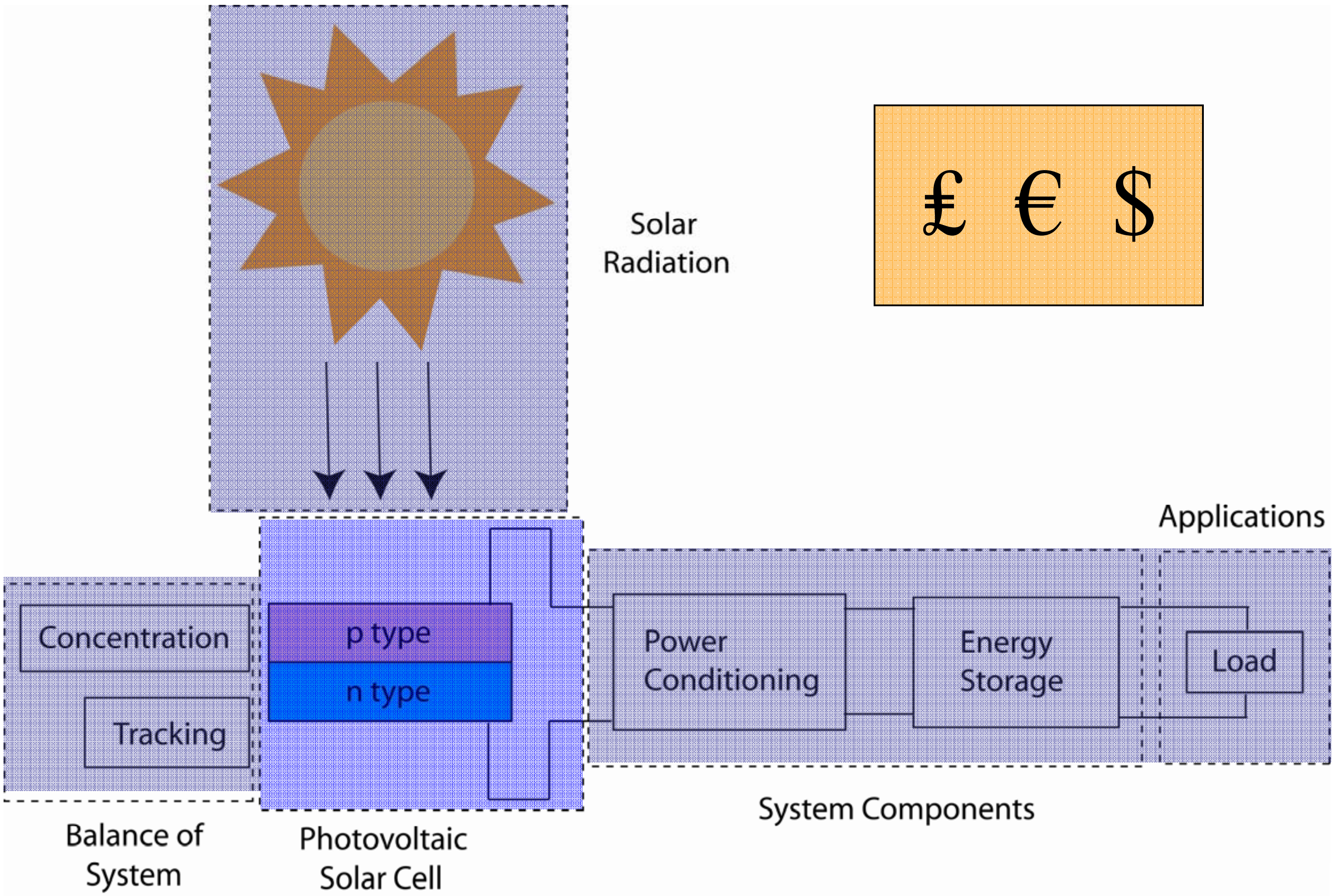
Economics

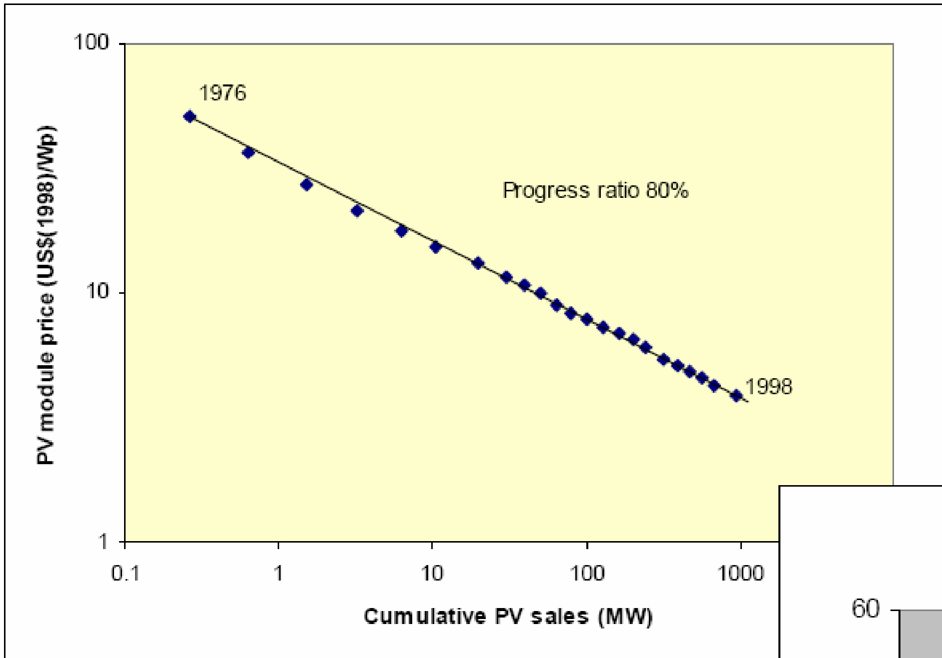


Solar
Radiation
£ € $
Applications
Concentration
Tracking
p type
n type
Power
Conditioning
Energy
Storage
Load
Balance of
System
Photovoltaic
Solar Cell
System Components

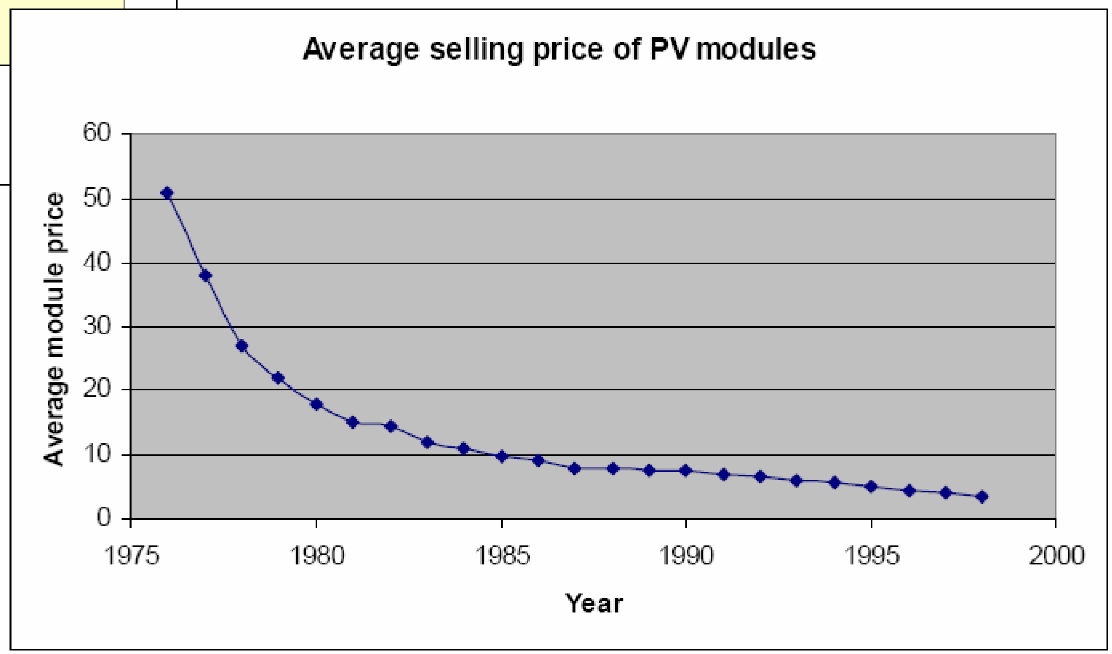
Economics

- Economics issues are a major factor, but do not necessarily give an exact answer; economics often considered in terms of social priorities
- Difficult to do economic comparison accurately due to differences in time frames and assumptions
- A key issue in economic analysis of power systems is that the value of money is not constant over time
  - Intrinsic value of money is not constant over time shown by inflation
  - Spending money has a cost associated with it
    - Cost of borrowing money, given by interest rate
    - Opportunity cost of spending money, given by discount rate

