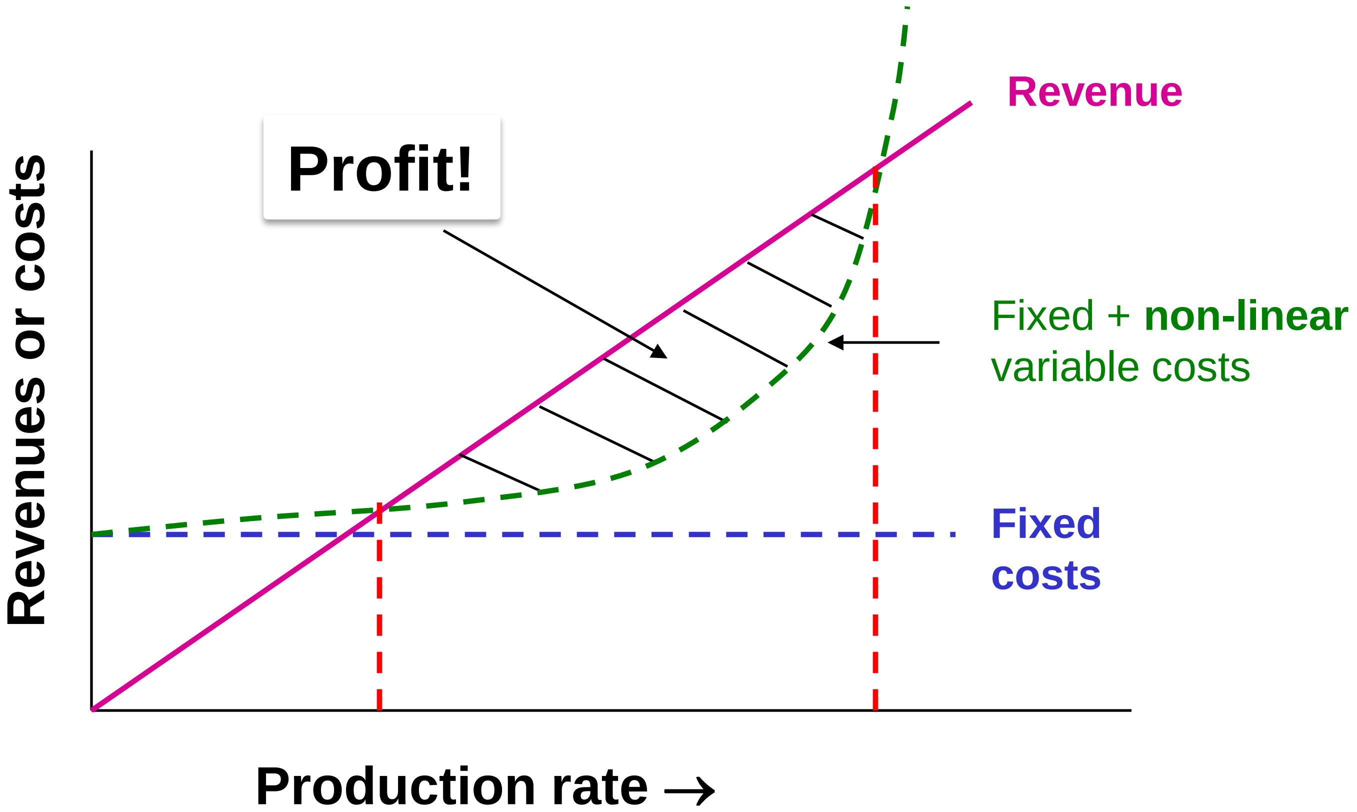
Use NPV $'s at the MARR discount %



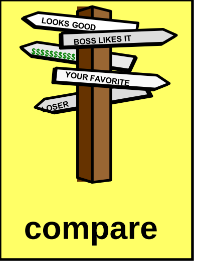
Comparison of alternatives

