SIERRA COLLEGE

Electrical Design 2 and Financial Analysis

Lesson Plan

- NABCEP Learning Objectives:
  Electric Design (part 2)
- Financial Analysis

Conductor Resistances*

AWG	SOLID COPPER	STRANDED COPPER
18	7.77	7.95
16	4.89	4.99
14	3.07	3.14
12	1.93	1.98
10	1.21	1.24
8	0.764	0.778
6	—	0.491
4	—	0.308
3	—	0.245
2	—	0.194
1	—	0.154
0 (1/0)	—	0.122
00 (2/0)	—	0.0967

* in Ω/kft at 75°C (167°F)

- Larger conductors have lower resistance for a given length.

- Understanding PV module specifications and electrical design limits

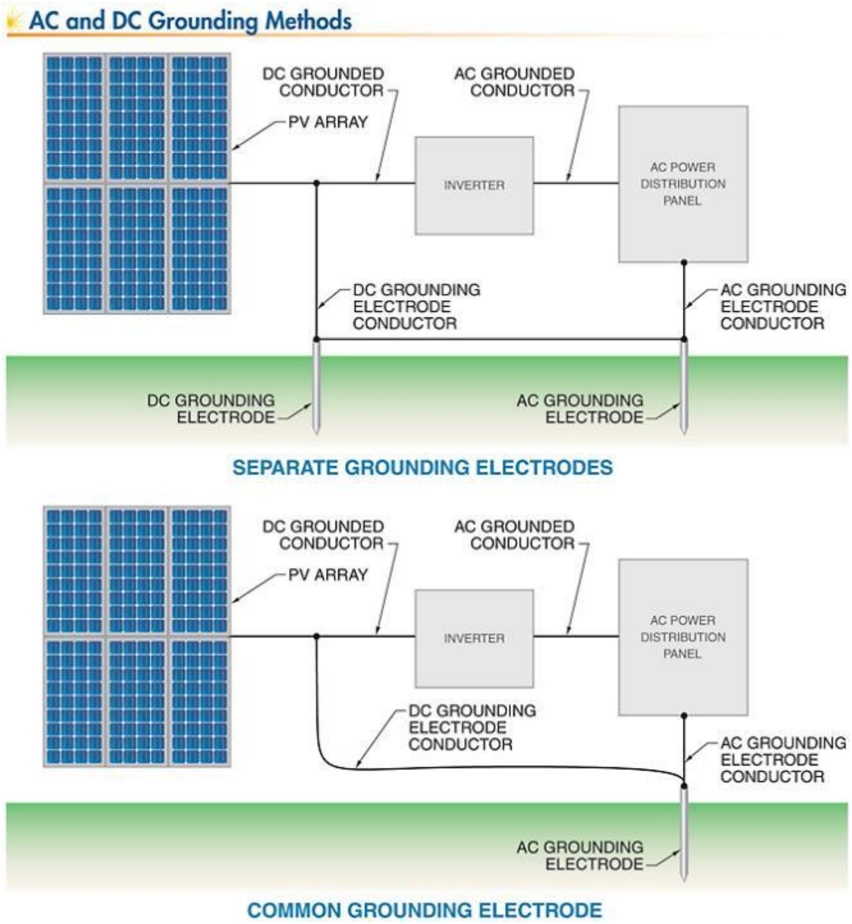
Electrical Characteristics

	1000W/m^2 (STC[1])
Maximum Power (P_{max})	220W
Voltage at MPP (V_{mpp})	29.0V
Current at MPP (I_{mpp})	7.6A
Short circuit current (I_{sc})	8.4A
Open circuit voltage (V_{oc})	36.2V

Specifications

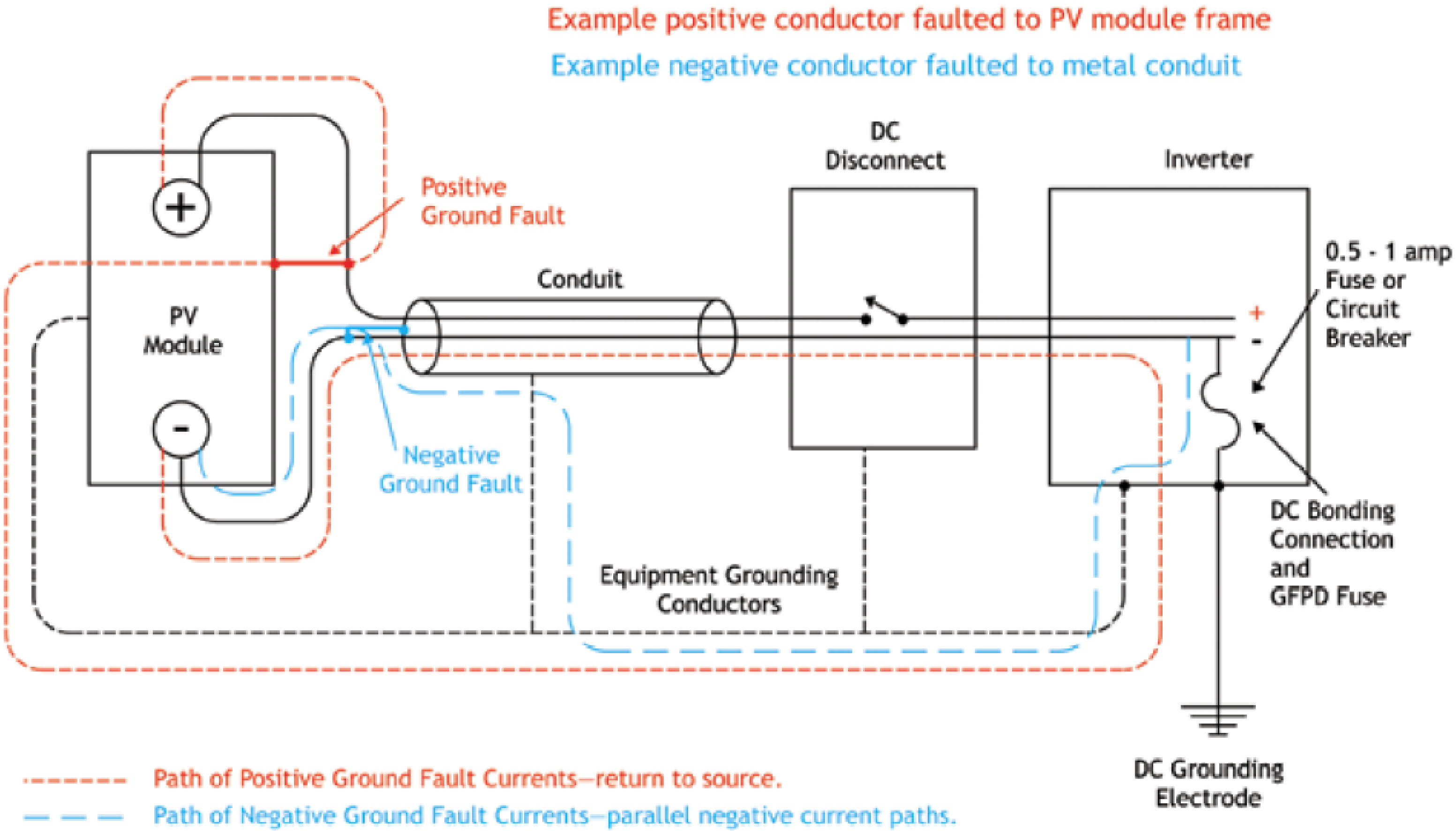
Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (Pmax)	135W (+5%／−5%)
Maximum Power Voltage (Vmpp)	17.7V
Maximum Power Current (Impp)	7.63A
Open Circuit Voltage (Voc)	22.1V
Short Circuit Current (Isc)	8.37A
Max System Voltage	600V
Temperature Coefficient of Voc	−.080 V/℃
Temperature Coefficient of Isc	5.02×10^{-3} A/℃

