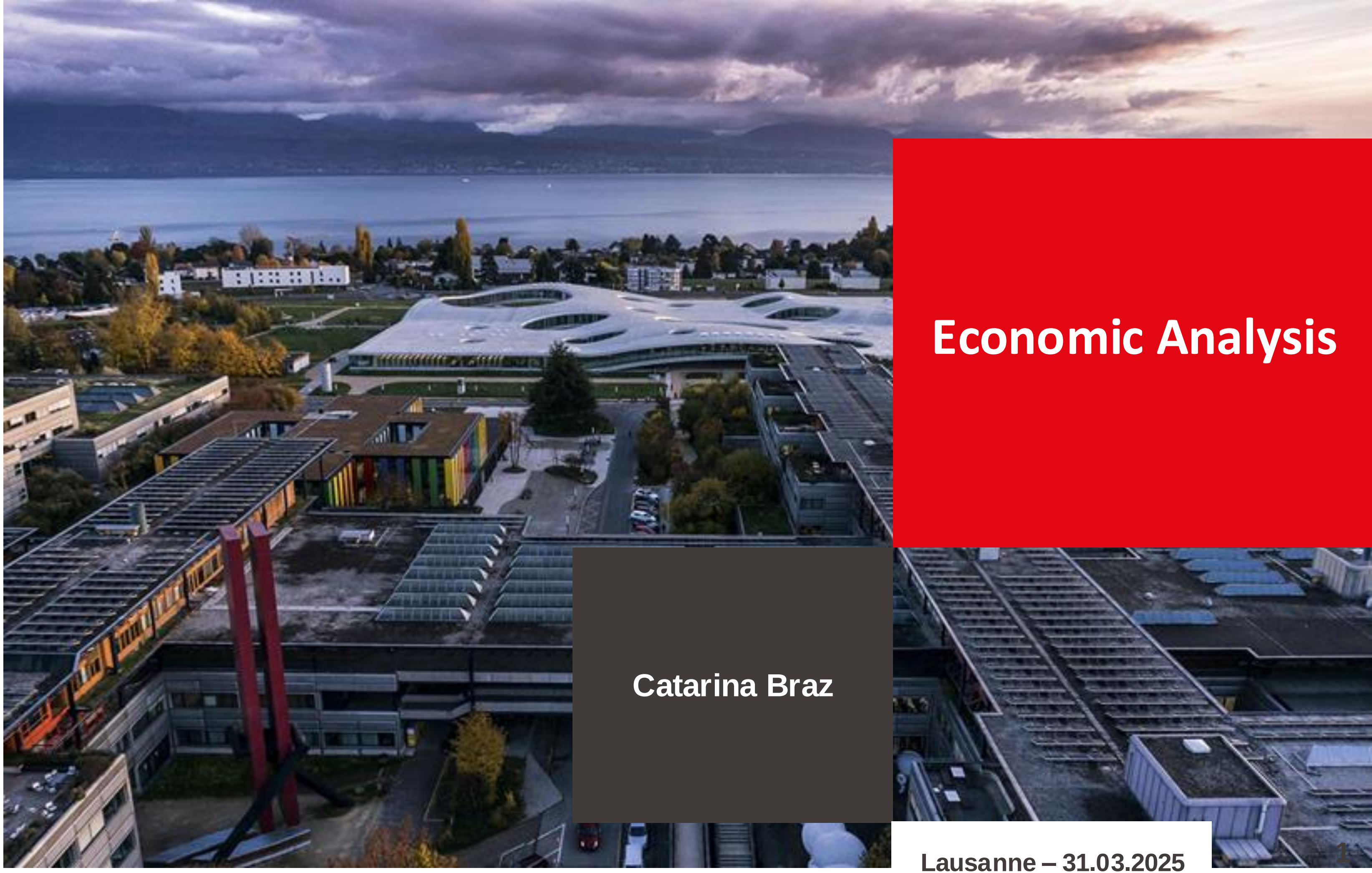


Economic Analysis

Catarina Braz

Lausanne – 31.03.2025

Today's schedule

- 08:30 - 09:00 Quiz 3
- 09:10 - 09:40 (Catarina) Gate 3: Economic analysis
- 09:50 - 10:50 (Arthur) Aspen Tutorial 5: Chemical reactors + Aspen convergence
- 11:00 - 16:00 Teamwork: Gate 2