Costs



100
10
1
1976
Progress ratio 80%
1998
0.1
1
10
100
1000
Cumulative PV sales (MW)
PV module price (US$(1998)/Wp)



Average selling price of PV modules
60
50
40
30
20
10
0
1975
1980
1985
1990
1995
2000
Year
Average module price

Cost of PV

Units of cost $/W

- Module cost normally quoted as $\$/W_p$ (peak watt). This means the cost of the module divided by the amount of power it produces under standard AM1.5 conditions
- The $/W figure is a number for comparing various solar cell technologies but should not be used directly in determining the useful power produced by a PV system
- If the efficiencies of the two technologies being compared are radically different, a $/W figure doesn't accurately reflect the true cost of electricity from two types of solar cells – use the cost of electricity
- For technologies with similar efficiencies, the lower $/W figure makes a technology more desirable, efficiency must be kept above a certain level though

Cost of PV

$\$/m^2$ cost

- Another way of measuring cost is $\$/m^2$. It is useful when looking at the various other materials components costs of a PV module which depend on area rather than the power produced
- Conversion from $/W to $\$/m^2$:

$$\frac{\$}{m^2} = \frac{\$}{W} \times \frac{1000W}{m^2} \times \eta = \frac{\$}{W} \times \frac{\text{Watts from module } (W_p)}{\text{Area of module } (A)}$$

- For two technologies with identical $/W cost, the higher the higher efficiency module will have the higher $\$/m^2$ cost and hence is more desirable
- For technologies with different efficiencies knowing only the $\$/m^2$ is not enough to effectively compare them
- Higher efficiency technologies typically have much higher $\$/m^2$ figures than lower efficiency, lower cost technologies

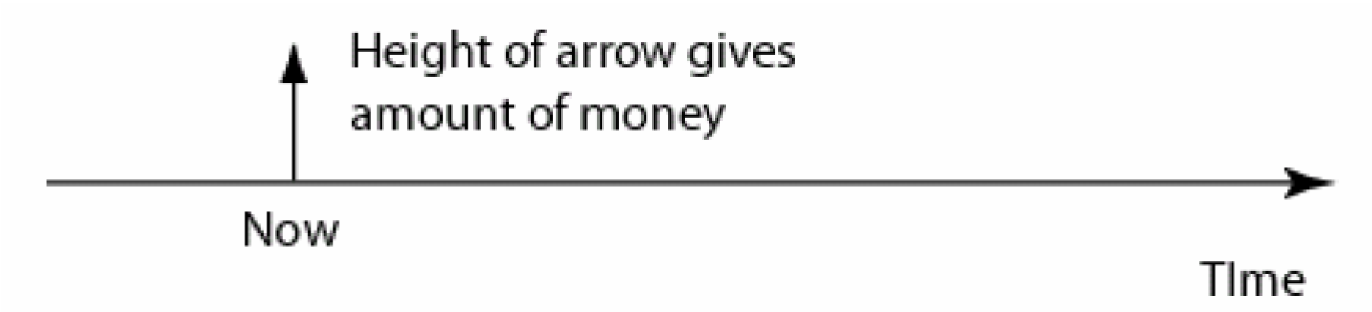
Cost of Electricity

Cost of Electricity (COE)

- Both $/$W_p$ and $/m2 only take into account the cost of PV, not other components and system costs
- Cost of electricity ($/kWhr) takes into account many other factors in a PV system
- COE is used to compare one type of electricity generating system to another **when the same set of assumptions has gone into each cost analysis**
- In practical terms, this means that one can only compare COE when the figures are produced by the same author and only ‘ball park’ figure comparisons can be made for different costing studies
- Impact of inflation, currency fluctuations, BOS costs, maintenance etc. needs to be taken into account when comparing various costing studies