*STC : Irradiance 1000W/m^2, AM1.5 spectrum, cell temperature 25℃



- There are two acceptable methods of grounding both the AC and DC sides of a PV system.

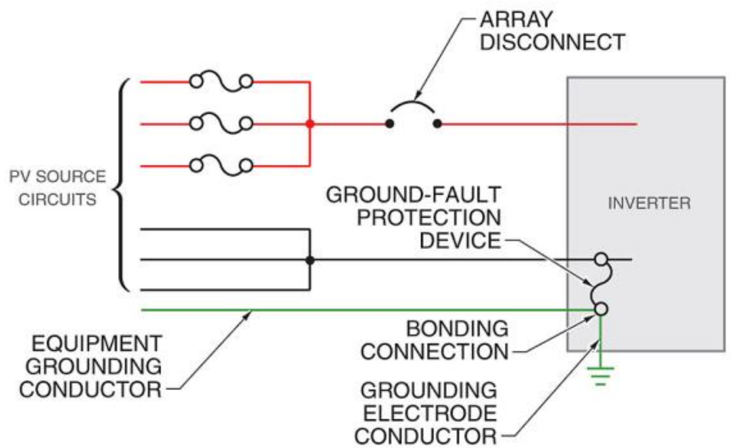
Ground-Fault Current Paths



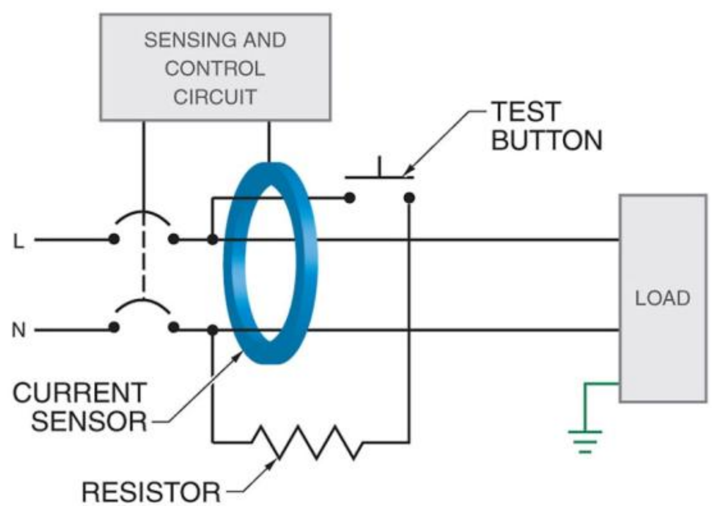
All ground-fault currents must flow through the DC bonding connection.

Any time positive or negative ground-fault currents exceed ground-fault fuse/breaker rating, that device opens and ground-fault currents are interrupted.

Array Ground-Fault Protection with Inverter Fuse



Ground-Fault Circuit Interrupter



- A ground-fault circuit interrupter (GFCI) senses differences between the current in the grounded and ungrounded conductors, indicating a ground fault, and opens the circuit in response.

- Many articles in the NEC® are applicable to the electrical integration of a PV system, particularly Article 690.

Selected Applicable NEC® Articles

110*	Requirements for Electrical Installations
200	Use and Identification of Grounded Conductors
210*	Branch Circuits
220	Branch-Circuit, Feeder, and Service Calculations
230*	Services
240*	Overcurrent Protection
250*	Grounding and Bonding
280	Surge Arrestors
285	Transient Voltage Surge Suppressors: TVSSs
300	Wiring Methods
310*	Conductors for General Wiring
334	Nonmetallic-Sheathed Cable: Types NM, NMC, and NMS
338	Service-Entrance Cable: Types SE and USE
340*	Underground Feeder and Branch Circuit Cable: Type UF
400*	Flexible Cords and Cables
422	Appliances
445	Generators
450*	Transformers and Transformer Vaults
480*	Storage Batteries
490*	Equipment, Over 600 Volts, Nominal
690	Solar Photovoltaic Systems
702	Optional Standby Systems
705*	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating at Less Than 50 Volts

* Articles directly referenced in Article 690

- What do we mean by PV financial analysis?
- Why do we care?
- How do we measure?

- Important terms
  - PNL NOPAT
  - GM% OPEx
  - ROI PAYBACK
  - Lifecycle Cost Analysis IRR
  - Time Value of Money Discount rate
  - NPV

PNL NOPAT = Profit & Loss, Net Operating Profit After Tax

GM% = Gross Margin Percentage

OPEx = Operating Expenses

ROI = Return on Investment

PAYBACK = Payback period required for avoided costs of alternate energy system to match the cost of chosen system

Lifecycle Cost Analysis = Total cost of all expenses incurred over the life of a system

