Life Cycle Costing

- Engineering economy is the application of economic factors and criteria to evaluate alternatives, considering the time value of money.
- The engineering economy study involves computing a specific economic measure of worth for estimated cash flows over a specific period of time.
- The terms interest, interest period and interest rate are useful in calculating equivalent sums of money for an interest period. Interest is the manifestation of the time value of money.

Simple Interest

- Simple interest is calculated using the principal only, ignoring any interest accrued in preceding interest periods.
- The total simple interest over several periods is computed as:

Simple Interest = (Principal)x(Number of Periods)x(Interest Rate)

- Here the interest rate is expressed in decimal form. The total sum accrued at the end of n interest periods is given by:

$$S = P(1 + n \cdot i)$$

S = Sum accrued at the end of interest periods (also called Future Worth)

P = Principal (also called Present Worth)

n = Number of interest periods (normally one year is taken as one interest period)

i = Interest rate (normally annual interest rate)

Compound Interest

- For compound interest, the interest accrued for each interest period is calculated on the principal plus the total amount of interest accumulated in all previous periods.
- Compound interest reflects the effect of the time value of money on the interest also. The interest for one period is calculated as:

Compound Interest =(Principal + All accrued Interest)x (Interest Rate)

- *The total sum accrued after a number of interest periods can be calculated from the following expression:*

$$S_n = P(1+i)^n$$

S_n *= Sum accrued at the end of n interest periods*

P = Principal

i = Interest rate expressed in decimal form (annual interest rate)

n = Number of interest periods (number of years)

Compound Interest-1

- We can see from the above two expressions that the sum accrued at the end of first year would be same for both simple interest and compound interest calculations .
- However, for interest periods greater than one year, the sum accrued for compound interest would be larger.
- What happens if the interest is compounded more than once in a year?
- We need to modify equation (2) and is given by:

$$S_n = P\left(1 + \frac{i}{m}\right)^{nm}$$

Compound Interest-2

- m = Number of periods the interest is compounded in one year
- i = Annual interest rate in decimal form
- n = Number of years

We can extend equation (3) to calculate the sum accrued if the interest is compounded continuously. Here m tends to ∞. Taking the limits such that m goes to infinity, we get the following expression:

$$S = P \cdot e^{in}$$

- For all practical purposes, equation (2) is used for interest calculations and repeated here for convenience:

$$S_n = P(1+i)^n$$

Compound Interest-3

Here,

- S_n = Future Worth of money .
- P = Present Worth of the money.
- (1+i)n = Future Worth Factor.

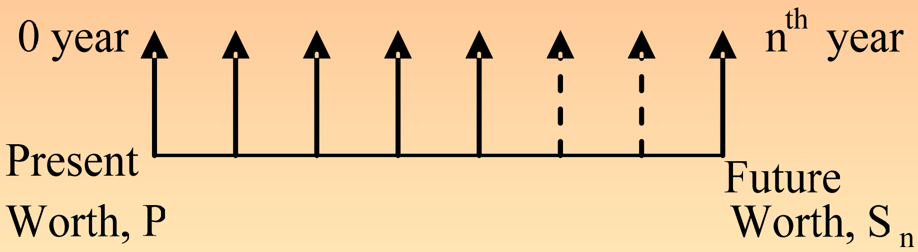
Given the present worth, annual interest rate and number of years, we can calculate the future worth.

- There may be situations when the future worth of money is given and we need to find the present worth of the money.
- The above equation can be re-arranged to calculate the present worth, given by:

$$P = \frac{S_n}{(1+i)^n}$$ Here, $\frac{1}{(1+i)^n}$ = Present Worth Factor

Compound Interest-4

- To carry out calculations, it is convenient to draw what is called as cash flow diagram.
- The following figure gives one such cash flow diagram:



- The cash flow diagram helps in analyzing the problem better.

Equations (2) and (5) are used in problems concerning single payment.

In today's world we deal with problems that involve annual/monthly equal payments such as home mortgage payments, vehicle loans or loans for consumer electronic goods.

