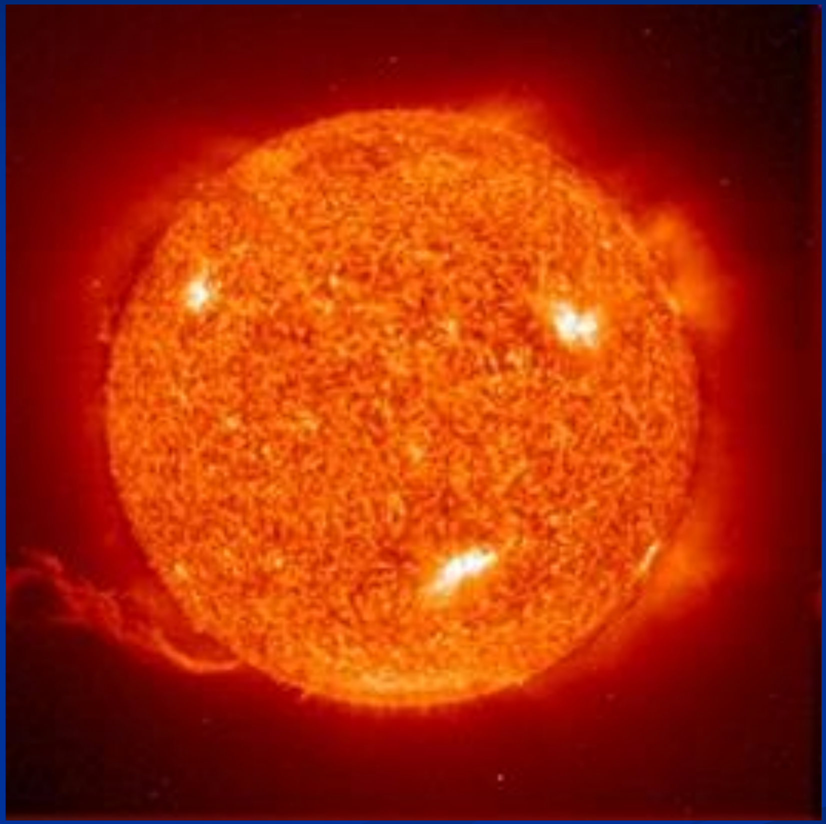
Solar Energy: The Ultimate Renewable Resource

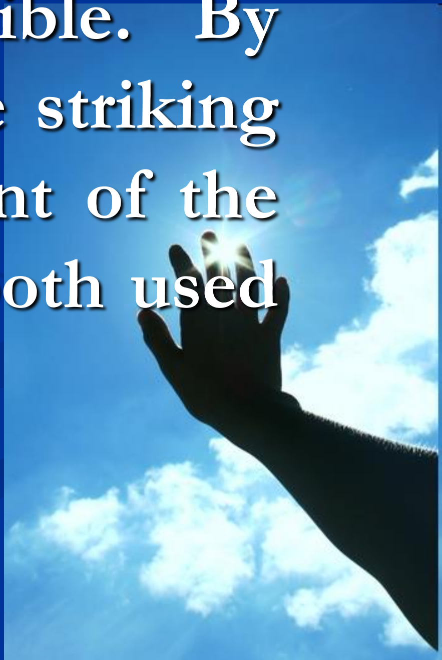
What is Solar Energy?

- Originates with the thermonuclear fusion reactions occurring in the sun.
- Represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves).
- Radiant energy from the sun has powered life on Earth for many millions of years.



Advantages and Disadvantages

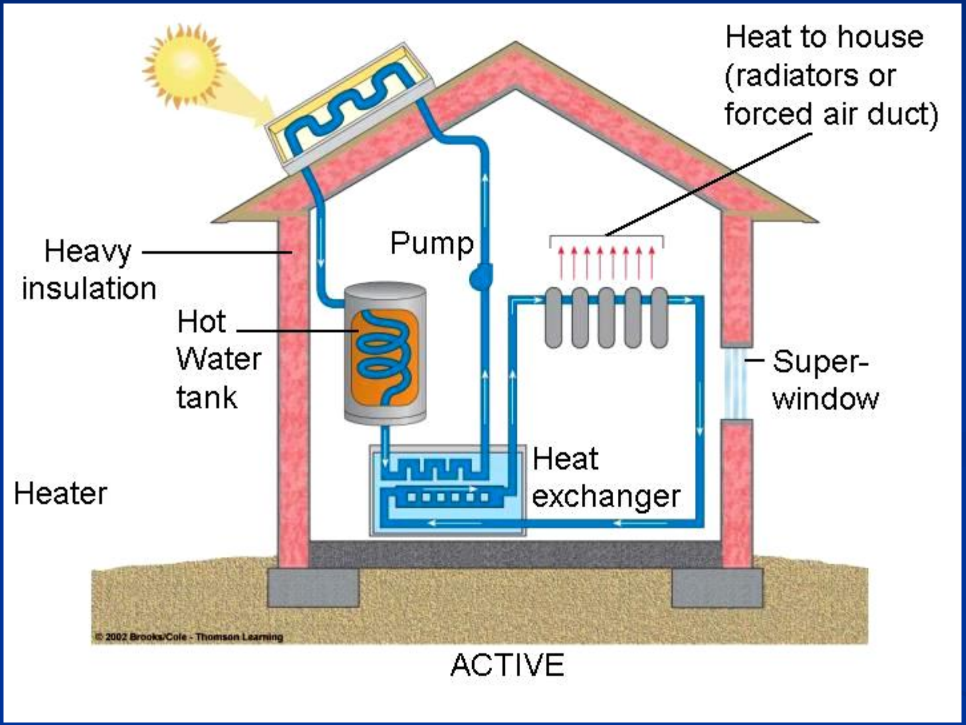
- Advantages
  - All chemical and radioactive polluting by products of the thermonuclear reactions remain behind on the sun, while only pure radiant energy reaches the Earth.
  - Energy reaching the earth is incredible. By one calculation, 30 days of sunshine striking the Earth have the energy equivalent of the total of all the planet's fossil fuels, both used and unused!



Advantages and Disadvantages

- Disadvantages
  - Sun does not shine consistently.
  - Solar energy is a diffuse source. To harness it, we must concentrate it into an amount and form that we can use, such as heat and electricity.

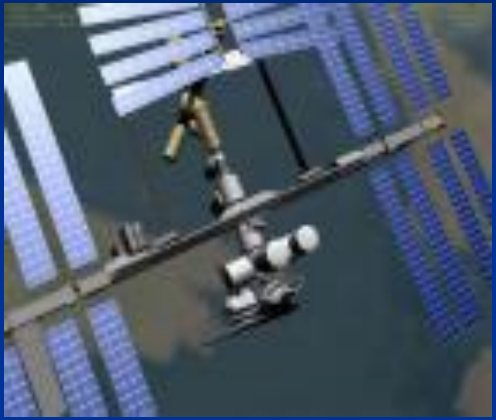
Solar Energy to Heat Living Spaces



- **Proper design of a building is for it to act as a solar collector and storage unit. This is achieved through three elements: insulation, collection, and storage.**

Main Application Areas – Off-grid

Water Pumping



Space

Telecom

Solar Home Systems

Main Application Areas
Grid Connected

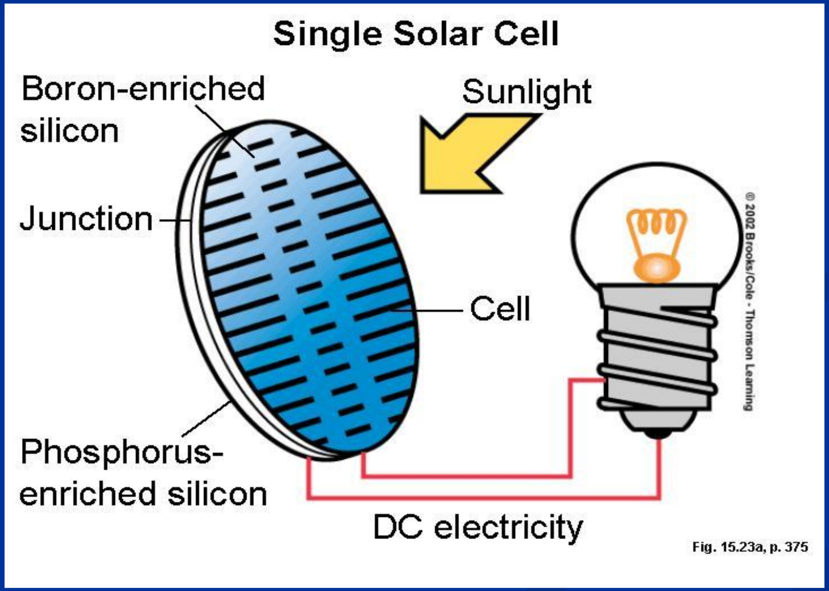
Commercial Building Systems (50 kW)

Residential Home Systems (2-8 kW)

PV Power Plants (> 100 kW)