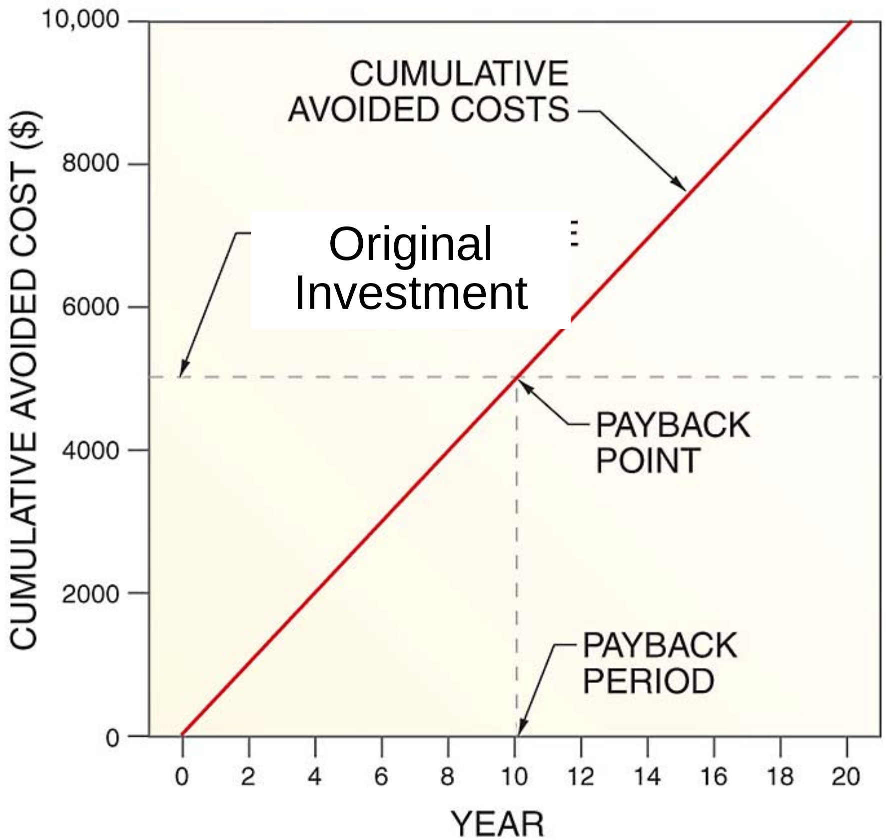
IRR = Internal Rate of Return

Time Value of Money = Value of money figuring in a given amount of
interest earned over a given amount of time

Discount rate = Rate at which future value of money is reduced to its present value

NPV = Net Present Value

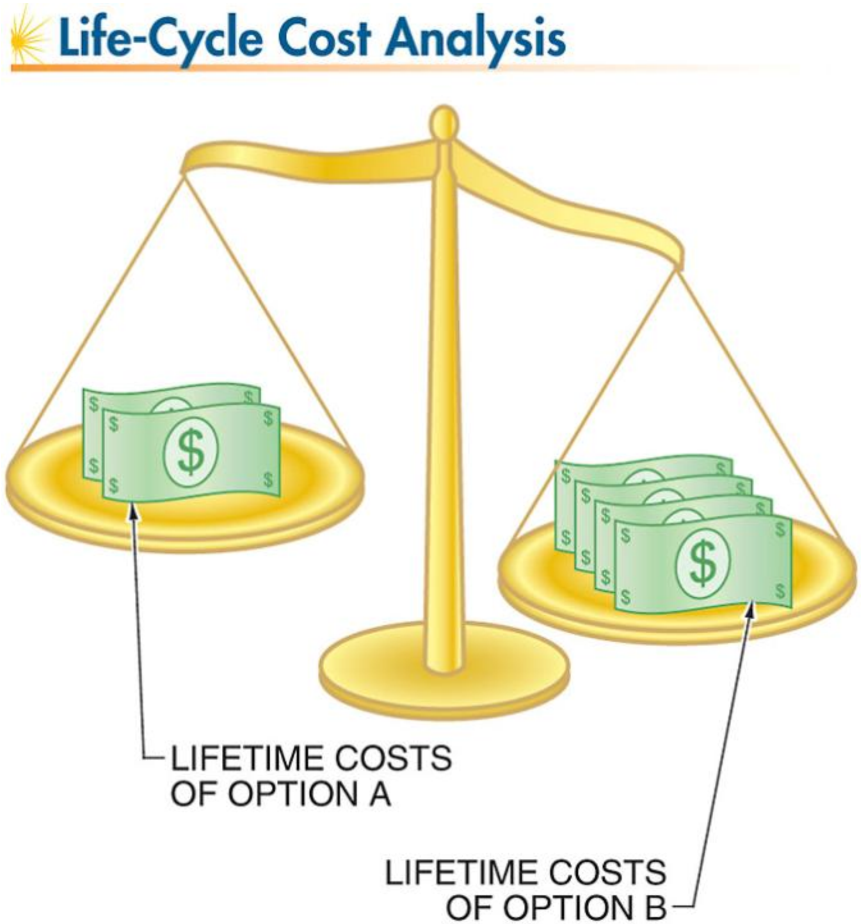
Payback Point



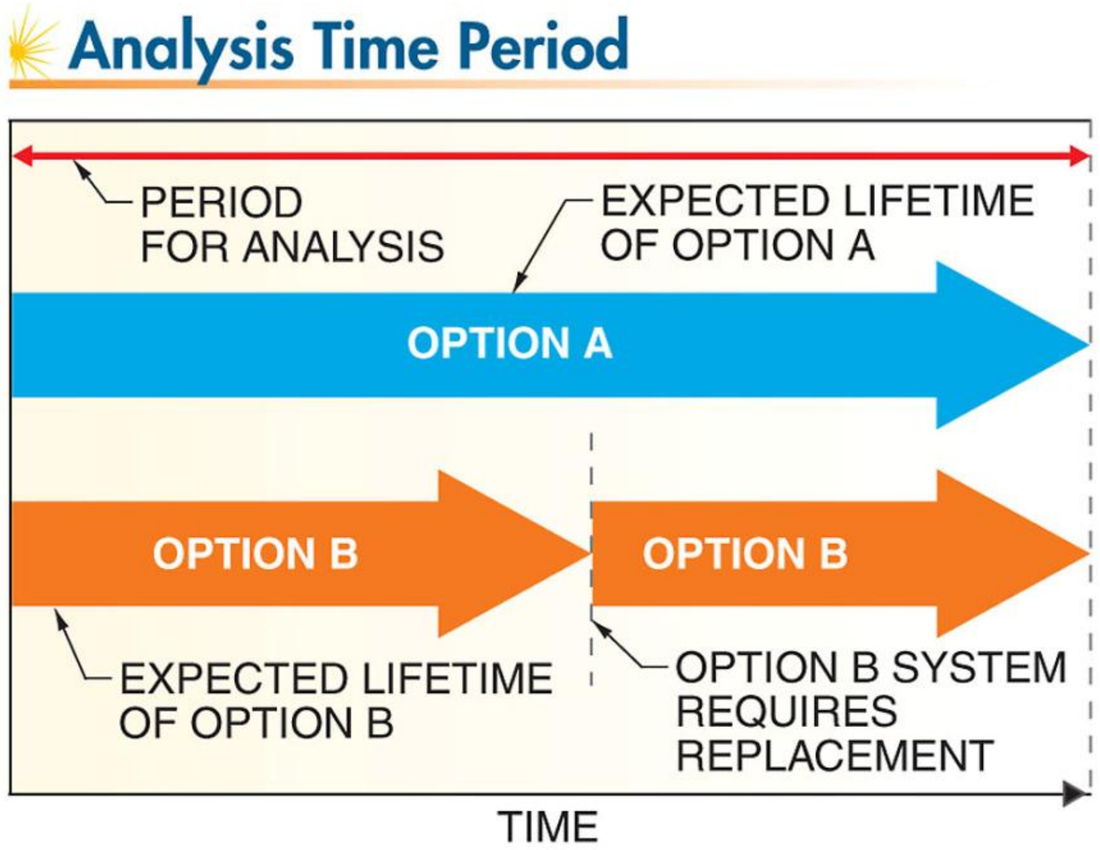
- What's the problem with payback method of analysis?