Gate 3: Economic Evaluation of Projects

Objective: Access financial viability and profitability

Main steps:

1. Identify costs and revenues
   1.1. Estimate capital expenditures (CAPEX)
   1.2. Estimate operating expenditures (OPEX)
   1.3. Estimate revenues
2. Calculate cash flows
3. Calculate discounted cash flows
4. Perform economic analysis

Sources of information:

- G. Towler, R. Sinnott, *Chemical Engineering Design*, 2021, Elsevier Science
- R. Turton, J.A. Shaeiwitz, D. Bhattacharyya, W.B. Whiting, *Analysis, Synthesis, and Design of Chemical Processes*, 2018, Pearson Education

1.1. Estimate capital expenditures (CAPEX)

- Fixed capital cost (FCI): Total cost of designing, constructing and installing a plant and the associated modifications needed to prepare the plant site:

$$FCI = ISBL + OSBL + D\&E + X$$

- $ISBL$: Inside battery limits investment – the cost of the plant itself:
  - Direct field costs: major process equipment (reactors, heat exchangers, etc), bulk items (piping, valves, solvents, catalysts, etc), civil works, installation labour and supervision.
  - Indirect field costs: construction costs (equipment rental, temporary water and power, etc), field expenses and services (canteens, specialists, etc), construction insurance, labour benefits and burdens (social security, workers compensation, etc.), miscellaneous overheads (local taxes, patent fees, etc)
- $OSBL$: Offsite investment – additions that must be made to the site infrastructure
  - Electric main substations, transformers, power generation plants, boilers, cooling towers, etc.
  - 20 – 50 % of $ISBL$
- $D\&E$: Design and engineering
  - Detailed design engineering of process equipment, piping and control systems, civil engineering, construction supervision, administrative charges, etc.
  - 30 % of ($ISBL$+ $OSBL$) for smaller projects, 10 % for larger projects
- X: Contingency charges
  - Changes in prices, currency fluctuations, other unexpected problems
  - minimum 10 % of ($ISBL$+ $OSBL$) can go up to 50 % if the technology is uncertain

1.1. Estimate capital expenditures (CAPEX)

Estimation of equipment cost

- **Most accurate:** current price quote from a suitable vendor
  - Search for manufacturer's catalogue prices
- **Next best:** cost data on previously purchased equipment of the same type
- **When no reliable cost data is available:** use cost correlations from chemical engineering textbooks:

Method 1. *Sinnott, 2020*

$$C_e = a + bS^n$$

C_e = purchased equipment cost on a U.S. Gulf Coast basis, Jan. 2007 (CE index (CEPCI) ¼ 509.7, NF refinery inflation index ¼ 2059.1)

a, b = cost constants

S = capacity or size parameter

n = exponent for that type of equipment

} available in *Sinnott, 2020*

- ✓ Check the validity of the correlations (lower and upper values of S)
- ✓ Prices are all for carbon steel equipment except when noted (use material factors available in Sinnott, 2020)
- ✓ Costs must be updated to current values and converted to international locations

1.1. Estimate capital expenditures (CAPEX)

Method 2. Turton, 2018

$$\log_{10} C_p^0 = K_1 + K_2 \log_{10} A + K_3 (\log_{10} A)^2$$

C_p^0 = cost of the equipment, at ambient operating pressure and using carbon steel construction, May to September of 2001

K_1, K_2, K_3 = cost constants

A = capacity or size parameter for the equipment

- **Correction for pressure and construction material:**
  - Bare Module and Material Factors for Heat Exchangers, Process Vessels, and Pumps

$$C_{BM} = C_p^0 F_{BM} = C_p^0 (B_1 + B_2 F_M F_P)$$

$$\log_{10} F_P = C_1 + C_2 \log_{10} P + C_3 (\log_{10} P)^2$$

C_{BM} = corrected cost

F_{BM} = Bare module cost factor

B_1, B_2 = Bare module constants

F_M, F_P = material and pressure factor

C_1, C_2, C_3 = pressure facture constants

} available in Turton, 2018

P = pressure in bar gauge or barg (1 bar = 0.0 barg)

Correlations for other equipment available in Turton, 2018

- ✓ Check the validity of the correlations (lower and upper values of A)
- ✓ Costs must be updated to current values and converted to international locations

