เทคโนโลยีด้านพลังงานแสงอาทิตย์ ~ปัจจุบันและทิศทางในอนาคต~

8 กรกฎาคม 2558

ศูนย์เอนเนอร์ยี่คอมเพล็กซ์ อาคารบี

กระทรวงพลังงาน

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ห้องปฏิบัติการเทคโนโลยีพลังงานแสงอาทิตย์

ศูนย์อิเล็กทรอนิกส์ และคอมพิวเตอร์แห่งชาติ (NECTEC)

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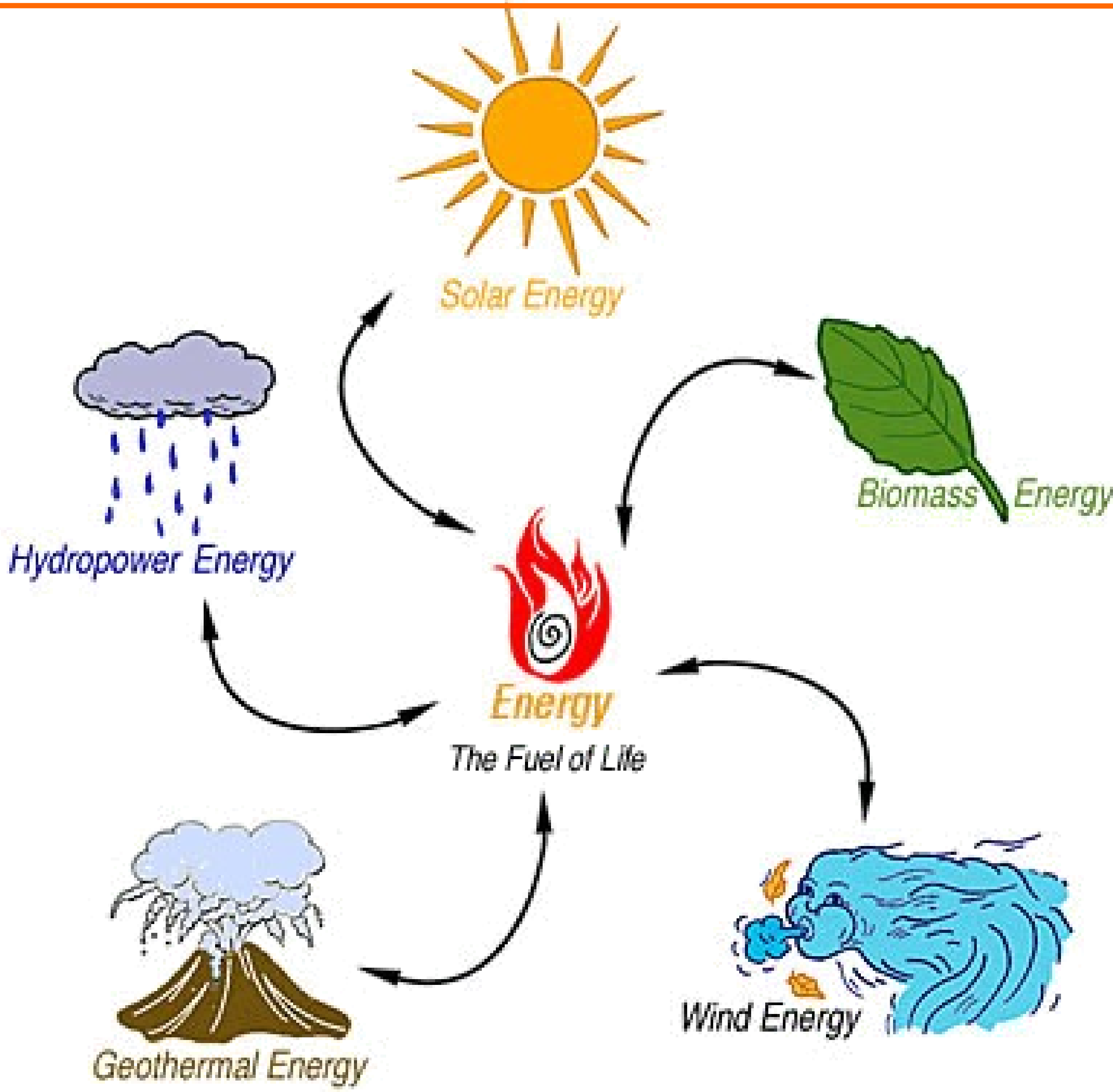
Outline

1. SOLAR ENERGY POTENTIAL

2. SOLAR ENERGY TECHNOLOGY
    2.1 Solar Thermal
    2.2 Solar Cell (Photovoltaic cell)
    2.3 Technology to support PV diffusion

3. SUMMARY

Renewable energy



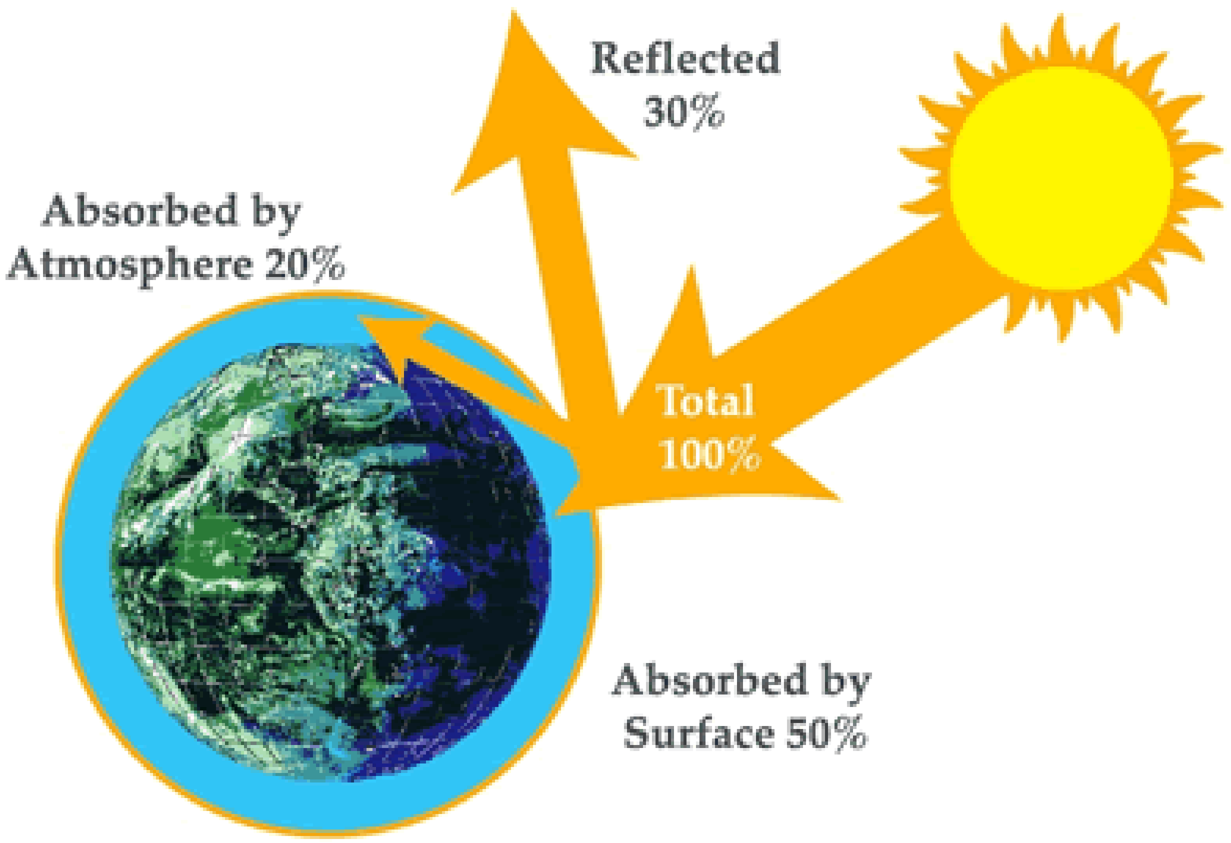
- Advantages of solar energy

✓ Free, available anywhere on earth
✓ Clean, can be supplied without environment pollution

- Disadvantages of solar energy

✗ Instability, performance depends on environmental conditions
✗ Relatively high cost

- Waves of very short length such x rays and gamma rays are absorbed in the atmosphere at extremely high attitude.
- Ultraviolet range is absorbed by the layer of ozone (O_3) located a 15~40 km above the earth's surface.
- Infrared range is absorbed by water vapor and CO_2.



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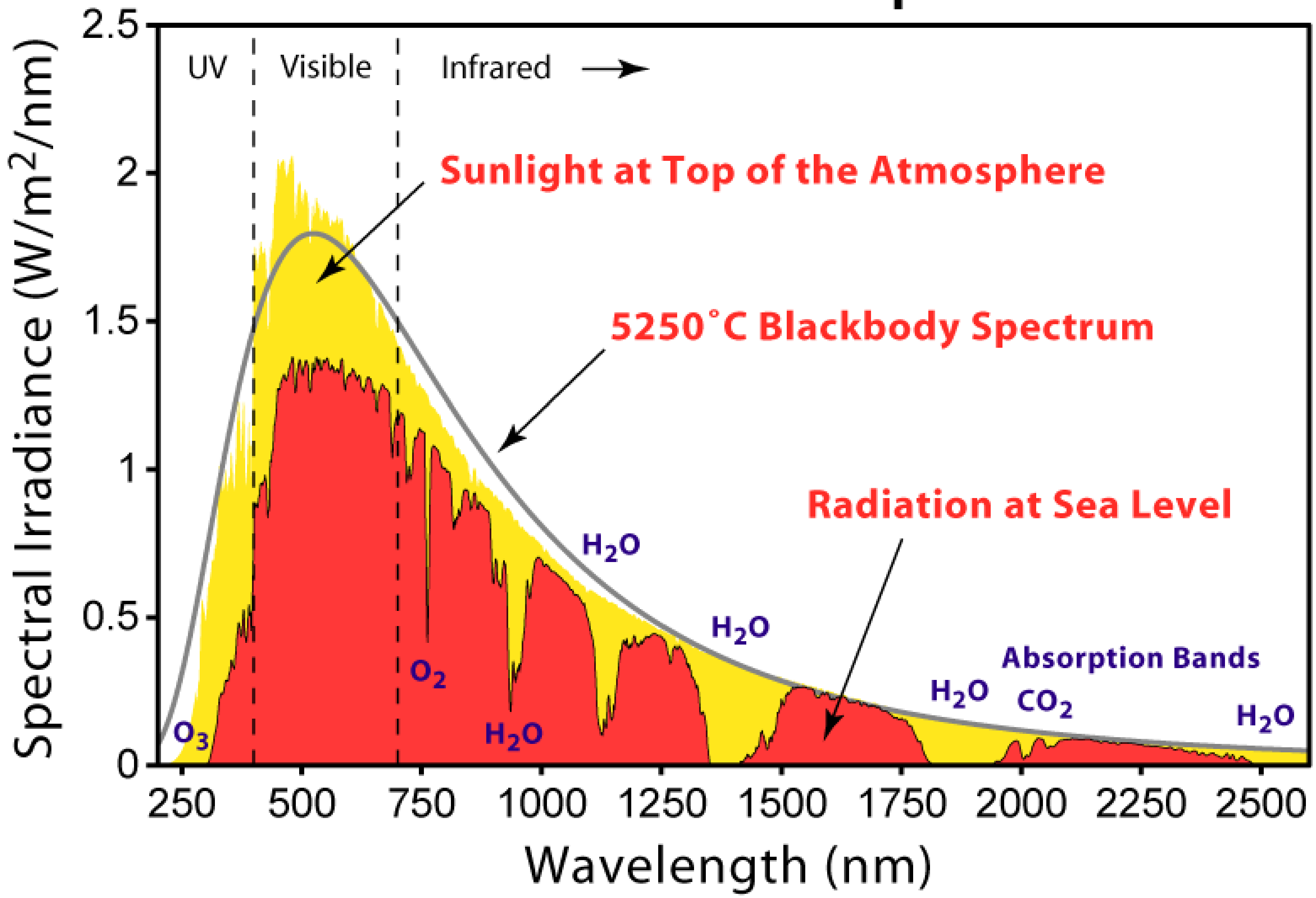
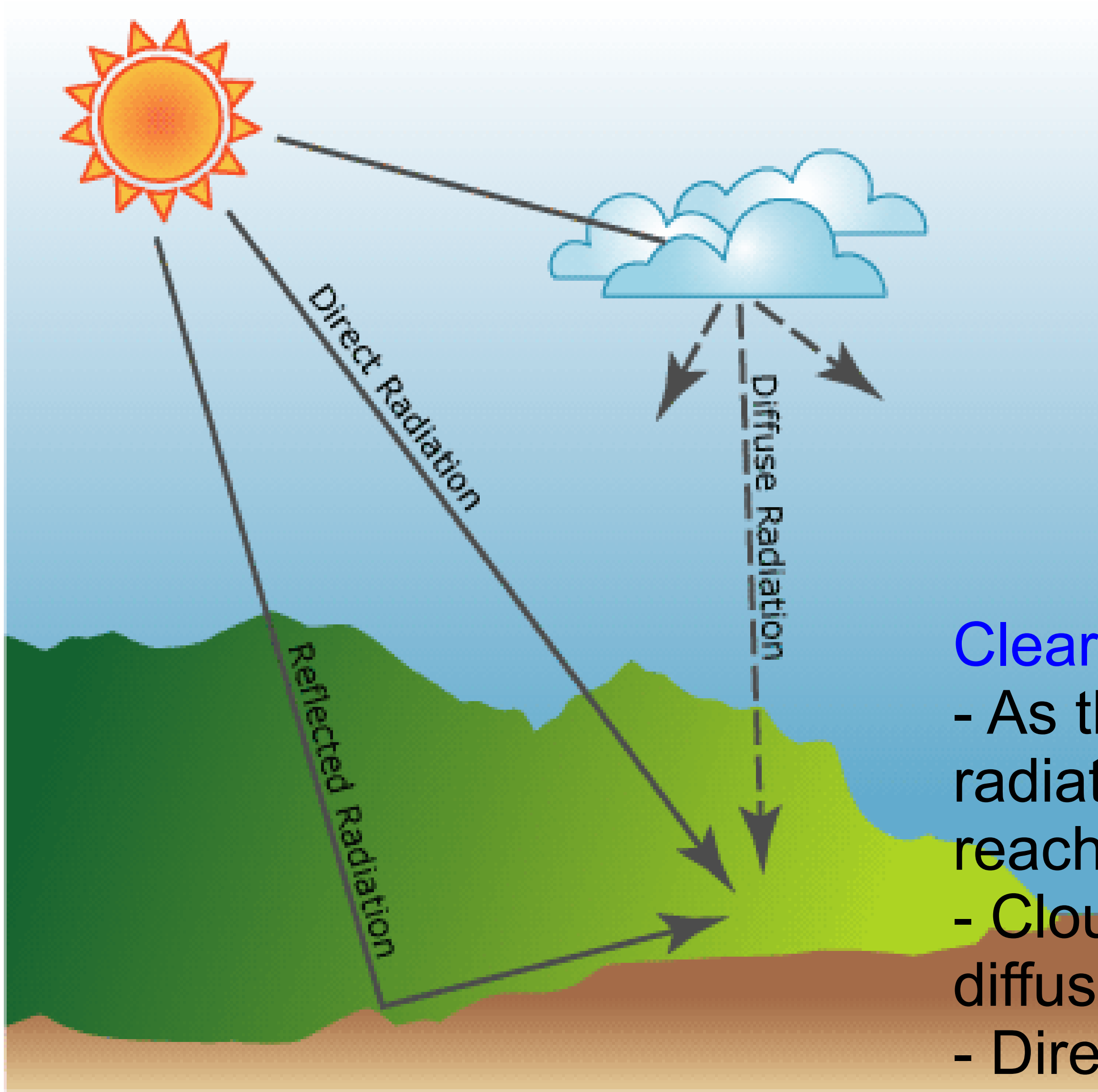
Solar Radiation Spectrum



The radiation wavelength that is important to solar energy applications is between 0.15 and 3 μm (= 150 ~ 3000 nm).



- Direct radiation:
Solar radiation traveling on a straight line from the sun down to the surface of the earth.

- Diffuse radiation:
Scattered radiation by molecules and particles in the atmosphere but still reaches earth's surface.