Photovoltaics

- Photo+voltaic = convert light to electricity



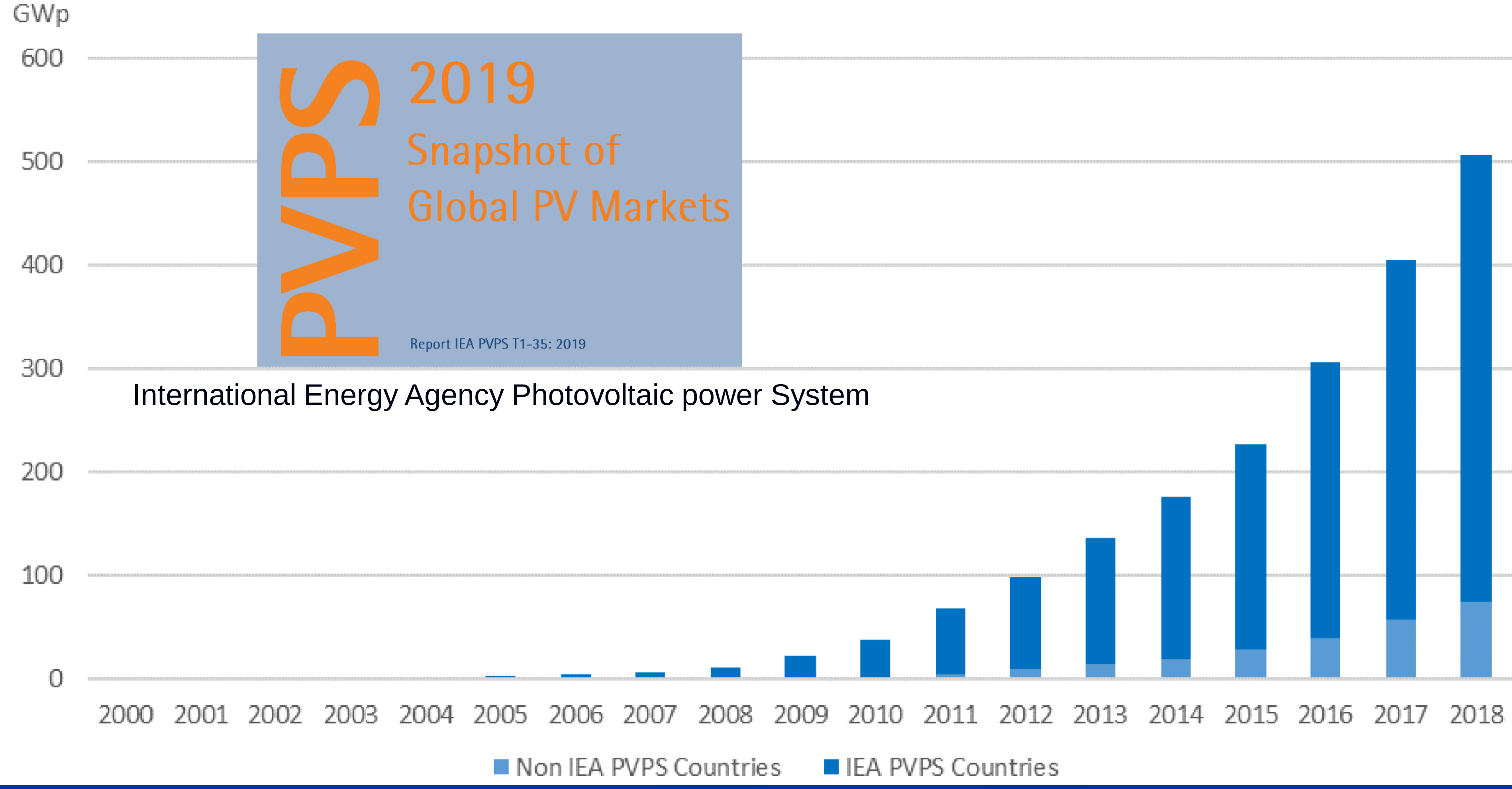
Solar Cells Background

- 1839 - French physicist A. E. Becquerel first recognized the photovoltaic effect.
- 1883 - first solar cell built, by Charles Fritts, coated semiconductor selenium with an extremely thin layer of gold to form the junctions.
- 1954 - Bell Laboratories, experimenting with semiconductors, accidentally found that silicon doped with certain impurities was very sensitive to light. Daryl Chapin, Calvin Fuller and Gerald Pearson, invented the first practical device for converting sunlight into useful electrical power. Resulted in the production of the first practical solar cells with a sunlight energy conversion efficiency of around 6%.
- 1958 - First spacecraft to use solar panels was US satellite Vanguard

http://en.wikipedia.org/wiki/Solar_cell

Driven by Space Applications in Early Days

Global evolution of PV installations



TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2018

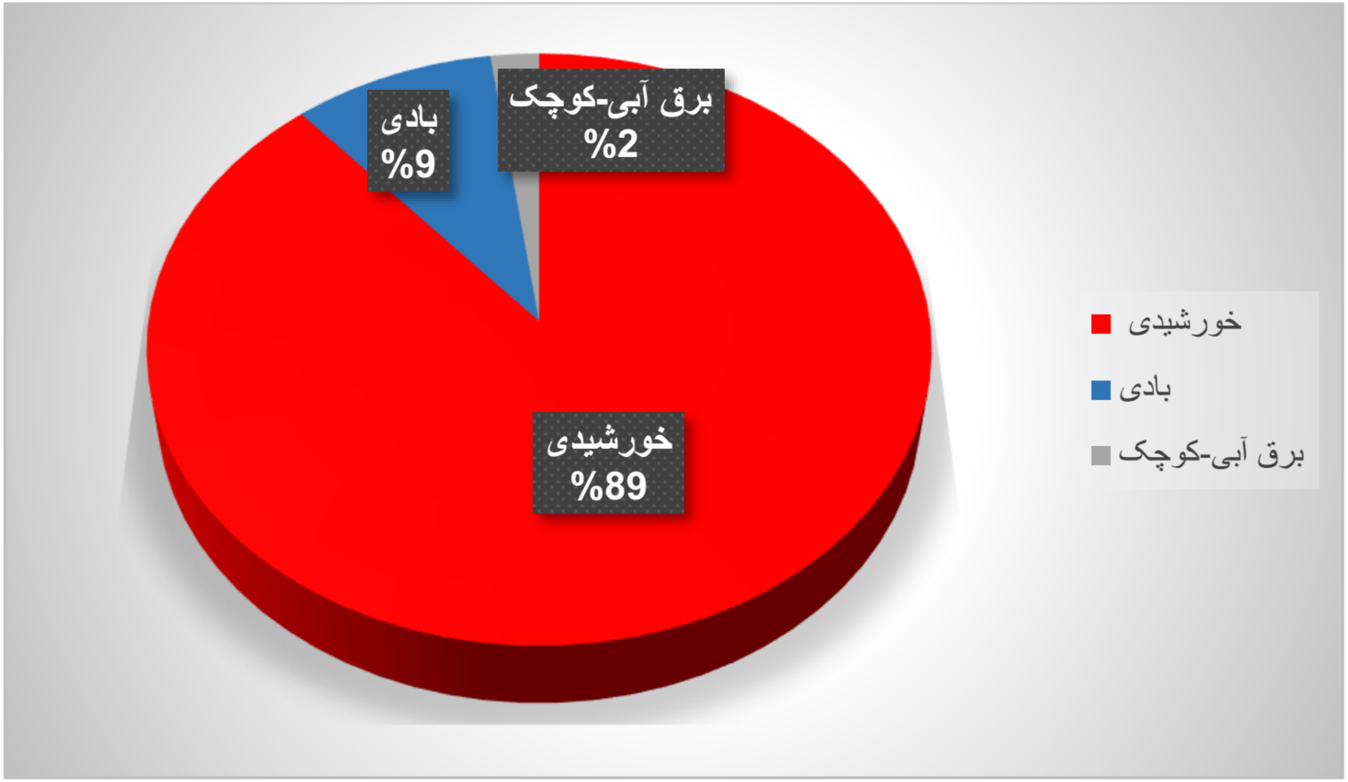
FOR ANNUAL INSTALLED CAPACITY			FOR CUMULATIVE CAPACITY		
1	China	45,0 GW	1	China	176,1 GW
2	India	10,8 GW	2	USA	62,2 GW
3	USA	10,6 GW	3	Japan	56,0 GW
4	Japan	6,5 GW	4	Germany	45,4 GW
5	Australia	3,8 GW	5	India	32,9 GW
6	Germany	3,0 GW	6	Italy	20,1 GW
7	Mexico	2,7 GW	7	UK	13,0 GW
8	Korea	2,0 GW	8	Australia	11,3 GW
9	Turkey	1,6 GW	9	France	9,0 GW
10	Netherlands	1,3 GW	10	Korea	7,9 GW
	UE*	8,3 GW		EU*	115,0 GW

مرجع:

وزارت نیرو

سازمان انرژی‌های تجدیدپذیر و بهره‌وری انرژی برق (ساتبا)

نگاهی اجمالی به عملکرد نیروگاه‌های تجدیدپذیر کشور در سال ۹۷



نیروگاه	تولید MW
خورشیدی	۱۲۱/۳۵
بادی	۱۲/۵
برق آبی-کوچک	۳
مجموع	۱۳۶/۸۵

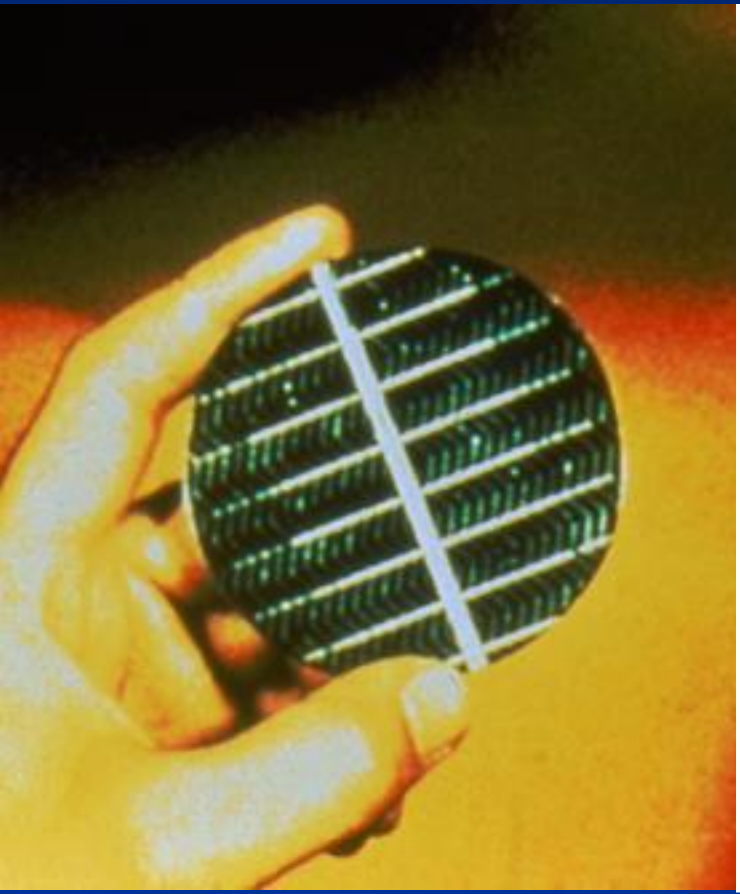
جدول (۱-۱) عملکرد نیروگاه‌های تجدیدپذیر کشور ۹۷-۱۳۹۴