1.1. Estimate capital expenditures (CAPEX)

Cost escalation

- **Effect of capacity on purchased equipment cost:**

$$\frac{C_a}{C_b} = \left(\frac{A_a}{A_b}\right)^n$$

C = Purchased cost

A = equipment cost attribute (size/capacity)

n = Cost exponent (exponents available in Annex I)

a refers to equipment with the required attribute, b refers to equipment with the base attribute

- **Effect of time on purchased equipment cost**
  - The prices of the materials of construction and the costs of labour are subject to inflation
  - Cost indexes are tools used to measure changes in the cost of goods and services over time, tracking the inflation or deflation rates in specific sectors or economies

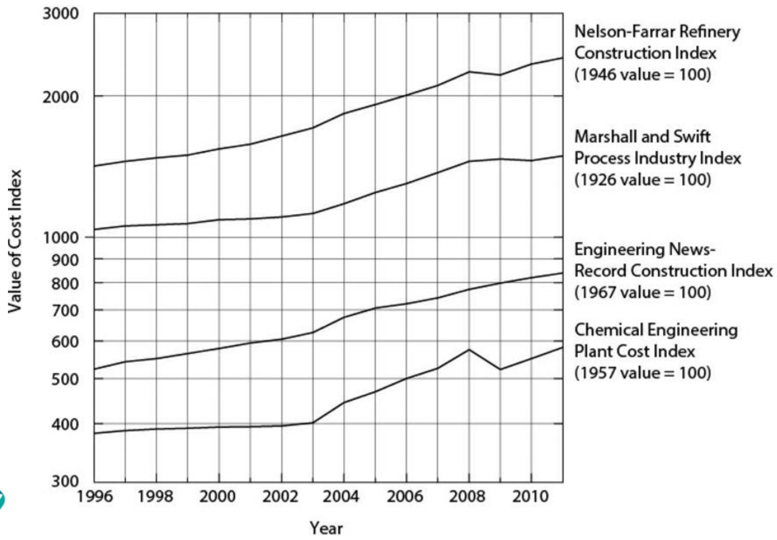
$$\text{Cost in year A} = \text{Cost in year B} \times \frac{\text{Cost index in year A}}{\text{Cost index in year B}}$$

The longer the period over which the correlation is made the more unreliable the estimate.

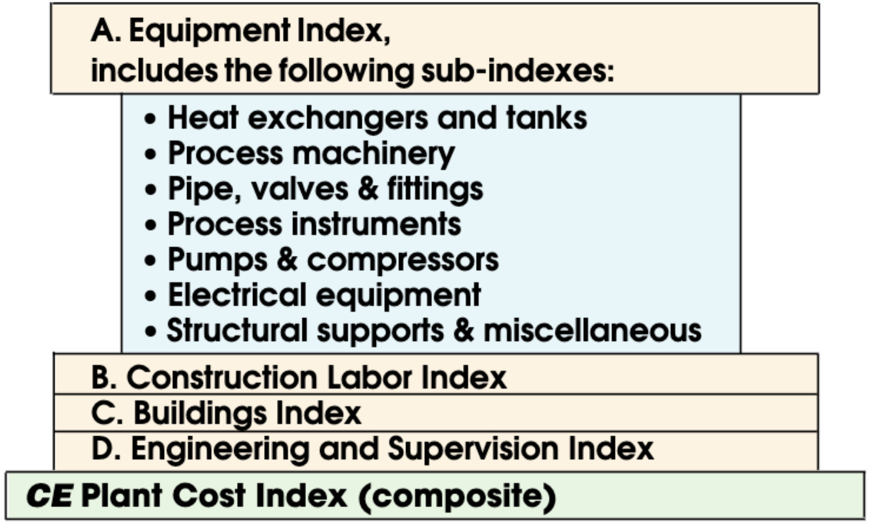
1.1. Estimate capital expenditures (CAPEX)

Cost escalation

- Effect of time on purchased equipment cost



Variations in Several Commonly Used Cost Indexes over a 15-Year Period (1996–2011). Source: R. Turton, J.A. Shaeiwitz, D. Bhattacharyya, W.B. Whiting, Analysis, Synthesis, and Design of Chemical Processes, 2018, Pearson Education



Structure of the CEPCI.
Source: https://www.chemengonline.com/Assets/File/CEPCI_2002.pdf

1.1. Estimate capital expenditures (CAPEX)

Cost escalation

▪ Location factors

Most plant and equipment cost data is given on a U.S. Gulf Coast (USGC) or Northwest Europe (NEW) basis

The cost of building a plant in any other location will depend on:

- Local fabrication and construction infrastructure
- Local labour availability and cost
- Costs of shipping or transporting equipment to site
- Import duties or other local tariffs
- Currency exchange rates, which affect the relative cost of locally purchased items such as bulk materials, when converted to a conventional pricing basis such as Euros or U.S. dollars.

