TEQIP-III Short Course on Systems Analysis of Biofuels and Bioproducts

Module 3: Techno-Economic Analysis

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1

Goals of this Lecture

Introduce the Techno-Economic Analysis

Learning Objectives

By the end of this lecture, you must be able to:

1. Able to perform basic techno-economic analysis using Excel
2. Develop familiarity with SuperPro for performing TEA analysis

2

Techno-Economic Analysis

- ***"what are the energetic, economic and environmental benefits associated with this technology?"***
- The TEA is used to
  - assess the technical and economic viability of a process, and
  - identify the optimal unit processes and performance conditions

  considering ***both*** technical and economic factors.

3

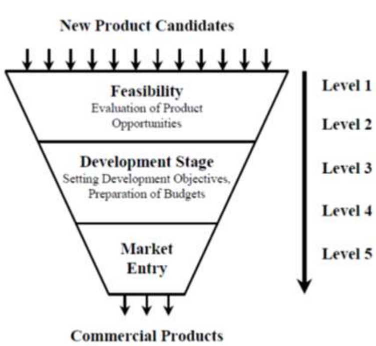
Techno-Economic Analysis

Which Estimate?

1. Order of magnitude estimate: ±10 to 50% accuracy
2. Study estimate (factored estimate): ±30%
3. Preliminary estimate (budget authorization estimate): ±20%
4. Definitive estimate (project control estimate): ±10%
5. Detailed estimate (firm or contractor's estimate): ±5%

4

Techno-Economic Analysis



5

Techno-Economic Analysis

Basic Steps

Step 1: Base design.
Step 2: Material and energy balances.
Step 3: Optimization requirements in the process
Step 4: Direct costs estimation.
Step 5: Indirect cost estimation.
Step 6: Fixed capital expenses.
Step 7: Operational expenses.
Step 8: Cash flow analysis.

6

Techno-Economic Analysis

Basic Steps

Step 4: Direct costs estimation.

Purchase Equipment Cost (PEC)

Estimate the cost:

$$\text{New Cost} = \text{Original Cost}\left(\frac{\text{New Size}^*}{\text{Original Size}^*}\right)^{\text{exp}}$$

- Or characteristic linearly related to the size

exp range is from 0.6-0.7.

7

Techno-Economic Analysis

Basic Steps

Step 4: Direct costs estimation.

Purchase Equipment Cost (PEC)

Adjust the cost for current time using one of the cost indexes

Year	MSI (1926=100)	CEPCI (1958-59=100)	CPI (1982=100)
1990	915.1	357.6	135.44
1995	1,027.5	381.1	157.93
2000	1,089.0	394.1	178.45
2005	1,260.9	468.2	202.38
2010	1,457.4	550.8	225.96
2015	1,598.1	556.8	237.017
2018	1,638.2	603.1	251.07
2019	---	607.5	255.657

8

Techno-Economic Analysis

Step 4: Direct costs estimation: Equipment Sizing

Problem: A fermenter of 2,525 m3 volume costs $450,000 in 2007. What would a fermenter of 3,500 m3 volume cost in 2013? Use a power law coefficient of 0.66 for sizing.

Solution

Given data:

A fermenter with a 2,525 m3 volume costs $450,000 in 2007.

Power law coefficient: 0.66

1$ in 2007 = $1.12 in 2013 [Using the consumer price index (CPI)

Inflation calculator: http://www.bls.gov/data/inflation_calculator.htm]

Calculations:

Fermenter_3500 (in 2007 $) =$450,000 ⟦(3,500/2525)⟧^0.66=$558,219

Fermenter_3500(in 2013 $)=$558,219 x 1.12= $625,206 ~ $625,000

Answer: A 3,500 m3 volume fermenter will cost an estimated $625,000 in 2013.