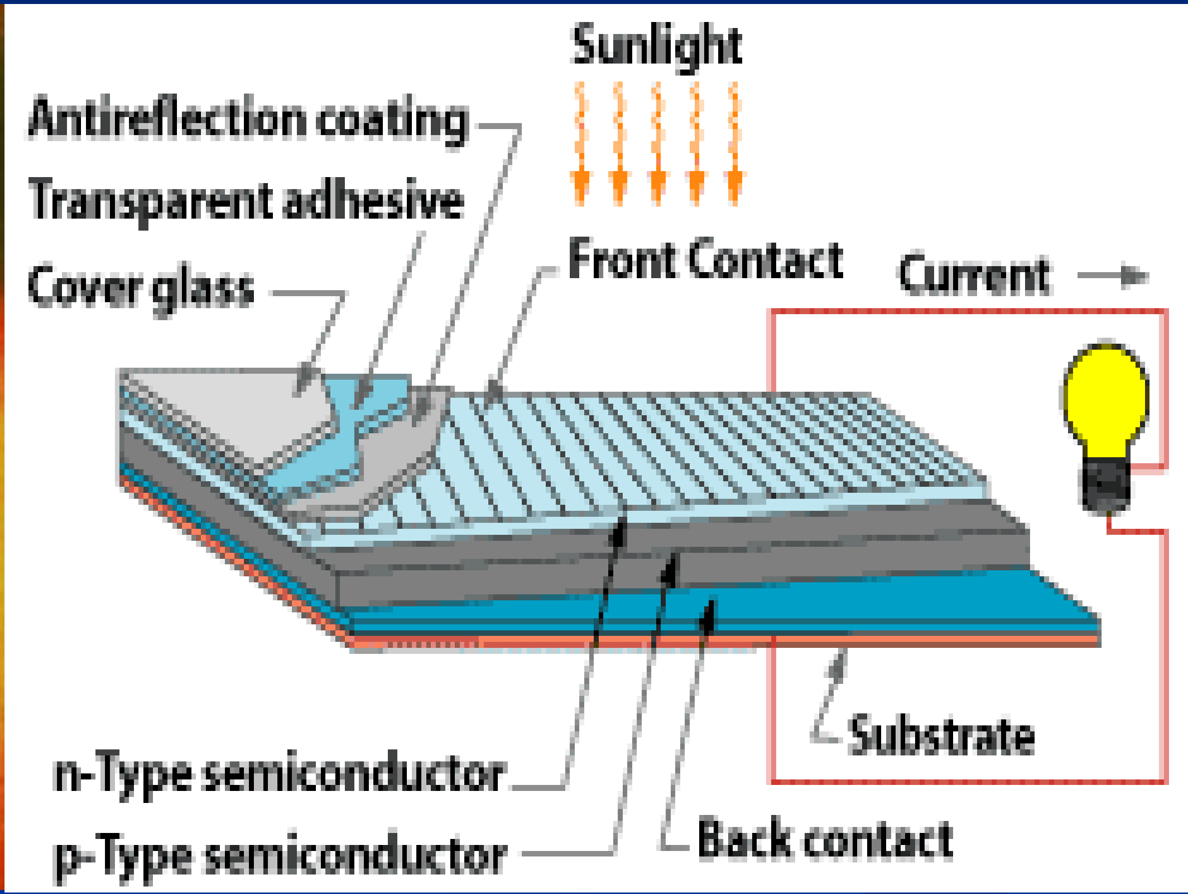
نیروگاه‌های	بادی	خورشیدی	برق-آبی کوچک	زیست توده	بازیافت تلفات حرارتی	مجموع (MW)
۱۳۹۴	۵٤/۵۹	۰/۷۱	۰/٤٤	۵/٦٦	۰	٦۱/٤۰
۱۳۹۵	۳۷/۵۰	۳۱/۰۷	۰/٤۱	٤/۹	۱۳/٦	۸۷/٤۸
۱۳۹٦)	۱۷۳/٤٦	۱۳۹/۷۳	۹	۰	۰	۳۲۲/۱۹
۱۳۹۷	۱۲/۵	۱۲۱/۳۵	۳	۰	۰	۱۳٦/۸۵
مجموع ۹۷-۱۳۹٤	۲۷۸/۰۵	۲۹۲/۸٦	۱۲/۸۵	۱۰/۵٦	۱۳/٦	٦۰۷/۹۲
مجموع ماقبل ۱۳۹٤	٦/٦۱	۸	۷۵/۳۵	۰	۰	۸۹/۹٦
مقیاس کوچک (پشت بامی)[1]	۳۵					
جمع کل تجدیدپذیر کشور	۲۸٤/٦٦	۳۰۰/۸٦	۸۸/۲	۱۰/۵٦	۱۳/٦	٦۹۷/۸۸

ظرفیت نصب شده نیروگاهی	میزان (MW)	سهم(درصد)
بخاری	۱۵۸۲۹	۱۹/۷۷
گازی	۲۵۳۵۵	۳۱/۶۷
چرخه ترکیبی	۲۳۴۸۶	۲۹/۳۴
برق آبی	۱۱۹۳۸	۱۴/۹۱
اتمی	۱۰۲۰	۱/۲۷
تولید پراکنده (شامل ۲۵۳ MW خودتامین)	۱۳۳۵	۱/۶۷
انرژی های تجدید پذیر	۶۵۱	۰/۸۱
دیزلی	۴۳۹	۰/۵۵
کل ظرفیت نصب شده	۸۰۰۵۳	۱۰۰