These differences are often captured in cost estimating by using a location factor (LF_A):

$$\text{Cost of plant in location A} = \text{cost of plant on USGC} \times LF_A$$

available in *Sinnott, 2020*

1.1. Estimate capital expenditures (CAPEX)

Calculate $ISBL$: Single factor methods

- $ISBL$ fixed capital cost of a plant is given as a function of the total purchased equipment cost by the equation:

$$C = F \sum C_e$$

C = total plant $ISBL$ capital cost (including engineering costs)

$\sum C_e$ = total delivered cost of all the major equipment items: reactors, tanks, columns, heat exchangers, furnaces, etc

F = an installation factor, widely known as the Lang factor

- $F = 3.1$ for solids processing plant
- $F = 4.74$ for fluids processing plant
- $F = 3.63$ for mixed fluids-solids processing plant

➢ More detailed factorial estimates are also available in G. Towler, R. Sinnott, Chemical Engineering Design, 2021, Elsevier Science

1.1. Estimate capital expenditures (CAPEX)

Determine working capital

- Additional money needed, above what it costs to build the plant, to start the plant up and run it until it starts earning income (15 % of FCI for petrochemical plants), or:

Component	Typicaly estimated as:
Raw material inventory	Two weeks' cost of raw materials
Product and by-product inventory	Two weeks' cost of production
Cash on hand	One week's cost of production
Accounts receivable (products shipped but not yet paid for)	One month's cost of production
Credit for accounts payable – feedstocks, solvents, catalysts, etc. received but not yet paid for	One month's delivered costs
Spare parts inventory	1% to 2% of FCI

Working capital = Seven weeks' cash cost of production minus two weeks' feedstock costs plus 1-2% of the fixed capital investment

1.2. Estimate operating expenditures (OPEX)

- **Variable costs of production:** Costs that are proportional to the plant output or operation rate
  - Raw materials consumed by the process
  - Utilities – fuel burned in process heaters, steam, cooling water, electricity, raw water, instrument air, nitrogen and other services brought in from elsewhere on the site
  - Consumables – solvents, acids, bases, inert materials, corrosion inhibitors, additives, catalysts and adsorbents that require continuous or frequent replacement.
  - Effluent disposal
  - Packaging and shipping – drums, bags, tankers, freight charges, etc.

1.2. Estimate operating expenditures (OPEX)

- **Fixed costs of production:** Costs incurred regardless of the plant operation rate or output. If the plant cuts back its production these costs are not reduced.

Component	Typicaly estimated as:
Operating labour	60 000 $ per shift position per year on a US Gulf Coast basis (Sinnott, 2020)
Supervision	25 % of operating labour
Direct salary overhead (payroll taxes, health insurance, etc)	40 – 60 % of operating labour plus supervision
Maintenace	3 – 5 % of FCI
Property taxes and insurance	1 – 2 % of FCI
Rent of land and/or buildings	1 – 2 % $ISBL$ plus $OSBL$ (if land is bought the cost is added to the FCI)
General plant overhead (Human resources, R&D, etc)	65% of total labour (Operating labour + supervision + direct overhead) plus maintenance
Environmental charges	1 % of $ISBL$ plus $OSBL$
License fees and royalty payments	i.e., those not capitalized at the start of the project
Capital charges	These include interest payments due on any debt or loans used to finance the project, but do not include expected returns on invested equity capital – see slide 18
Sales and marketing costs	In some cases, these are considered part of general plant overhead. They can vary from almost zero for some commodities to millions of dollars a year for branded items such as foods, toiletries, drugs and cosmetics