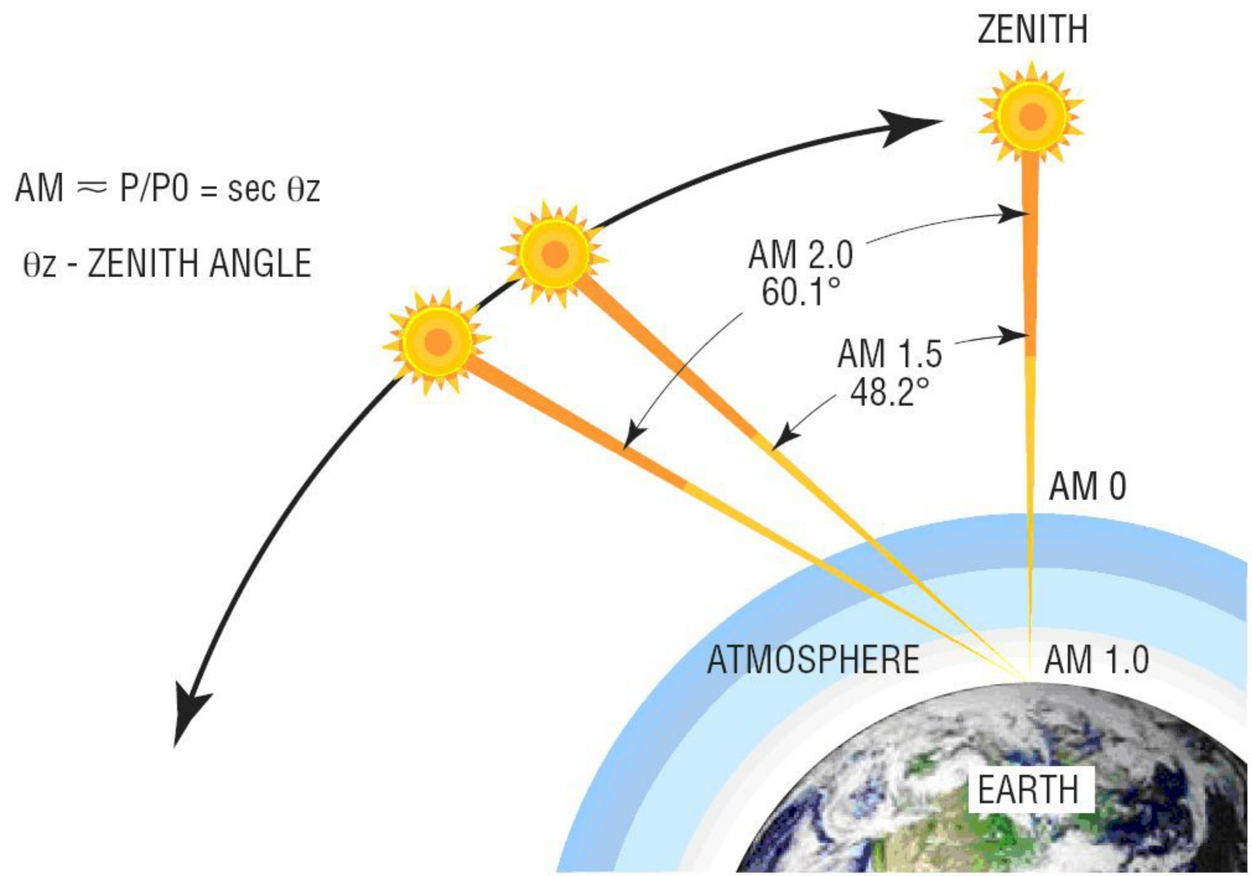
Clear sky : Direct 85%, Diffuse 15%

- As the sun goes lower, diffuse radiation keeps going up until it reaches 40%.
- Clouds and pollution also increase diffuse radiation.
- Direct/ Diffuse ratio varies with latitude and climate.

Air Mass (AM)

AM is defined as the length of path traversed in reaching sea level relative to that at the zenith.

- Outside the earth AM = 0
- At sea level when the sun is at its zenith AM = 1



Solar Radiation Measuring Equipment

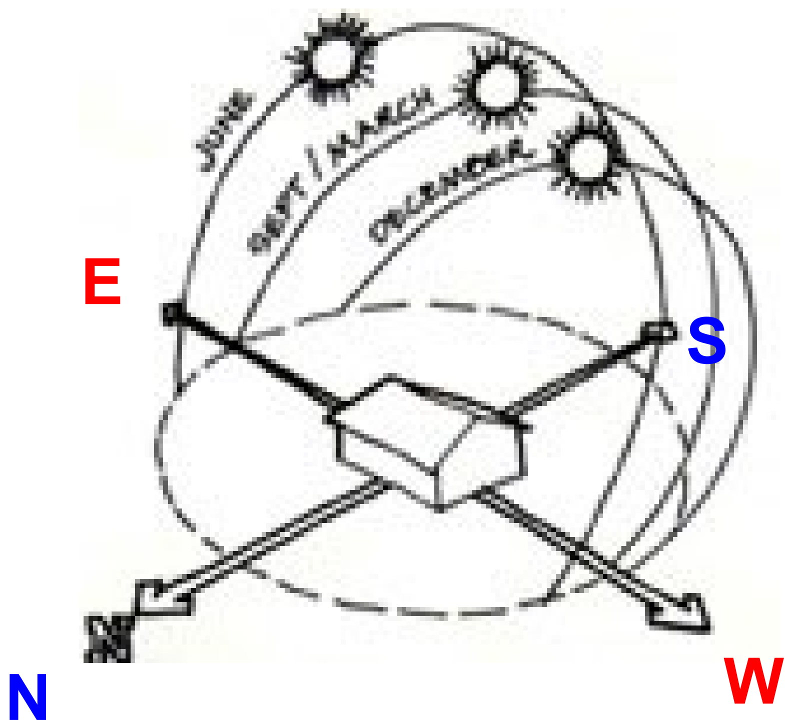
1) Pyranometer

For measuring total (direct and diffuse) radiation

2) Pyrheliometer

For measuring only direct radiation

The amount of solar irradiance on a terrestrial surface at a given location and time depends on the **orientation** and **<u>slope of the surface</u>**.

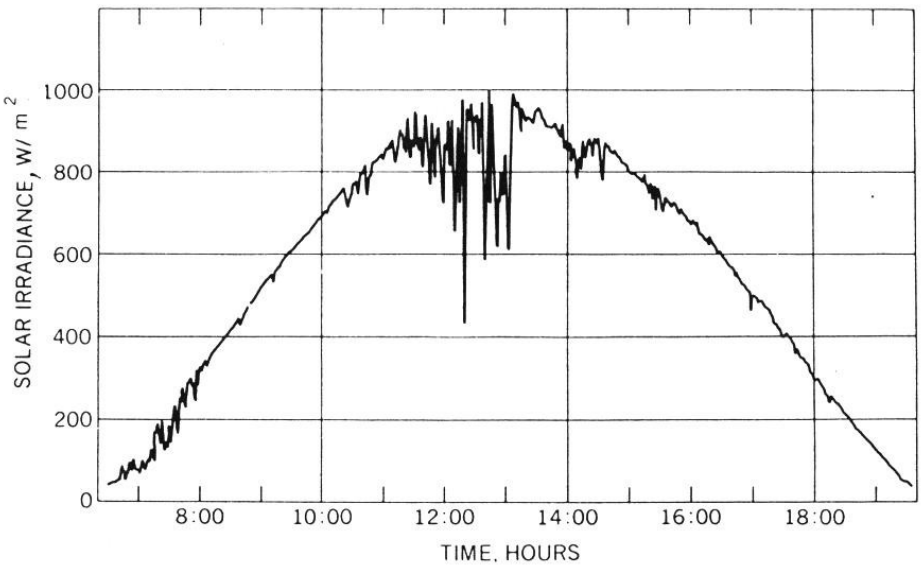


- The solar cell or collector should be oriented directly to the equator, **facing south** (in Northern hemisphere).

- The optimum tilt angle of the solar cell (or collector) is equal to the latitude of the location.

Thailand: longitude east 100^o
latitude **14~15^o**

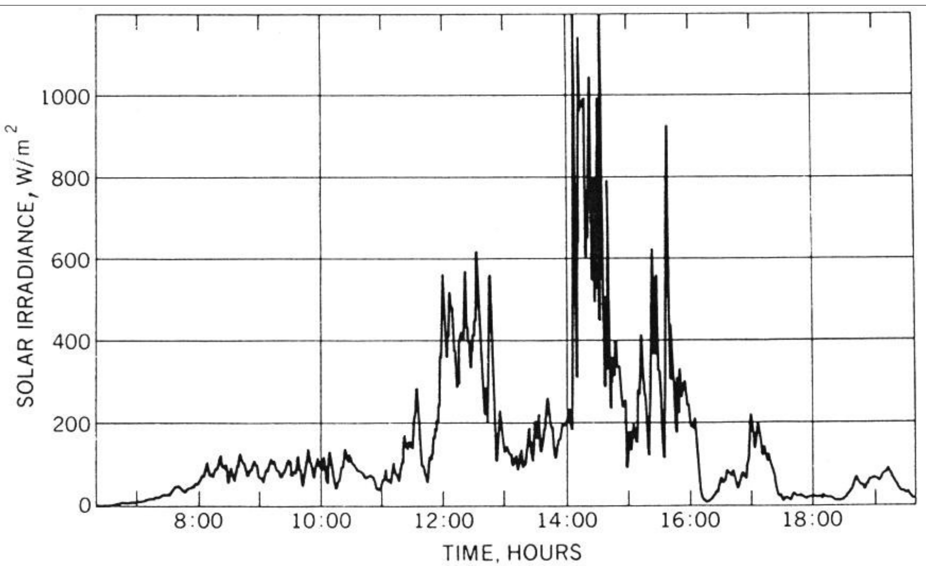
Time dependent solar irradiance



(a)

Sunny day
Clear sky

Maximum solar irradiance at noon



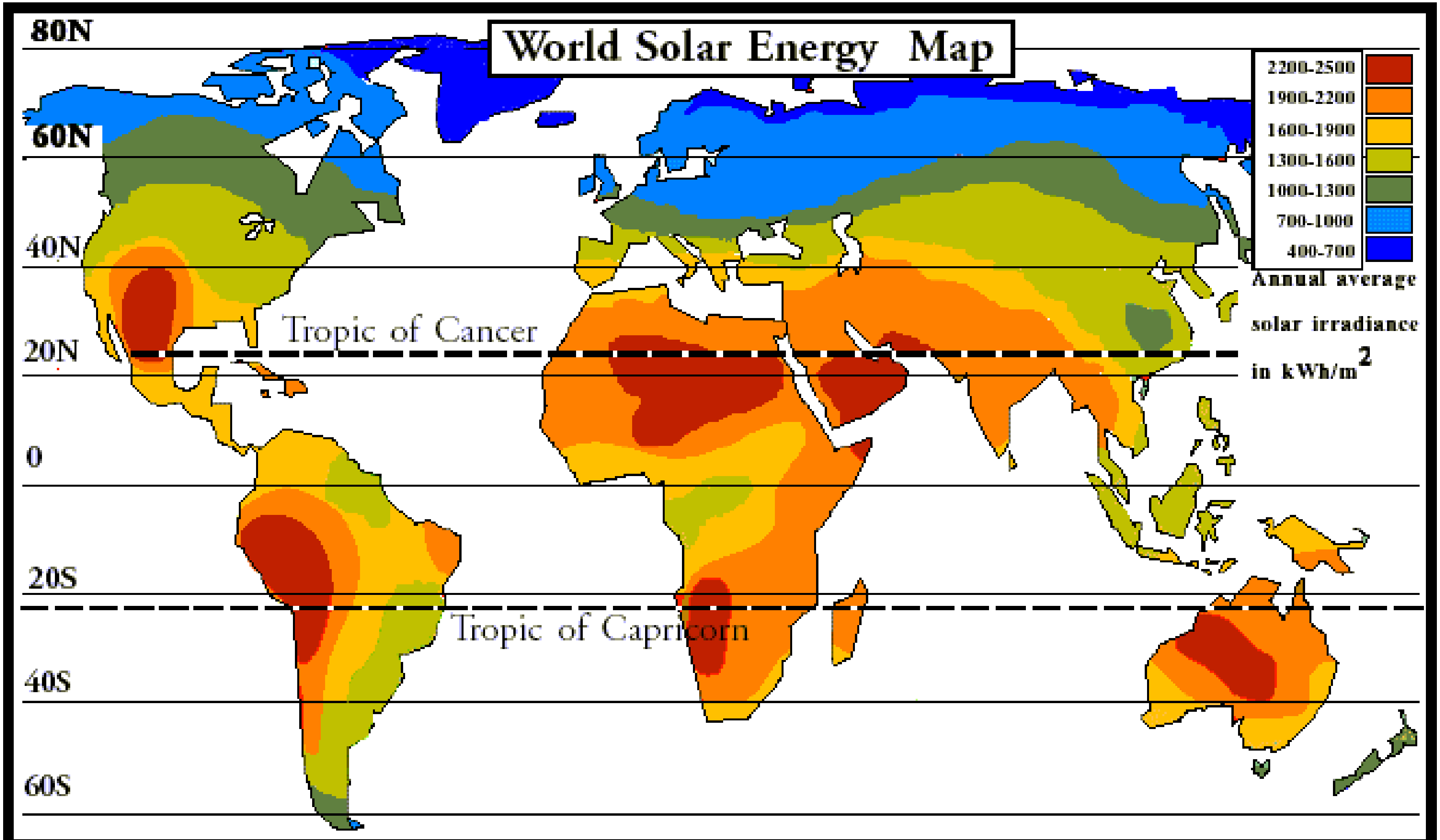
(b)

Cloudy day

Solar irradiance at any point on earth depends on

1. the ozone layer thickness
2. the distance traveled through the atmosphere to reach that point
3. the amount of haze in air (dust particle, water vapor..etc)
4. the extent of the cloud cover

World Solar Energy Map



High potential of solar energy in low latitude regions (+- 25°)

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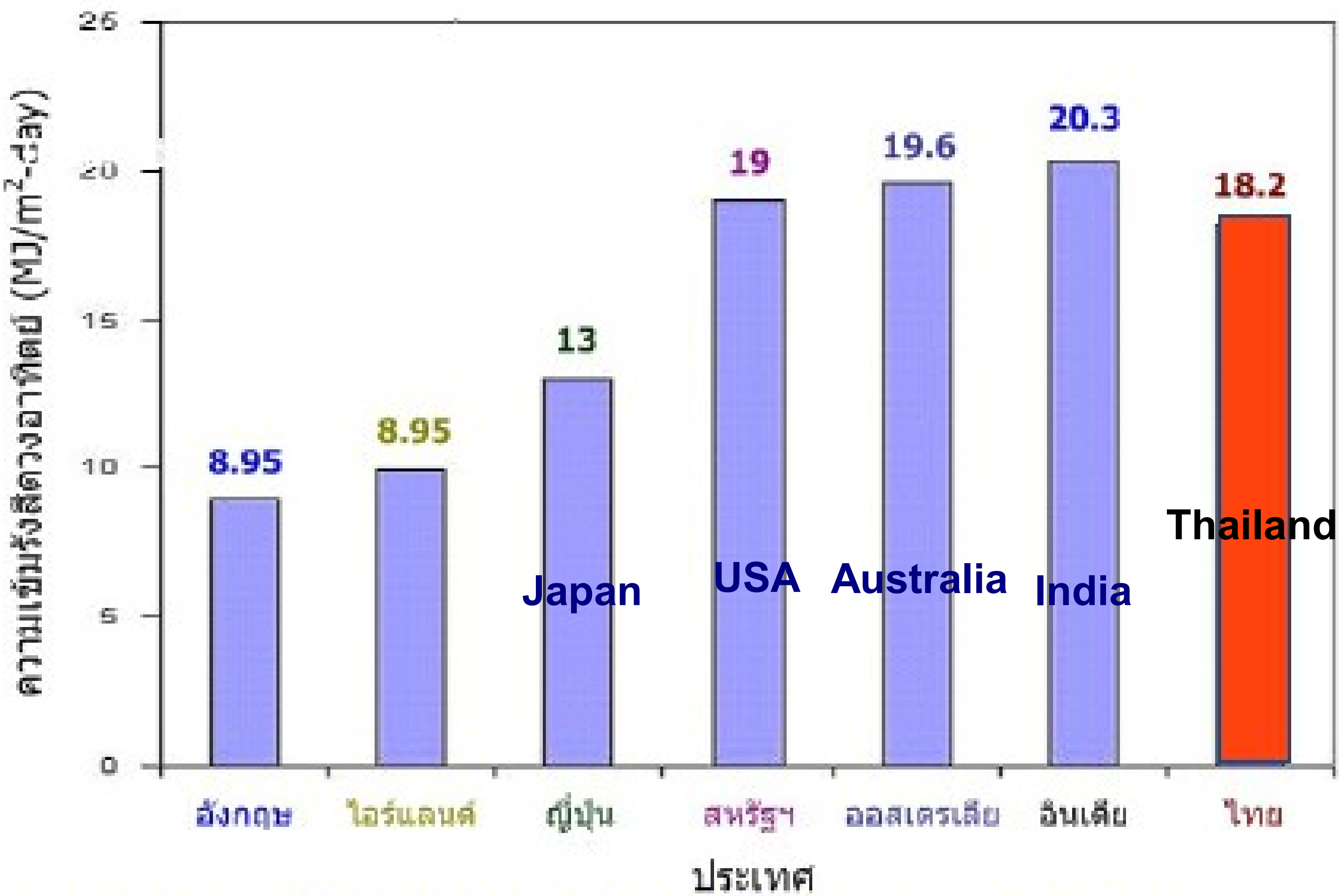
Worldwide Solar Radiation & Thailand



ข้อมูลจาก SOLAR CELL (PV) DEVELOPMENT IN THAILAND, Oct. 2009 กระทรวงพลังงาน

A Driving Force for National Science and Technology Capability

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•Potentials of Solar Energy inThailand

Daily Solar Radiation 18.2 MJ/m^2 -day

Central and Northeastern regions
1,400 KWh/m^2-yr

Best season: January~ April

*Dr.Serm Janjai Silpakorn University

2. SOLAR ENERGY TECHNOLOGY

2.1 SOLAR THERMAL

Solar energy applications

- Old time: Solar thermal applications
  - Drying crop, human's food
  - Drying clothes
  - Growing plants

- Only recently, during the last 50 years, has solar energy been harnessed with specialized equipment and used as an alternative source of energy.

I. Solar thermal Solar collector, Solar cooker

II. Solar electricity Photovoltaic (PV)

SOLAR COLLECTORS

- **Solar collector** is a device that *absorbs the incoming solar radiation, converts it into heat and transfers the heat to a fluid (air, water, oil)* flowing through the collector.