Compound Interest-5

- The following relationships hold good for problems involving such uniform series:

$$P = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)$$

P = Present worth

A = Uniform Annual amount (installments)

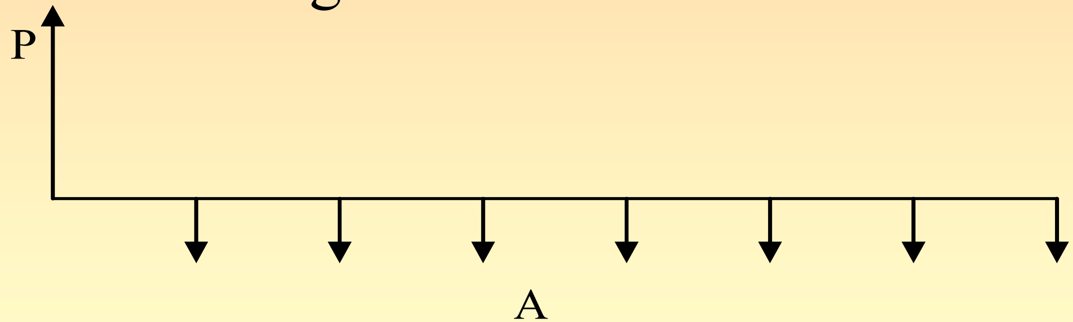
$$S_n = A\left(\frac{\left((1+i)^n - 1\right)}{i}\right)$$

S_n = Future worth

From these equations, we can calculate present worth or future worth given uniform annual amounts

Compound Interest-6

- We can also calculate the uniform annual amounts given either present worth or the future worth.
- A typical example would be person borrowing money from a financial institute for buying a vehicle.
- Knowing the interest rate and number of installments, the person can calculate the uniform equal amounts he or she has to pay depending on the amount borrowed.
- A typical cash flow diagram would look as follows:



- The up-arrow indicates the amount 'coming in' such as borrowing and the down arrow indicates the amount 'going out' such re-payments towards the borrowing.

Inflation

- In all the above equations, we had assumed that there is no inflation .
- Inflation is an increase in the amount of money necessary to obtain the same amount of product before the inflated price was present.
- Inflation occurs due to downward change in the value of the currency.
- If ‘C’ is the cash in hand today for buying a product, f is the inflation rate, then the amount we need to pay for the same product after n years would be $C(1 + f)^n$, assuming uniform inflation over the years.
- The present worth of such money with interest component added is given by:

Inflation-1

$$P_f = C \cdot \frac{(1+f)^n}{(1+i)^n}$$

P_f = Present worth with inflation taken into account.

If i = f, no change in worth, year after year.

If i > f, save and do not buy the product now.

If i < f, buy the product now and do not save.

- An important relationship between the present worth and the uniform annual amount taking inflation into account is given by the following equation:

$$P = A \cdot \left(\frac{1+f}{i-f}\right) \cdot \left[1 - \left(\frac{1+f}{1+i}\right)^n\right]$$

for $i \neq f$. If i = f, then we get the following relationship:

$$P = A \cdot n$$

Life Cycle Cost

- Life cycle costing or LCC is an important factor for comparing the alternatives and deciding on a particular process for completing a project.
- The different components taken into account for calculating LCC are:

  LCC = Capital + Replacement cost + Maintenance cost + Energy cost – Salvage

- Here, Capital is the present worth. Replacement cost that may occur at a later years need to converted to present worth.
- Maintenance cost is annual maintenance cost and needs to be converted to present worth and so is the energy cost.

Life Cycle Cost-1

- Salvage is the money that is obtained while disposing the machinery at the end of life cycle period.
- Even this amount has to be converted to present worth for calculating LCC.
- Once we have the LCC value, we can easily find the Annual Life Cycle Costing using the following equation:

$$ALCC = \frac{LCC}{\left(\frac{1+f)}{i-f}\right)\cdot\left[1-\left(\frac{1+f}{1+i}\right)^{n}\right]}$$

Comparison of Alternative Energy Systems using Life Cycle Cost Analysis

- Electricity is a major secondary energy carrier and is predominantly produced from fossil fuels .
- Challenging concerns of the fossil fuel based power generation are depletion of fossil fuels and global warming caused by greenhouse gases (GHG) from the combustion of fossil fuels.
- To achieve the goal of environmental sustainability in the power sector, a major action would be to reduce the high reliance on fossil fuels by resorting to the use of clean/renewable sources and efficient generation/use of electricity.