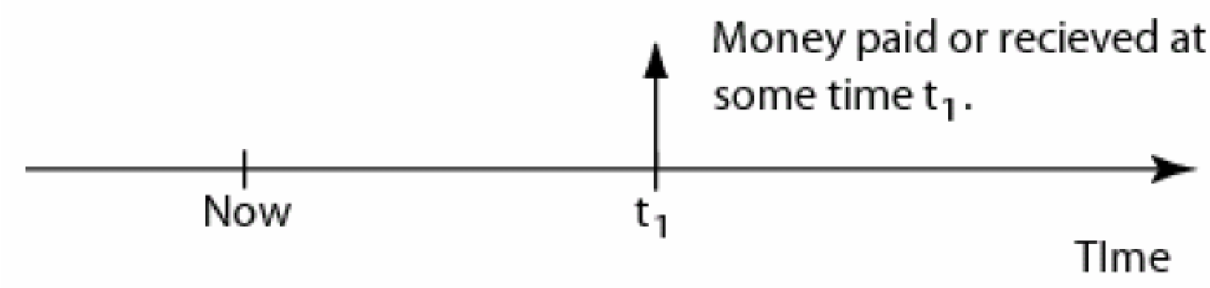
Time Value of Money

- Because costs depend on time at which money is spent, a comparison of costs must convert all expenditures or incomes to the same time frame
- Commonly used time frames:
  - Now: In this case, the time value of money is called Nett Present Value (NPV) or Present Worth
    - NPV commonly used for decisions in purchasing, comparing costs
    - Arrow up indicates received, down indicates payment



Time Value of Money

- Some specified point in the future, called Nett Future Value (NFV). This is a single value.
  - Useful for investing or planning calculations: you want to know the future value of your money



$$\frac{\text{Future Worth}}{\text{Present Worth}} = \left(F/P, i\%, n\right) = (1+i)^n$$

$$\frac{\text{Present Worth}}{\text{Future Worth}} = \left(P/F, i\%, n\right) = \frac{1}{(1+i)^n}$$

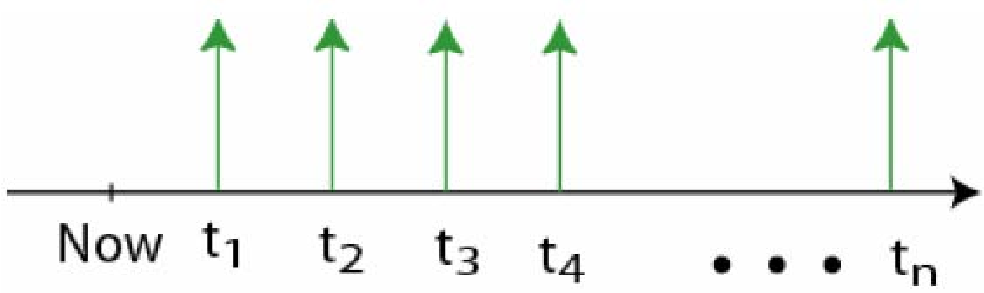
Where *i* is the interest rate and *n* is the payment period

Time Value of Money

- **Some time in the past**
  - When using historical costs, can use money as it was valued at that time. This is often called nominal dollars or real dollars or constant dollars
  - Can correct each historical data point to some other year's currency. In this case, it is called real or constant dollars, and the year to which it is normalized must be given
  - In order to correct, need to know the historical inflation or consumer price index (CPI) for that particular currency

Time Value of Money

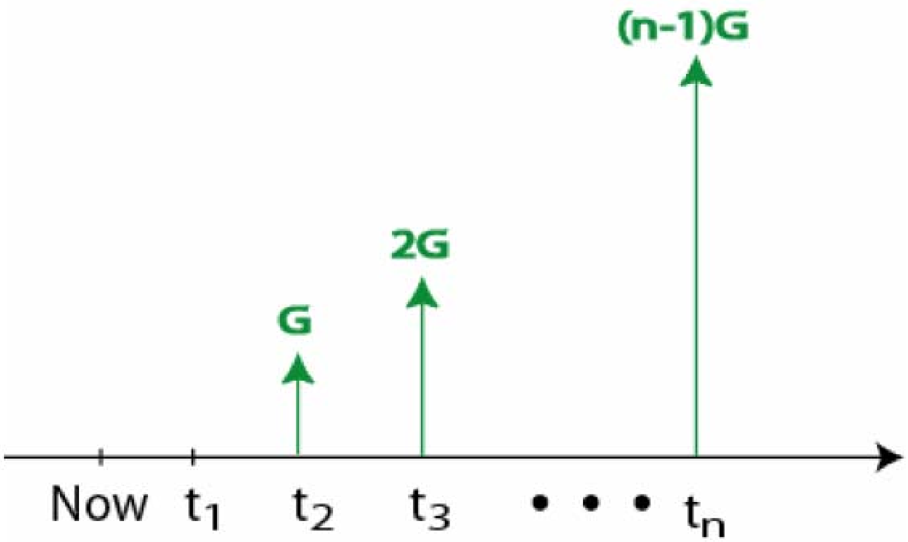
- A series of repeating payments
  - Repeating payments used in several types of cases: payback of loans, ongoing costs, sinking fund, capital recovery
    - Payments may be constant or increasing
  - Can convert a single payment to a series of payments. This is called amortized or annualized



$$\frac{\text{Annualized}}{\text{Present Worth}} = \left(A/P, i\%, n\right) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Time Value of Money