1.3. Estimate revenues, margins and profits

- **Revenues:** incomes earned from sales of main products and by-products. Determined based on predictions of overall market growth.
- **Margins:** Sum of product and by-product revenues minus raw material costs

$$\text{Gross margin} = \text{Revenues} - \text{Raw materials costs}$$

- **Profits:** The cash cost of production (CCOP) is the sum of the fixed and variable production costs and represents the cost of making product

$$\text{CCOP} = \text{VCOP} + \text{FCOP}$$

Were:

VCOP = sum of all the variable costs of production minus by-product revenues

FCOP = sum of all the fixed costs of production

Gross profit:

$$\text{Gross profit} = \text{Main product revenues} - \text{CCOP}$$

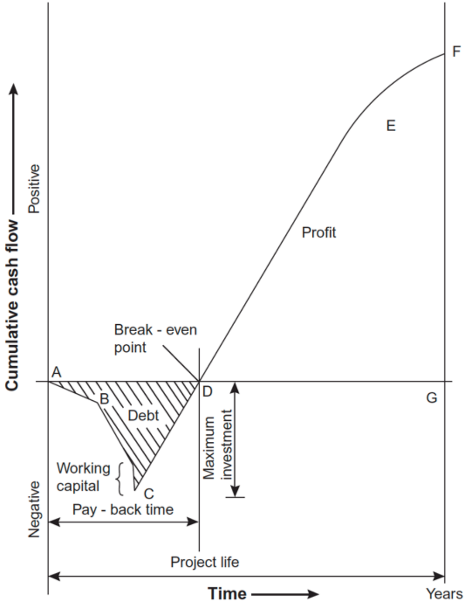
Net profit (or cash flow after tax) is the amount left after taxes are paid:

$$\text{Net profit} = \text{Gross profit} - \text{taxes}$$

➢ Excel template to calculate cost of production from Chemical Engineering Design: link

2. Calculate cash flows

- Cash flows are based on the best estimates of investment, operating costs, sales volume and sales price that can be made for the project



Project cash-flow diagram. Source: G. Towler, R. Sinnott, Chemical Engineering Design, 2021, Elsevier Science

- A–B: Initial investment for plant design.
- B–C: Capital for construction, start-up, and working capital.
- C–D: Net cash flow is positive, but the cumulative amount remains negative until investment repaid, at point D.
- D: Break-even point, marking payback time.
- D–E: Positive cumulative cash flow indicates return on investment.
- E–F: Cash flow may decline toward end of project due to increased costs and falling sales due to obsolescence of the plant. Point F represents final cumulative cash flow

2. Calculate cash flows

2.1. Determine start-up schedule

Example of start-up schedule

Year	Costs	Revenues	Notes
1	30% of fixed capital	0	Engineering + long lead-time items
2	40 – 60% of fixed capital	0	Procurement and construction
3	10 – 30% of FCI + working capital + FCOP + 30% VCOP	30% of design basis revenue	Remaining construction + Initial production
4	FCOP + 50-90% VCOP	50 – 90% of design basis revenue	Shake-down of plant
5+	FCOP + VCOP	100% of design basis revenue	Full production at design rates

2. Calculate cash flows

2.2. Taxes and depreciation

- Profits generated are subject to taxation dependent on the location where production activities take place
- Taxes allowances such as depreciation and/or investment incentives should also be considered when calculating the cash flows from a project

$$CF = P(1 - t_r) + Dt_r$$

CF = after tax cash flow

P = gross profit

D = sum of tax allowances (including depreciation charges)

t_r = rate of taxation

- Depreciation charges can be thought of as an allowance for the "wear and tear, deterioration or obsolescence of the property" because of its use
  - **Straight line depreciation:** The depreciable value, C_d, is depreciated over n years with annual depreciation charge D_i in year i, where:

$$D_i = \frac{C_d}{n}$$

The depreciable value, C_m, of an asset equals the initial cost, C, minus any salvage value after m years. In chemical plants, the salvage value is often taken as zero at the end of operations, as the plants typically continue to operate beyond the depreciable life.

$$C_m = C - \frac{mC_d}{n}$$

Some countries allow for more advantageous depreciation methods. See Chapter 6.5.3 of Sinnott, 2020 for more information

3. Calculate discounted cash flows

3.1. Determine cost of capital: Weighted average of the cost of debt and the cost of equity

- Debt contracts involve paying interest and repaying the principal (either at the end of the loan period or amortized over the period of the loan). Interest payments are a fixed cost.
- Equity capital is invested by shareholders, who expect returns through dividends or stock growth. Return expectation is expressed as the cost of equity, typically 25-30% in EU and US (*Sinnott, 2020*)

$$i_c = DR \times i_d + (1 - DR) i_e$$

i_c = cost of capital

DR = debt ratio

i_d = interest rate due on debt (cost of debt)

i_e = cost of equity

- The overall cost of capital sets the interest rate that is used in economic evaluation of projects.