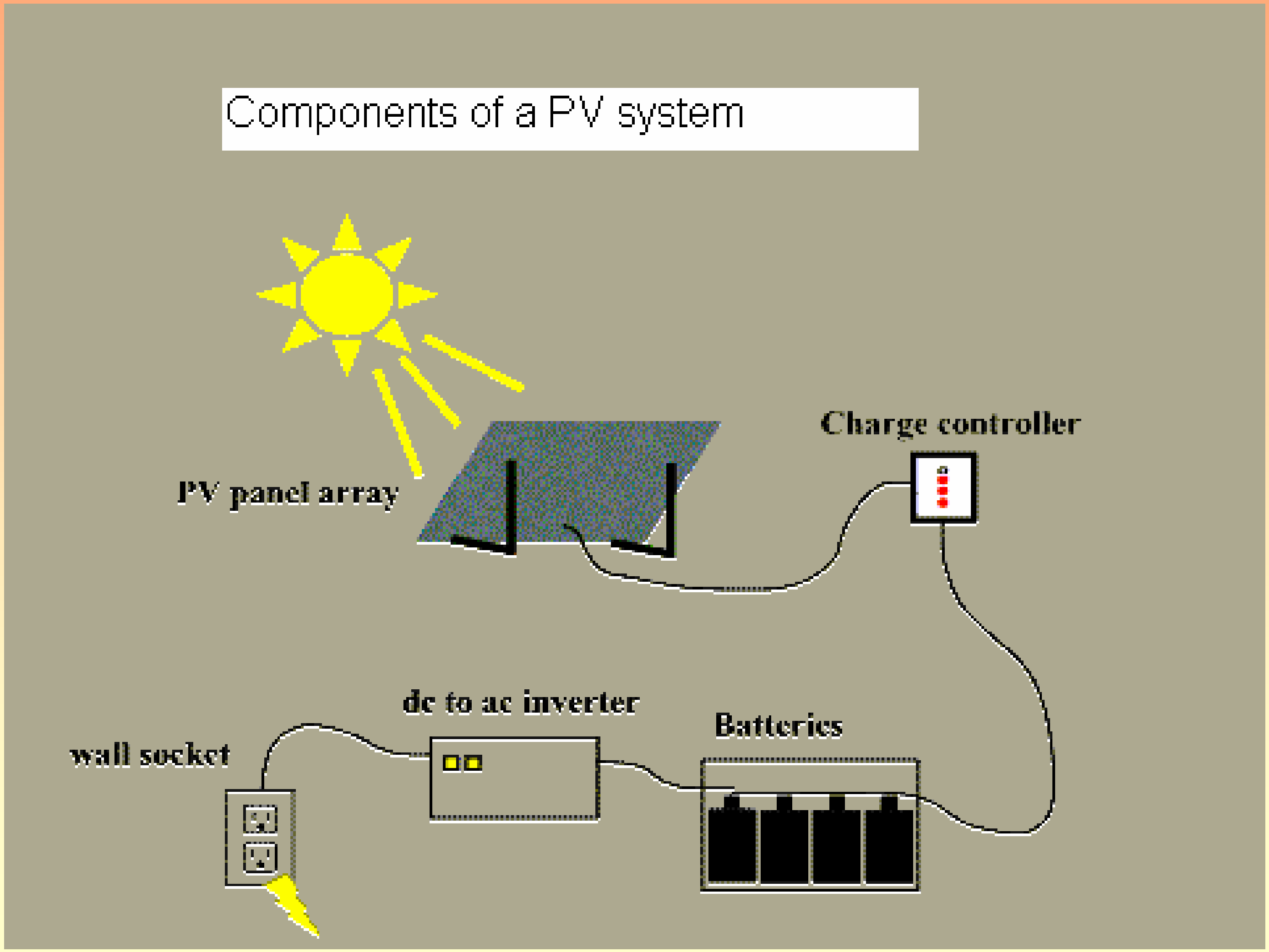
Comparison of Alternative Energy Systems using Life Cycle Cost Analysis