بطور متعارف، توان مصرفی یک منزل مسکونی: 3kw

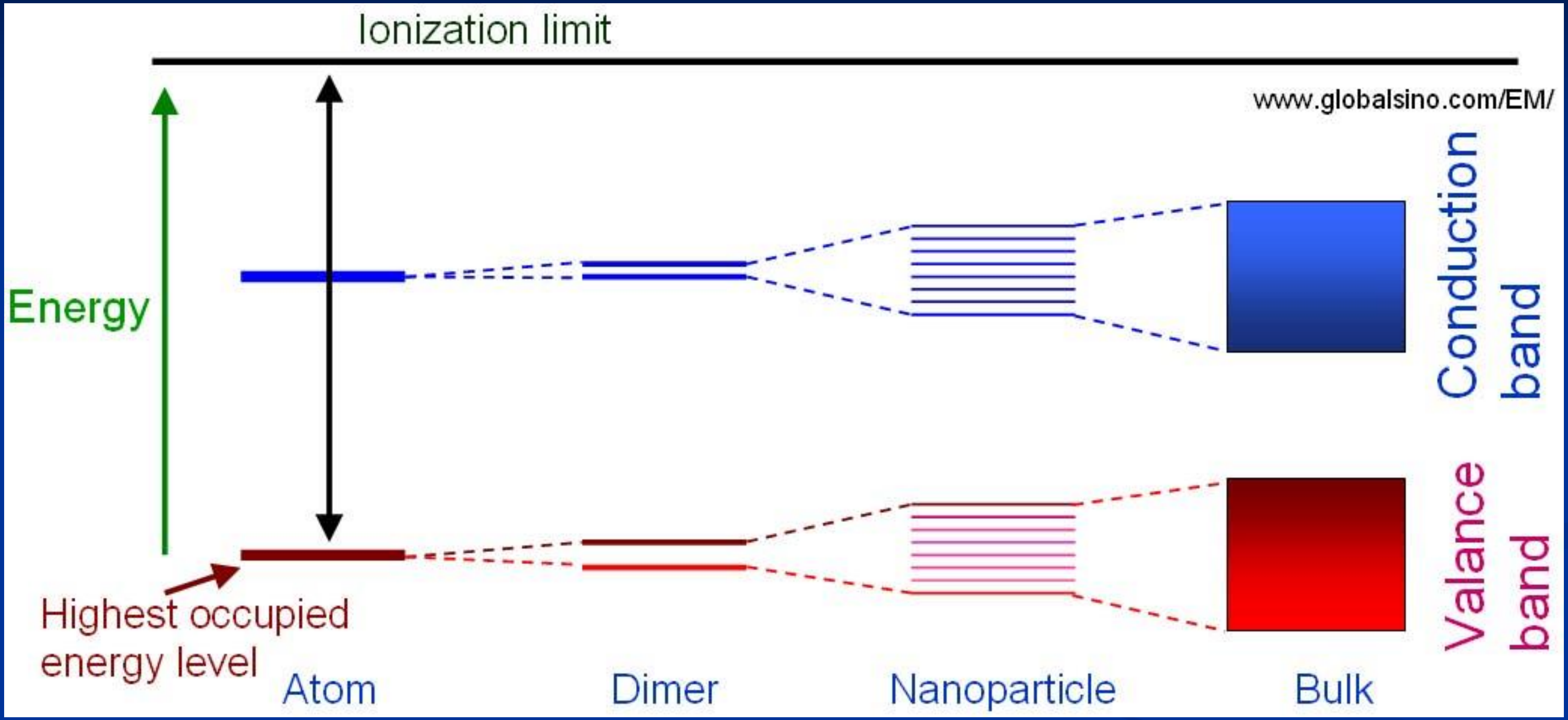
How does it work





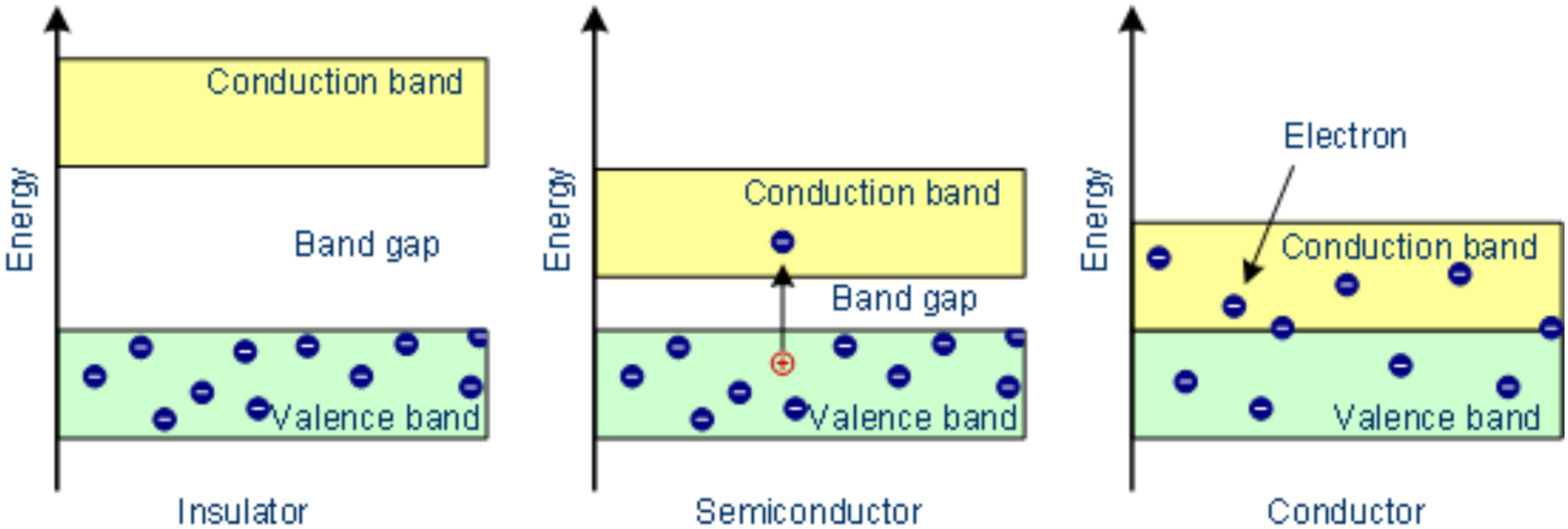
The heart of a photovoltaic system is a solid-state device called a solar cell.

Energy Band Formation in Solid



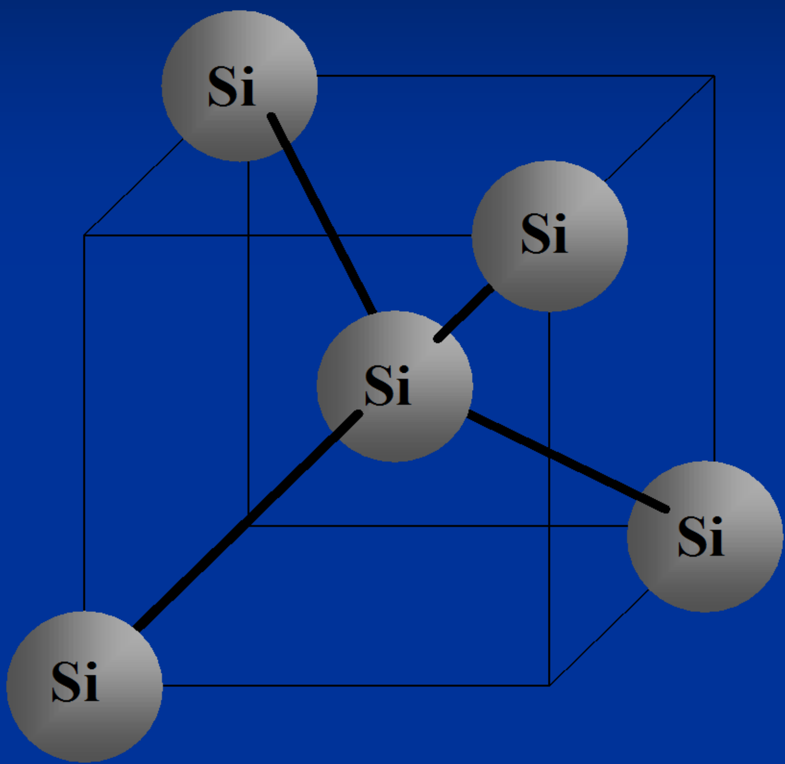
- Each isolated atom has discrete energy level, with two electrons of opposite spin occupying a state.
- When atoms are brought into close contact, these energy levels split.
- If there are a large number of atoms, the discrete energy levels form a "continuous" band.

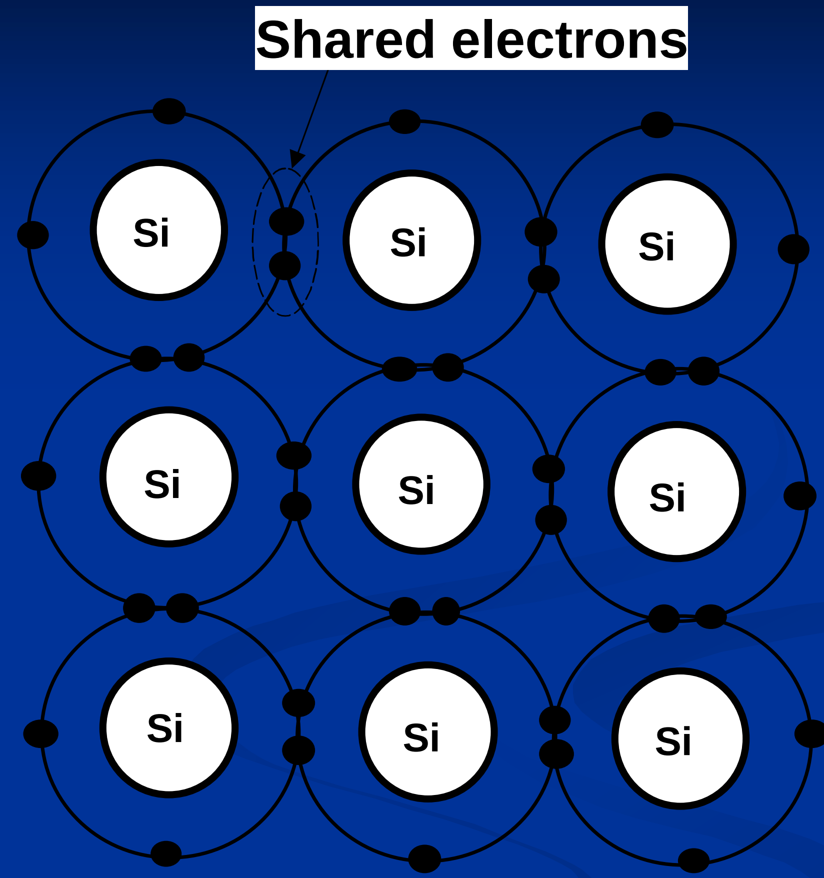
Energy Band Diagram of a Conductor, Semiconductor, and Insulator



- Semiconductor is interest because their conductivity can be readily modulated (by impurity doping or electrical potential), offering a pathway to control electronic circuits.

Silicon





- **Silicon is group IV element – with 4 electrons in their valence shell.**
- **When silicon atoms are brought together, each atom forms covalent bond with 4 silicon atoms in a tetrahedron geometry.**

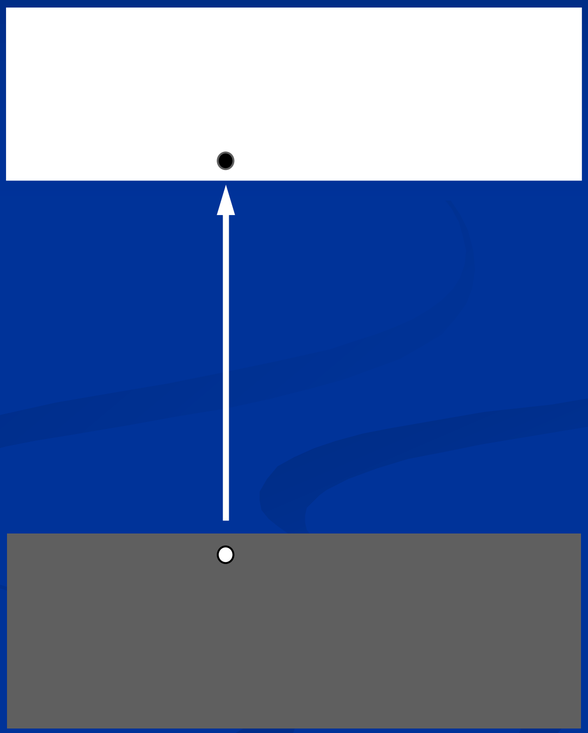
Intrinsic Semiconductor

- At 0 ºK, each electron is in its lowest energy state so each covalent bond position is filled.