3. Calculate discounted cash flows

3.2. Time value of money:

- Method of valuing an investment by discounting all its expected future cash flows back to the present using a discount rate.
- Allows for the comparison of the present value of these cash flows to the initial investment or other investment opportunities.

$$\text{Present value of Cash flow in year } n = \frac{CF_n}{(1+i)^n}$$

CF_n = Cash flow in year n

i = discount rate, typically the cost of capital

4. Perform economic analysis

- **Net present value (NPV):** Cumulative discounted cash position at the end of the project
  - A negative NPV means that the project is not financially justified

$$NPV = \sum_{n=1}^{n=t} \frac{CF_n}{(1+i)^n}$$

- **Internal rate of return (IRR):** discount rate that would result in a NPV of zero
  - Measure of the maximum interest rate that the project could pay and still break even by the end of the project life
  - If the IRR is greater than the organization's required rate of return, the project is viable.

$$\sum_{n=1}^{n=t} \frac{CF_n}{(1+IRR)^n} = 0$$

4. Perform economic analysis

- **Payback time:** time it takes for an investor to recover its initial investment through generated cash flows

$$\text{simple payback time} = \frac{\text{total investment}}{\text{average annual cash flow}}$$

  - The simple payback time neglects taxes and depreciation

- **Return on investment (ROI):** measure of the efficiency of an investment

$$\text{ROI} = \frac{\text{net annual profit}}{\text{total investment}} \times 100$$

  - If ROI is calculated as an average over the whole project:

$$\text{ROI} = \frac{\text{cumulative net profit}}{\text{plant life} \times \text{initial investment}} \times 100$$

4. Perform economic analysis

Company Name	Project Name	Adipic acid from phenol
Address	Project Number	Sheet 1

REV	DATE	BY	APVD	REV	DATE	BY	APVD
1	1.1.07	GPT					

ECONOMIC ANALYSIS
Adipic Acid from Phenol

Form XXXXX-YY-ZZ

Owner's Name		Capital Cost Basis Year	2006	
Plant Location	Northeast Asia	Units	Metric	
Case Description		On Stream	8,000 hr/yr	333.33 day/yr

REVENUES AND PRODUCTION COSTS

	$MM/yr
Main product revenue	560.0
Byproduct revenue	4.4
Raw materials cost	410.8
Utilities cost	47.3
Consumables cost	13.1
VCOP	466.8
Salary and overheads	16.4
Maintenance	10.8
Interest	3.6
Royalties	3.0
FCOP	33.8

CAPITAL COSTS

	$MM
ISBL Capital Cost	206.5
OSBL Capital Cost	82.6
Engineering Costs	28.9
Contingency	43.4
Total Fixed Capital Cost	361.3
Working Capital	59.5

CONSTRUCTION SCHEDULE

Year	% FC	% WC	% FCOP	% VCOP
1	30%	0%	0%	0%
2	70%	0%	0%	0%
3	0%	100%	100%	50%
4	0%	0%	100%	100%
5	0%	0%	100%	100%
6	0%	0%	100%	100%
7+	0%	0%	100%	100%

ECONOMIC ASSUMPTIONS

Cost of equity	25%	Debt ratio	0.5	Tax rate	35%
Cost of debt	5%			Depreciation method	Straight-line
Cost of capital	15.0%			Depreciation period	10 years