- In order to consider the long-term implications of power generation, a life cycle concept is adopted, which is a cradle-to-grave approach to analyse an energy system in its entire life cycle.
- Life cycle assessment (LCA) is an effective tool to pin point the environmental implications.
- Life cycle cost analysis (LCCA) provides effective evaluation to pinpoint cost effective alternatives.
- LCA and LCCA should be combined to identify cost effective power generation alternative scheme.

SOLAR PV

- To calculate the life cycle cost per KWh the basic components of a PV system are considered as follows.
  - PV panels
  - Batteries
  - Inverters
  - Charge controllers

SOLAR PV-1



Components of a PV system
Charge controller
PV panel array
dc to ac inverter
Batteries
wall socket

SOLAR PV-2

- We will ignore adding in the cost of the charge controller, since this is only a few hundred dollars (whereas the whole system cost will be in the thousands of dollars).
- The user specified variables will be:
  - Peak power required to power appliances
  - Total energy produced/consumed per day
  - Hours of sunshine (average)
- Cost of inverter as function of peak power required:
- The amount of peak power the system can deliver will be determined by the size of the system inverter .
- The inverter being the device which converts the dc battery power to ac.

SOLAR PV-3

$P_{peak\ ,usage} = P_{peak,\ ,inverter}$

- As determined by surveying current market prices for inverters, the costs of an inverter are about Rs.50 per watt, or (multiplying by 1000):

$$Cost_{inverter} = Rs.\ 50000/kilowatt$$

- Thus, the cost of the inverter, as a function of the peak power used, is therefore:
  - $Cost_{inverter\ (Ppeak,\ usage)} = {}_{Ppeak,\ usage}\ x\ Cost_{inverter}$
  - $Cost_{inverter} = P_{peak,\ usage}\ x\ Rs.\ 50000/kilowatt$

SOLAR PV-4

Cost of solar panels as a function of energy usage:

- The peak power produced by the solar panels is determined by the type and number of solar panels one uses:

  $P_{peak\ panels}$ = number of panels x power per panels

- But peak usage is not necessarily equal to peak panel power.

This is because the power generated by the solar panels is stored up over time by batteries.

- so more peak power (but not energy) can be delivered by the inverter than is produced by the panels.

$$E_{produced} = E_{used}$$

SOLAR PV-5

- Also, we need to know how long the sun shines each day on average. Let this be denoted by T_{sun},

T_{sun} = Hours of Sunshine on average.

Using the formula for power and energy (Power = Energy / Time), we have,

$$P_{\text{peak panels}} = E_{used} / T_{sun}.$$

As determined from a survey of current market prices

$Cost_{panels}$ = Rs. 4 Lakhs /Kilowatt.

$Cost_{panels}$ = (Eused / Tsun) x Rs. 4 Lakhs/kilo-watt

SOLAR PV-6

Cost of batteries as a function of energy usage:

- The amount of energy stored (by batteries) determines how much energy can be used after dark, or on a rainy day.
- The lifetimes of deep cycle batteries are fairly short (3 - 10 years), and depend on how well they are maintained (for example, one needs to avoid overcharging, and overdrawing.
- We will assume, in order not to discharge the battery more than 50%, that the batteries will be able to store twice the amount of energy we use:

$$E_{stored} = 2 \times E_{used}$$

SOLAR PV-7

- Presently, the cost of batteries is about Rs. 5000 per kilowatt-hour of storage:

$$Cost_{batteries} = \text{Rs. } 5000/\text{kilowatt-hour}$$

The cost of batteries, therefore, as a function of energy used, is

$$Cost_{batteries} = 2 \times E_{used} \times \$100/\text{kilowatt-hour}$$

Calculation of life cycle cost per KWh:

- Todays solar panels are estimated to last atleast 25 years. We will therefore use 25 years as our life time.