2 types of collectors

Non-concentrating

- Flat plate collector
- Evacuated tube collector

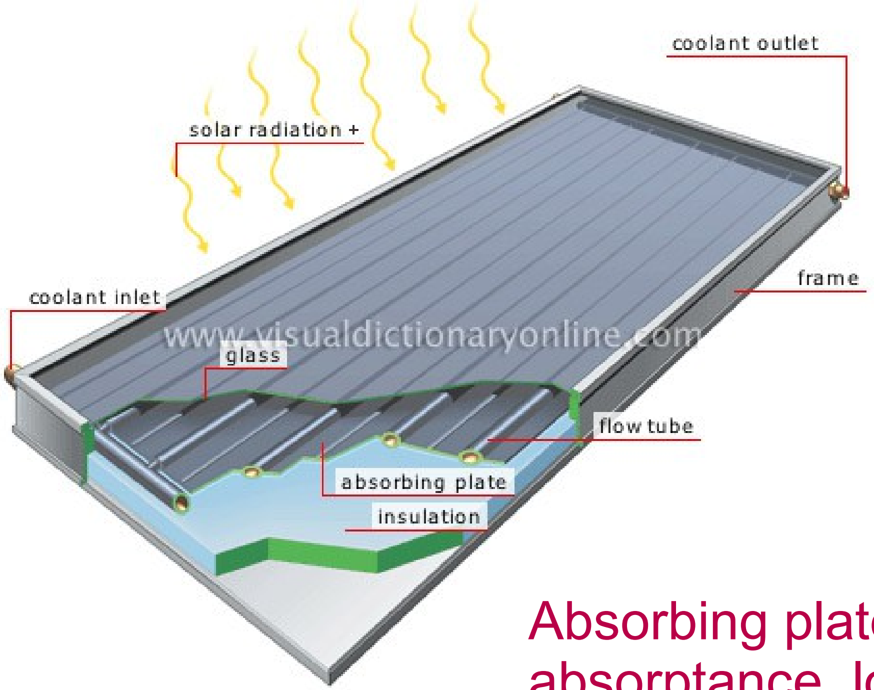
Concentrating

- Parabolic trough
- Parabolic dish
- Central receiver tower

Type of collector	Concentration Ratio	Typical Working Temperature Range (°C)
Flat plate collector	1	**≤ 70**
High – efficiency flat plate collector	1	**60 – 120**
Fixed concentrator	2 – 5	**100 – 150**
Parabolic trough collector	10 – 50	**150 – 350**
Parabolic dish collector	200 – 2000	**250 – 700**
Central receiver tower	200 – 2000	**400 – 1000**

Non-concentrating

• Flat Plate Collector

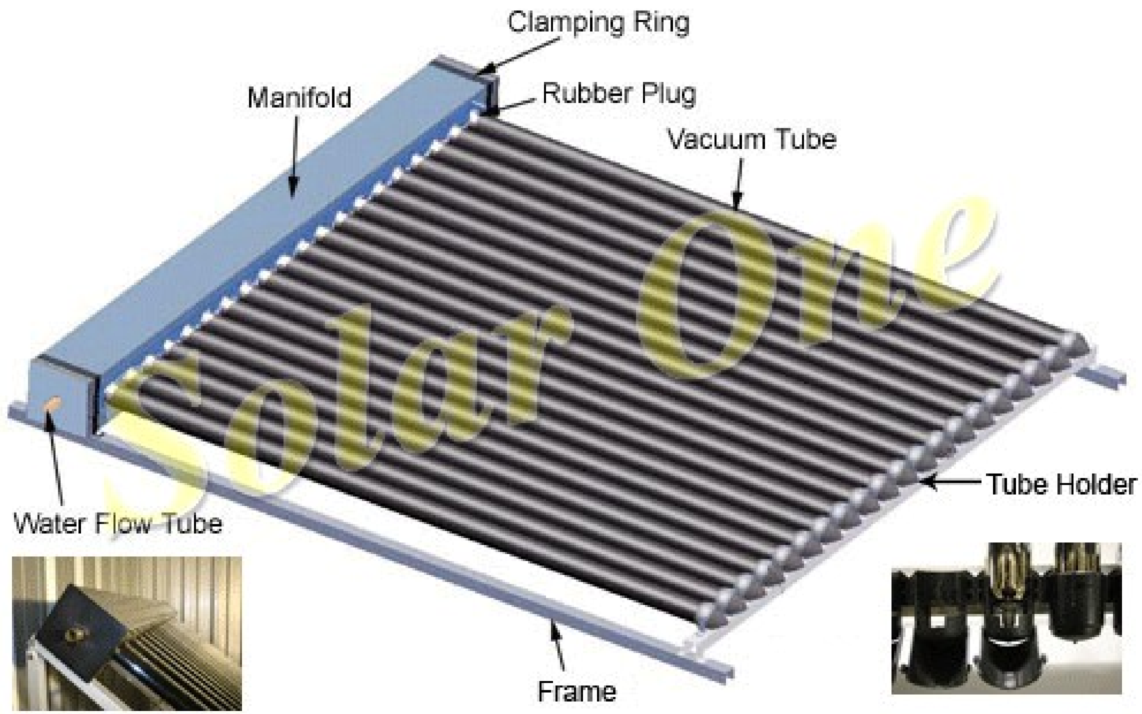


Absorbing plate: high absorptance, low emittance

Selective coating material: Black chrome

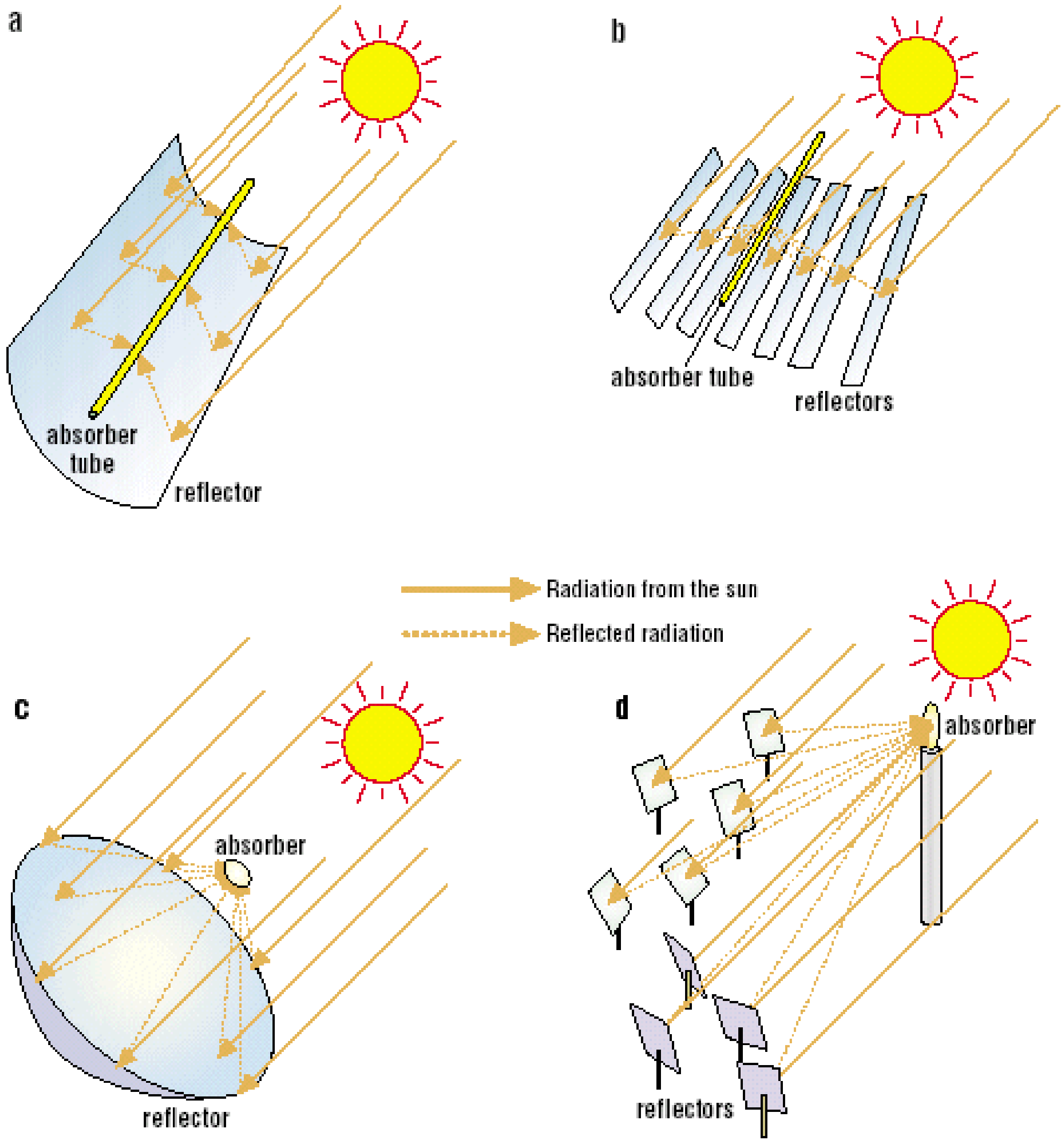
- ❑ **Moderate cost**
- ❑ **Collect both direct and diffuse radiation**

• Evacuated Tube Collector (ETC)



- ❑ Higher cost
- ❑ No convection losses
- ❑ High temperature
- ❑ Cold climates
- ❑ Fragile
- ❑ Snow is less of a problem
- ❑ Installation can be more complicate

Concentrating collector



Concentration ratio

$C = A_a / A_r$

A_a : aperture area

A_r : receiver absorber area

- High conversion efficiency but need direct radiation

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• **Parabolic trough collector**

- **Parabolic dish**

• **Central receiver tower**

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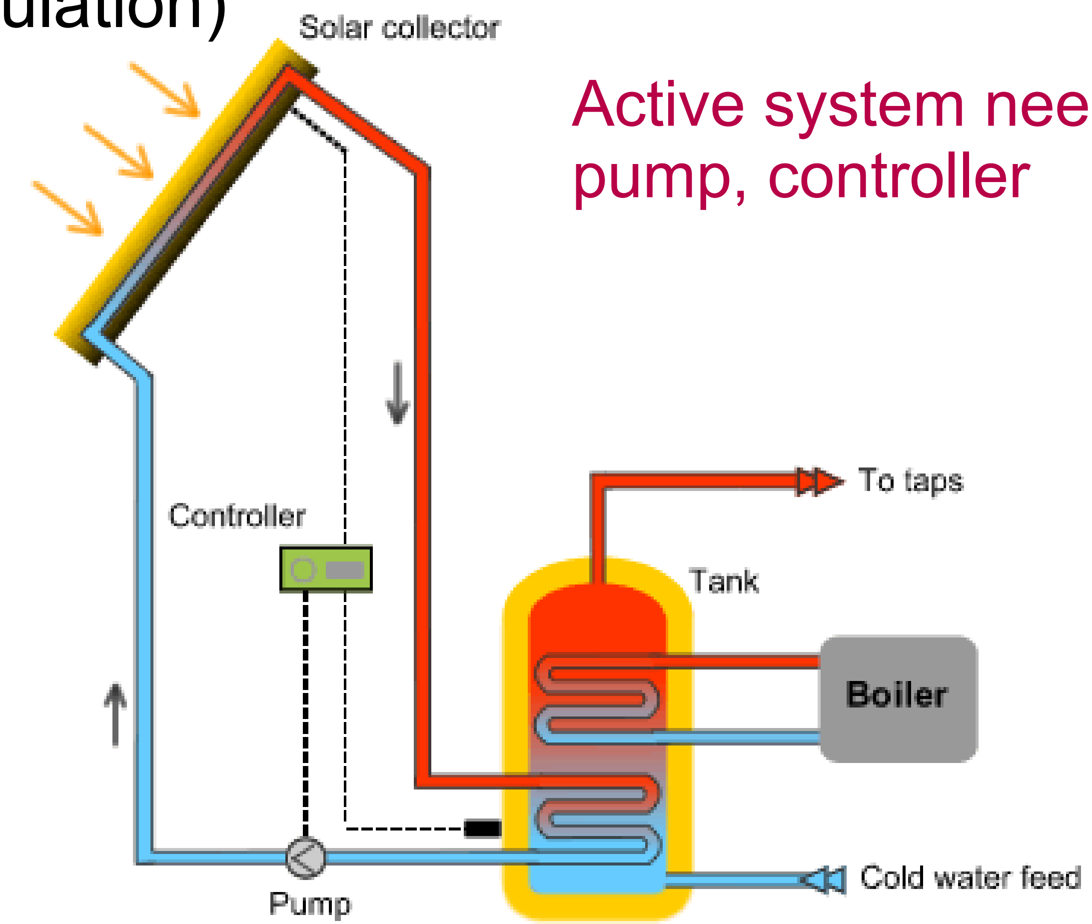
Solar cooker

• Solar Water Heating Systems

The most popular application of solar energy is domestic water heating (low temperature).

1) Passive (Natural)
2) Active (Forced circulation)



Active system needs pump, controller

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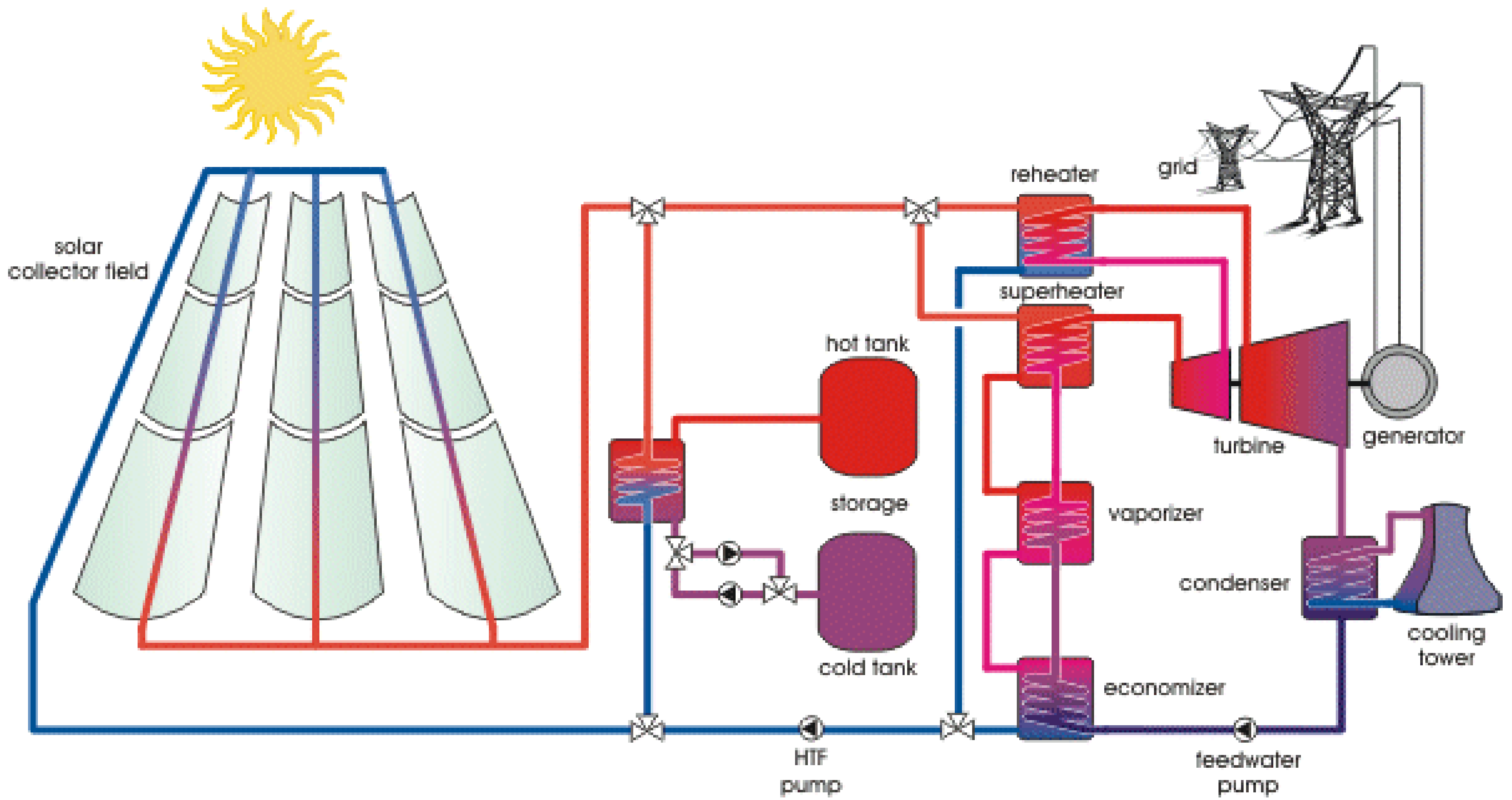
Solar thermal power plant