9

Techno-Economic Analysis

Basic Steps

Step 4: Direct costs estimation:

Purchases Equipment cost, PEC

Direct capital costs, DC= PEC x (combined lang factor or sum of individual lang factors for each type of costs such as installation)

Indirect Capital Costs, IDC= Direct Capital costs x indirect cost factor

Fixed capital expenses, FCE= DC+IDC

10

Techno-Economic Analysis

Basic Steps

Step 4: Direct costs estimation: Lang factors

Direct Costs	
Purchased Equipment Costs (PEC)	15-40% of the fixed capital expenses
Installation	25-55% of PEC
Instrumentation	6-30% of PEC
Piping	10-80% of PEC
Electrical	10-40% of PEC
Land and buildings (new site)	10-80% of PEC
Site preparation and yard improvement	8-20% of PEC
Utilities and other services	30-80% of PEC
Indirect Costs	
Engineering and Supervision	15-30% of PEC
Contractors fee	2-8% of PEC
Contingency	5-15% of PEC
Startup expenses	8-10% of PEC

The factors can be obtained from handbooks (Perry and Green, 1998; RSMeans, 2009; Westney, 1997), textbooks (Peters and Timmerhaus, 1991) or expert opinion.

11

Techno-Economic Analysis

Basic Steps

Step 5: Indirect cost estimation.

Indirect costs refer to costs such as contractor fees, engineering costs and contingency cost. These costs are typically specified as a percentage of the direct costs.

Step 6: Fixed capital expenses.

Fixed capital expenses are calculated as the sum of the direct and indirect costs for the plant. Often it is convenient to refer to total fixed capital expenses in terms of investment per installed capacity (CAPEX) when comparing similar size plants with different installed technologies.

12

Techno-Economic Analysis

Basic Steps

Step 7: Operational Expenses (OPEX).

- Fixed operational expenses (Facility dependent costs)
  - Interest on loans
  - Depreciation
  - Local taxes
  - Insurance
- Variable operational expenses
  - Raw material costs
  - Utilities
  - Labor costs
  - Consumables
  - Waste product disposal
  - Regular maintenance
  - Royalties, Product advertising

13

Techno-Economic Analysis

Basic Steps

Step 8: Cash Flow Analysis

- Expected production
- Expected sales and revenues
- Net cash flow (for a given year)=Revenue-Costs

14

Economic Viability

- Return on Investment
- Net present value,

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

- Internal rate of return (r)

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

Where, C_n refers to the cash flow during the year n, for a total of N years. Discount rate is i.

- Payback period :

$$\text{Payback period} = n^- + \frac{S_{n^-}}{S_{n^-+1}}$$

Where, n^- is the last period with a negative cumulative cash flow, S_{n^-} is the cumulative cash flow at the end of the time period n^- and S_{n^-+1} is the cumulative cash flow for the time period $n^- + 1$.

15

Economic Viability: Example

A 50,000 ton/year biodiesel plant that has an estimated fixed capital investment of \$9.3 million. The simplified reaction for biodiesel production can be represented by:

$C_{57}H_{104}O_6$ (Triolein) + 3 CH_3OH (Methanol)→ 3 $C_{19}H_{36}O_2$ (Biodiesel) + $C_3H_8O_3$ (Glycerol)

885.43 kg (Triolein) + 96.12 kg (Methanol)→ 889.5 kg (Biodiesel) + 92.1 kg (Glycerol)

Calculate the unit production cost of biodiesel at 100% efficiency of the overall process.

Data for this problem were obtained from (Apostolakou et al., 2009).

Given Data

Inputs: Rapeseed oil @ \$1,100/ton; methanol @ \$300/ton, NaOH and HCL (catalysts) @\$8.26/ton biodiesel. Assume crude glycerol prices at \$100/ton.

Utilities: Heating (as high pressure and low pressure steam) 1.4 GJ/ton biodiesel @ \$10/GJ and electricity 30kWh/ton biodiesel @ \$0.15/kWh.

Labor costs: 15 operators @ \$40,000/year-person + overhead costs (insurance, supervision, laboratory costs) of \$36,000/year-person.

Other costs (miscellaneous materials, maintenance, capital charges, insurance, taxes and others): 20% of the fixed capital expenses (FCE). Assume overheads as 5% of the direct costs.

16

Economic Viability: Example

Solution

For one metric tonne (t) of biodiesel: 0.995 t Rapeseed oil, 0.1081 t methanol are required and 0.1035 t of glycerol is produced as a coproduct.