- Timing of Cash
- Cash after payback
- Arbitrary standard

- The payback point occurs when the cumulative avoided cost equal the initial investment.

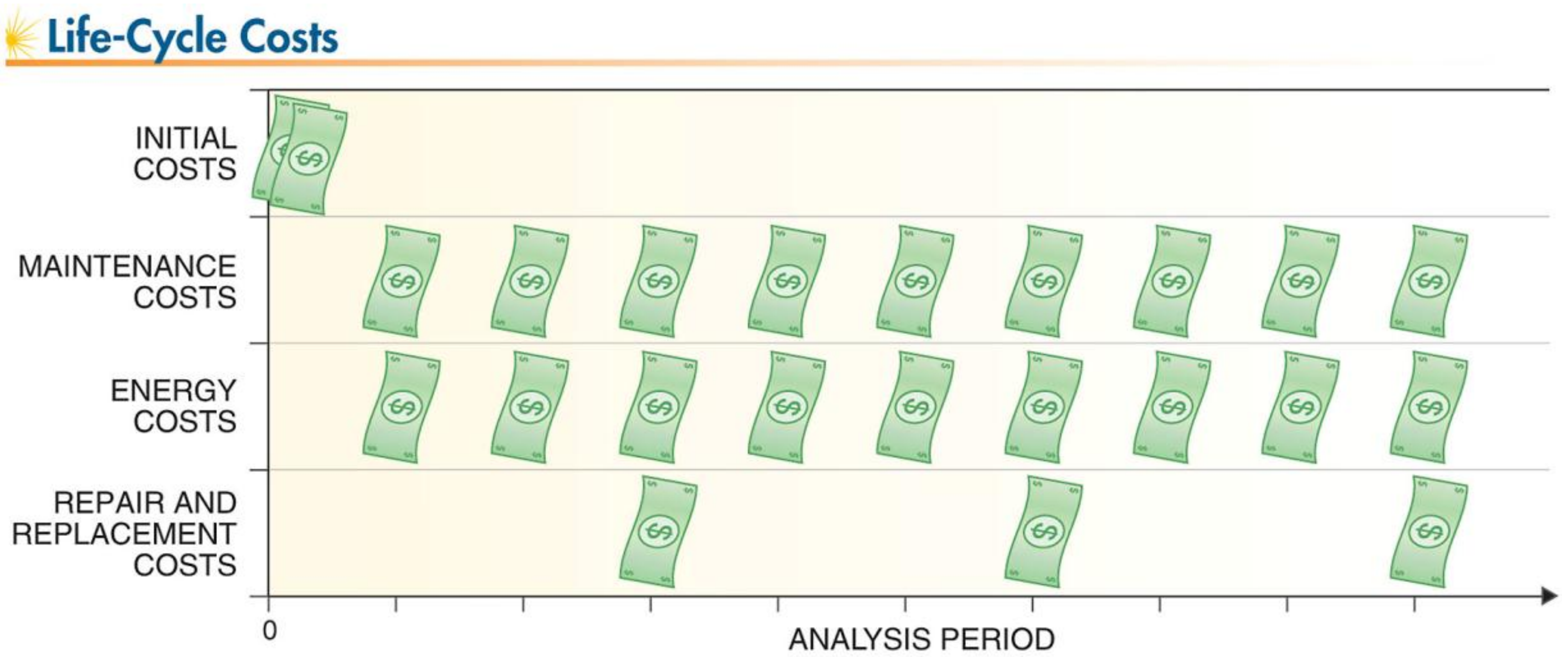


- A life-cycle cost analysis compares the life-cycle costs of various electricity-supply options.



- Each system option must meet the same requirements, including the length of time used to calculate life-cycle cost.

- The various types of life-cycle costs occur at different points in the life cycle of a system.



- The life-cycle cost analysis of an engine-generator system includes each type of cost.

Life-Cycle Costs for Engine Generator

LIFE-CYCLE COSTS

System: Engine Generator

Cost Description	Cost/Year	Single Cost Year
Initial Costs		
System Purchase and Installation	$8,500	0
Maintenance Costs		
Engine Inspection and Oil Changes	$200	
Energy Costs		
Diesel Fuel	$2,145	
Repair and Replacement Costs		
Engine Rebuild	$1,000	5
Engine Rebuild	$1,000	10
Engine Rebuild	$1,000	15
Inverter Replacement	$2,000	10
Battery Bank Replacement	$1,500	8
Battery Bank Replacement	$1,500	16
Salvage Value		
Salvage	$1,500	20

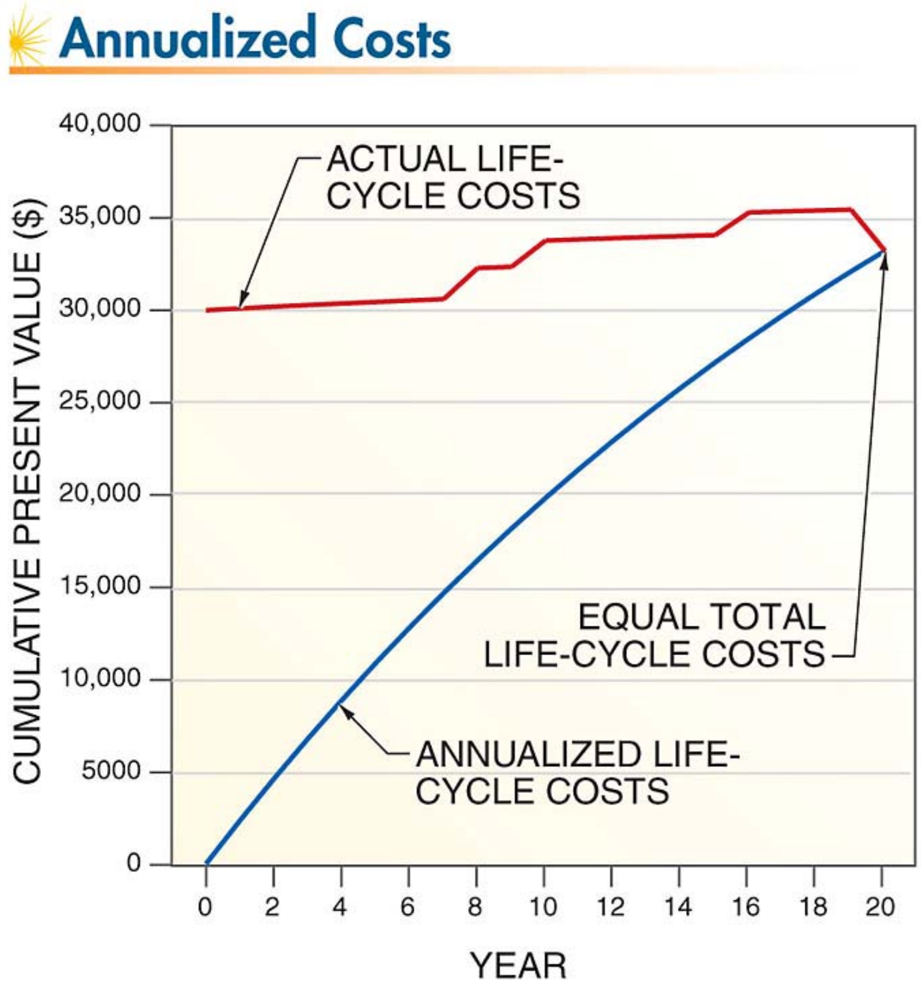
- The most significant costs in the life cycle of a PV system are the initial costs.