Sensitivity analysis

Key parameter: production (sales) rate

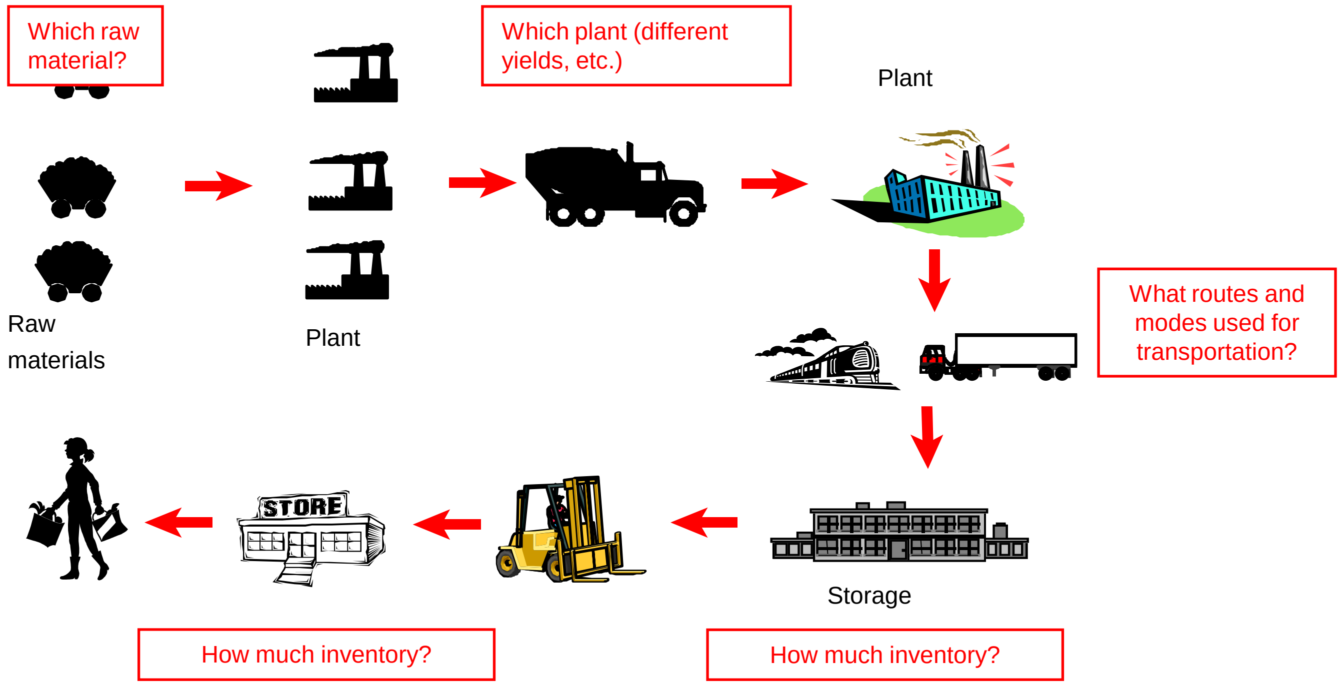


Why might this type of non-linearity occur?