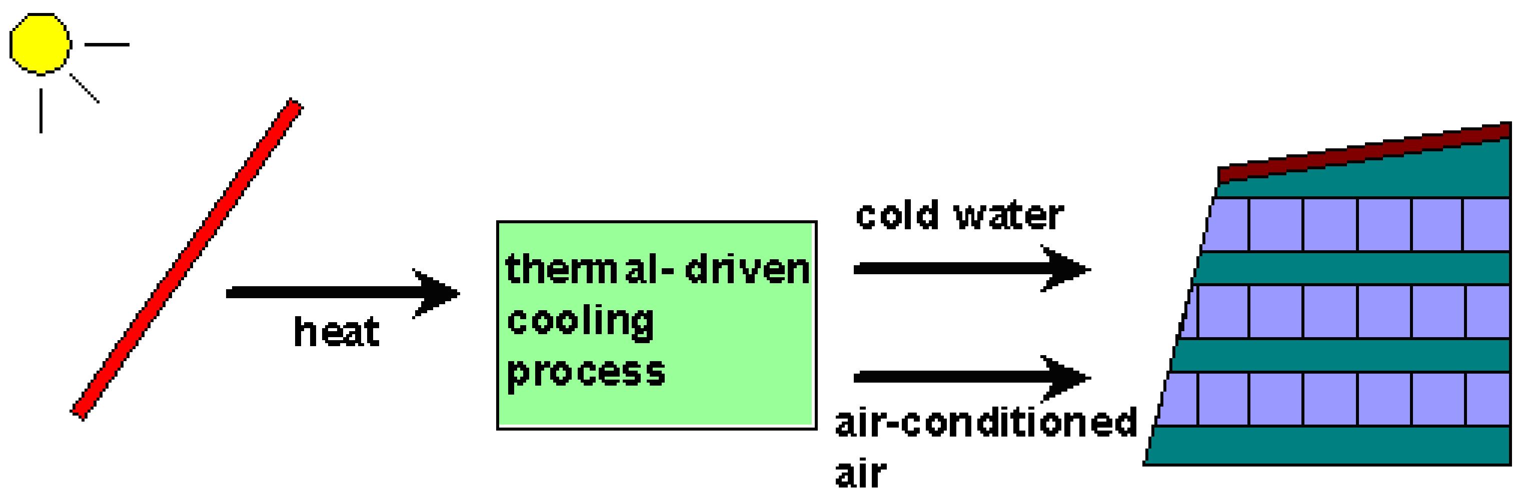
Generating electricity



Solar cooling

solar gain

cooling burden



Chiller

Solar collector

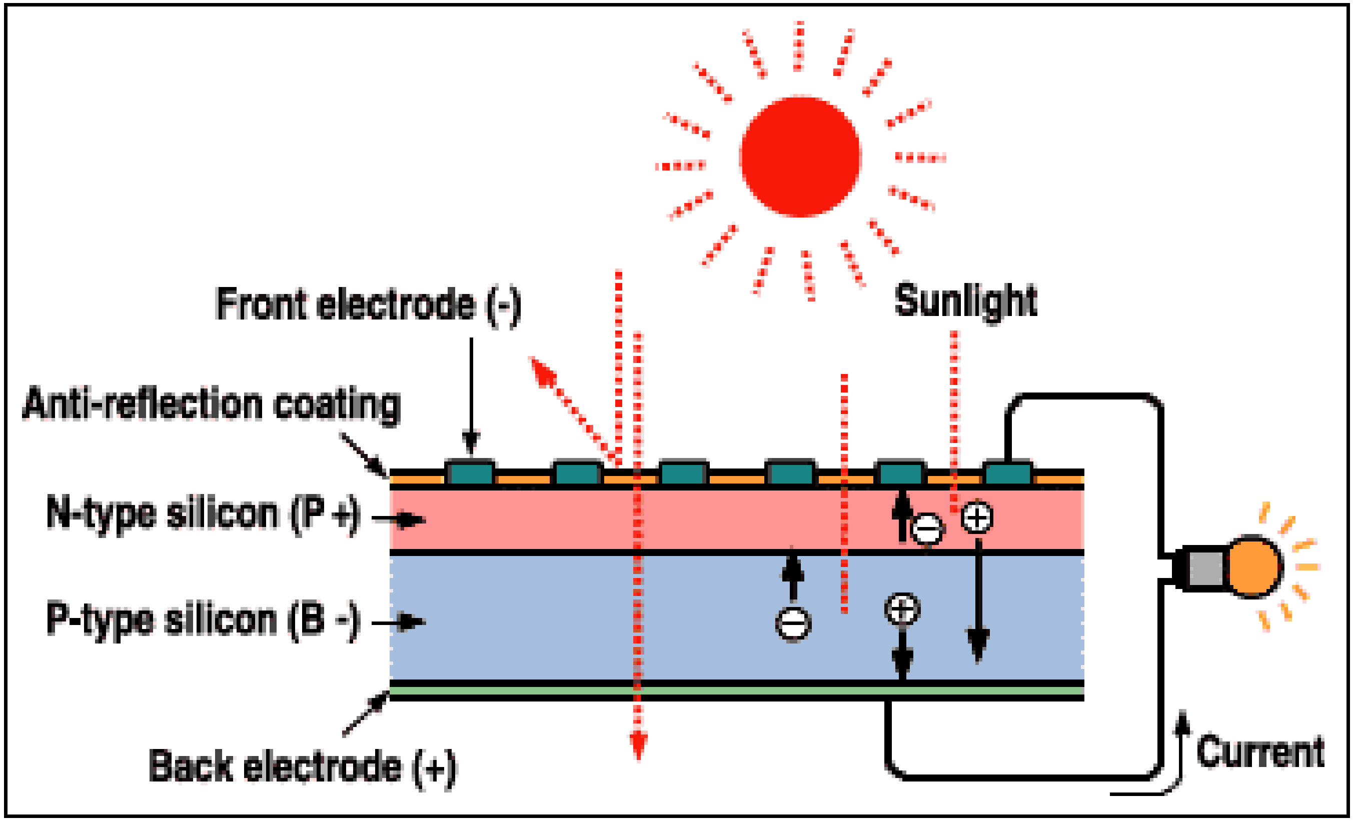
2. SOLAR ENERGY TECHNOLOGY

2.2: SOLAR CELL

Photovoltaic effect

Phenomenon that certain materials produce electric current when they are exposed to light.

Solar cell (also called photovoltaic cell) is a electrical device that convert the energy of light directly into electricity.



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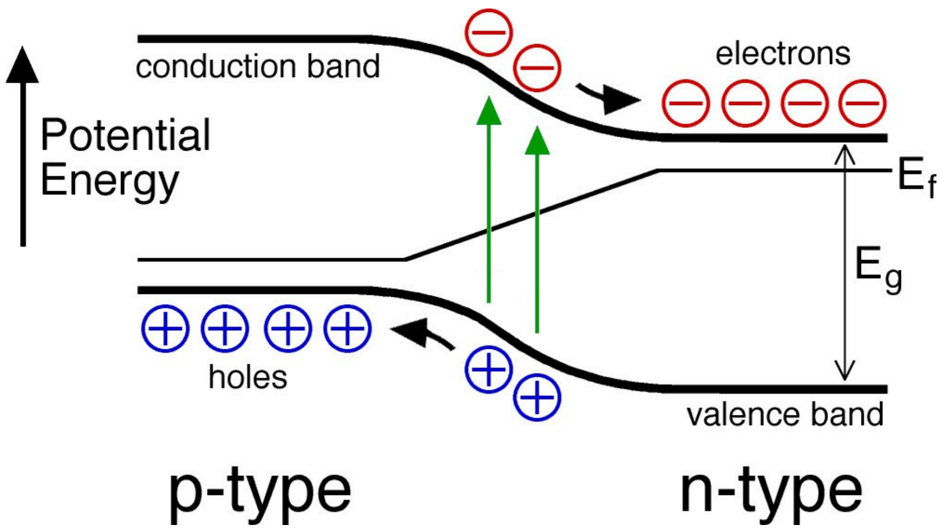
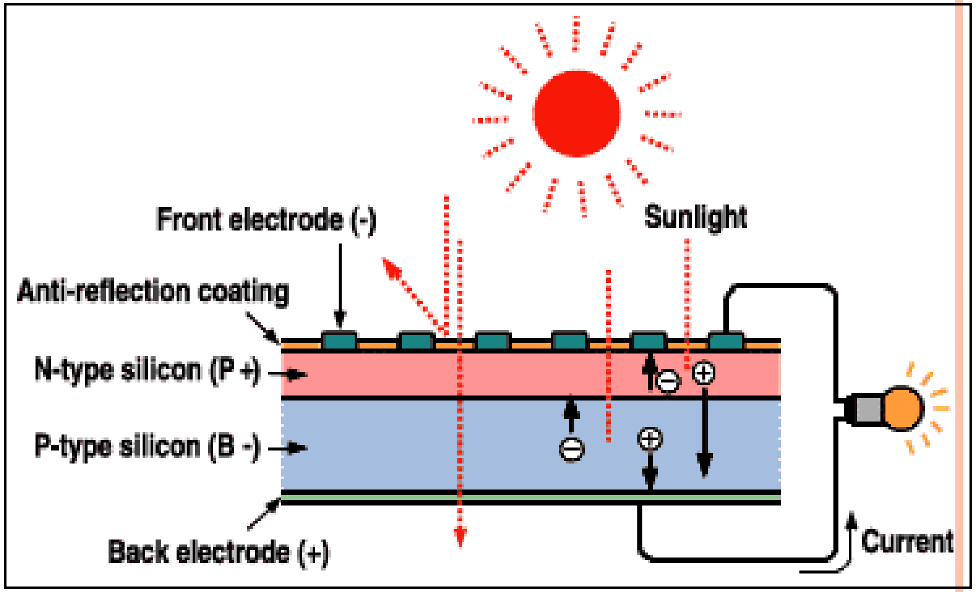
p-n junction



How solar cells work?



When a photon of the correct energy strikes the solar cell,

- Photons from the sun create the electron-hole pair.
- Electron is energized to conduction band and leave a hole in valence band.
- The electrons will be attracted to n type side and holes will be attracted to p type side.
- If circuit is completed, electricity flows.

Advantage and disadvantage of PV

Advantage

- Clean, no pollution
- No noise, no moving parts
- Little maintenance is required

Disadvantage

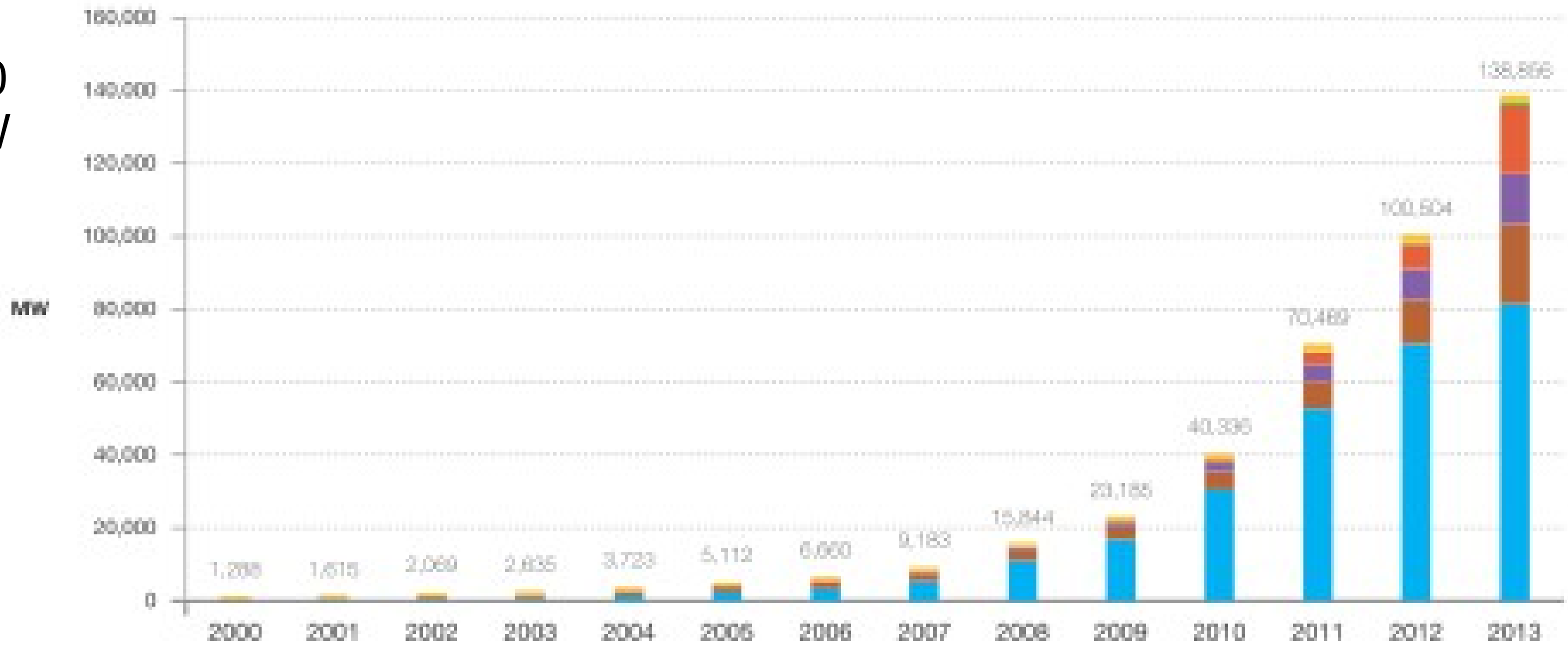
- Expensive
- Relying on weather

PV technologies

- **Solar cells**
  - **Silicon-based**
    - **Thin film**
      - Amorphous Silicon
      - Microcrystalline Silicon
    - **Crystalline**
      - Mono crystalline
      - Poly or multi crystalline
  - **Non Silicon-based (Compound)**
    - CdTe
    - CIS, CIGS
    - GaAs, InGaP/GaAs
    - Dye sensitized, Polymer, Organic

World cumulative PV installation

140
GW



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
RoW	751	807	887	964	993	1,003	1,108	1,150	1,226	1,306	1,590	2,098	2,098	2,098
MEA	n/a	n/a	n/a	n/a	1	1	1	2	3	25	80	205	570	953
China	19	24	42	52	62	70	80	100	140	300	800	3,300	6,800	18,600
Americas	21	24	54	102	163	246	355	522	828	1,328	2,410	4,590	8,365	13,727
APAC	368	496	686	916	1,198	1,502	1,827	2,098	2,628	3,373	4,951	7,513	12,159	21,992
Europe	129	265	399	601	1,306	2,291	3,288	5,312	11,020	16,854	30,505	52,764	70,513	81,488
Total	**1,288**	**1,615**	**2,069**	**2,635**	**3,723**	**5,112**	**6,660**	**9,183**	**15,844**	**23,185**	**40,336**	**70,469**	**100,504**	**138,856**

RoW: Rest of the World. MEA: Middle East and Africa. APAC: Asia Pacific.
Methodology used for RoW data collection has changed in 2012.

Figure 1 - Evolution of global PV cumulative installed capacity 2000-2013

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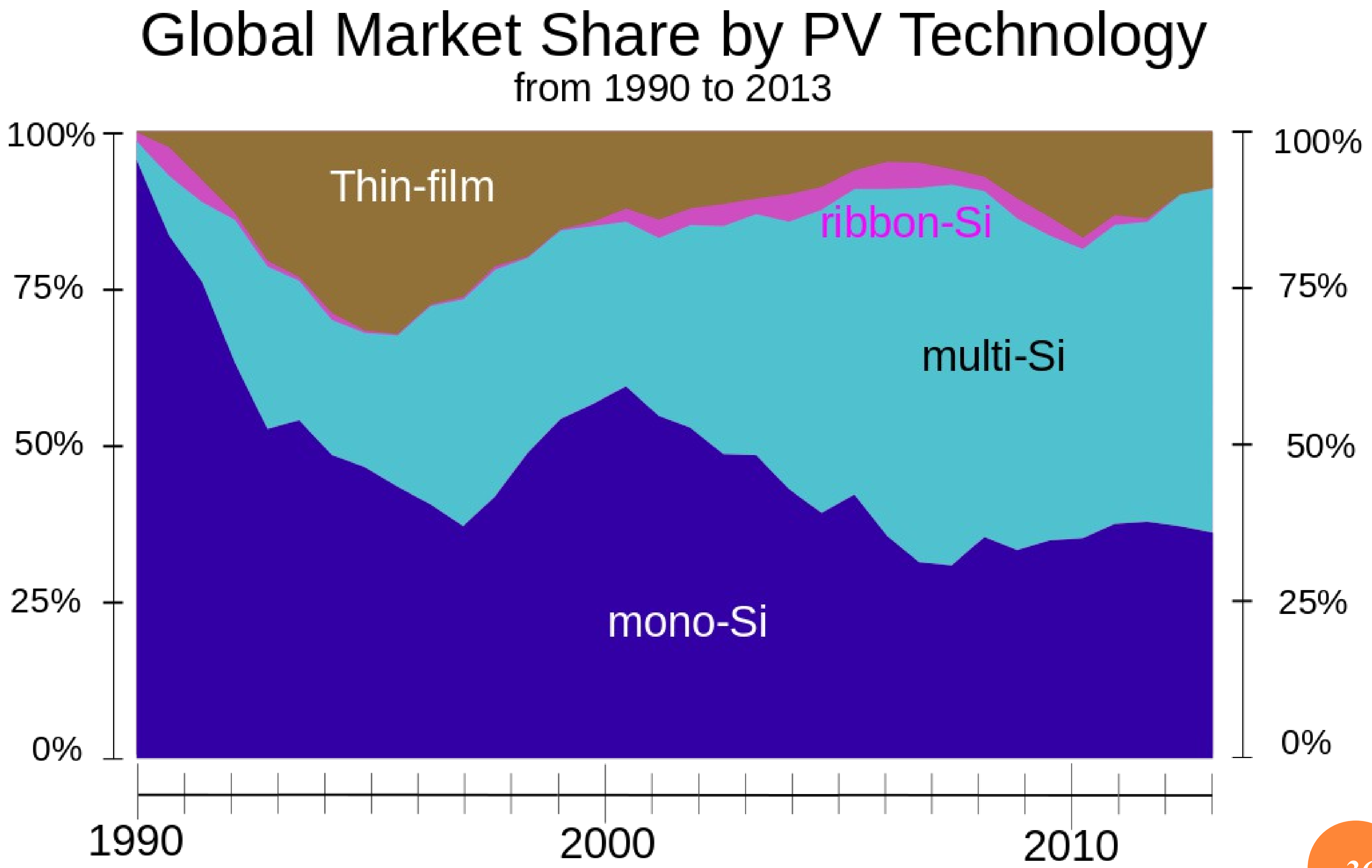
Source: EPIA -Global market outlook for photovoltaic 2014-2018

- About 90% of the total production is crystalline Si (mono and multi c-Si).