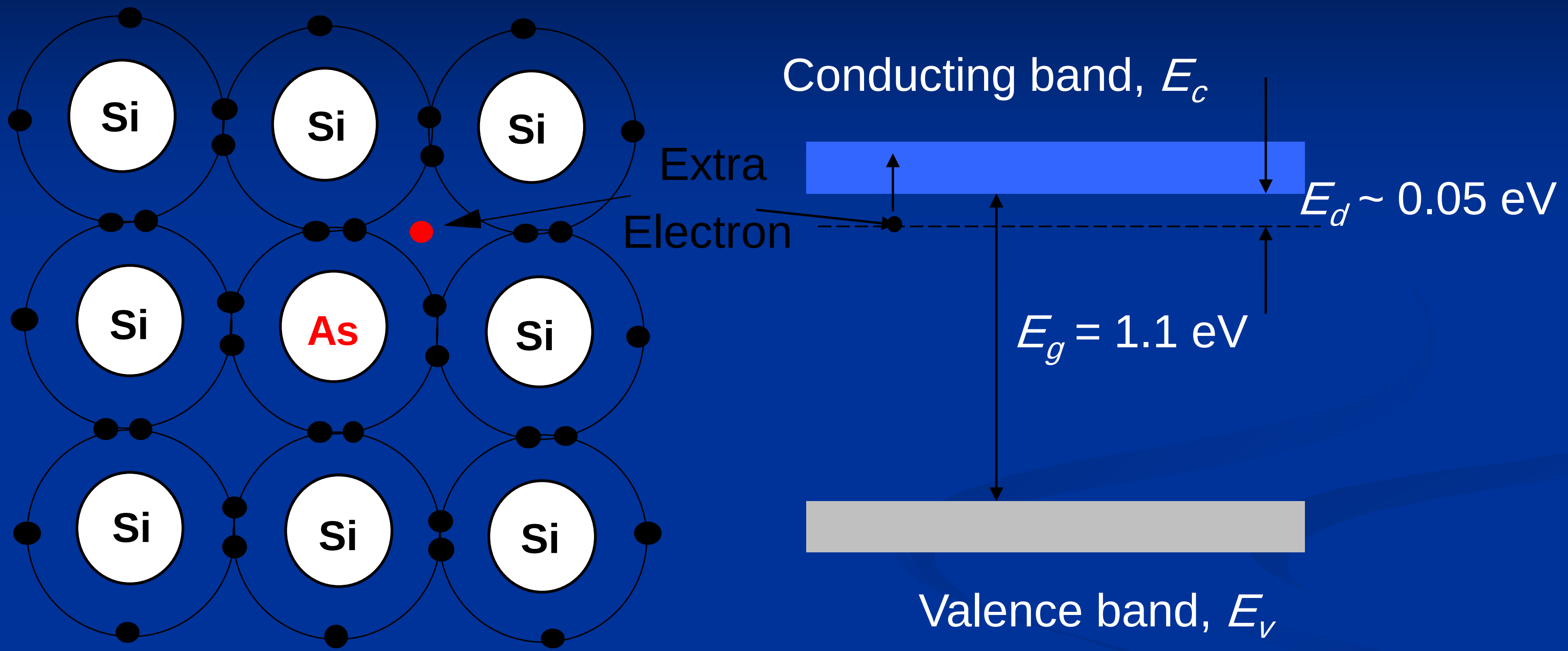
  => At 0 ºK, silicon is an insulator.

- As temperature increases, the valence electrons gain thermal energy. If a valence electron gains enough energy (Eg), it may break its covalent bond and move away from its original position. This electron is free to move within the crystal.

- Semiconductor Eg ~1eV, a few electrons can be excited (e.g. 1/billion)

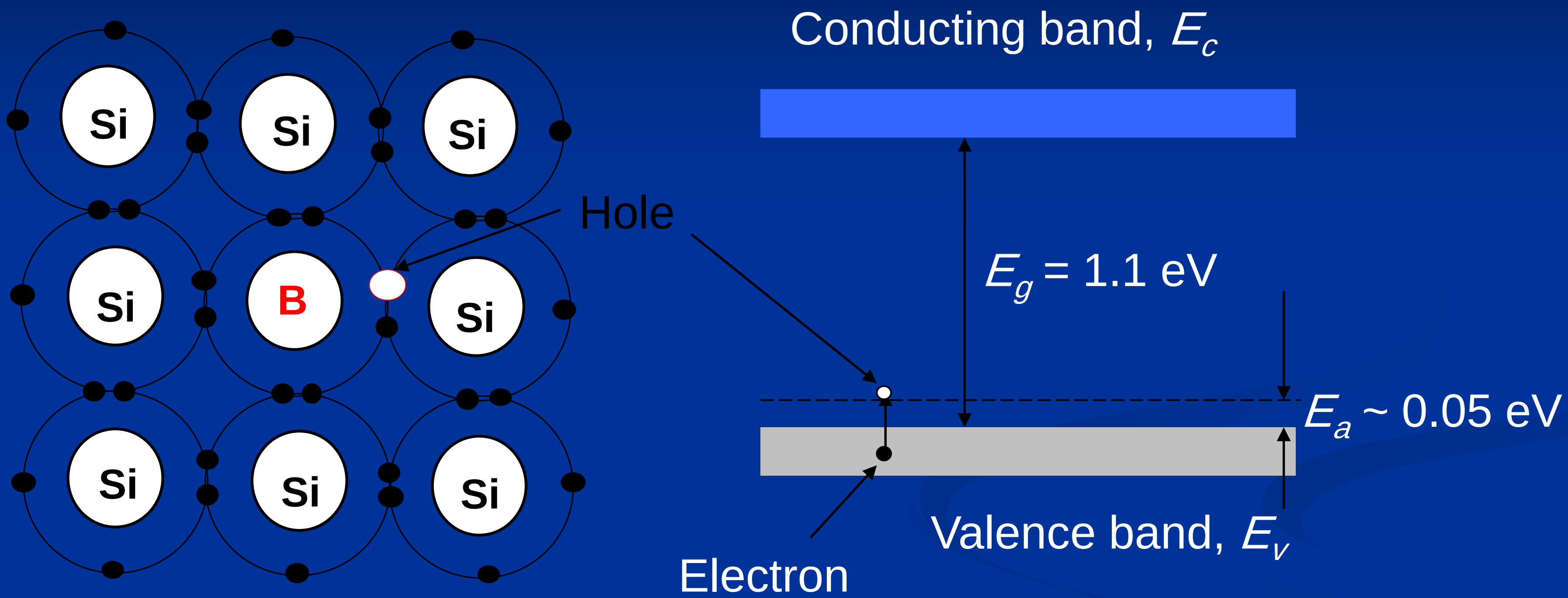


Extrinsic Semiconductor, n-type Doping



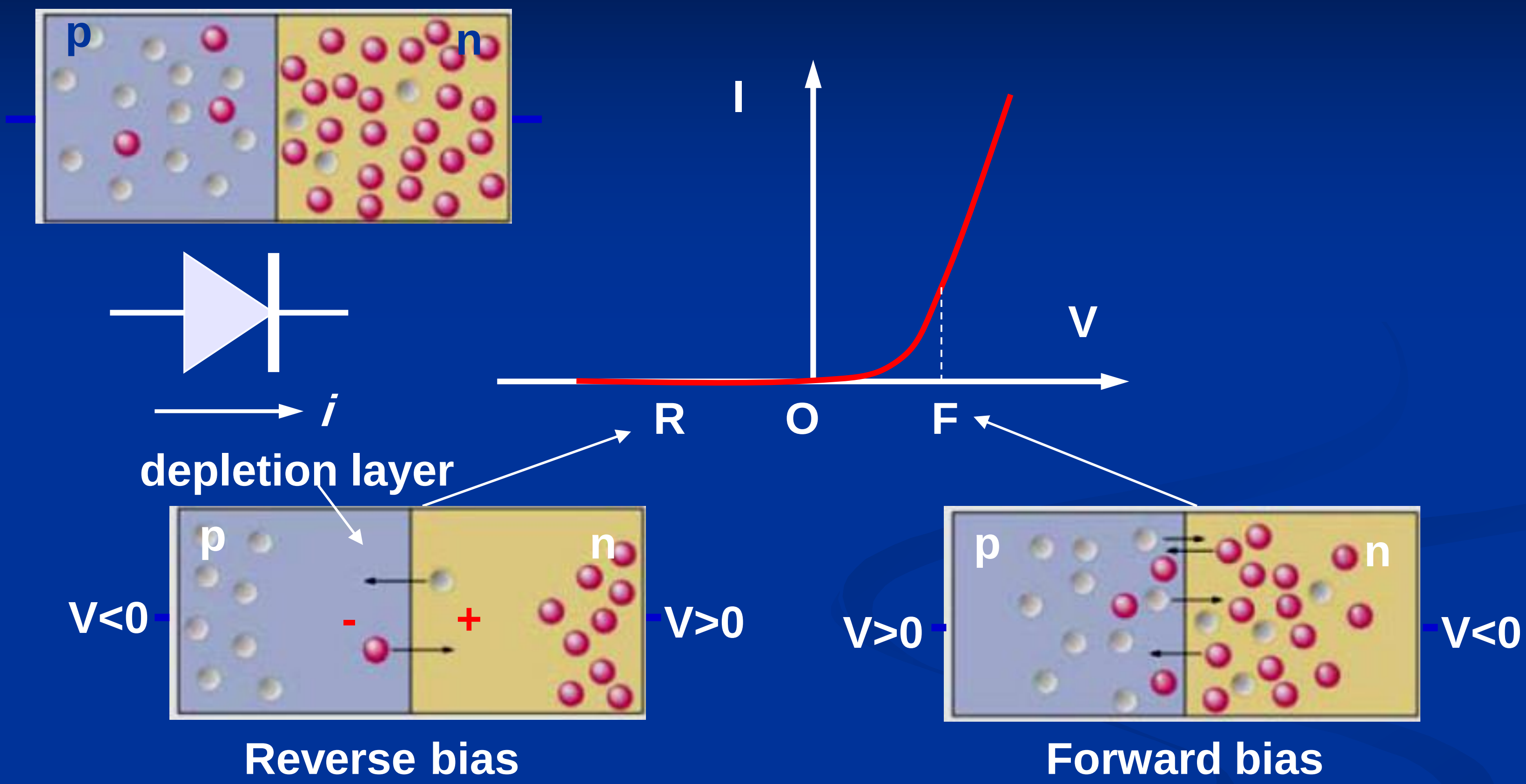
- Doping silicon lattice with group V elements can creates extra electrons in the conduction band — **negative charge carriers (n-type), As- donor**.
- Doping concentration #/cm^3 (10^{16}/cm^3 ~ 1/million).