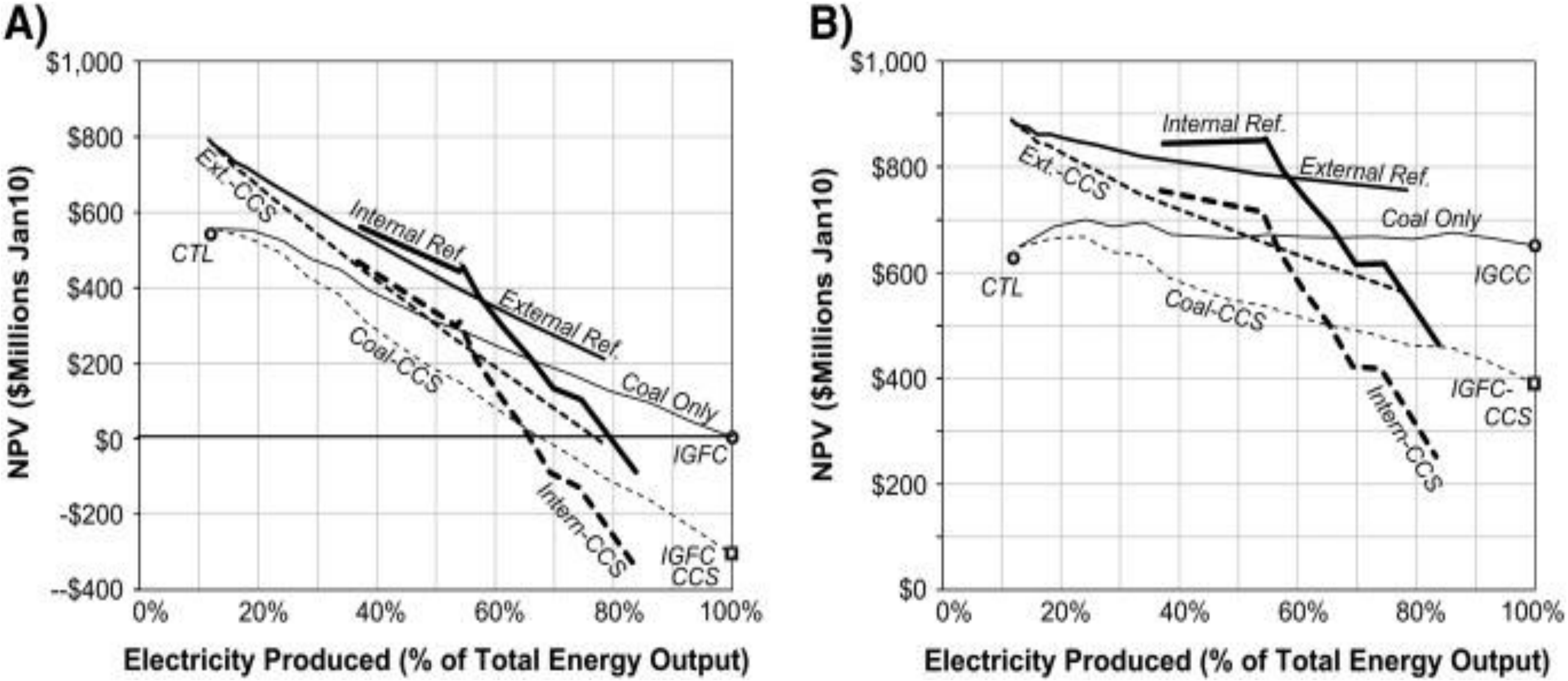


Comparison of alternatives

Sensitivity analysis



As we increase production, we may use more expensive raw materials, less efficient process units, exceed contracts and pay more for energy, etc. The costs might increase rapidly!



Electricity sold at 7c/kWh

Electricity sold at 10c/kWh

Fig.7 (A) The net present value of the six design strategies as a function of the electricity production at the base case market prices (B) The same when the price of electricity is raised to 10c/kWH

Thomas A. Adams II , Paul I. Barton

Combining coal gasification, natural gas reforming, and solid oxide fuel cells for efficient polygeneration with CO2 capture and sequestration