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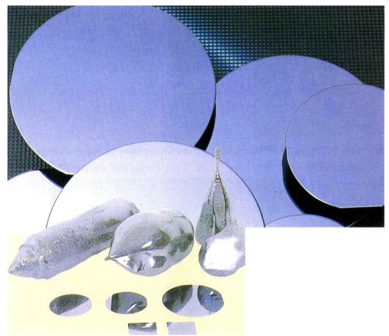
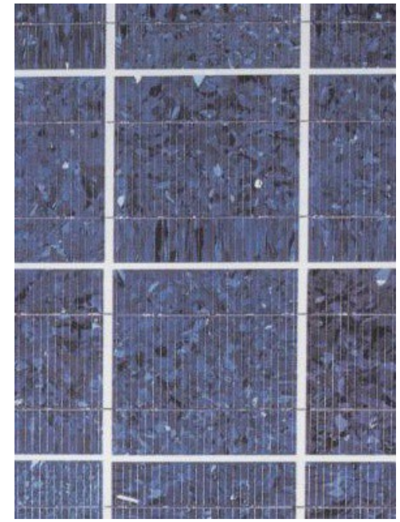
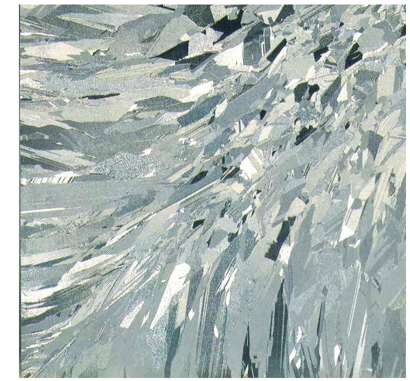
Source: Fraunhofer ISE Annual report 2014

Crystalline silicon solar cells

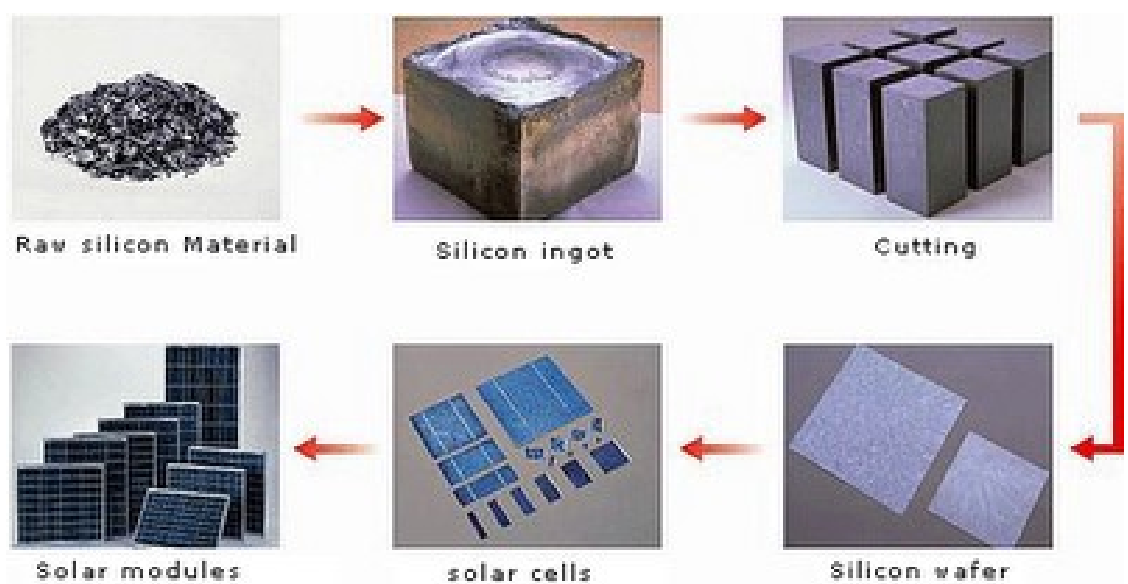


Mono c-Si

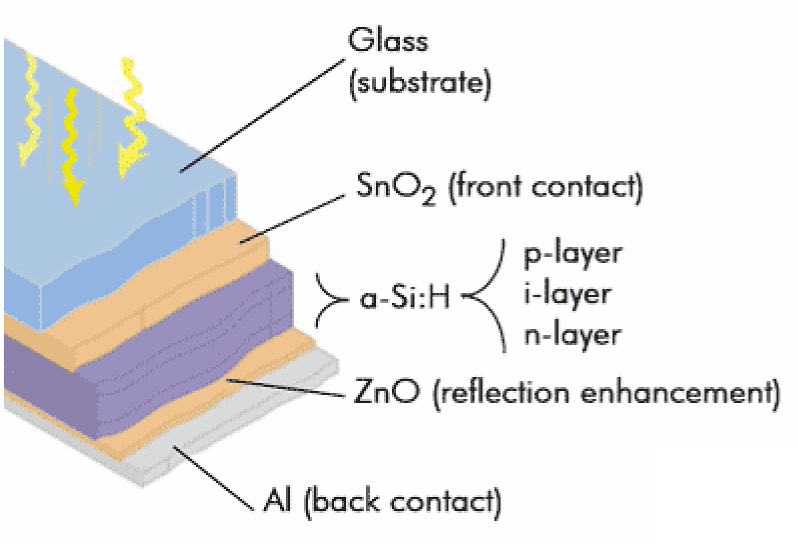




Multi c-Si



Thin film silicon solar cell

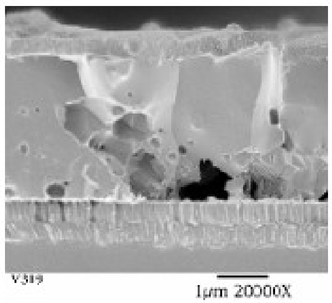


- Deposition of silicon thin films on substrate (glass)
- Plasma enhanced vapor deposition (PECVD) technique
- Main gas source: SiH_4, H_2

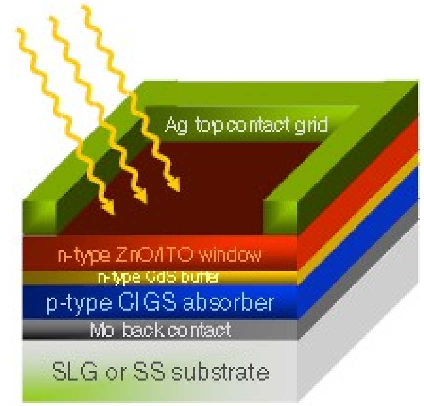

Thin film Si
Mono c-Si
Poly c-Si

Copper Indium Galliuam Selenide (CIGS)

What is CIGS?



- Copper
- Indium
- Gallium
- diSelenide



Copper Indium diSelenide

Extremely high absorption - 99% of available light absorbed within 1μm

\+

Gallium

Greatly boosts the light-absorbing band gap, moving it closer to the solar spectrum


CIGS MODULE

Cadmium Telluride (CdTe)

- CdTe absorbs sunlight at close to the ideal wavelength (capturing more energy at shorter wavelength than Si).
- Relatively low cost
- Cadmium (Cd) is toxic and Tellurium (Te) is rare element.

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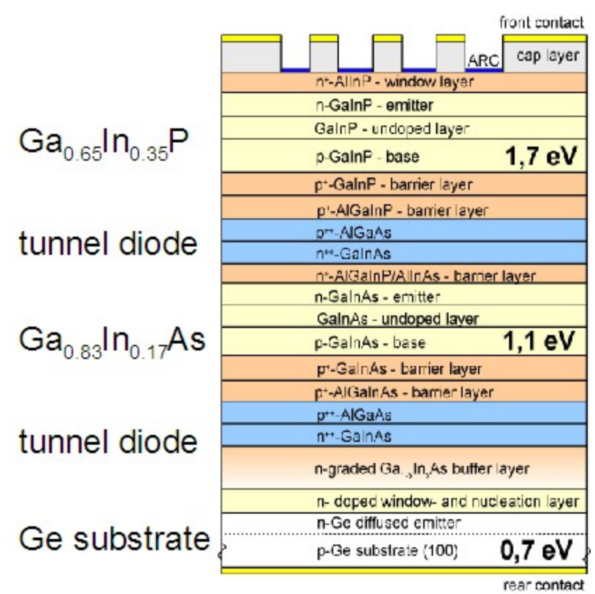
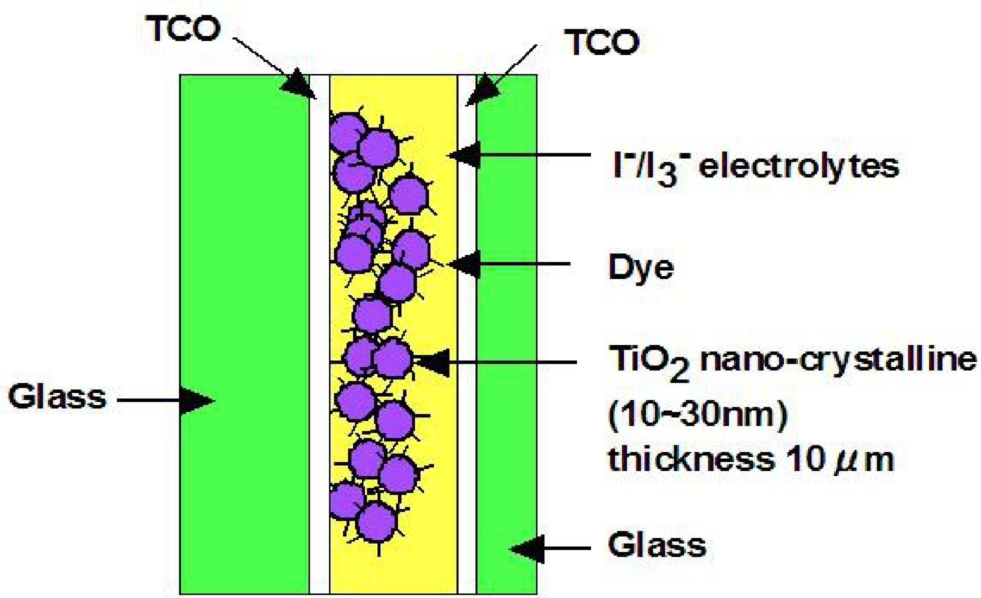
Gallium arsenide (GaAs)

- III-V group
- High absorption coefficient and high carrier mobility >>> ideal material for solar cell
- 25-41%, in single- and multi-junction solar cells
- Very good for space application
- High cost, compared with other thin film solar cells

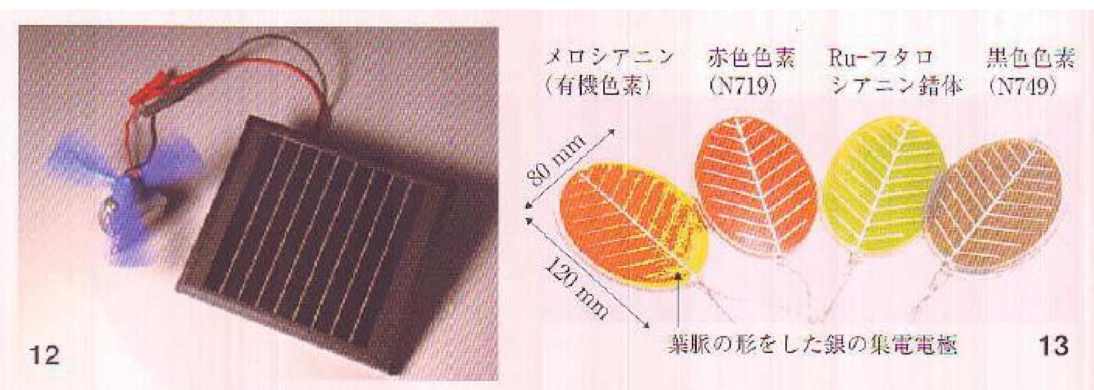


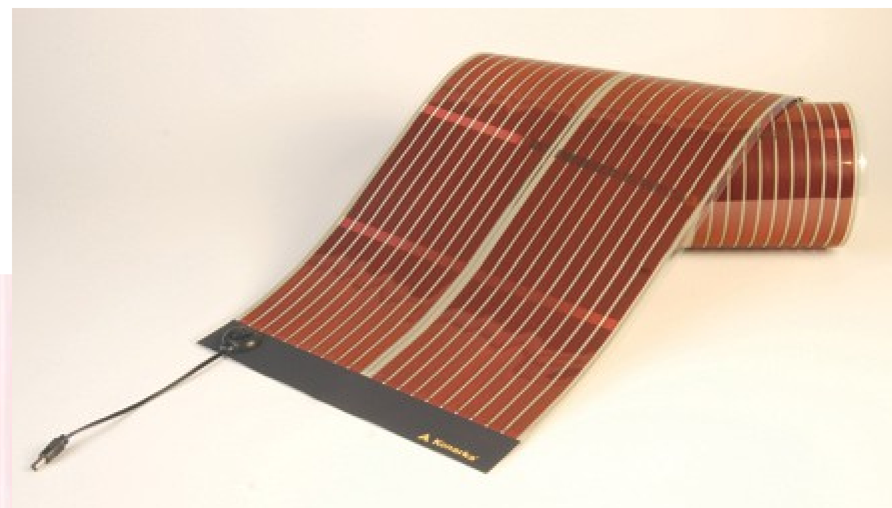
Dye sensitized/ Organic photovoltaic (OPV)



- ✓ No use of vacuum machine
- ✓ Low cost
- ✓ Printable

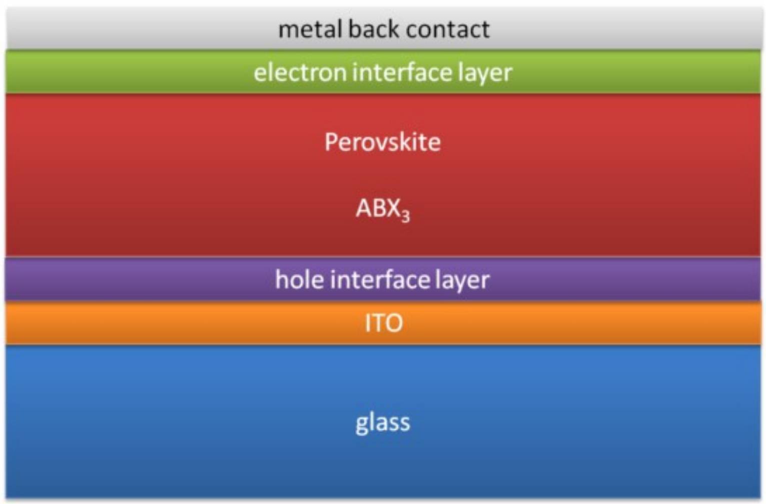
- ✗ Low efficiency
- ✗ Lifetime and stability issues

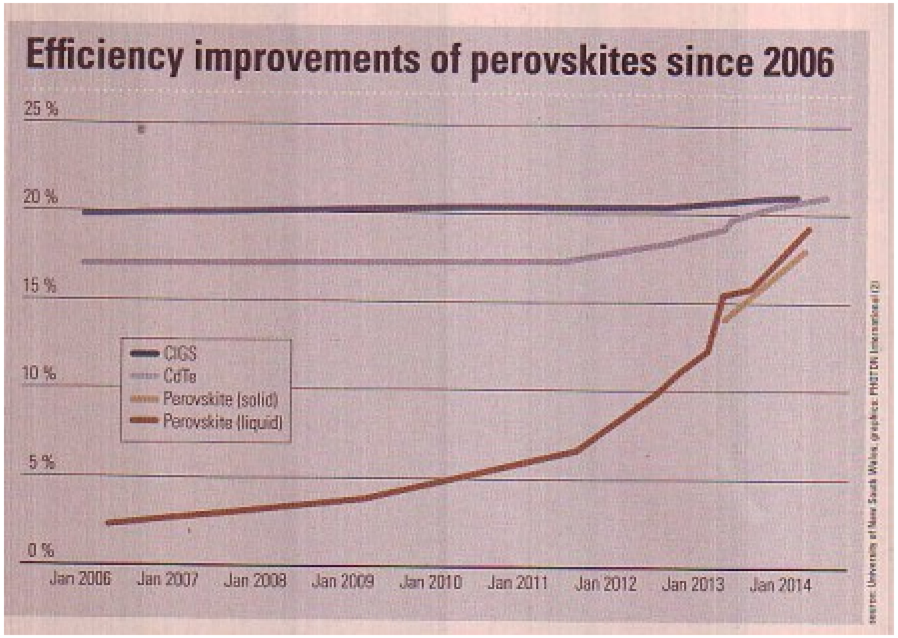




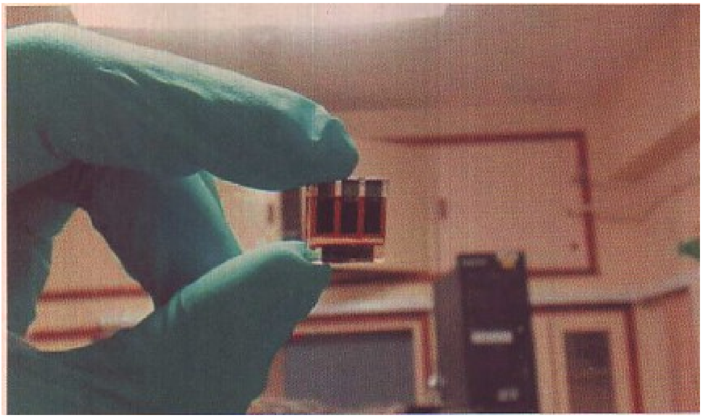
Perovskite

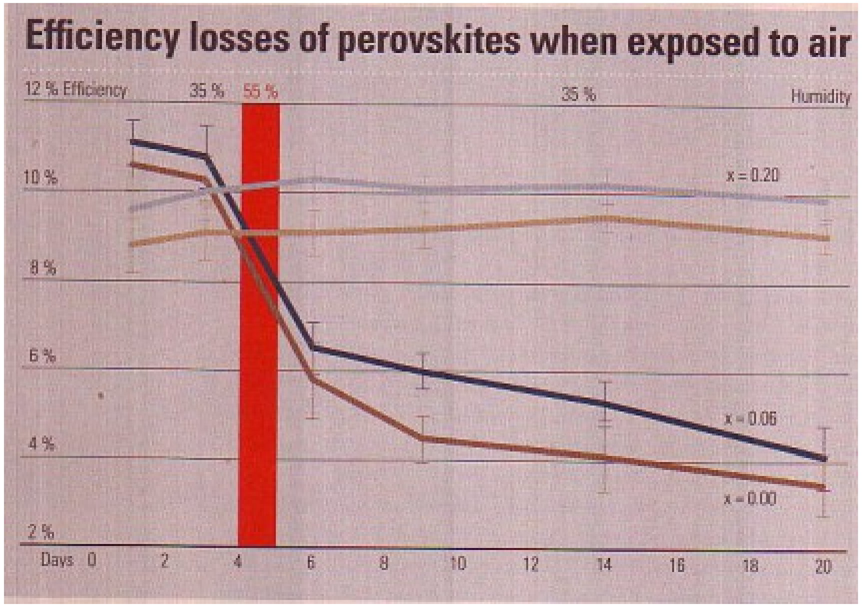
Rapid improvement





Stability issue





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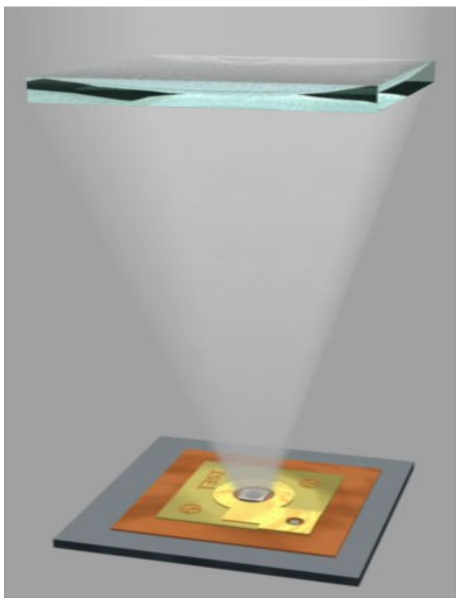
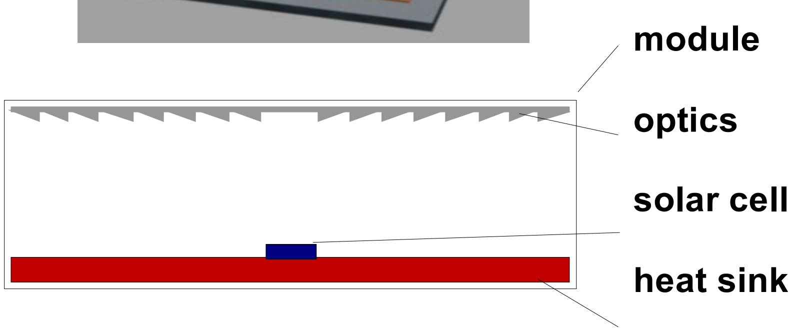
Source: Photon International , October 2014