Life-Cycle Costs for PV System

LIFE-CYCLE COSTS

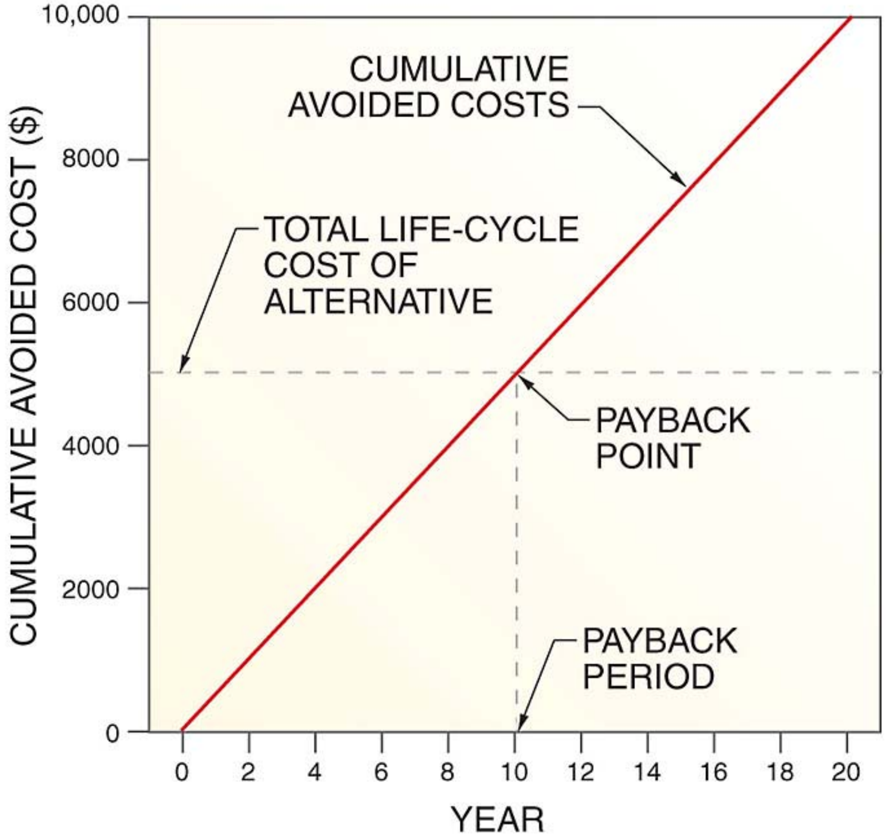
System: PV System

Cost Description	Cost/Year	Single Cost Year
Initial Costs		
System Purchase and Installation	$30,000	0
Maintenance Costs		
Inspections	$100	
Energy Costs		
Repair and Replacement Costs		
Inverter Replacement	$2,000	10
Battery Bank & Module Replacements	$2,200	8
Battery Bank & Module Replacements	$2,200	16
Salvage Value		
Salvage	$5,000	20



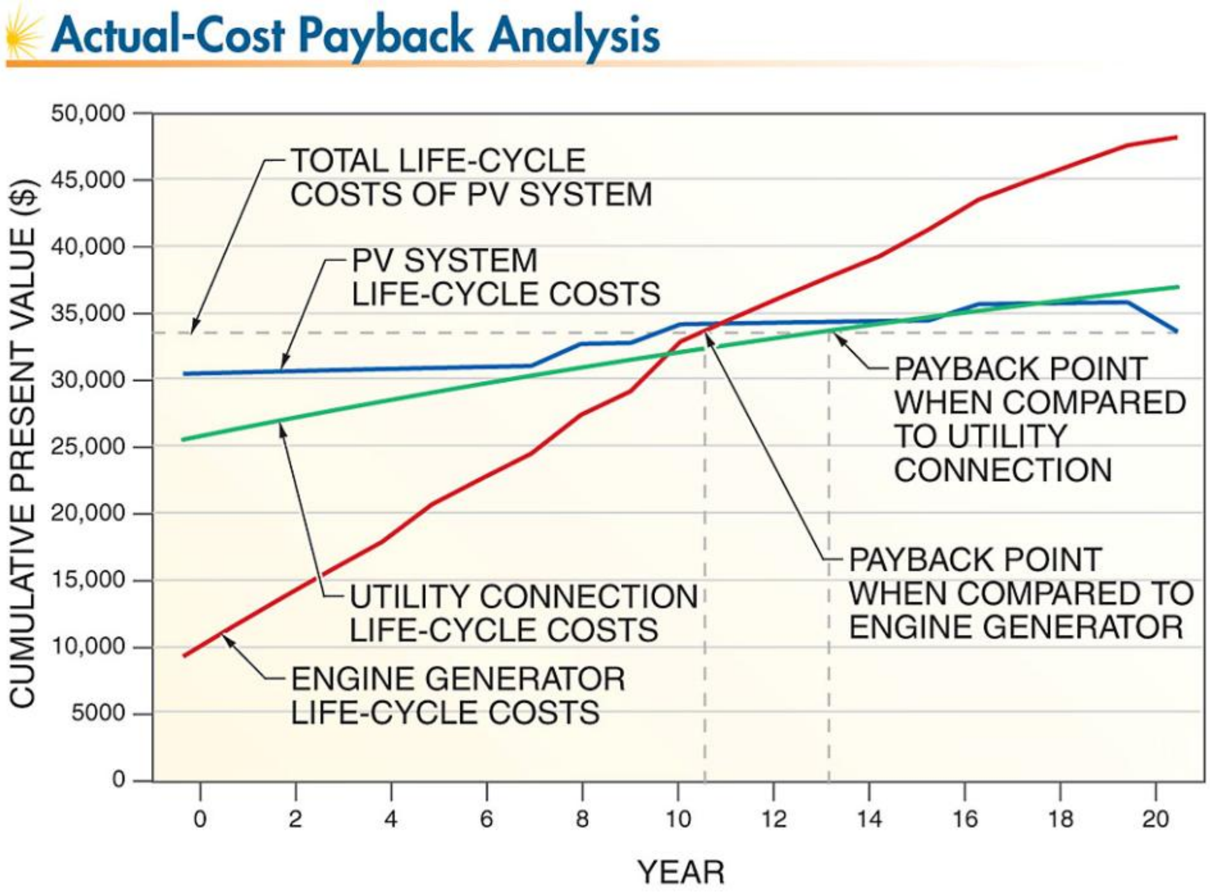
- Annualizing costs spreads costs evenly over the operating period, but results in the same total life-cycle cost for a system.