Fuel Processing Technology Volume 92, Issue 10 2011 2105 - 2115

http://dx.doi.org/10.1016/j.fuproc.2011.06.019

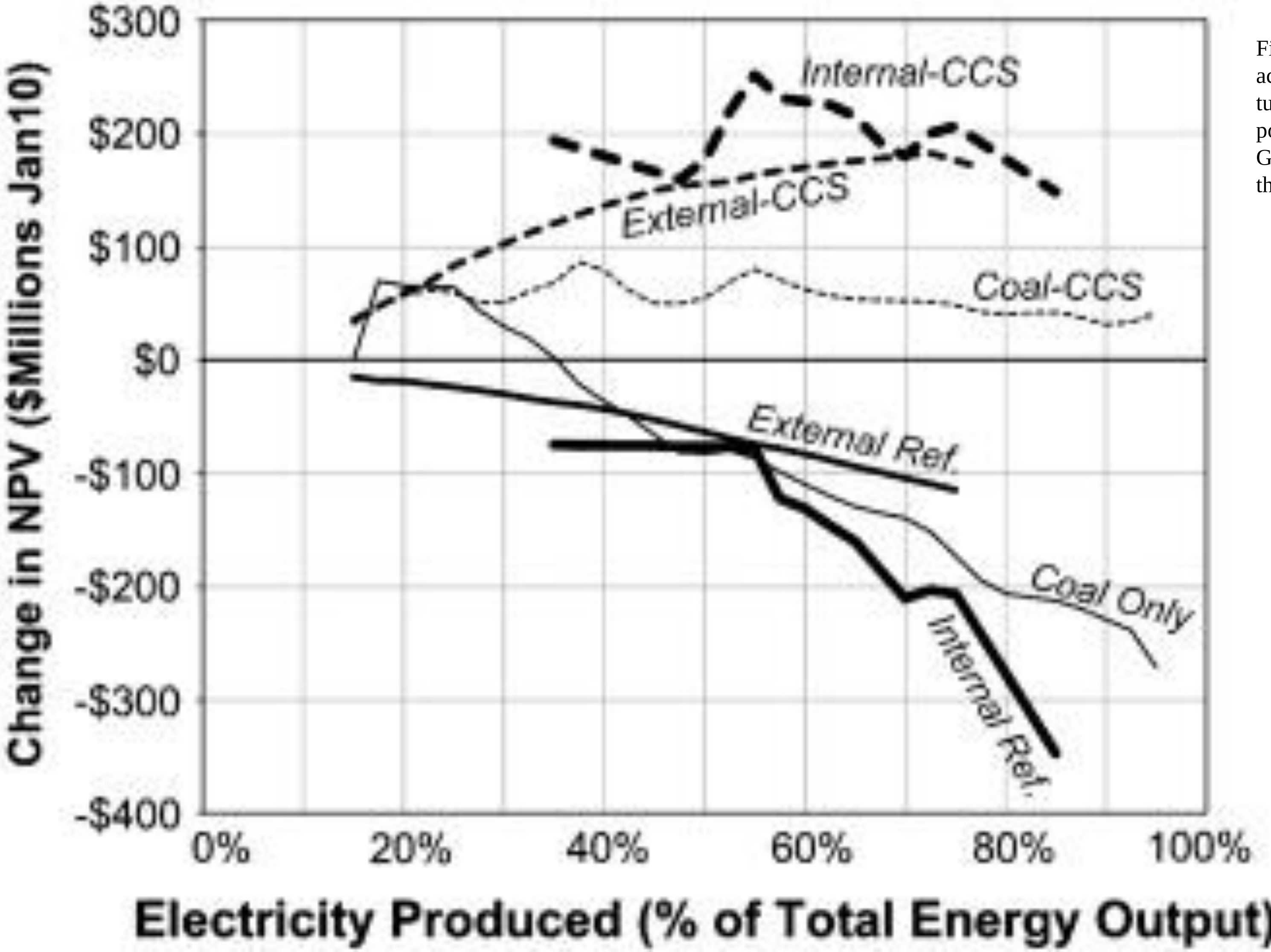


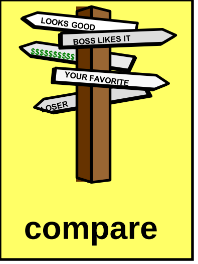
Fig.8 The change in the NPV achieved by switching from a gas turbine to SOFCs as the primary power generator (compared to GT-based cases as a function of the electricity production at t...

Thomas A. Adams II , Paul I. Barton

Combining coal gasification, natural gas reforming, and solid oxide fuel cells for efficient polygeneration with CO2 capture and sequestration