SOLAR PV-8

1	PV panel	Rs. 4 Lakhs/KW	25 Years
2	Inverter	Rs. 50000/KW	25 Years
3	Battery	Rs. 10000/KWh	5 Years

- Let us say i=10%

Capital Cost = 4Lakhs+ 50000+ 10000=Rs. 460000

Replacement Cost = $\frac{10000}{(1+i)^5} + \frac{10000}{(1+i)^{10}} + \frac{10000}{(1+i)^{15}} + \frac{10000}{(1+i)^{20}}$

=Rs. 13945/KWh

Maintenance Cost: As we are considering only from generating point of view maintenance cost is negligible part.

Energy Cost: It does not require any external energy (because the system uses sun energy) to produce the electrical energy.

SOLAR PV-9

CASE STUDY:

For a large home let us say

$$\text{Life Cycle Cost} = 5 \times 50000 + \frac{20}{6} \times 400000 + 20 \times 10000 + 13945 \times 20$$

=Rs. 2062233.333

$$\text{Total KWh}_{\text{used}} = 25 \text{ Years} \times 365 \text{ Days} \times E_{used}$$

$= 9125\ E_{used}$

Therefore Cost per KWh = Life Cycle Cost / (9125 E_{used})

=Rs. 11.3 per KWh

SOLAR THERMAL PLANT

- The major components of this system to be considered in calculating life cycle cost are:
  - Heat energy Collectors
  - Boiler
  - Steam turbine
  - electric generator

SOLAR THERMAL PLANT-1

- The costs of the above mentioned components are listed in the following table.

Item	Cost in Rs/KW	Life period
Heat energy collectors	25000	20years
Boiler+ steam turbine	13900	10years
Electric generator	5500	10years
Accessories, tools	1000	5years

SOLAR THERMAL PLANT-2

- Now let us say interest rate i=10%

  Then the life cycle cost per KW is calculated as follows:

Capital Cost = Cost of (heat energy collectors+boiler +steam turbine+ electric generator+accessories)

= 25000+13900+5500+1000

=Rs.45400

$$\text{Replacement Cost} = \frac{13900}{(1+.1)^{10}} + \frac{5500}{(1+.1)^{10}} + \frac{1000}{(1+.1)^{5}} + \frac{1000}{(1+.1)^{10}} + \frac{1000}{(1+.1)^{15}}$$

= Rs.8725.4

SOLAR THERMAL PLANT-3

Maintenance cost = 1% of total capital cost per year

= Rs. 3865.15

Therefore,

Life cycle cost per KW = 45400+8725.4+3865.15

=Rs.57990.55

MICRO HYDEL PLANT

- These plants are used for power requirements less than 100KW.
- The costs of all major components are specified in the table, the costs of civil works and permits are not included.

1. Approximate Micro Hydel system Costs (Battery based):

Component	100W (flow rate 4lps and head at 5m.	lifetime
Penstock	Rs 32500	10years
Turbine-generator	Rs 125000	
Controller	Rs 20000	

MICRO HYDEL PLANT-1

Batteries	Rs 26000	5years
Inverter	Rs 60000	
Power house	Rs 10000	
Miscellaneous	Rs 10000	
Maintenance	Rs 2000per year	

Estimates provided by Energy Alternatives Ltd.

MICRO HYDEL PLANT-2

Now let us say ,

- Interest rate i=10%
- Life period =20years

Then,

Capital Cost(C) = Cost of (Penstock + Turbine-Gen + Controller + Batteries + Inverter + (Power house+ Miscellaneous)

= Rs.283500

Replacement Cost(R):

Penstock

$$\text{Battery} = \frac{26000}{(1+.1)^5} + \frac{26000}{(1+.1)^{10}} + \frac{26000}{(1+.1)^{15}} = 32392$$

MICRO HYDEL PLANT-3

Therefore total replacement cost = Rs.44922

Maintenance Cost (M) $= \frac{20000}{0.1}\{1 - \frac{1}{(1+.1)^{20}}\} = 17027$

Life Cycle Cost (LCC) = C+R+M

= Rs.332919.