Concentrating PV (CPV)

- High conversion efficiency
- High cost
- Use only direct radiation
- Sensitive to soiling





High-concentration PV

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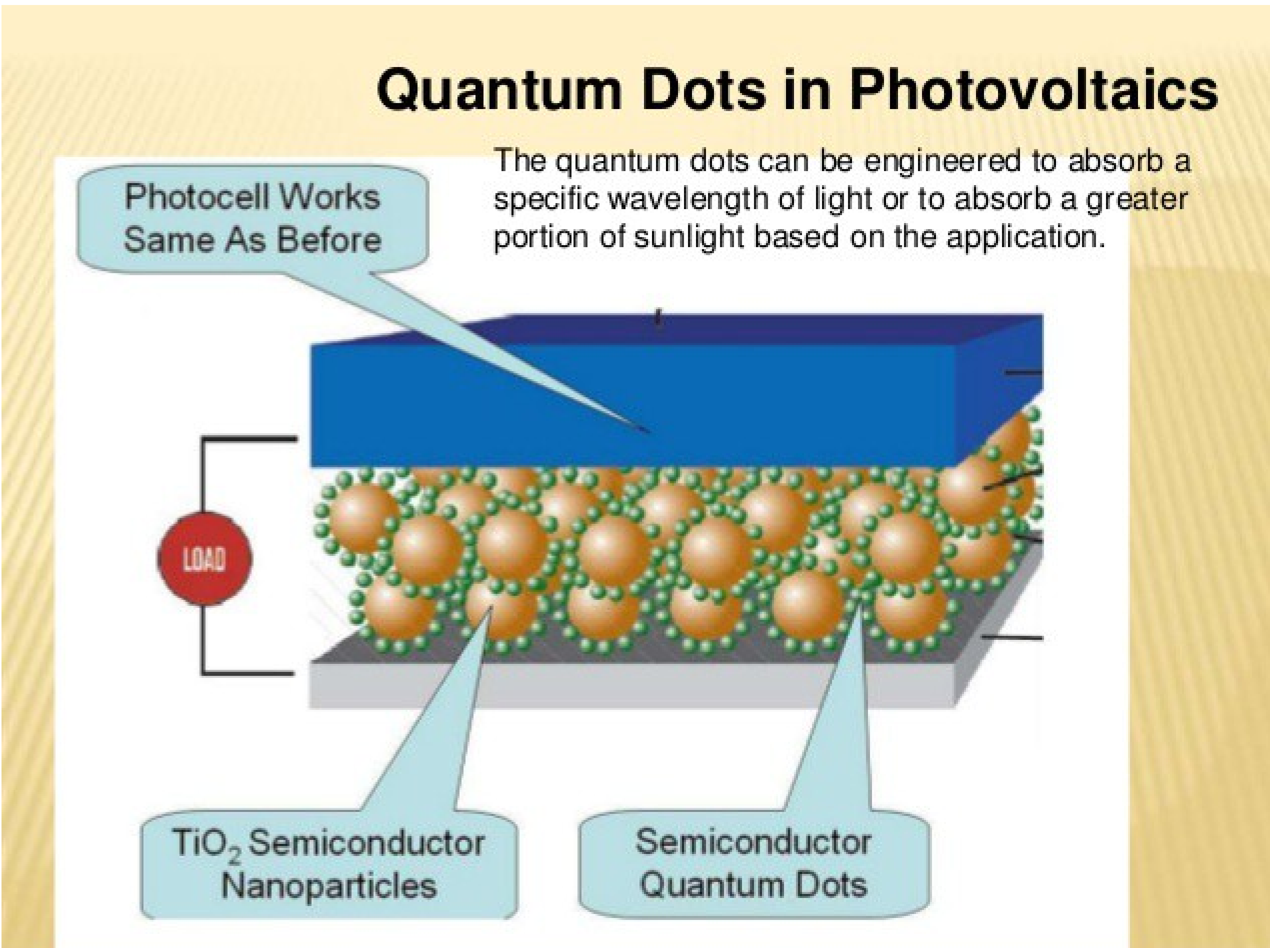
Novel PV concepts

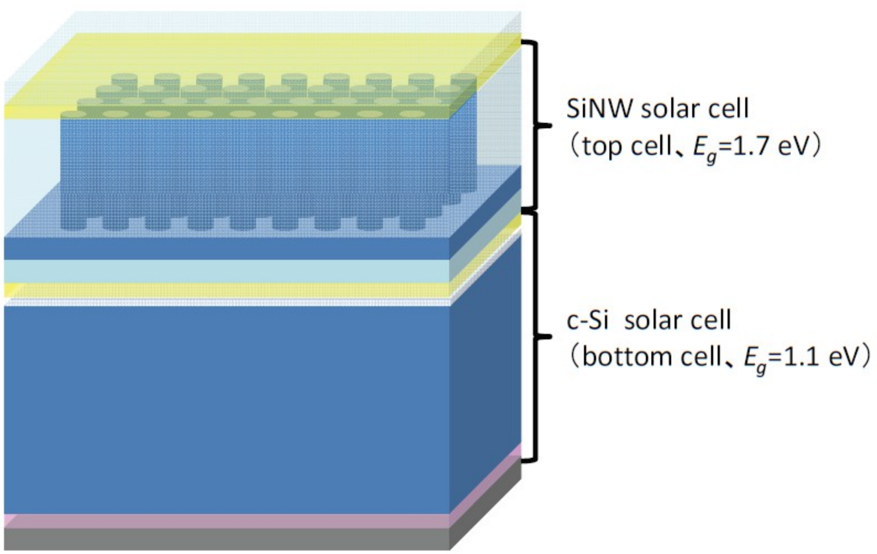
Quantum dot solar cell



High efficient c-Si solar cell

High Efficiency SiNW/Si Tandem Solar Cells

Target eff > 30%



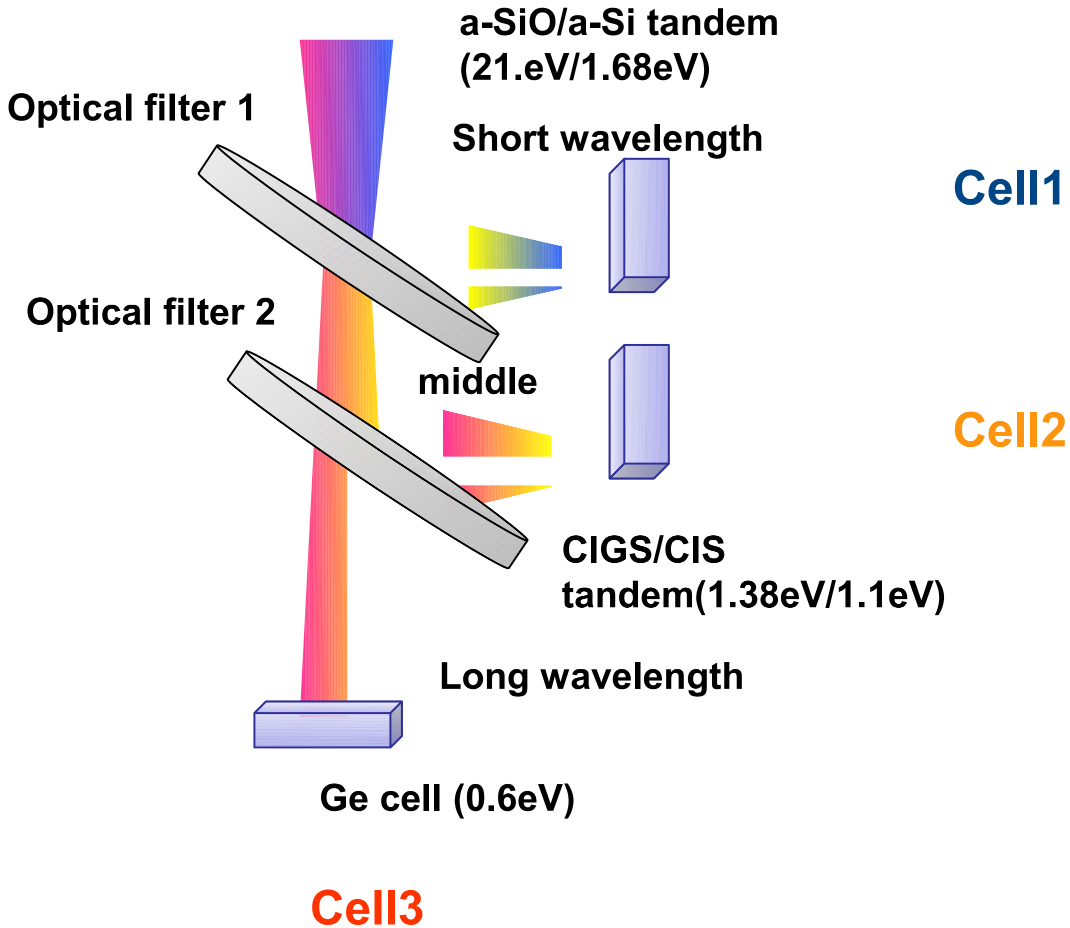
Top: Si nanowire cell

Bottom: Crystalline Si cell

Source: FUTURE-PV Innovation, JST Japan

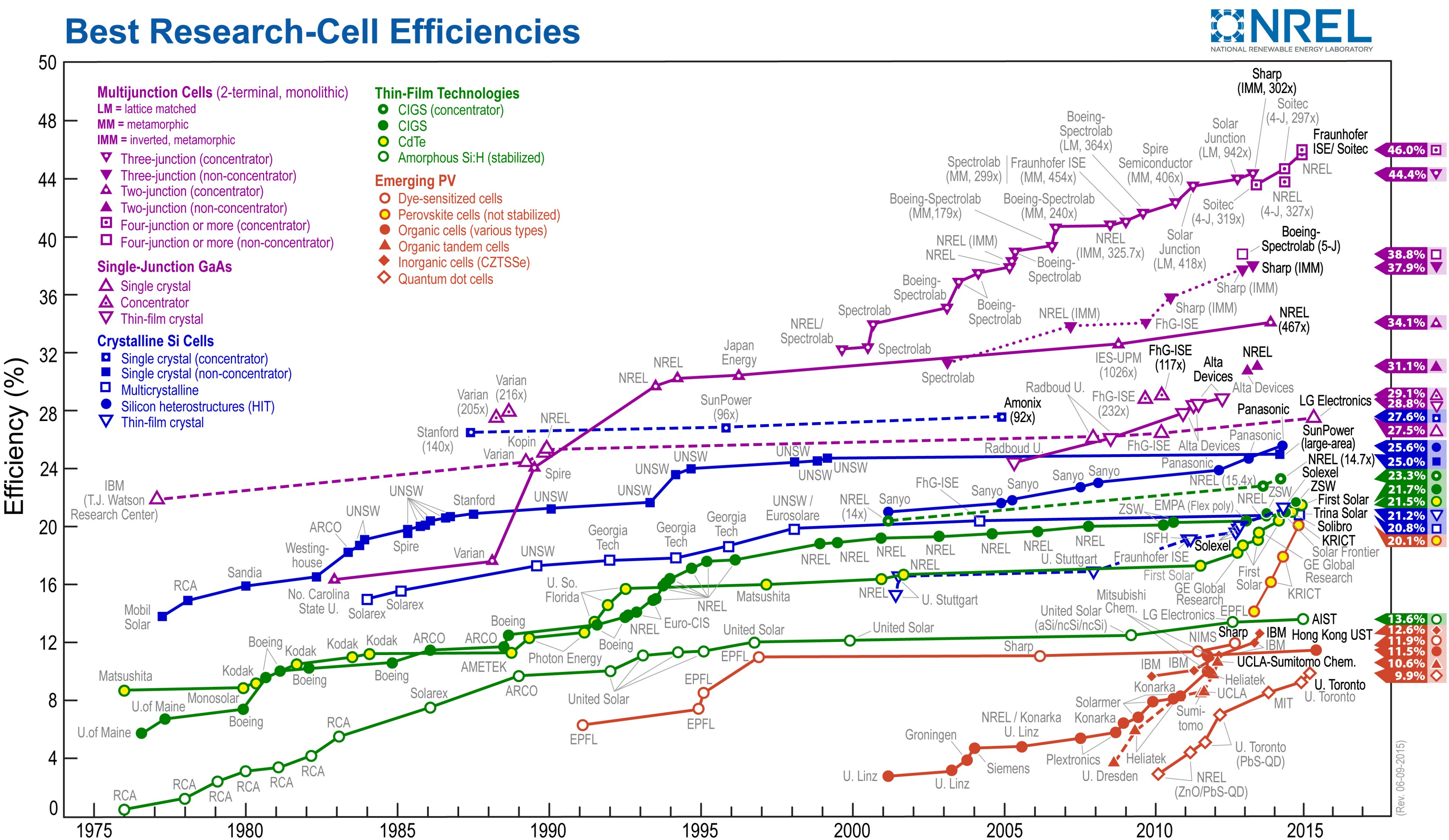
Full spectrum solar cell

Spectral Splitting Structure with dual optical filters



Source: Thin Film Full Spectrum Solar Cells with Low Concentration Ratios, NEDO Japan

BEST CELL EFFICIENCIES -Lab scale



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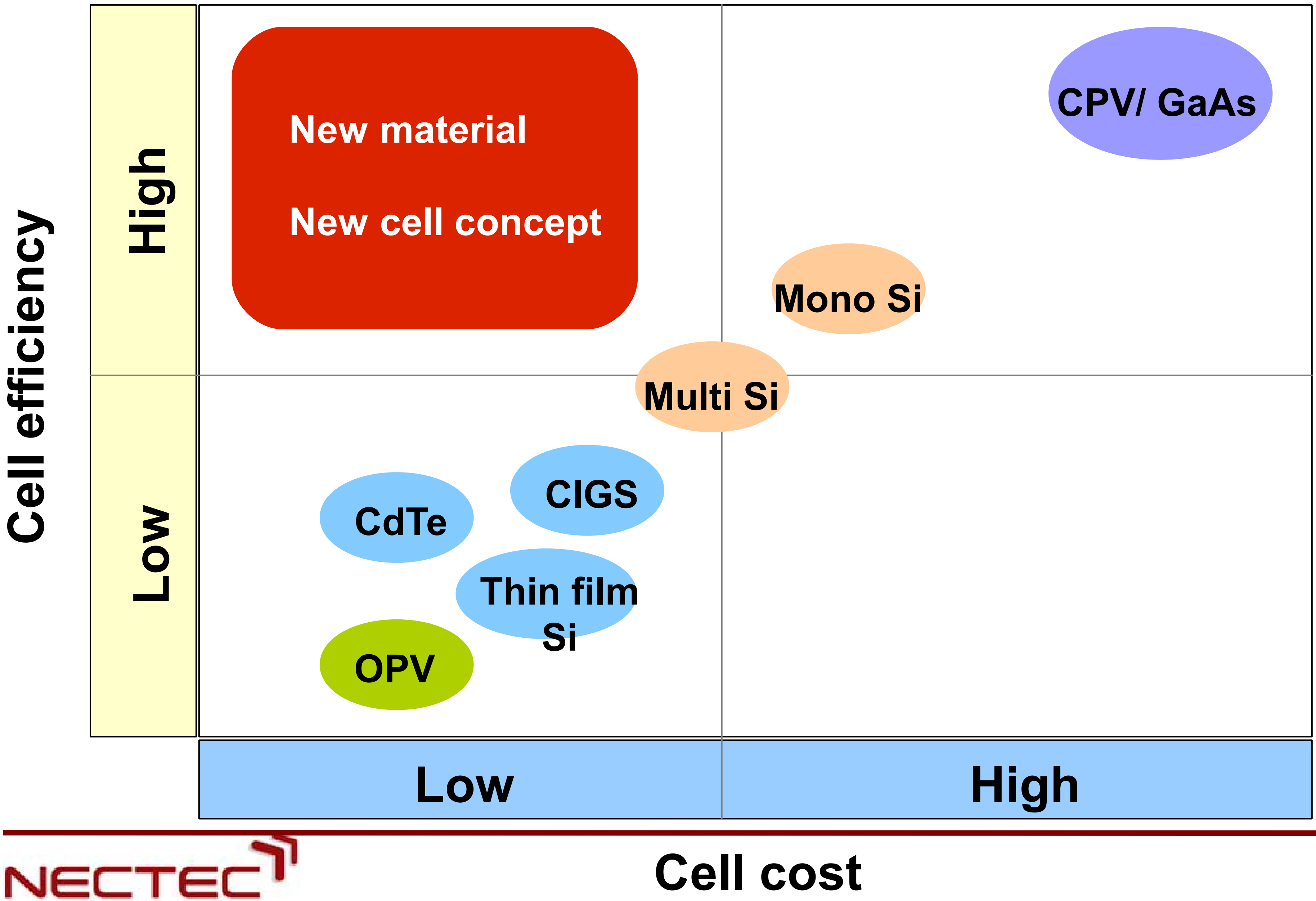
Current status of different PV technologies