Extrinsic Semiconductor, p-type doping



- Doping silicon with group III elements can creates empty holes in the valence band — **positive charge carriers (p-type), B-(acceptor).**

p-n Junction (p-n diode)



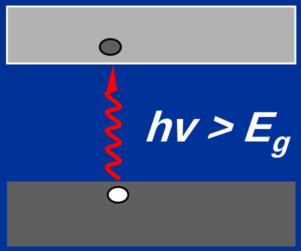
- A p-n junction is a junction formed by combining p-type and n-type semiconductors together in very close contact.
- In p-n junction, the current is only allowed to flow along one direction from p-type to n-type materials.

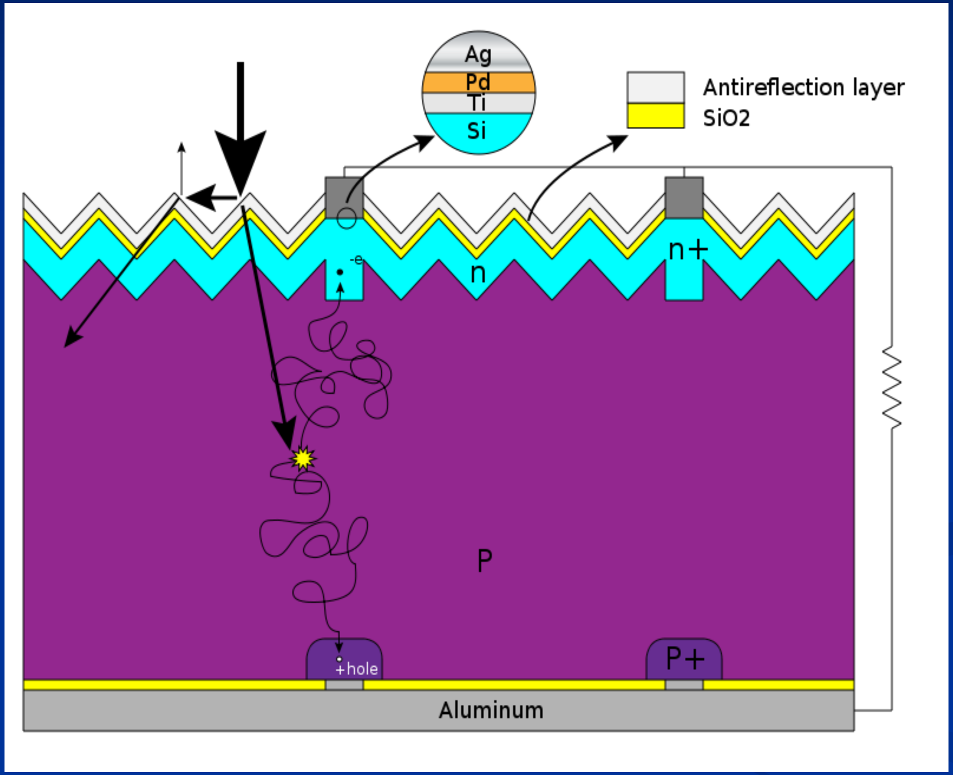
p-n Junction (p-n diode)

- A p-n junction is the basic device component for many functional electronic devices listed above.

  - **Solar Cells**
  - Light-emitting Diodes
  - Diode Lasers
  - Photodetectors
  - Transistors

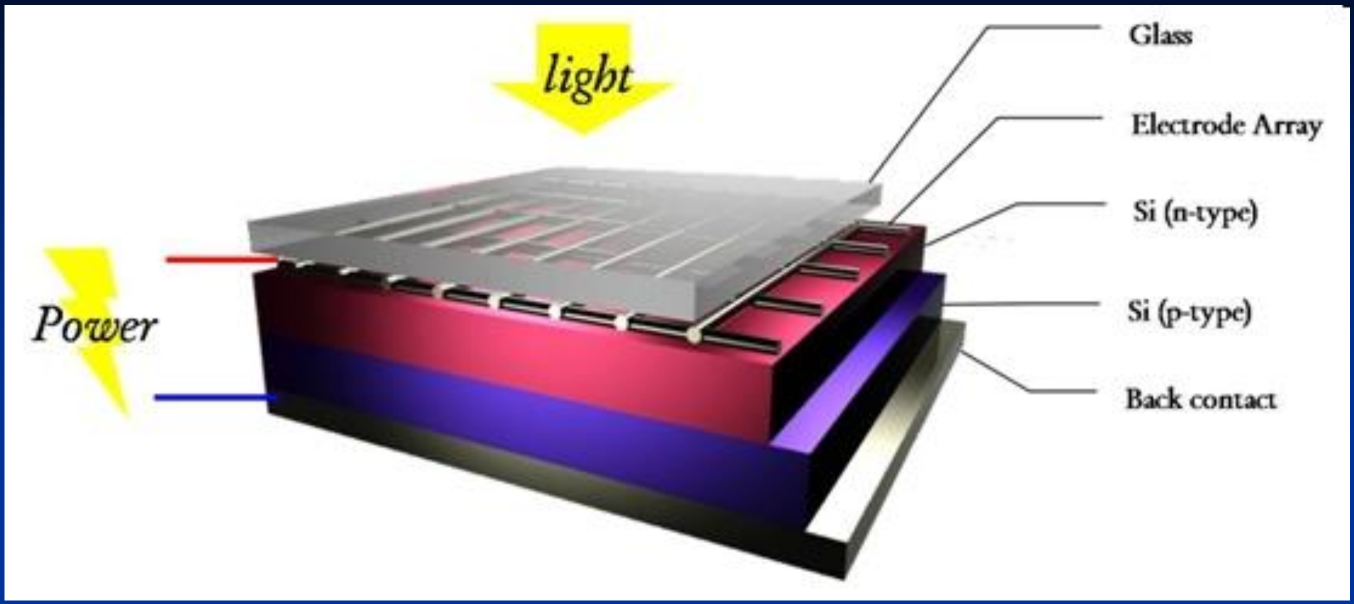
How Solar Cells Work



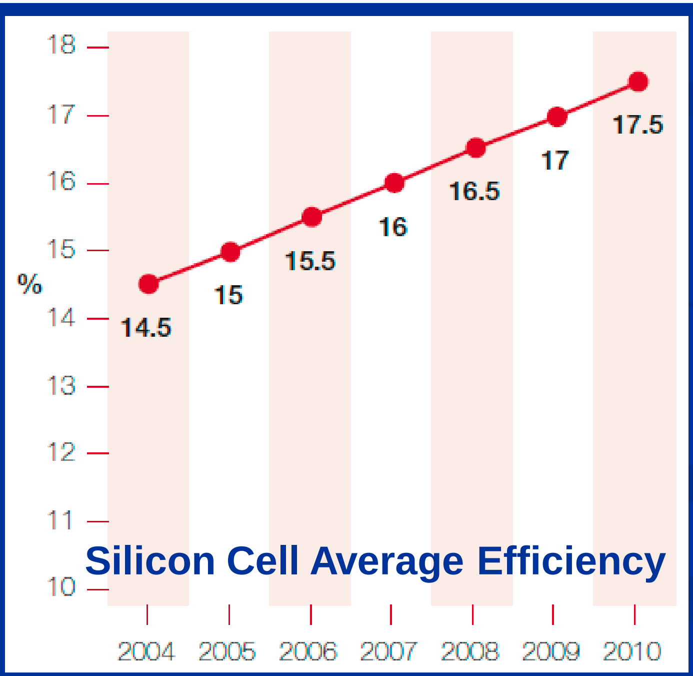


- Photons in sunlight hit the solar panel and are absorbed by semiconducting materials to create electron hole pairs.
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity.