MICRO HYDEL PLANT-4

Approximate Micro Hydel system Costs (AC-Direct system):

Component	3.5 KW (flow rate at 14lps and head at 50m)	Life time
Penstock	Rs.80000	15years
Turbine-Gen	Rs.165000	
Controller	Rs.95000	
Power house	Rs.50000	
Miscellaneous	Rs.82500	
Installations	Rs.100000	
Maintenance	Rs.1000 per year	

Estimates provided by Thomson and Howe Energy Systems Inc.

MICRO HYDEL PLANT-5

- Now for a life period of 30 years, at an interest rate of 10%,

Capital Cost (C):

= Cost of (Penstock + Turbine - Gen + Powerhouse + Mis. + Installations)

= Rs.572500

Replacement Cost(R): $= \frac{80000}{(1+.1)^{15}}$

= Rs.19151

Maintenance Cost (M): = Rs.9426

Therefore,

Life Cycle Cost = C+R+M

= Rs.601077

BIOMASS PLANT

- The major components of Biogas plant are listed as follows.
  - Gassifier
  - Piping
  - Sand filter
  - Diesel engine
  - Electric Generator

BIOMASS PLANT-1

- The costs of different components of Biogas plant are specified in the following table.

Item	Cost in Rs.for 5KW plant	Life period
Biogas plant	127700	20years
Piping	8300	10years
Sand filter	4150	10years
7hp diesel engine	37700	15years
5KVA generator	78150	15years
Accessories, Tools	20750	10years
Engine room	16550	20years

BIOMASS PLANT-2

- Now let us say interest rate i=10%

  Then the life cycle cost is calculated as follows:

Capital Cost =127700+8300+4150+37700+78150+20750+16550

=Rs.293300

$$\text{Replacement Cost} = \frac{8300}{(1+.1)^{10}} + \frac{4150}{(1+.1)^{10}} + \frac{37700}{(1+.1)^{15}} + \frac{78150}{(1+.1)^{15}} + \frac{20750}{(1+.1)^{10}}$$

= Rs40533.6

Maintenance cost = 1% 0f total capital cost per year

= Rs. 24970.28

Therefore,

Life cycle cost =293300+40533.6+24970.58 = Rs.358803.8

WIND ENERGY SYSTEM

- The major components of a wind energy system are:
  - Wind mill
  - Gear box
  - Controller
  - Wind turbine
  - Electric generator

WIND ENERGY SYSTEM-1

- The costs of the above mentioned components are listed in the following table.

Item	Cost in Rs per KW	Life period
Wind mill	25000	20years
Gearbox	2500	10years
Controller	2000	10years
Wind turbine	10500	15years
Electric generator	5500	15years
Accessories	1000	5years

WIND ENERGY SYSTEM-2

- Now let us say interest rate i=10%

Then the life cycle cost per KW is calculated as follows:

Capital Cost = 25000+2500+2000+10500+5500+1000

=Rs. 46500

Replacement Cost =

$$\frac{2500}{(1+.1)^{10}}+\frac{2000}{(1+.1)^{10}}+\frac{10500}{(1+.1)^{15}}+\frac{5500}{(1+.1)^{15}}+\frac{1000}{(1+.1)^{5}}+\frac{1000}{(1+.1)^{10}}+\frac{1000}{(1+.1)^{15}}$$

= Rs.6811

Maintenance cost = 1% of total capital cost per year

= Rs. 3958.8

Therefore,

Life cycle cost per KW = 46500+6811+3958.8 =Rs57269.8

Remarks

- Different renewable sources are considered for Life Cycle Cost analysis.
- It was found that every source has its own advantage and disadvantage, depending upon their location of installation and in terms of various costs like capital, maintenance etc .
- The microhydel plant was found to be having less installation cost when compared to other plants.
- The capital cost required for Wind and Wave energy system found to be more.