PV type	TC for power (%/°C)	Lab efficiency *1 (%)	Module efficiency (%)	Cost per watt*2 (USD)
Mono c-Si (hetero type)	-0.45 (-0.30)	25.0	15-19	0.88-1.14
Multi c-Si	-0.45	20.4	13-15	0.80-0.85
a-Si/micromorph Si	-0.25	13.4	6-9	0.65-0.75
CIGS	-0.30	20.4	10-12	0.77-1.0
CdTe	-0.25	18.7	9-11	0.77-1.0
GaAs	-0.10	30.8	24.2	n.a
Organic	n.a	14.1	1-4	n.a
Concentrated PV	n.a	44.0	35	3.1-4.4

Source:
**1 NREL, Best Research-Cell Efficiencies updated June 2014.*
**2 Overall price in market (2013)*

PV cell efficiency vs cost

Eff >40%
Niche market



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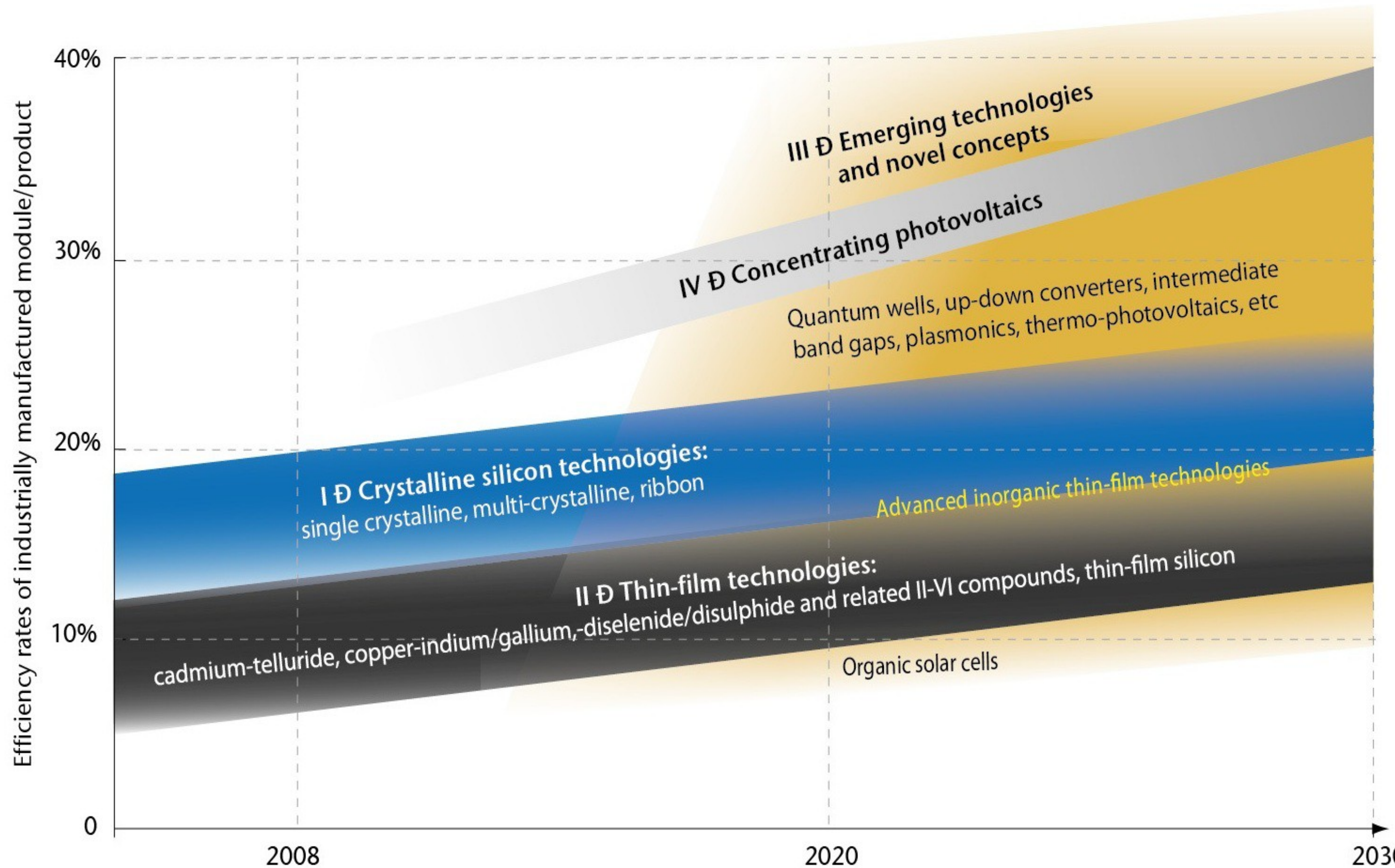
Photovoltaic technology status and prospects

- Current technologies will co-exist with emerging technologies.
- New technologies need time to prove performance and reliability.



Source: IEA PVPS.

PV Target by 2050

Target	2020	2030	2050
Module efficiency (%)	Crystalline up to 20% Thin film 15%	Crystalline up to 25% Thin film 18%	Novel concept up to 40%
Energy-pay-back time (year)	1	0.5	0.25
Operational lifetime (year)	30	35	40
Solar electricity cost (Euro/kWh)	0.12-0.15	0.06	0.03

Source: IEA PVPS

Not only module efficiency and cost,

module lifetime and energy-pay-back time are also topics of concern.

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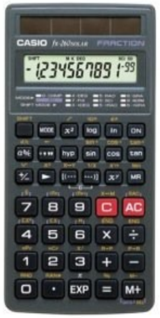
** Energy pay-back time: the time needed for the PV to repay the energy consumption for its manufacturing*

PV Applications

PV portable products: Lightening, charger.. etc



PV System

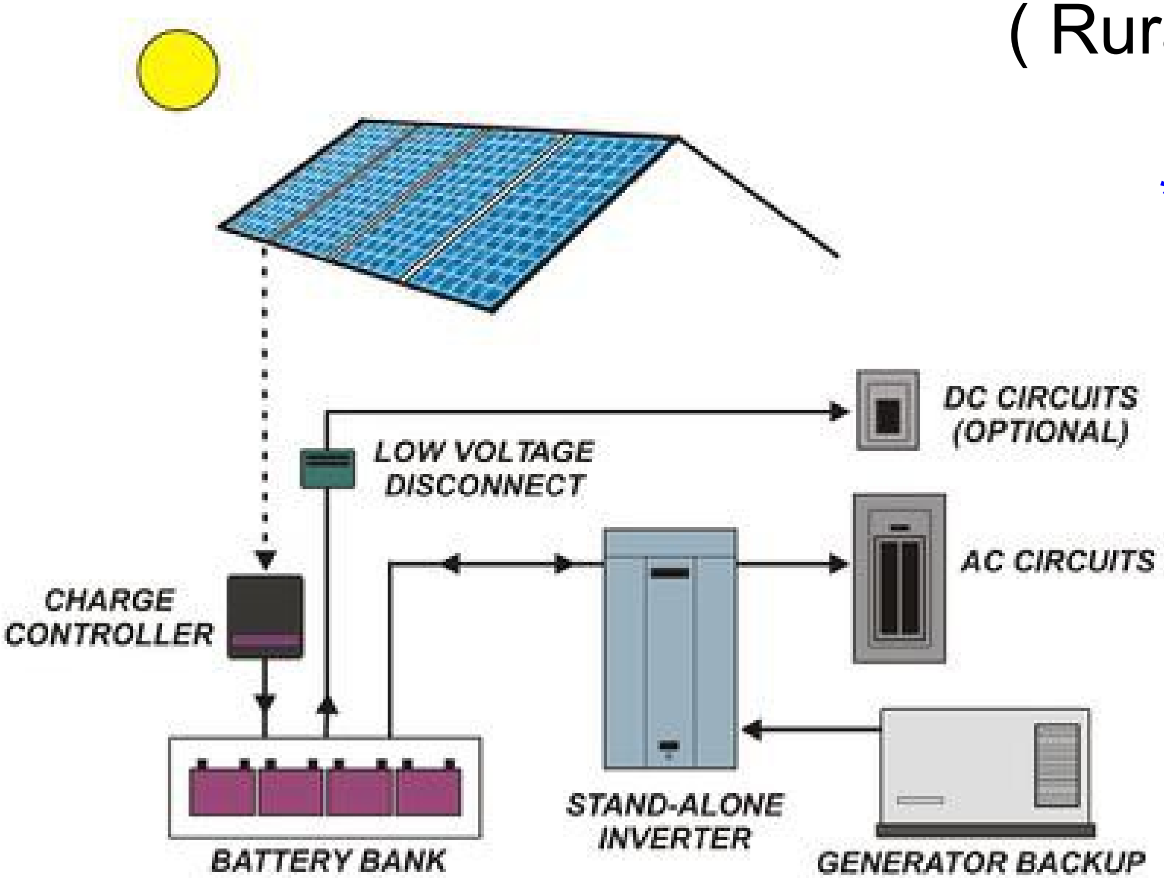
- Stand alone
- Grid-connected

Stand alone

Stand alone systems are used in areas that have no access to an electrical grid.

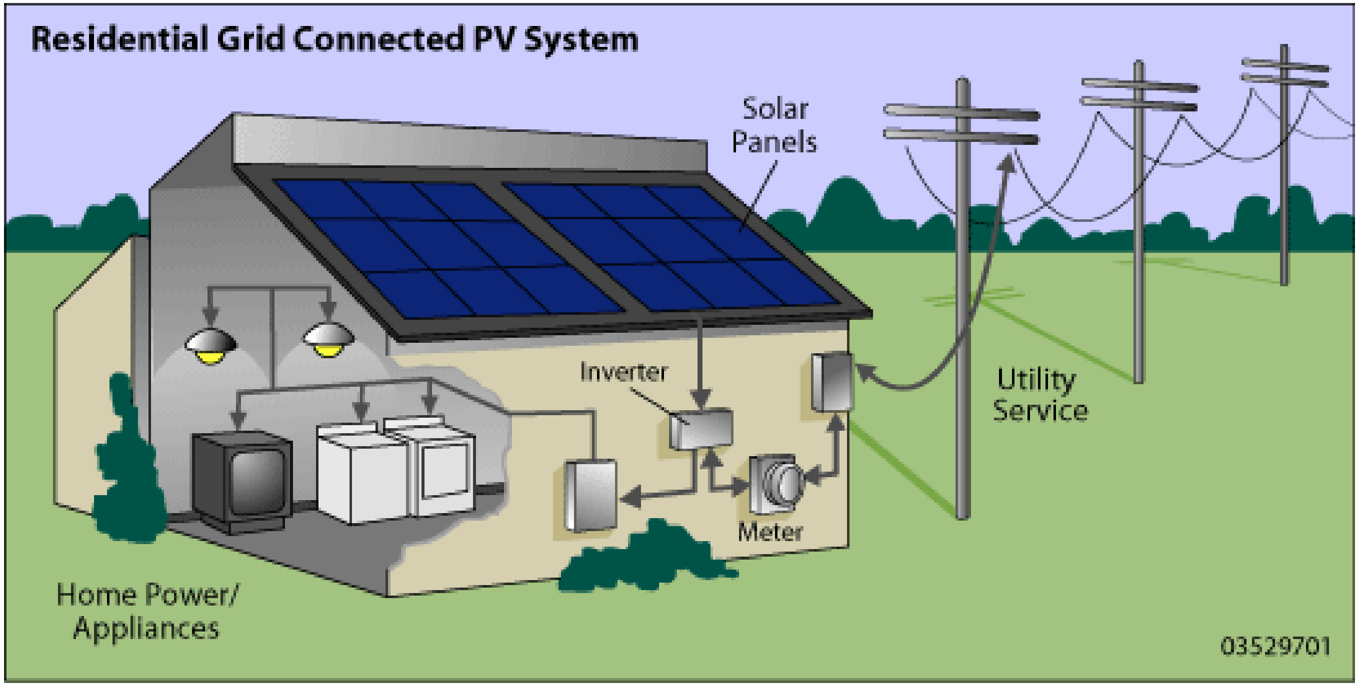
(Rural, mountains, islands)

*Batteries are necessary.



Energy produced normally being stored in batteries.

Grid connected



Solar farm (Solar power plant)

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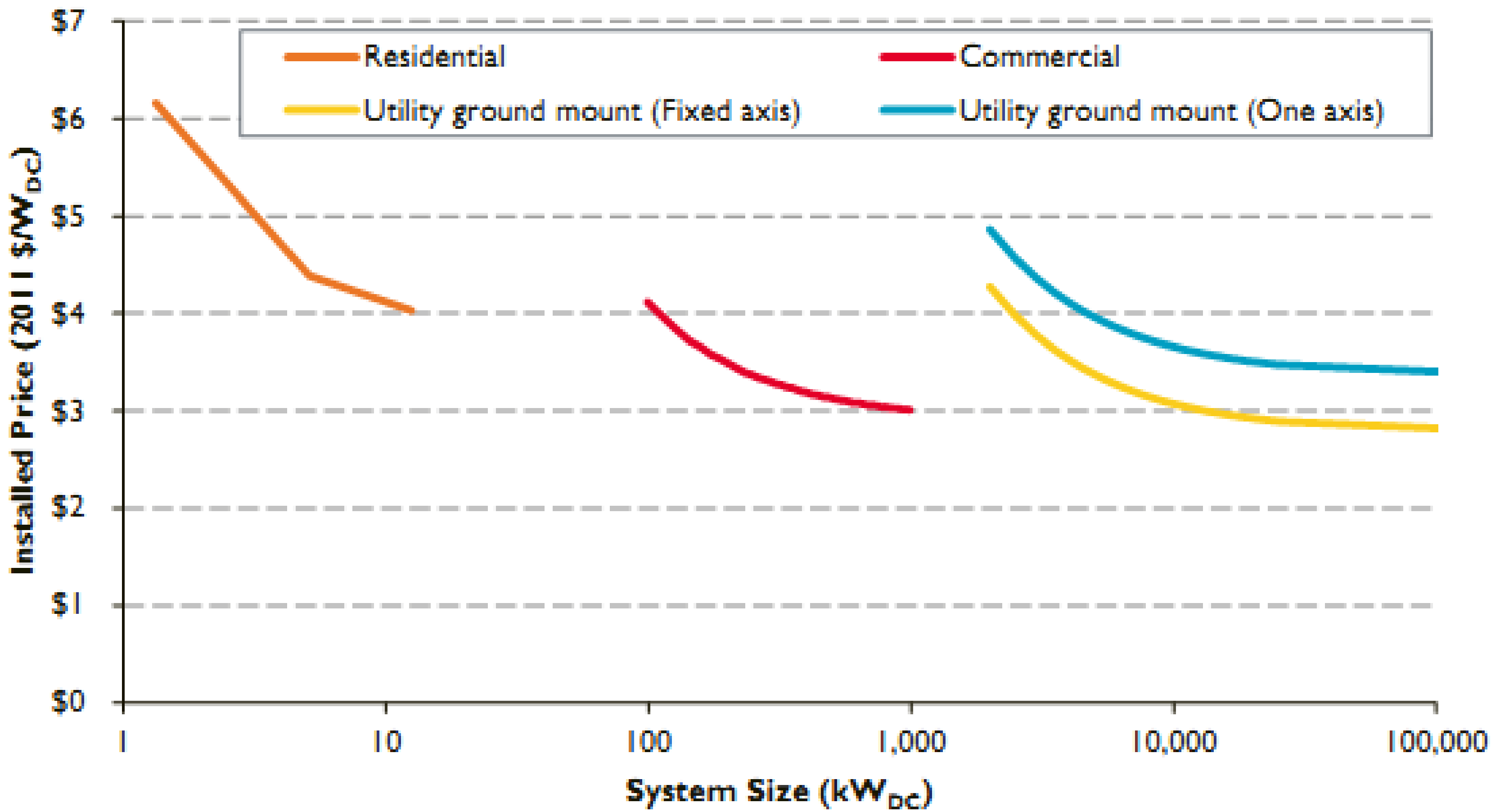
Economy-of-scale benefits: residential and commercial rooftop, ground-mount utility-scale PV