Fuel Processing Technology Volume 92, Issue 10 2011 2105 - 2115

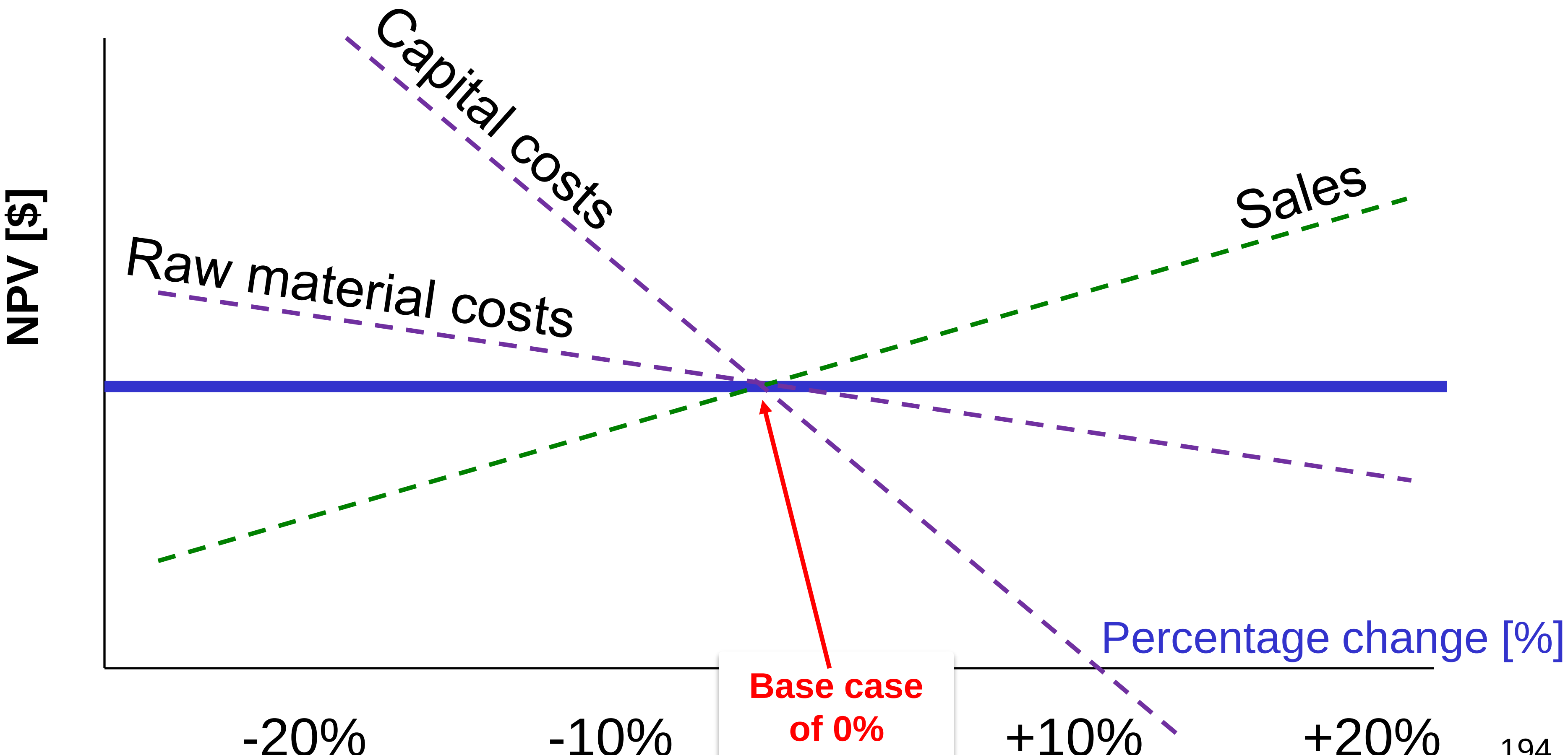
http://dx.doi.org/10.1016/j.fuproc.2011.06.019



Comparison of alternatives

Sensitivity analysis

Alternative visualization

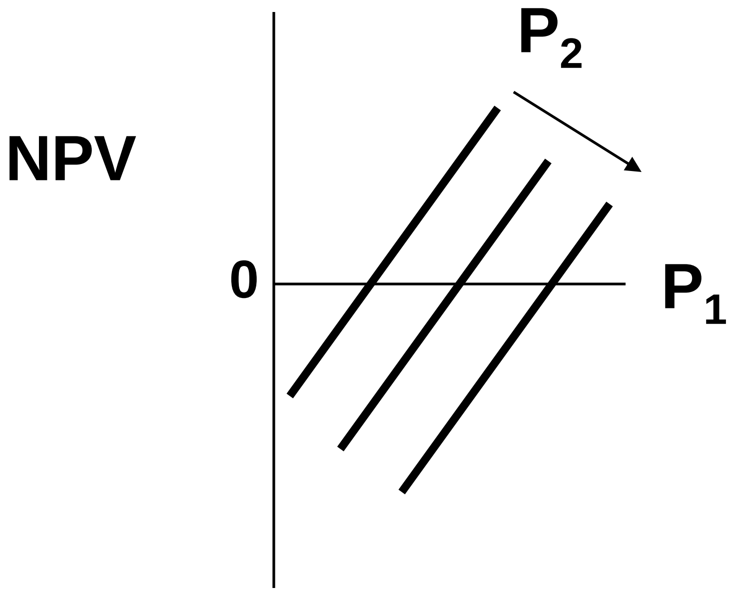


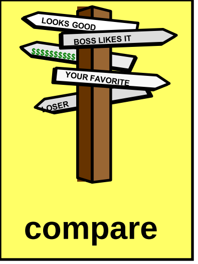
compare

Comparison of alternatives

Sensitivity analysis

Results can be presented graphically
for two parameters, P_1 and P_2





Comparison of alternatives

Sensitivity analysis

Apply scenario analysis to bound answer
for more than two parameters

Calculate three cases to “bracket” range of profitability

1. Using the “most likely” parameter values
2. Using the combination of likely “Worst Cases”
3. Using the combination of likely “Best Cases”

Careful: Don’t get too extreme (too unlikely) with the ranges, especially many concurrent (best) worst cases

compare

Comparison of alternatives

Sensitivity analysis

Apply scenario analysis to determine the expected (most likely) value

Calculate many cases (via computer)