- Payments may increase arithmetically (fixed increase amount each period)

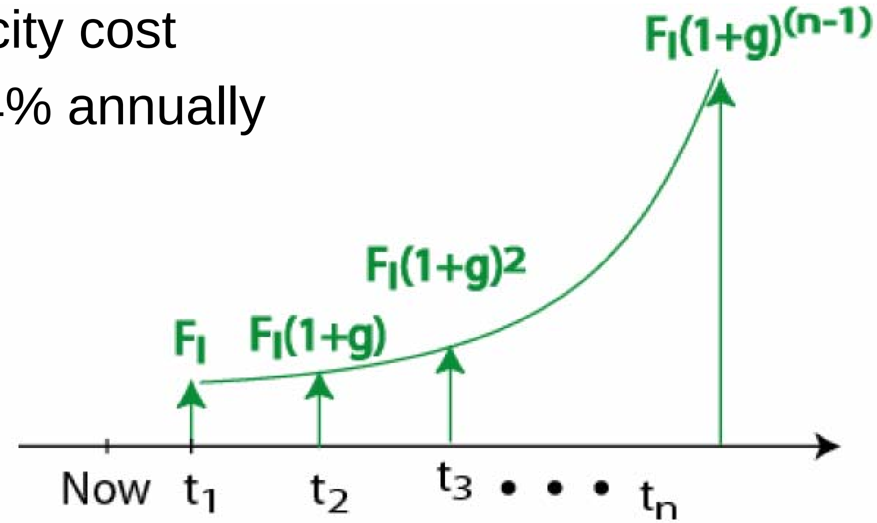


Note that the t_1 value is zero.

$$\frac{\text{Present Worth}}{\text{Arithmetic Gradient}} = \left(P/G, i\%, n\right) = \frac{(1+i)^n - in - 1}{i^2(1+i)^n}$$

Time Value of Money

- Payments may increase geometrically (increase by a percentage each period)
  - E.g. electricity cost increases 4% annually



g is growth rate

$$\frac{\text{Present Worth}}{\text{Geometric Gradient}} = \left(A/F_l, i\%, n\right) = \frac{(1+i)^n - (1+g)^n}{(1+i)^n (i-g)} \qquad i \neq g$$

$$\frac{\text{Present Worth}}{\text{Geometric Gradient}} = \left(A/F_l, i\%, n\right) = \frac{n}{(1+i)} \qquad i = g$$

Rates affecting the time value of money

- The rate used to calculate the nett value of money depends on what you are doing with the money
  - Interest rate: Applies to borrowing (or lending) money
    - This is the rate that you are charged (or get) per year to borrow a certain amount of money
    - Practically, the interest rate is related to the inflation rate
    - Any money that is borrowed must be corrected for the inflation rate
    - Interest can be compounded or simple: in compounding, the interest earned in one period earns interest in the next
    - If the interest rate is different from the compounding rate, need to calculate effective rate:

$$i_a = \left(1 + \frac{r}{m}\right)^m - 1$$

Where r is the simple interest rate and m is the compounding period

Rates affecting the time value of money

- Inflation rate
  - Tells how the value of money changes over time
  - Usually used to correct Nett Future Value into a Nett Present Value
  - Several different ways to measure inflation: most common is change in the consumer price index (CPI)

- Discount rate
  - This is effectively the rate you COULD get if you invested the money rather than spending it
  - Discount rate used to determine if an investment is worthwhile
- Internal rate of return
  - The internal rate of return is often used to determine if a particular investment is worthwhile

Rates affecting the time value of money

- Inflation, interest and discount rates will affect the difference between present and future payments
  - High values of inflation rate
    - Favours spending money and having a fixed value asset (unless you have to borrow money)
  - High interest rates
    - Does not favour borrowing money – systems with high initial costs are at a disadvantage
  - High discount rates
    - Place a greater value of having cash than having a particular asset
    - Discount rates are often set as policy by an organization or institution