Yearly cost calculation

$$\text{Variable costs} = \text{Raw materials} + \text{Utilities}$$
$$= 50{,}000(0.995 \times \$1100 + 0.1081 \times \$300 + \$8.26) + 50{,}000(1.4 \times \$10 + 30 \times \$0.15)$$
$$= \$\frac{57{,}684{,}500}{\text{yr}}$$
$$\text{Fixed costs} = \text{Operating labor costs} + \text{Other fixed costs}$$
$$= 15 \times (\$40{,}000 + \$36{,}000) + \$9{,}400{,}000 \times 0.2 = \frac{\$3{,}020{,}000}{\text{yr}}$$
$$\text{Direct production costs} = \text{Variable costs} + \text{Fixed costs} = \frac{\$60{,}704{,}500}{\text{yr}}$$
$$\text{Annual production cost} = \text{Direct costs} + \text{General overheads} = \$60{,}704{,}500 \times 1.05 = \$63{,}739{,}725$$
$$\text{Coproduct revenue} = 50{,}000 \times 0.1035 \times \$100 = \$517{,}500/\text{yr}$$
$$\text{Net production cost} = \text{Annual production cost} - \text{Coproduct Revenue} = \$63{,}222{,}225$$
$$\text{Unit production cost} = \frac{\text{Net production cost}}{\text{Yearly output}} = \frac{\$63{,}222{,}225/yr}{50{,}000\ t/yr} = \$\mathbf{1{,}264.4}\ \textbf{/t biodiesel}$$

Therefore the unit production cost of biodiesel is \$1,264.4/t of biodiesel (or \$1.103/L biodiesel using a density of 872.5 kg/m^3 for biodiesel).

17

Economic Viability: Example

Cash flow analysis for ethanol plant (all numbers in millions $)

Given data			Calculated data			
Year	Expenses	Revenues	Net cash flow	Cumulative cash flow	IRR calculation	NPV calculation
0	23.4	0	-23.4	-23.4	-23.40	-23.40
1	31.2	0	-31.2	-54.6	-27.48	-28.36
2	23.4	0	-23.4	-78	-18.16	-19.34
3	109	119	10	-68	6.83	7.51
4	109	119	10	-58	6.02	6.83
5	109	119	10	-48	5.30	6.21
6	109	119	10	-38	4.67	5.64
7	109	119	10	-28	4.11	5.13
8	109	119	10	-18	3.62	4.67
9	109	119	10	-8	3.19	4.24
10	109	119	10	2	2.81	3.86
11	109	119	10	12	2.48	3.50
12	109	119	10	22	2.18	3.19
13	95	119	24	46	4.61	6.95
14	95	119	24	70	4.06	6.32
15	95	119	24	94	3.58	5.75
16	95	119	24	118	3.15	5.22
17	95	119	24	142	2.78	4.75
18	95	119	24	166	2.44	4.32
19	95	119	24	190	2.15	3.92
20	95	119	24	214	1.90	3.57
21	95	119	24	238	1.67	3.24
22	95	119	24	262	1.47	2.95
				Total NPV	0.00	26.67
				Rate	0.135	0.1

Payback period, P = 9 + (|-8|/10) =9.8 yr.

IRR = 0.135 corresponding to the total NPV of 0.

Total NPV with a discount rate of 10% is \$26.67 million.

18

Economic Viability: Example

You are an engineer in a corn ethanol plant (producing 200 million L ethanol/year and 239,180 metric tons DDGS/year) who has to make a decision about installing a new dryer for DDGS. There are two alternatives both of which have a life of 15 years: A first generation natural gas based dryer with an overall efficiency of 83% and an improved design with 85% efficiency. However the improved design dryer costs $1.5 million more than the first generation dryer. Assume that 2 kg water/kg DDGS are evaporated, and natural gas prices are $0.003788/MJ. Latent heat of evaporation of water is 2.27 MJ/kg. Which of the two dryers would you recommend?