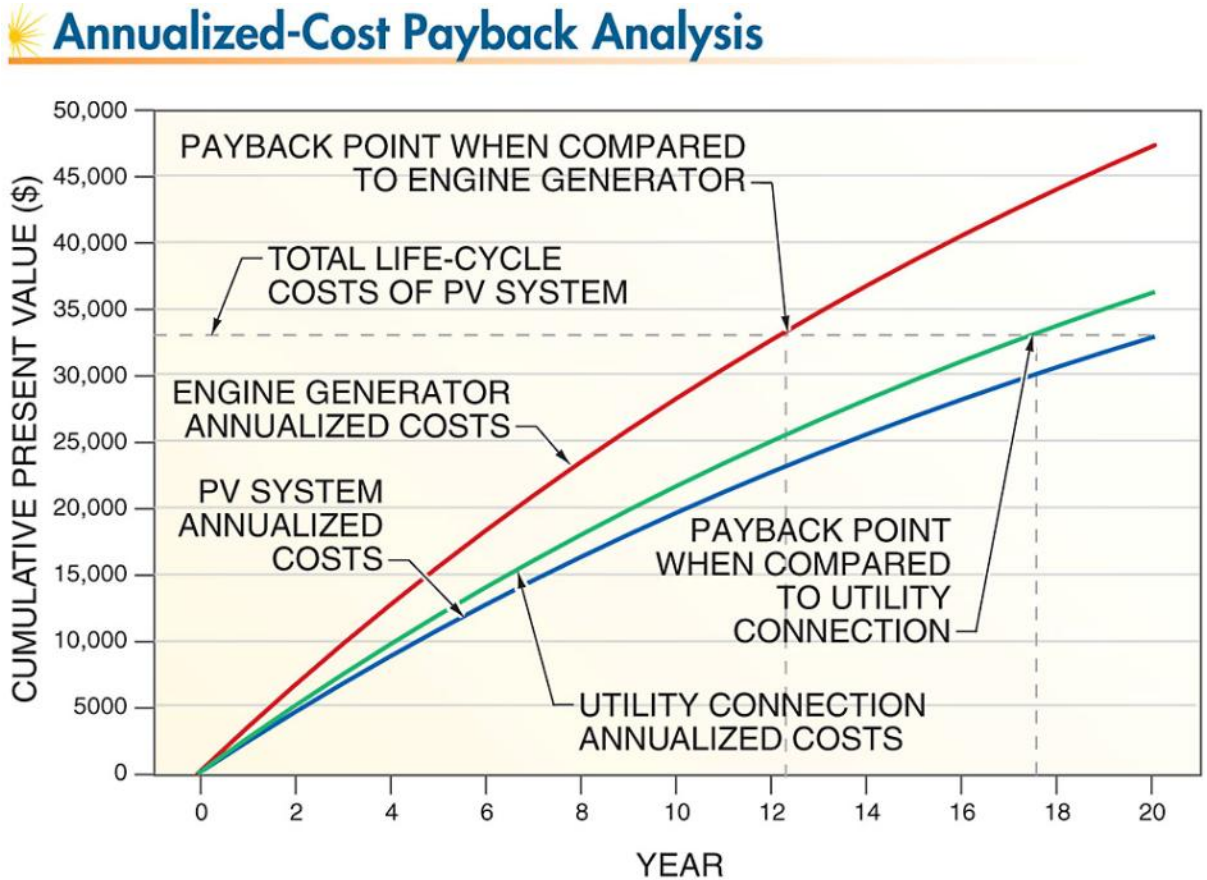
Payback Point



- The payback point occurs when the cumulative avoided cost of one system matches the total life-cycle cost of another system.

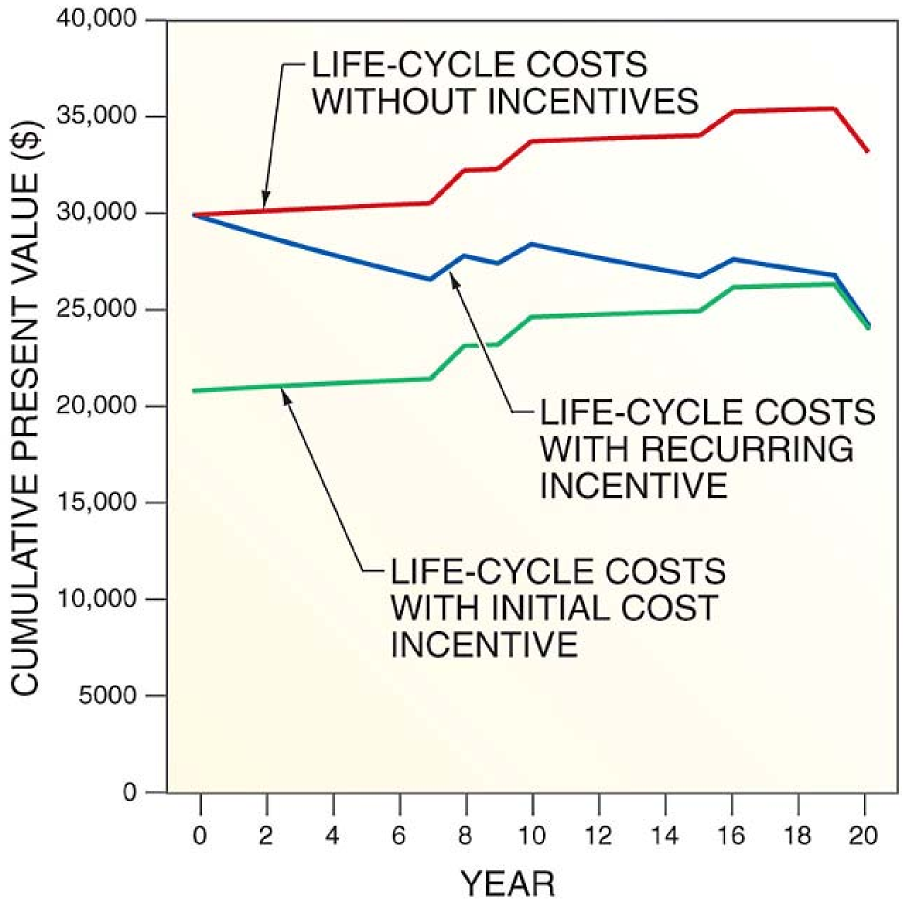
- The payback point can be determined by comparing the actual life-cycle costs of the various system options.