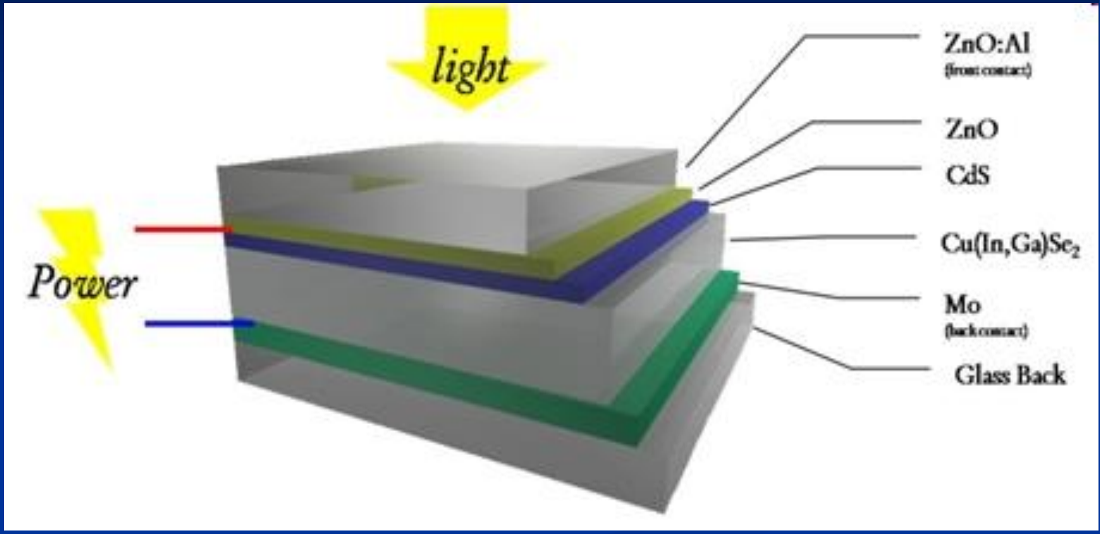
First Generation



- Limit efficiency 31%

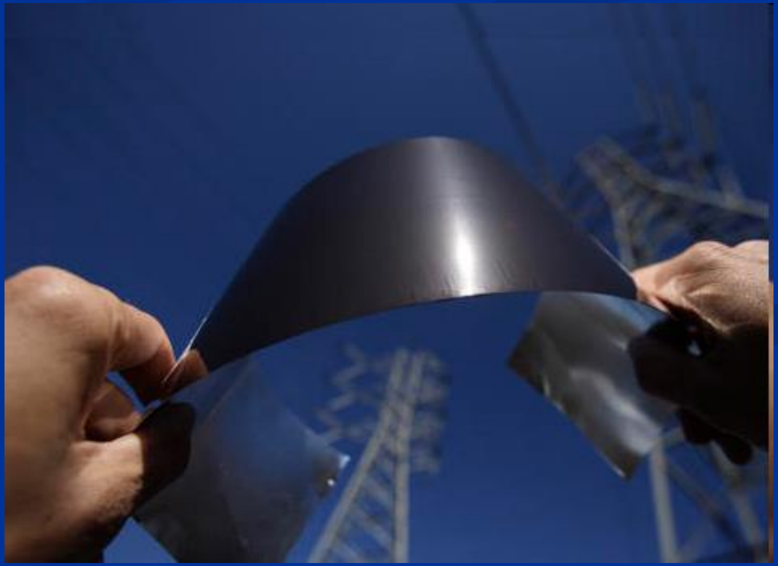


Second Generation
– Thin Film Cells



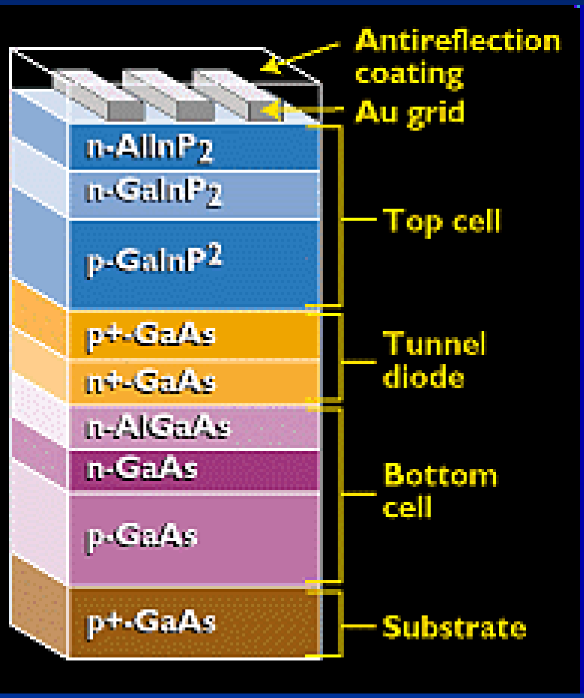
CdTe 4.7% & CIGS 0.5% of 2007 Production

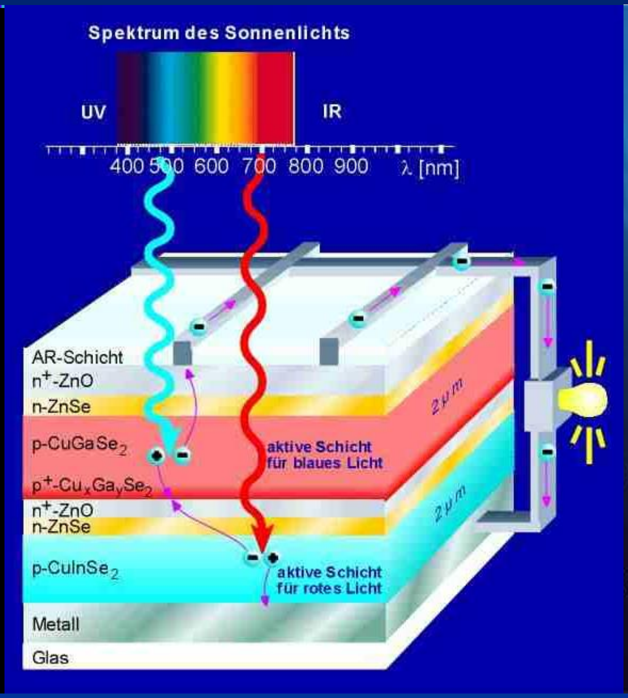
- New materials and processes to improve efficiency and reduce cost.
- Thin film cells use about 1% of the expensive semiconductors compared to First Generation cells.

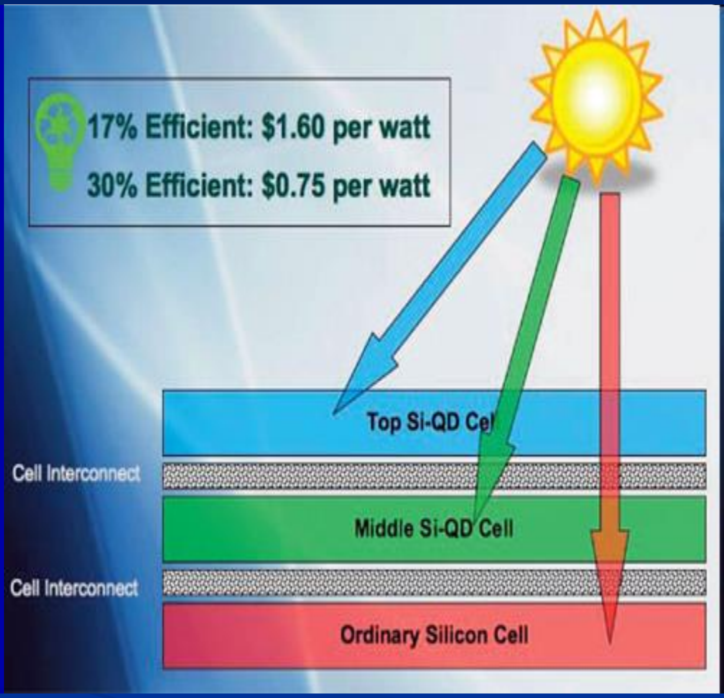


- CdTe – 8 – 11% efficiency (18% demonstrated)
- CIGS – 7-11% efficiency (20% demonstrated)