19

Economic Viability: Example

Solution

Given data and assumptions:

- Annual DDGS production: 239,180 ton (dry wt.)
- Water evaporation requirements and latent heat: 2 kg/kg DDGS and 2.26MJ/kg water, respectively
- Efficiencies of conventional and improved dryer: 83 and 85%, respectively
- Capital cost difference between dryers: $1.5 million
- Life of dryers: 15 years
- Natural gas price: $0.003788/MJ ($4/MMBtu)
- Annul loan interest and discount rates: 8 and 5%, respectively

$$\text{Quantity of water to be evaporated} = 239{,}180 \text{ metric ton DDGS} \times 2\ {}^{\text{kg}}/_{\text{kg DDGS}} = 478{,}360$$

$$\text{Heat energy required to evaporate above quantity of water} = 478{,}360 \times 1000 \times 2.26 \text{ MJ}$$

$$\text{Savings in energy} = 478{,}360 \times 1000 \times 2.26 \times ({}^{1}/_{0.83} - {}^{1}/_{0.85}) \text{ MJ} = 30{,}647{,}586 \text{ MJ}$$

$$\text{Economic value of energy savings} = 30{,}647{,}586 \text{ MJ} \times \$0.003788/\text{MJ} = \$116{,}093$$

$$\text{Annual interest for the loan} = 1{,}500{,}000 \times 0.08 = \$120{,}000$$

$$\text{Total annual savings} = \$116{,}093 - \$120{,}000 = -\$3{,}907$$

$$\text{Net present value (NPV) of the annual savings } (-\$3{,}907/\text{yr over 15 yr} = -\$40{,}443$$

NPV of total investment = $-\$40{,}443 - \$1{,}500{,}000 = -1{,}540{,}443 < 0$

Answer: *Since NPV < 0, this implies that an investment of additional $1.5 million in the new dryer with 5% higher efficiency has worse economic returns therefore must NOT be selected over the conventional dryer.*

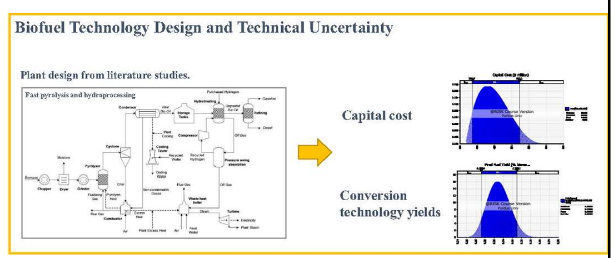
20

Sensitivity and Uncertainty Analysis

- Difference between Uncertainty and sensitivity analysis
- How should we perform sensitivity analysis?
  - Changing the model input and parameter values
- Various Types of Uncertainties
  - Inherent randomness (aleatory uncertainty)
  - Measurement error
  - Systematic error
  - Natural variation
  - Model uncertainty
  - Subjective judgement
- What is Monte-Carlo Analysis?

21

Stochastic methods used in TEA



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22

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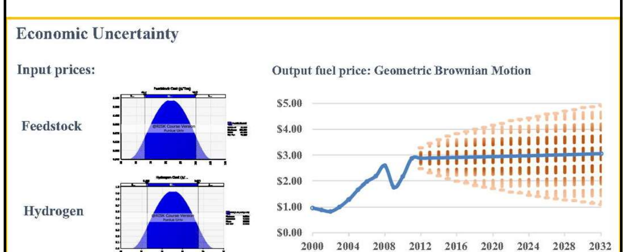

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23

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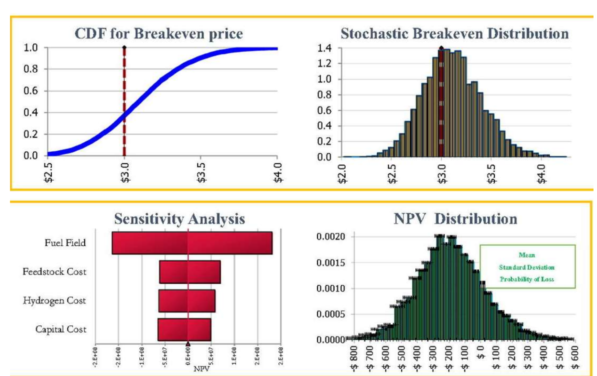