1. Estimate the distribution of parameter values
2. Define many cases, each with sampled values for each parameter. Solve each case for the profit measure.
3. Calculate the "Expected value of profitability"

$$E(P) = \sum_{k=1}^{n} f_k P_k$$

n = number of samples

P_k = profitability for scenario *k* using sampled parameters

f_k = probability of scenario *k*

compare

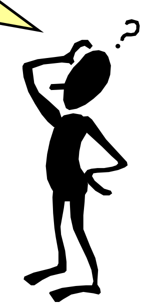
Comparison of alternatives

Sensitivity analysis

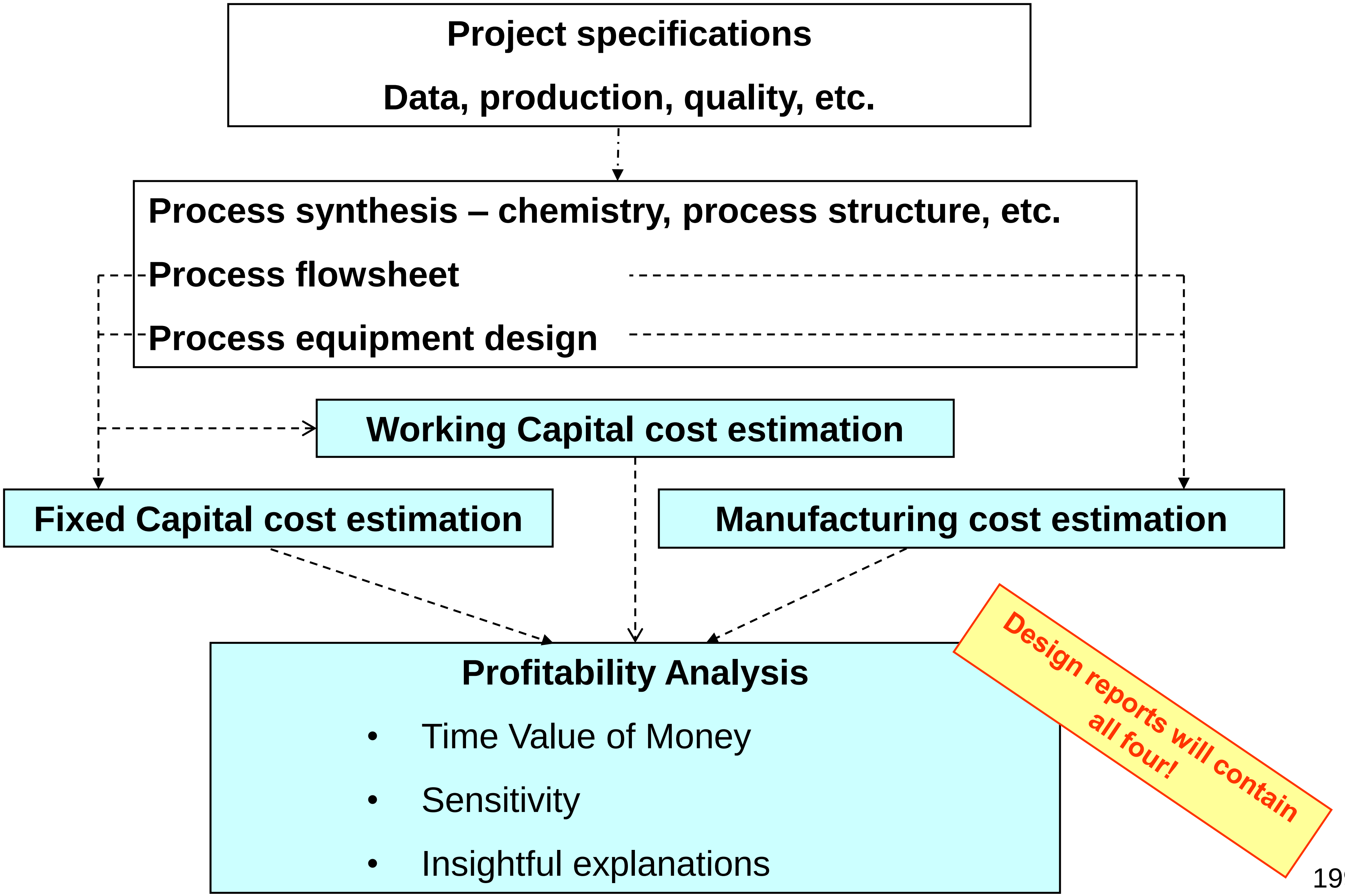
When defining scenarios, consider what is likely to change in a manner to influence the project decision.