CASH FLOW ANALYSIS

All figures in $MM unless indicated

Project year	Cap Ex	Revenue	CCOP	Gr. Profit	Deprcn	Taxbl Inc	Tax Paid	Cash Flow	PV of CF	NPV
1	108.4	0.0	0.0	0.0	0.0	0.0	0.0	-108.4	-94.3	-94.3
2	252.9	0.0	0.0	0.0	0.0	0.0	0.0	-252.9	-191.2	-285.5
3	59.5	280.0	267.2	12.8	36.1	-23.3	0.0	-46.7	-30.7	-316.2
4	0.0	560.0	500.6	59.4	36.1	23.3	0.0	59.4	34.0	-282.2
5	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	25.5	-256.8
6	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	22.2	-234.6
7	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	19.3	-215.3
8	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	16.8	-198.6
9	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	14.6	-184.0
10	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	12.7	-171.3
11	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	11.0	-160.3
12	0.0	560.0	500.6	59.4	36.1	23.3	8.1	51.3	9.6	-150.7
13	0.0	560.0	500.6	59.4	0.0	59.4	8.1	51.3	8.3	-142.4
14	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	5.5	-136.9
15	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	4.7	-132.2
16	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	4.1	-128.1
17	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	3.6	-124.5
18	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	3.1	-121.4
19	0.0	560.0	500.6	59.4	0.0	59.4	20.8	38.6	2.7	-118.7
20	-59.5	560.0	500.6	59.4	0.0	59.4	20.8	98.1	6.0	-112.7

ECONOMIC ANALYSIS

Average cash flow	44.7 $MM/yr	NPV	10 years	-171.3 $MM	IRR	10 years	-2.0%
Simple pay-back period	9.4 yrs		15 years	-132.2 $MM		15 years	5.6%
Return on investment (10 yrs)	3.32%		20 years	-112.7 $MM		20 years	8.4%
Return on investment (15 yrs)	5.77%	NPV to yr	19	-118.7 $MM			

➢ Excel template to perform the economic analysis from Chemical Engineering Design: link

EPFL

Thank you!

Catarina Braz

Annex I

Chemical Engineers' Handbook, Perry, R.H., Green, D.W., and Maloney, J.O. (eds.), 7th ed., 1997