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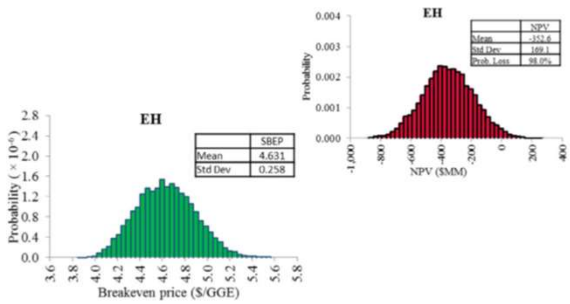
24

Newer methods used in TEA

- Stochastic TEA Methods



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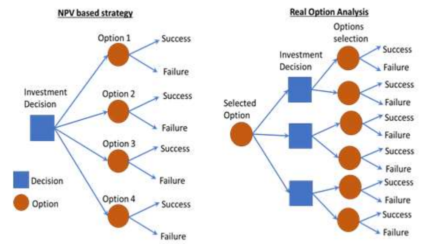
25

Real Options Analysis

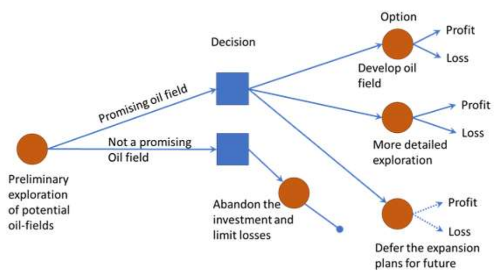
- Real Options are "the right but not the obligation to acquire, expand, contract, abandon or switch some or all of an economic asset on fixed terms on or before the time the opportunity ceases to be available"



26

Real Options Analysis

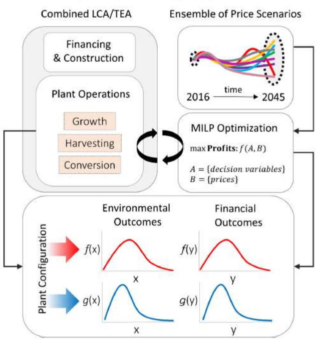
- Real Options Example for oil field development:



27

Real Options Analysis

Real Options framework for algal biofuel production facility design



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28

Real Options Analysis

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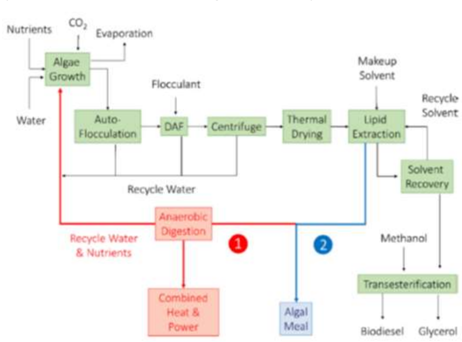

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29

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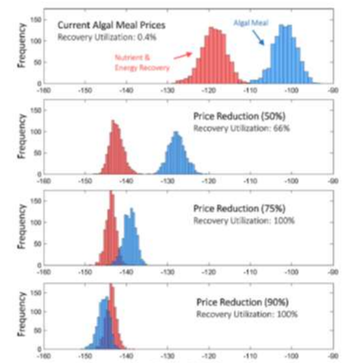

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30

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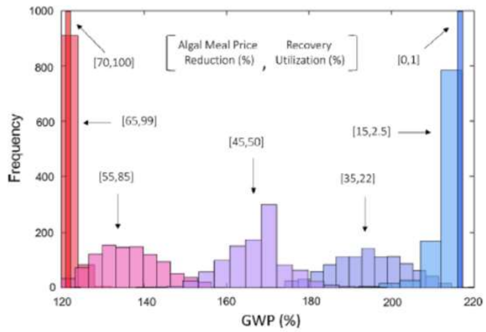

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31

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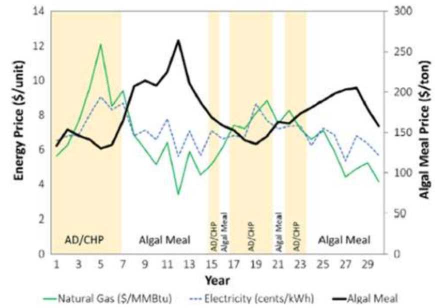

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32

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33

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THANK YOU

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34