- Market demand
- Tax rate
- Time to construct plant
- Values for cost of equipment, feed, energy

Which of these are likely to have substantial uncertainty?



Schematic of Economic Analysis



ENGINEERING ECONOMICS
Reporting Results

- Cover letter provides summary of key findings
- The basis of the study is clearly explained, highlighting key elements included/not included
- All estimates reported with error ranges
- Recommendation based on profitability using time-value-of-money method
- Distribution of costs shown clearly (cash flow diagrams and pie charts are helpful).
- Sensitivity analysis is essential

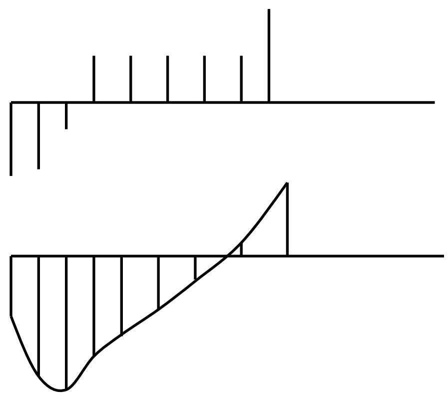
Engineering economics

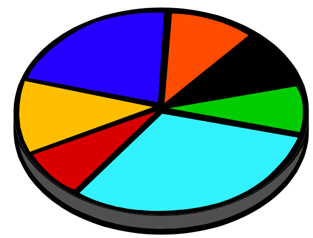
Reporting results: Numbers do not speak for themselves

Cash Flow Diagram

(at each period)

Cumulative Cash Flow Diagram

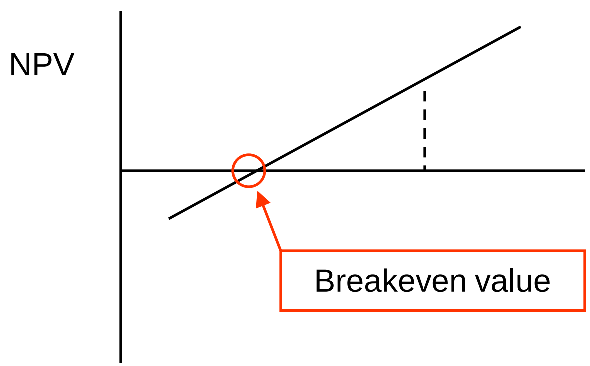




Capital: What equipment accounts for large shares of investment?

Manufacturing: What contributes large share (raw material, energy, personnel?

Sensitivity



How will you explain the results of your design project?

ENGINEERING ECONOMICS
Lessons learned the hard way

- Do not "fall in love" with a project. You must not continue to invest because you have already invested.

  Engineering economics always "looks forward".

- Do involve all stakeholders and people with knowledge early in the project

- Do not be too conservative in an environment of rapidly changing technology

  Tendency is to accept only "proven technology". But, large benefits come from large competitive advantage from new technology.

ENGINEERING ECONOMICS
Lessons learned the hard way

- Do prototype key technical approaches before making final decisions
- Do not allow the boss to direct your decision.
- Do use checklists to consider all important factors when project planning and estimating costs
- Do perform a thorough sensitivity analysis and consider the likelihood that key assumptions might not be fulfilled.
- Do report all estimates with error bounds, not necessarily symmetrical (e.g., -30% to +70%)

Capital Cost Estimating

COST ESTIMATION

Learning Project 6: Covering the topic, extending beyond these visual aids

- Search for computer programs available to supply data and perform estimation calculations? Summarize strengths and weaknesses of each.
- Search for cost data bases for other equipment, food processes, environmental processes, pharmaceuticals, etc. Summarize strengths and weaknesses of each.
- Provide a cost estimate for the distillation process on page 2-65 in Dr. Wood’s Process Design and Engineering Practice.
- Develop a checklist for estimating the project cost for a new plant.

Conclusion of Engineering Economics

1. Time value of money
2. Quantitative measures of profitability
3. Estimation of costs
4. Systematic comparison of alternatives

You know the basics and are able to learn additional methods to perform well as a professional engineer.