Third Generation
– Multi-junction Cells

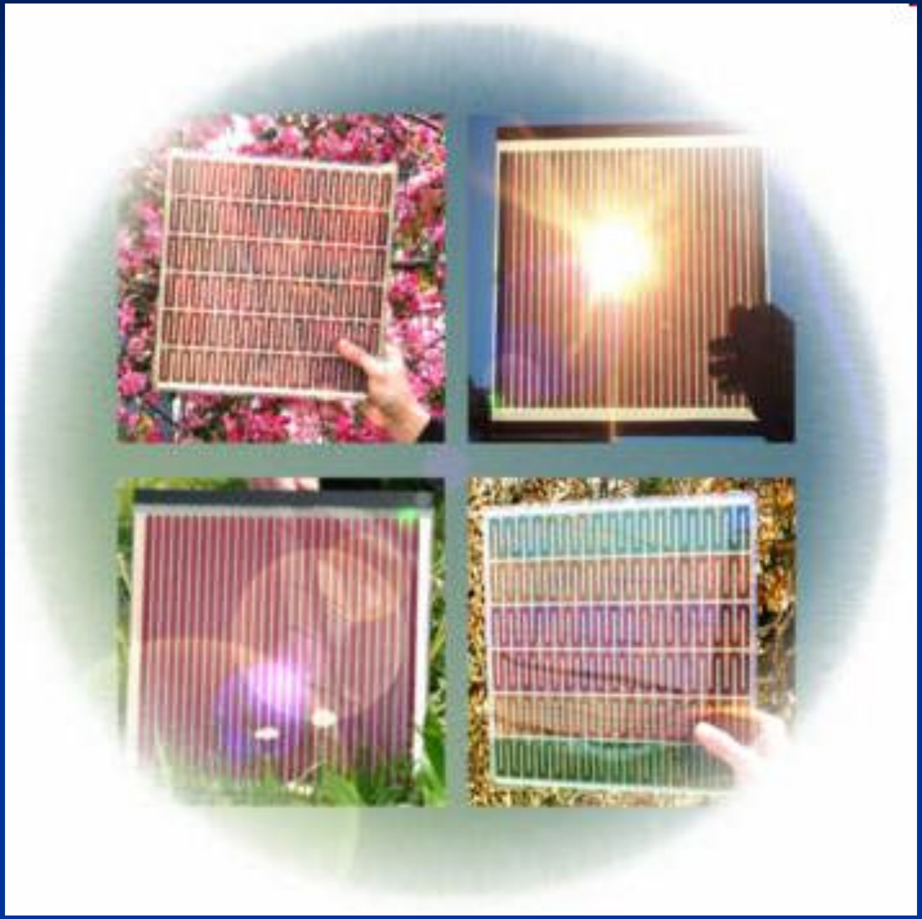


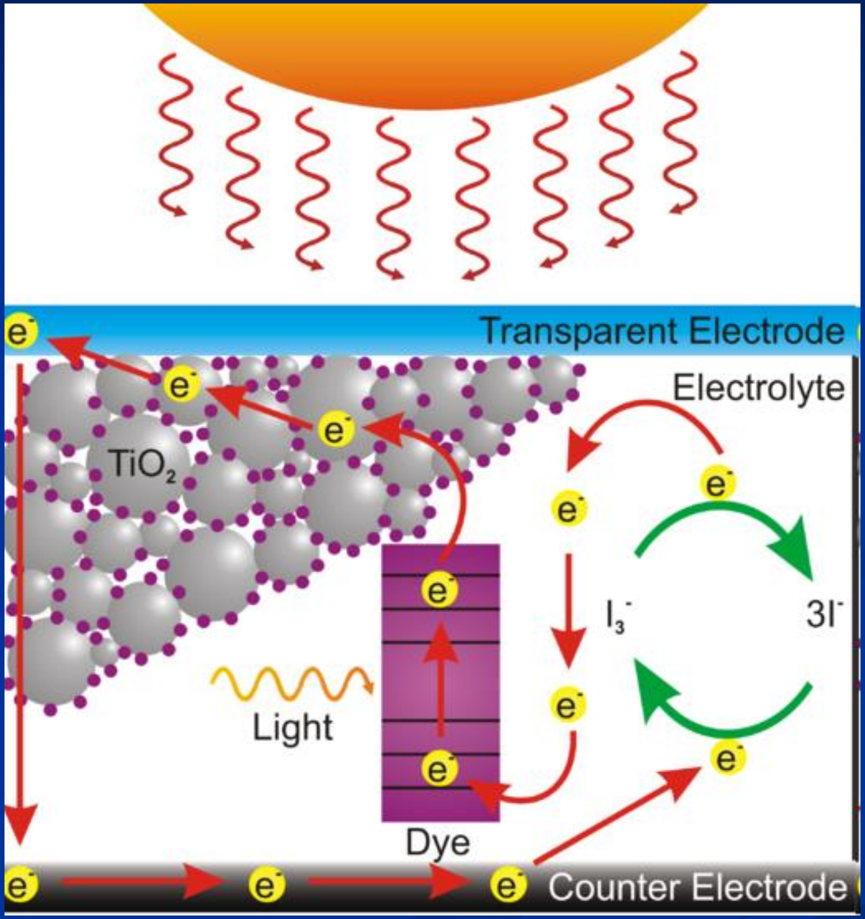




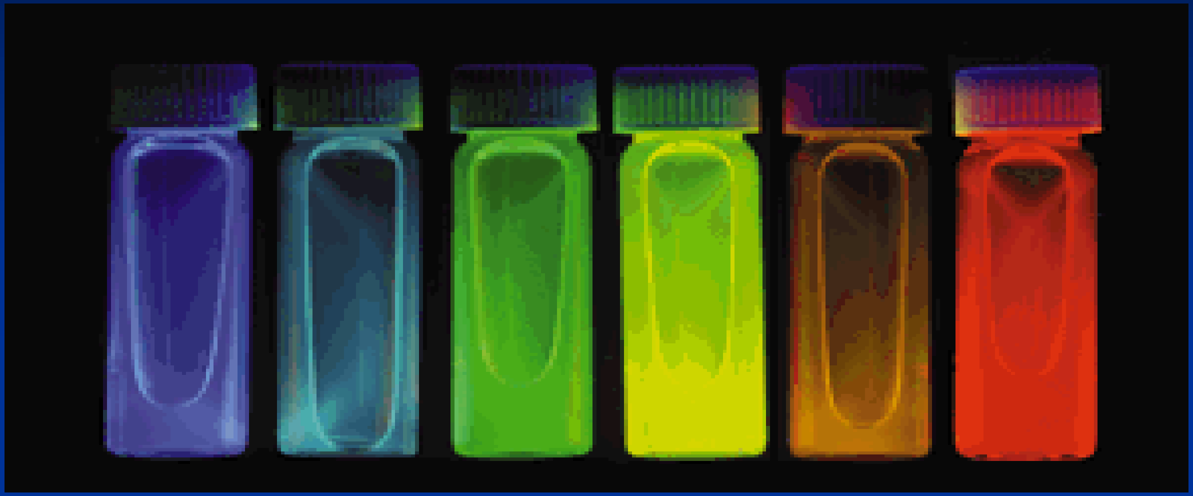
- **Enhance poor electrical performance while maintaining very low production costs.**
- Current research is targeting **conversion efficiencies of 30-60%** while retaining low cost materials and manufacturing techniques.
- Multi-junction cells – 30% efficiency (40-43% demonstrated)

Dye Sensitized Solar Cell



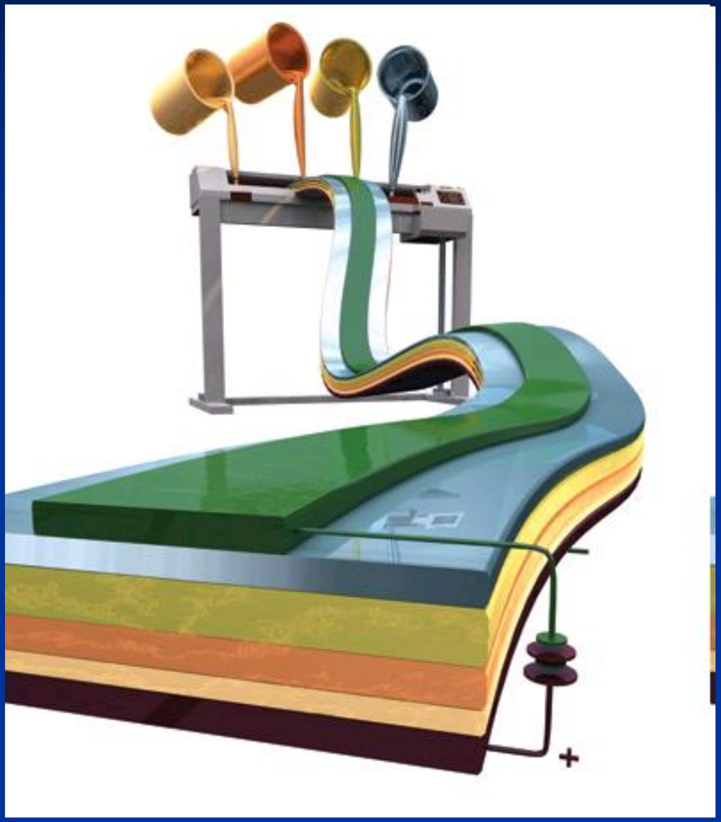


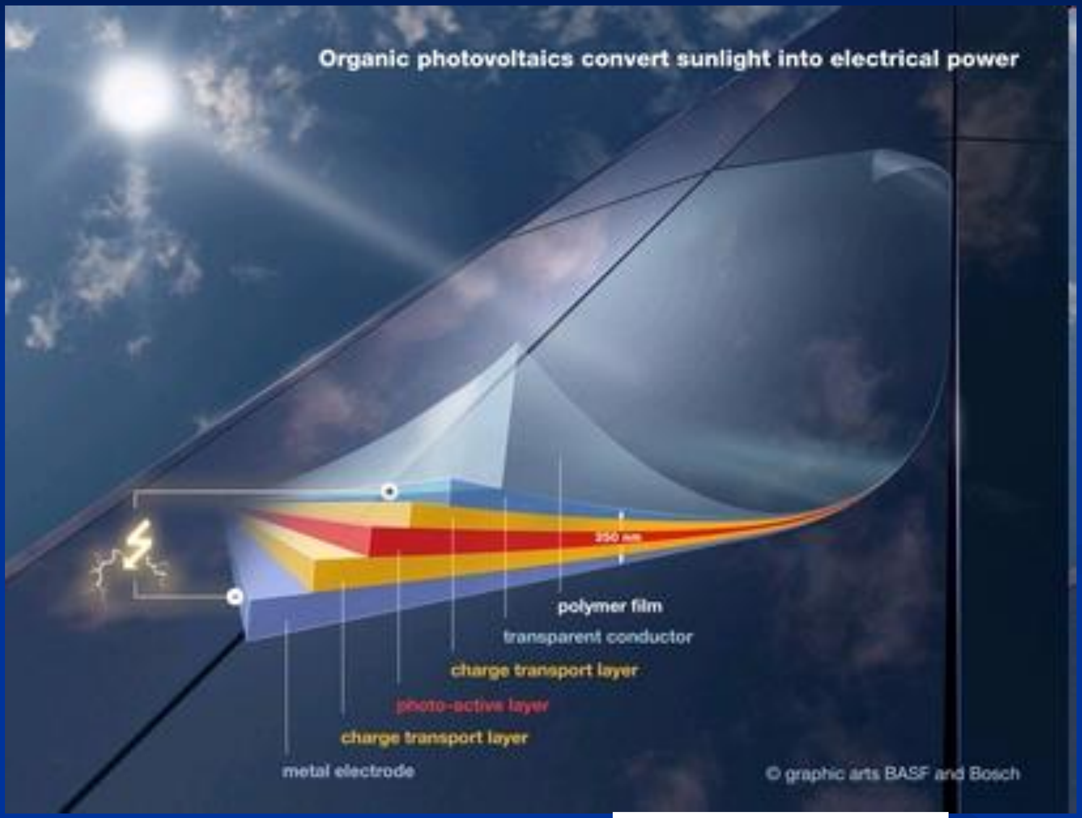
Future Generation
– Printable Cells

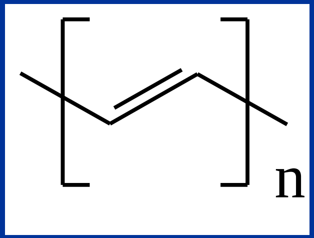


Solution Processible Semiconductor

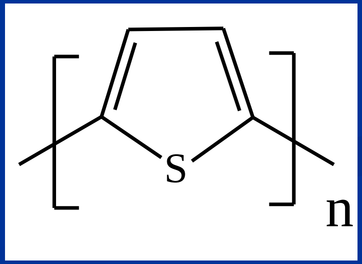
Organic Photovoltaics Convert Sunlight into Electrical Power.



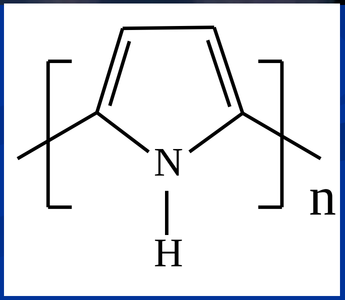




Trans-polyacetylene (t-PA)



Polythiophene (PT)



Polypyrrole (PPY)