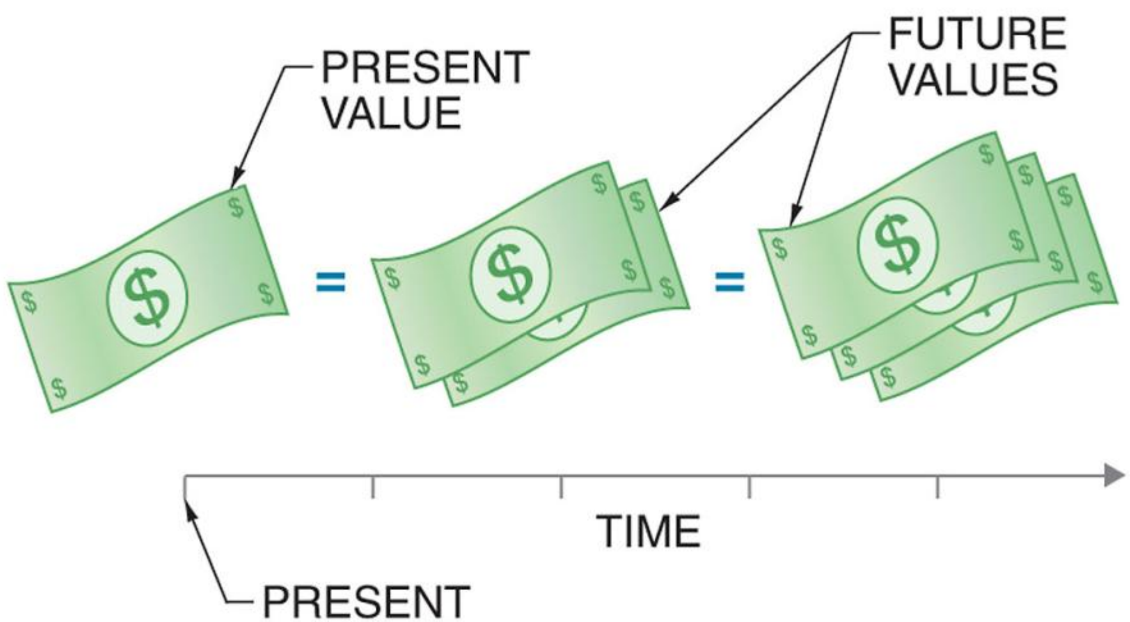
- The annualized-cost method of determining the payback period is relatively simple, though it may be less accurate than the actual-cost method.

Life-Cycle Costs with Incentives



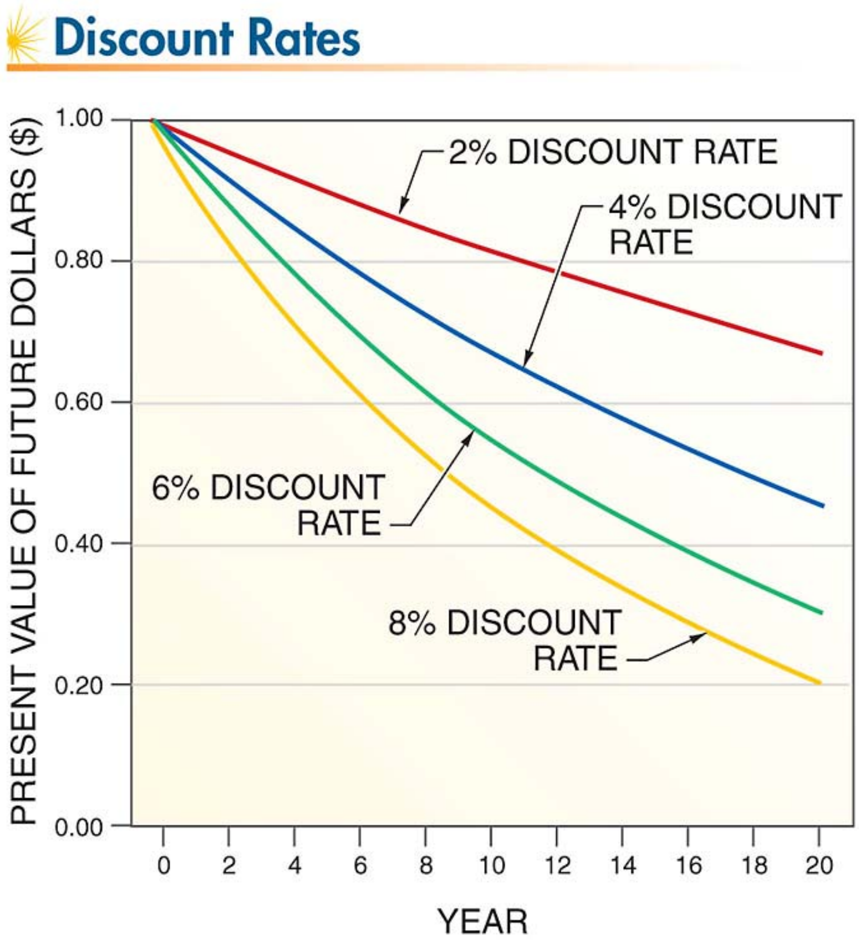
- Incentives affect the total life-cycle cost differently, depending on how and when they are applied.