Cost of Electricity

- The cost of electricity is the total cost of the system over it's lifetime (usually it's NPV) divided by the total energy produced during it's lifetime
- Total costs
  - Initial costs (may attract interest etc.)
  - Maintenance costs
  - Recurring costs
  - Salvage value
- Initial costs
  - Consists of cost of components, land, installation
  - Some costs scale with amount of power, saome scale with space (usually in renewable energy systems)

Cost of Electricity

- Maintenance and operating costs
  - Will typically increase throughout the life of the system, but in systems where the maintenance cost is low compared to tohers, this effect may be ignored
  - Maintenance cost usually low in renewable energy systems
  - Typically high for conventional fossil fuel or nuclear plants
  - For conventional systems, these costs can be very difficult to estimate over the life of the system, since this requires a prediction about the future costs of fuels, labour etc.
- Recurring costs
  - Usually involve payments for replacement items on a regular basis

Cost of Electricity

- Salvage value
  - The total costs are the costs expended over the life of the system, less the value of the system at the end of the life of the system
  - Often, the salvage value is close to zero for many energy generating systems. This is due simply to the long life of many energy generating systems
  - Instead of having salvage value, some systems may have large costs at the end of life. Think nuclear energy, think disposal, think de-commissioning of the plant
  - When the end of life costs are high compared to other costs, the cost of electricity becomes extremely sensitive to information furthest away from the present, i.e. the least accurate assumptions

Cost of Electricity

- Most appropriate way to compare cost is to do life cycle costing (LCC), where all the costs over the life time of the system are scaled back to the same time frame and then added up
  - The COE is then the total electricity produced divided by the total corrected cost
- Sensitivity of costing
  - The sensitivity of the cost of electricity is often highly dependent on assumptions of inflation, discount rates etc.
  - Operating costs, which do not have a large dependence on assumptions, are often compared but can also be misleading

Finding COE

- Find total costs of PV system over life of system
  - Initial costs (costs of modules, inverter, batteries, wiring, installation, mounting, loads etc..
  - Other installation costs
  - Future costs need to be rated at a different value
    - Ongoing costs (battery replacement, fuel costs)
    - Maintenance costs
    - Operational costs
    - Repair costs
    - Replacement costs
- Determine life of system
  - Generally is assumed to be at least the warranty period

Finding COE

- Find costs associated with borrowing and using money
  - Interest rate: cost of borrowing money. High values are detrimental to PV, since it is a capital intensive type of energy (generally 90% initial)
  - Inflation rate: High rates generally favourable for PV
  - Discount rate: Large discount rates mean that low value is placed on future costs and benefits, and high value is placed on present capital. Since PV is capital intensive, high values are detrimental to PV systems.
  - Ongoing costs may have a different lifetime, interest rates etc. than initial system costs