TABLE 9-50 Typical Exponents for Equipment Cost versus Capacity

Equipment	Size	Unit	Approximate cost, $000	Size range	Exponent
Agitator, turbine, top entry, open, FOB	10 (7.5)	hp (kW)	7.0	2–30 (1.5–22.4)	0.45
Agitator, turbine, top entry, closed, FOB	10 (7.5)	hp (kW)	10.7	2–200 (1.5–150)	0.56
Blower, centrifugal, 4 lbf/in² (27.6 kN/m²), DEL, excluding motor	10 (4.72)	10^3 sft³/min (sm³/s)	67	0.5–150 (0.24–71)	0.60
Cone crusher, FOB, crusher only	100 (74.6)	hp (kW)	130	30–300 (22.4–224)	0.92
Jaw crusher, FOB, excluding motor	10 (7.5)	hp (kW)	34	1–60 (0.75–44.7)	0.65
Jaw crusher, FOB, excluding motor	100 (74.6)	hp (kW)	284	60–400 (44.7–300)	0.81
Centrifugal pump, C/S, FOB, excluding motor	10 (7.5)	hp (kW)	1.6	0.5–40 (0.37–30)	0.30
Centrifugal pump, C/S, FOB, excluding motor	100 (74.6)	hp (kW)	4.4	40–400 (30–300)	0.67
Conveyor, belt, C/S, FOB, excluding motor	100 (9.3)	ft² (m²)	6.7	60–200 (5.6–18.6)	0.50
Conveyor, screw, C/S, DEL, excluding motor	70 (540)	ft × m diameter (m × mm diameter)	10	50–100 (390–780)	0.46
Centrifuge, automatic batch, horizontal, C/S, FOB	20 (1.86)	Filter area, ft² (m²)	100	7–80 (0.65–7.43)	0.65
Compressor, reciprocating, <1000 lbf/in², FOB, including motor	300 (224)	hp (kW)	133	1–20000 (0.75–1490)	0.84
Crystallizer, forced circulation, C/S, FOB	100 (91)	ton/day (Mg/day)	283	10–1000 (9.1–970)	0.59
Dryer, drum, C/S, FOB, excluding motor	100 (9.3)	ft² (m²)	73	10–400 (0.9–37)	0.52
Dryer, vacuum, shelf, C/S, FOB, excluding trays, vacuum equipment	100 (9.3)	ft² (m²)	17	15–1000 (1.4–93)	0.56
Dust collector, cloth, shaker type, FOB, including motors	10^4 (4.7)	sft³/min (m³/s)	17	10^3–5 × 10^4 (0.47–23.6)	0.79
Dust collector, multicyclones, FOB	10^4 (4.7)	sft³/min (m³/s)	7	10^3–1.5 × 10^5 (0.47–70.8)	0.66
	10^4 (4.7)	ft³/min at 40°C (m³/s)	77	10^3–8 × 10^4 (0.47–73.8)	0.39
Electrostatic precipitator, FOB	2 × 10^5 (94)		383	8 × 10^4–10^6 (37.8–472)	0.81
Ejector, single-stage, 100 psig, steam, FOB	3 (10^{-2})	lb/h (air/mmHg absolute)	2.7	0.2–30 (6.8 × 10^{-4}–0.1)	0.50
Ejector, two-stage, FOB, including condenser, piping	1 (3.4 × 10^{-3})	[kg/h/(N/m²)]	6.3	0.2–10 (6.8 × 10^{-4}–3.4 × 10^{-2})	0.43
Ejector, multistage, FOB, including condenser, piping	10 (3.4 × 10^{-2})	[kg/h/(N/m²)]	16.7	0.2–100 (6.8 × 10^{-4}–0.34)	0.26
Filter, vertical-pressure leaf, C/S, DEL	100 (9.3)	ft² (m²)	17	30–1500 (2.8–140)	0.57
Filter, plate and frame, C/S, DEL	100 (9.3)	ft² (m²)	5.7	10–1000 (0.9–93)	0.55
Filter, vacuum rotary drum, C/S, FOB, including motor	100 (9.3)	ft² (m²)	63.3	10–1500 (0.9–140)	0.48
Heat exchanger, shell-tube, floating head, C/S, DEL; fixed tube × 0.85; U tube × 0.87; kettle × 1.35	1000 (93)	ft² (m²)	21.7	20–20000 (1.9–1860)	0.59
Heat exchanger, thermal screw, C/S, FOB, excluding motor	100 (9.3)	ft² (m²)	33	10–400 (0.9–37)	0.78
Kettle, jacketed, glass-lined, FOB	100 (0.38)	U.S. gal (m³)	53	50–1000 (0.2–3.8)	0.48
Motors, ac induction, wound rotor, TEFC, FOB	10 (7.5)	hp (kW)	12.3	10–25 (7.5–18.6)	0.56
Motors, ac induction, wound rotor, TEFC, FOB	70 (52)	hp (kW)	19.3	25–200 (18.6–149)	0.77
Piping, typical straight run, C/S, FOB, $/ft					
Installed: $/ft × 6 to 7	6 (152)	Nominal diameter in (mm)	0.0093	1–24 (25–610)	1.33
Complex network: FOB $/ft × 2					
Installed: $/ft × 13					
Pressure vessel horizontal drum (150 psig), C/S	1000 (3.8)	U.S. gal (m³)	6.3	100–80000 (0.4–302)	0.62
Jacketed reactors, including mixer, FOB	100 (0.38)	U.S. gal (m³)	9.3	10–4000 (0.04–15.1)	0.53
Refrigeration, packaged mechanical, INST	100 (351.7)	U.S. tons (kW)	133	10–1000 (35.2–3520)	0.73
Screen, vibrating, single-deck, DEL, including motor	500 (46)	ft² (m²)	10	150–700 (14–65)	0.62
Stack, carbon steel		ft (m)	—	20–150 (6.1–45.7)	1.00
Tanks: atm, horizontal cylinder, C/S, FOB	1000 (3.8)	U.S. gal (m³)	4.7	100–40000 (0.4–151)	0.57
Vertical cylinder, C/S, FOB	1000 (3.8)	U.S. gal (m³)	3.3	100–20000 (0.4–76)	0.30
Vertical jacketed, C/S, FOB	1000 (3.8)	U.S. gal (m³)	15	70–1500 (0.26–5.7)	0.57
Vertical agitated, C/S, FOB, including motor	1000 (3.8)	U.S. gal (m³)	12.3	100–20000 (0.4–76)	0.50
Towers, distillation including internals, INST	4000 (trays)	$\left(\frac{\text{feed, lb/year}}{10^6}\right)^{0.65}$	3300	300–30000	1.00

NOTE: All costs are North American values with M & S = 1000.