Value of Money

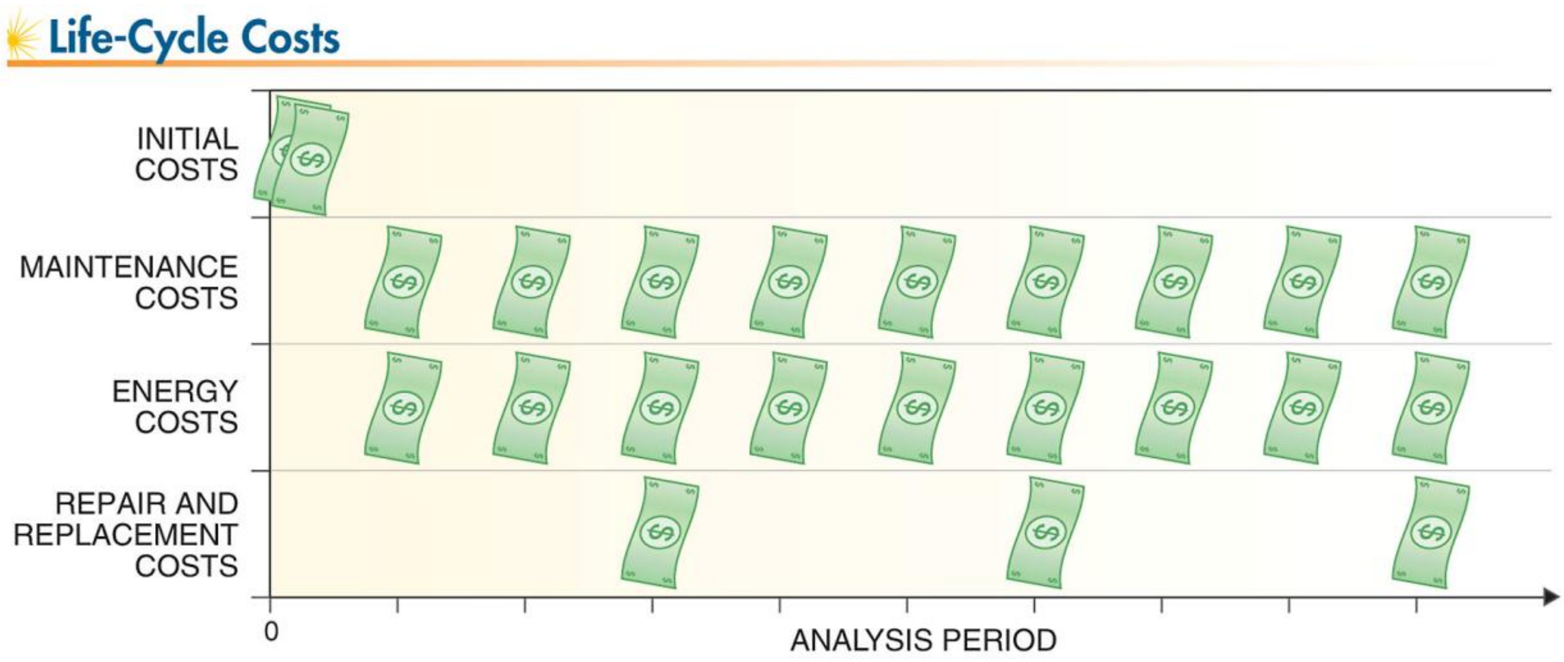


- A certain amount of present money is equal to a greater face-value amount of future money. The difference in face value depends on the difference in time.

- The present value of future money falls more quickly with higher discount rates.



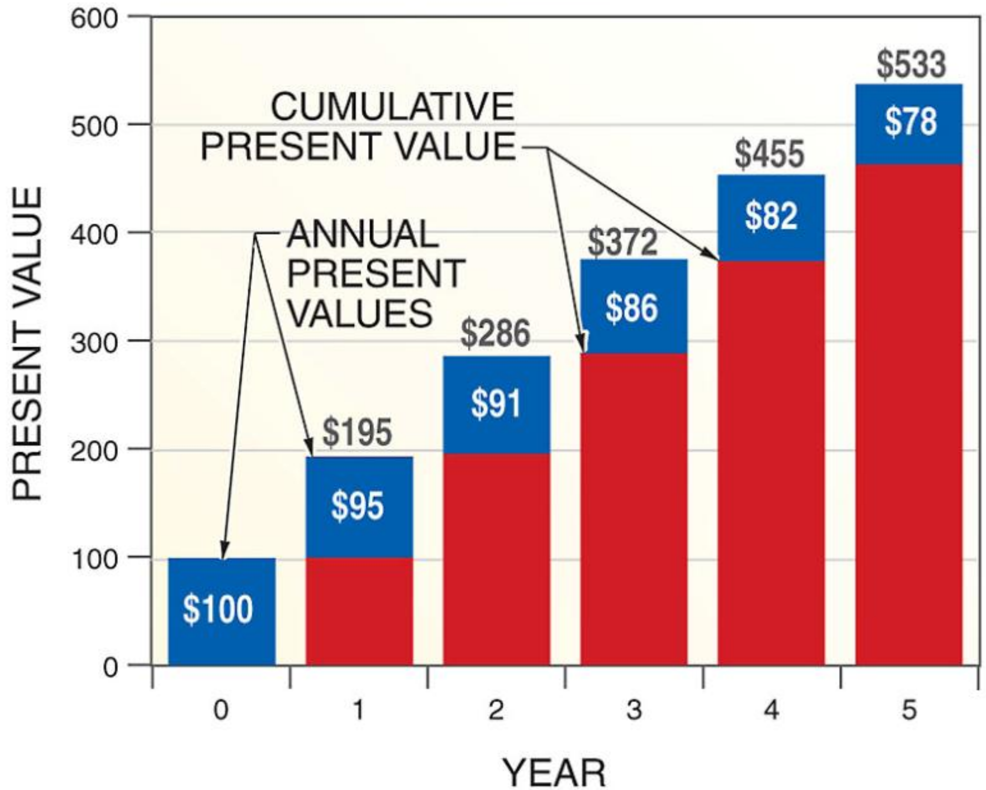
- The various types of life-cycle costs occur at different points in the life cycle of a system.



- NPV requires more math...

$$NPV = -C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + \ldots CT/(1+r)^T$$

Recurring Costs



- Related costs that occur every year are calculated and added together for each year to determine the total present value.

- The life-cycle cost analysis of an engine-generator system includes each type of cost.

Life-Cycle Costs for Engine Generator

LIFE-CYCLE COSTS

System: Engine Generator

General Discount Rate: 0.04
Energy Costs Discount Rate: 0.03

Cost Description	Cost/Year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value
Initial Costs					
System Purchase and Installation	$8,500	0		1.000	$8,500
Maintenance Costs					
Engine Inspection and Oil Changes	$200		20	13.59	$2,718
Energy Costs					
Diesel Fuel	$2,145		20	14.88	$31,918
Repair and Replacement Costs					
Engine Rebuild	$1,000	5		0.822	$822
Engine Rebuild	$1,000	10		0.676	$676
Engine Rebuild	$1,000	15		0.555	$555
Inverter Replacement	$2,000	10		0.676	$1,352
Battery Bank Replacement	$1,500	8		0.731	$1,097
Battery Bank Replacement	$1,500	16		0.534	$801
Salvage Value					
Salvage	$1,500	20		0.456	-$684
				Total Life Cycle Costs	**$47,755**

- The most significant costs in the life cycle of a PV system are the initial costs.

Life-Cycle Costs for PV System

LIFE-CYCLE COSTS

System: PV System

General Discount Rate: 0.04
Energy Costs Discount Rate: 0.03

Cost Description	Cost/Year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value
Initial Costs					
System Purchase and Installation	$30,000	0		1.000	$30,000
Maintenance Costs					
Inspections	$100		20	13.59	$1,359
Energy Costs					
Repair and Replacement Costs					
Inverter Replacement	$2,000	10		0.676	$1,352
Battery Bank & Module Replacements	$2,200	8		0.731	$1,608
Battery Bank & Module Replacements	$2,200	16		0.534	$1,175
Salvage Value					
Salvage	$5,000	20		0.456	-$2,280
				Total Life Cycle Costs	**$33,214**

- Internal rate of Return is the resulting r if NPV = 0

$$NPV = -C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + \dots CT/(1+r)^T$$

$$0 = -C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + \dots CT/(1+r)^T$$

Does not require discount rate to solve

Scale problem

Timing problem

Sometimes referred to as ‘hurdle rate’