- Pay back period will in general be the lifetime of the system

Cost of Electricity

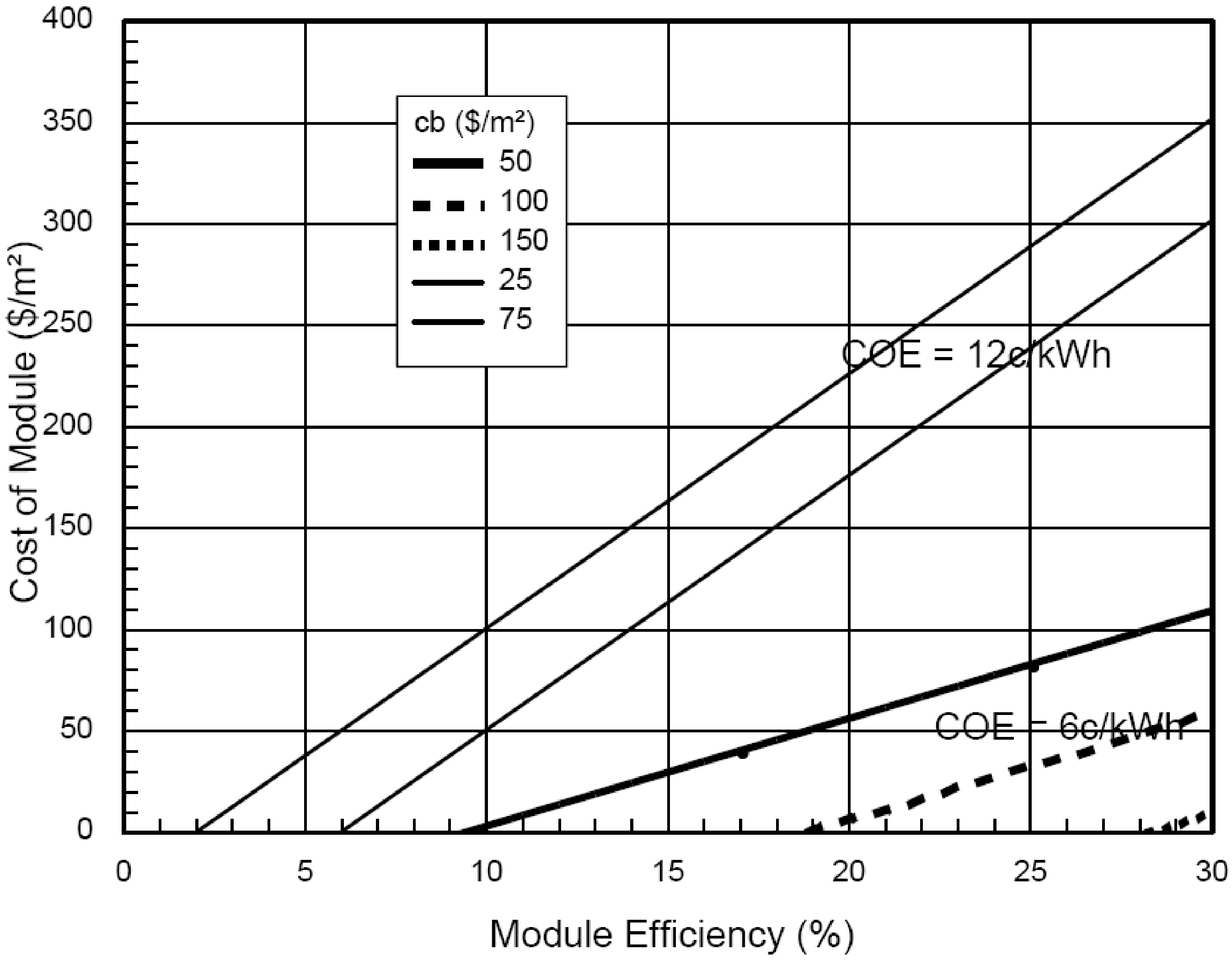
- COE = [(annualized cost of PV system)/(annual energy production)] + operating costs + maintenance

$$COE = \frac{(c_m + c_b)}{S\eta} F + OM$$

Where

c_m is the PV module cost (in $/m^2)
c_b is the BOS cost (in $/m^2)
η is the efficiency
S is annual incident solar energy in kWhr/m^2/yr
OM is operating and maintenance costs
F is the cost associated with borrowing money

Cost of Electricity



Reducing Costs

- Improve BOS performance (without increasing costs)
  - Closer match between components, maximum power point tracking etc.
  - More efficient components
  - Improved storage
- Reduce BOS costs
  - Incorporate modules into rooftops
  - Improved inverter design, power conditioning
- Improve module performance with optical concentration
  - Concentrators replace additional solar cells with cheaper optics
  - Commercially may be difficult to implement due to tracking, increased temperature, reduced utilization of indirect light and optical losses in system
  - Low scale concentration (4-20x) can use conventional cell designs, high concentrations suited primarily to large scale utility use and require high efficiency 'lab type' cells

Reducing Costs

- Reduce solar cell substrate material cost
  - Silicon wafer costs are roughly 30-40% of total cell cost, therefore use thin-films
  - Reduce wafer thickness on crystalline solar cells (requires new design, especially rear surface)
  - Increase wafer diameter (more watts per piece)
  - Increase ingot length and reduce kerf losses in sawing
  - Reduce silicon feedstock costs
- Increase cell efficiency with novel solar cell designs
  - Bifacial technologies
  - Advance screen printing techniques
- Lower cost technologies

Reducing Costs

- Reduce processing/materials costs through process engineering
  - Increased throughput, increased yield
  - Novel processes, materials and concepts
  - Increased wafer area
- Other financing schemes for PV
  - Present costing studies assume that the system is financed. Because of the large initial costs involved in a PV system, this can have a significant impact on the COE for a PV system
- Economies of scale