Source: NREL, Photovoltaic Pricing Trends, November 2012

Hybrid system

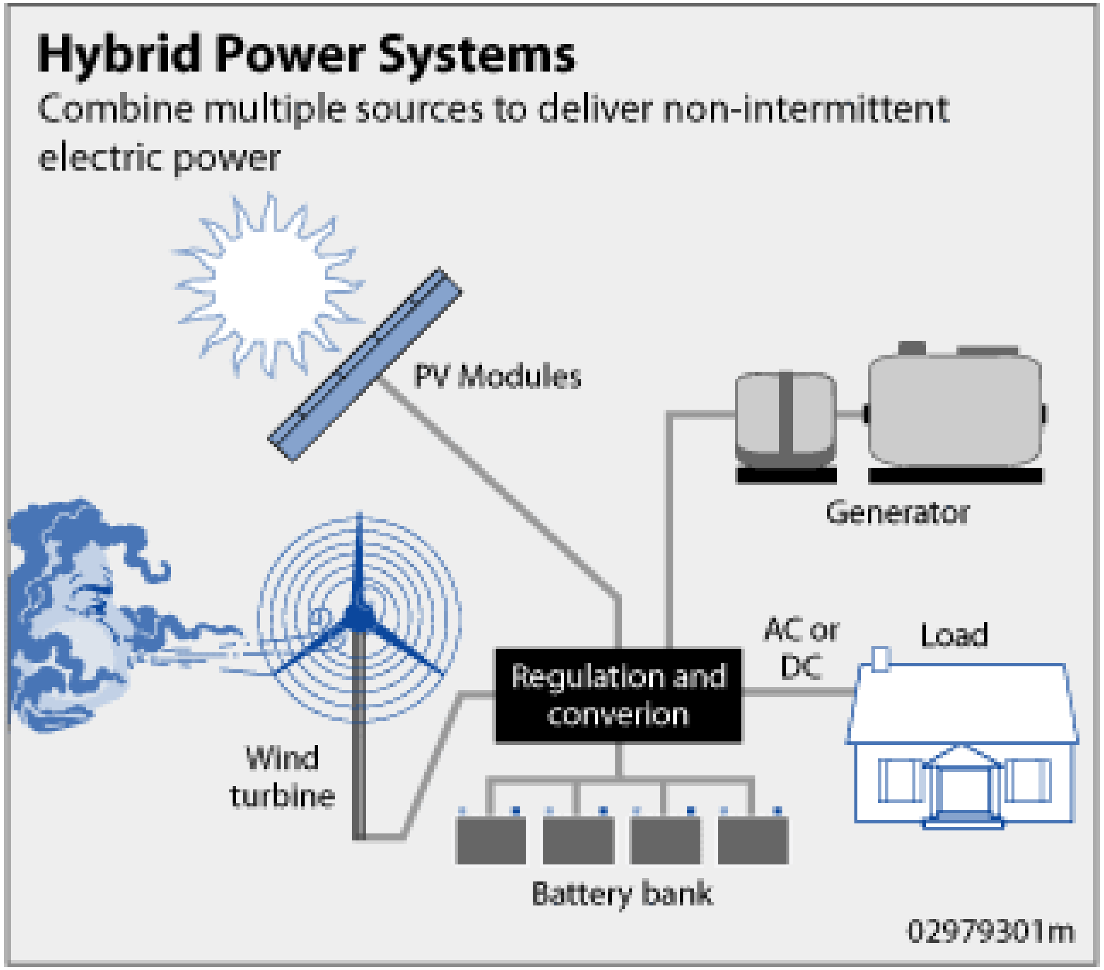
More than one type of electricity generator is employed.

<u>Example</u>

PV + Wind

PV + Hydro

PV + diesel engine



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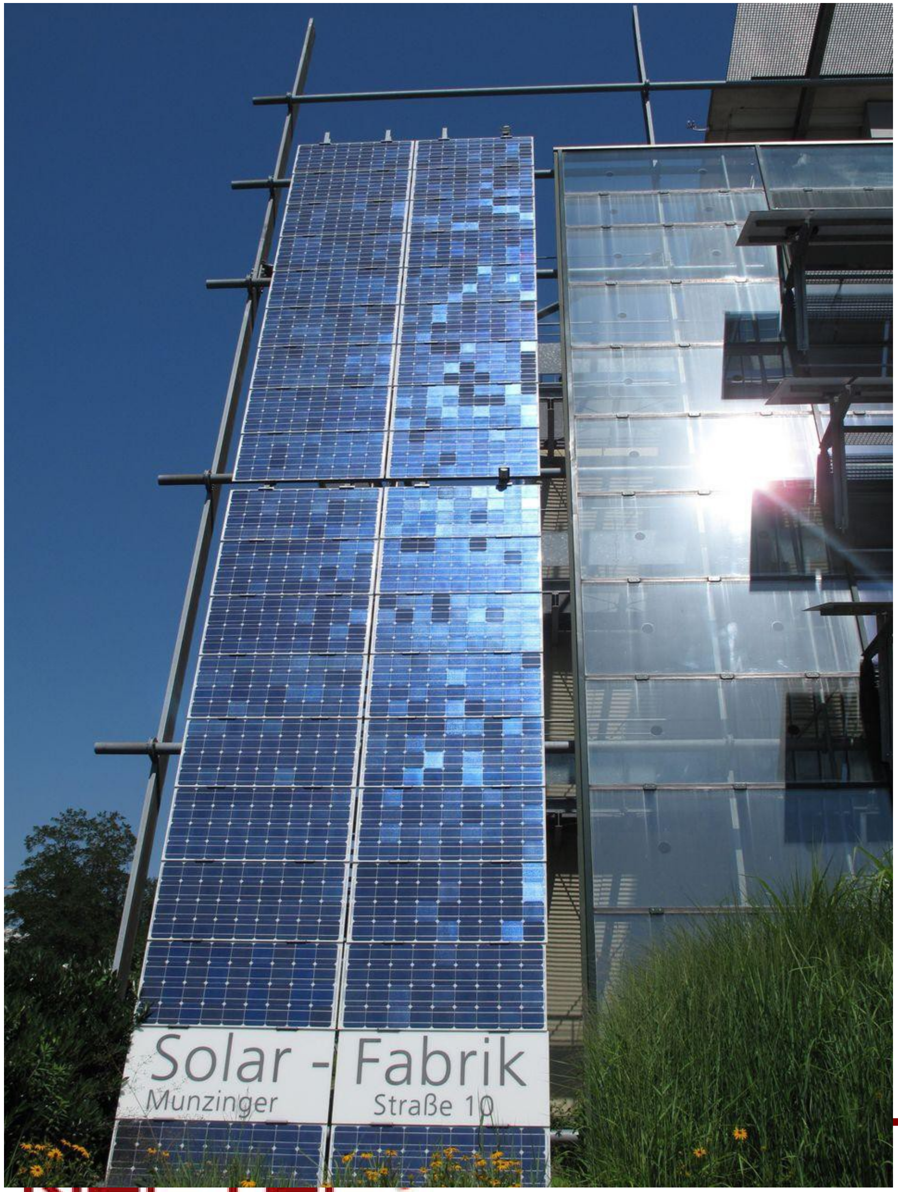
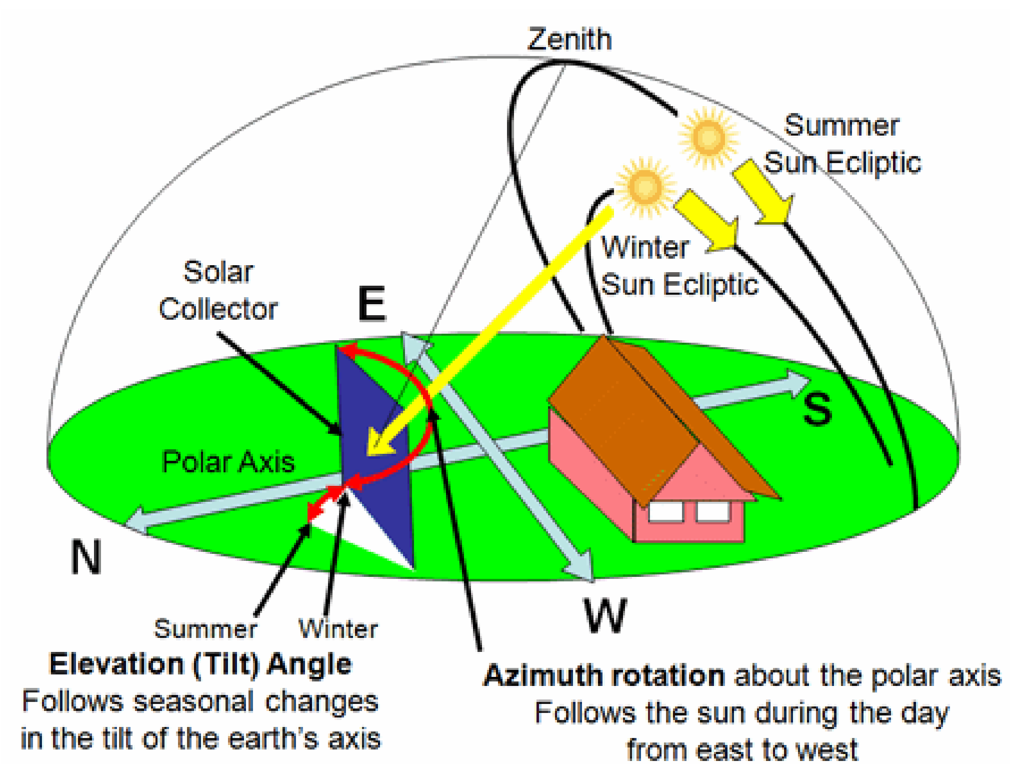
Building Integrated Photovoltaic (BIPV)

A special application in which PV are installed either in the facade or roof or any part of a building.



PV Tracking system

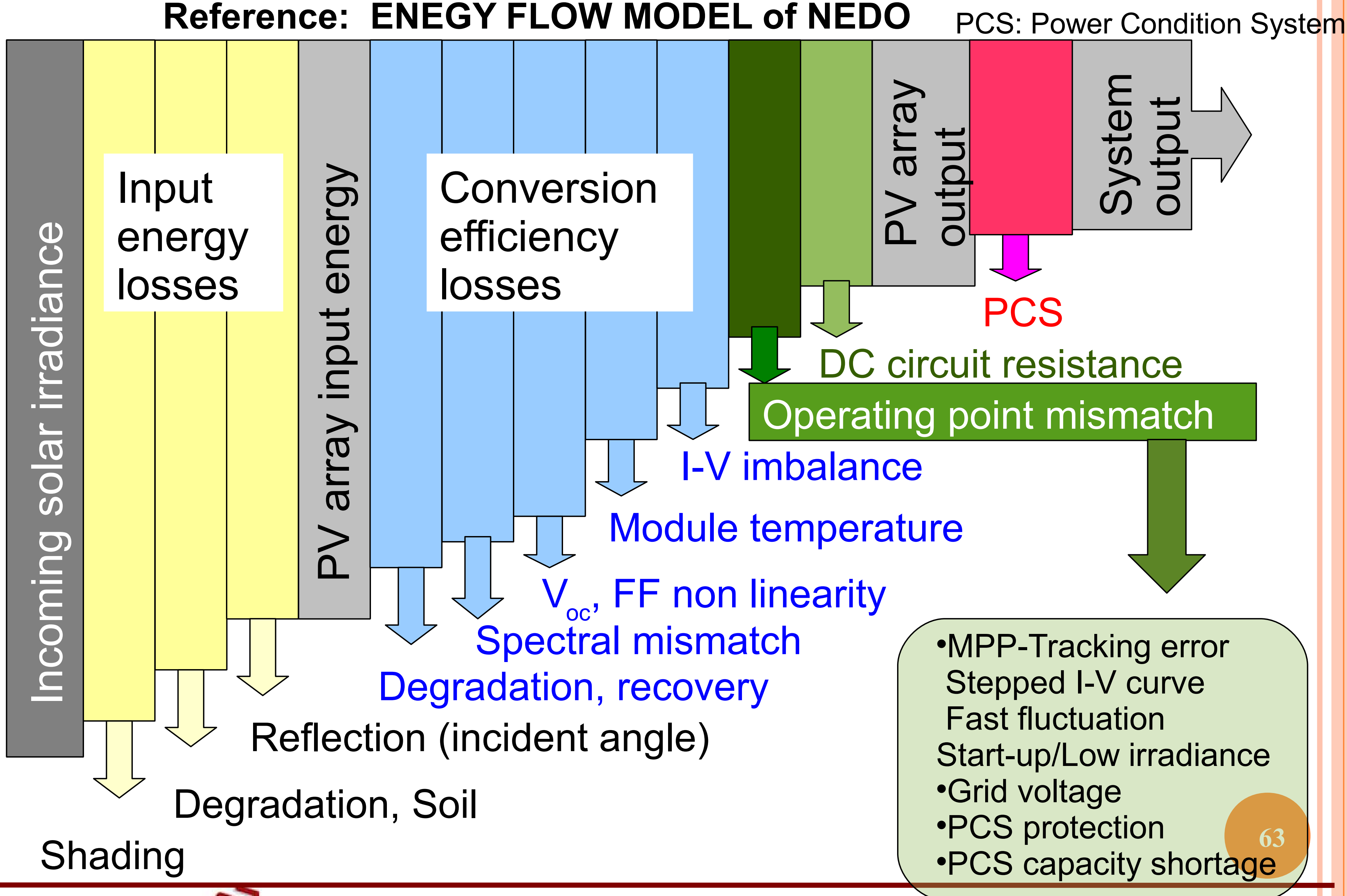
• The amount of energy captured by a solar system can be maximized of the collector or PV can **follow the ecliptic path of the sun** so that the plane of the collector or PV is always perpendicular to the direction of the sun.



Solar Tracking

Energy loss in PV system

Reference: ENEGY FLOW MODEL of NEDO



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PV R&D

Basic research

- Materials
- Cell concepts
- Processes

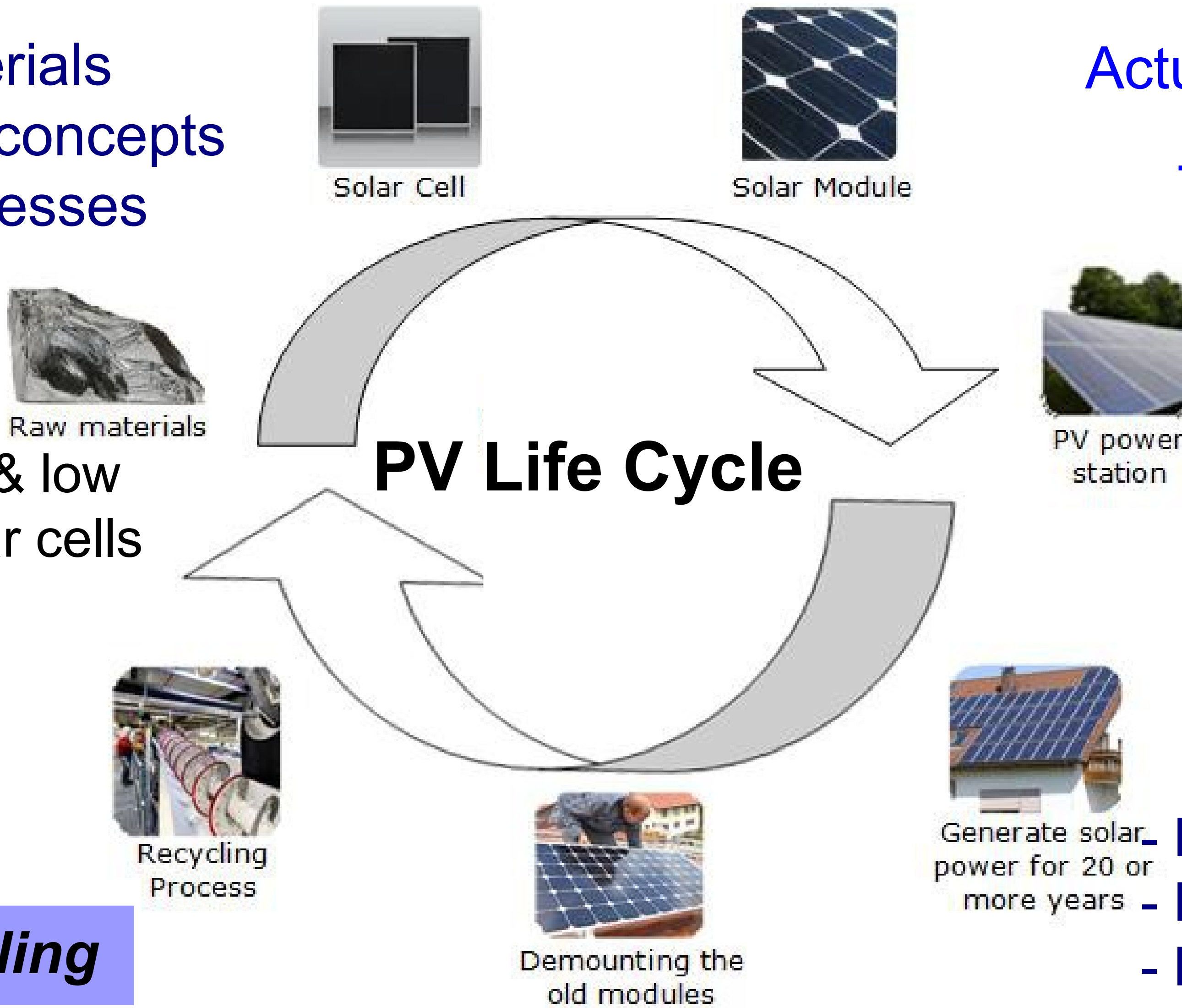
High eff & low cost solar cells

Field test

Actual performance

+Reliability analysis

Standardization& Certification



PV system

- Energy loss
- Eff. improvement
- PV Inspection
- Monitoring system
- Hybrid system
- Grid penetration
- PID

Recycling

- Material recycle
- Reduction of waste

Technologies to support PV diffusion

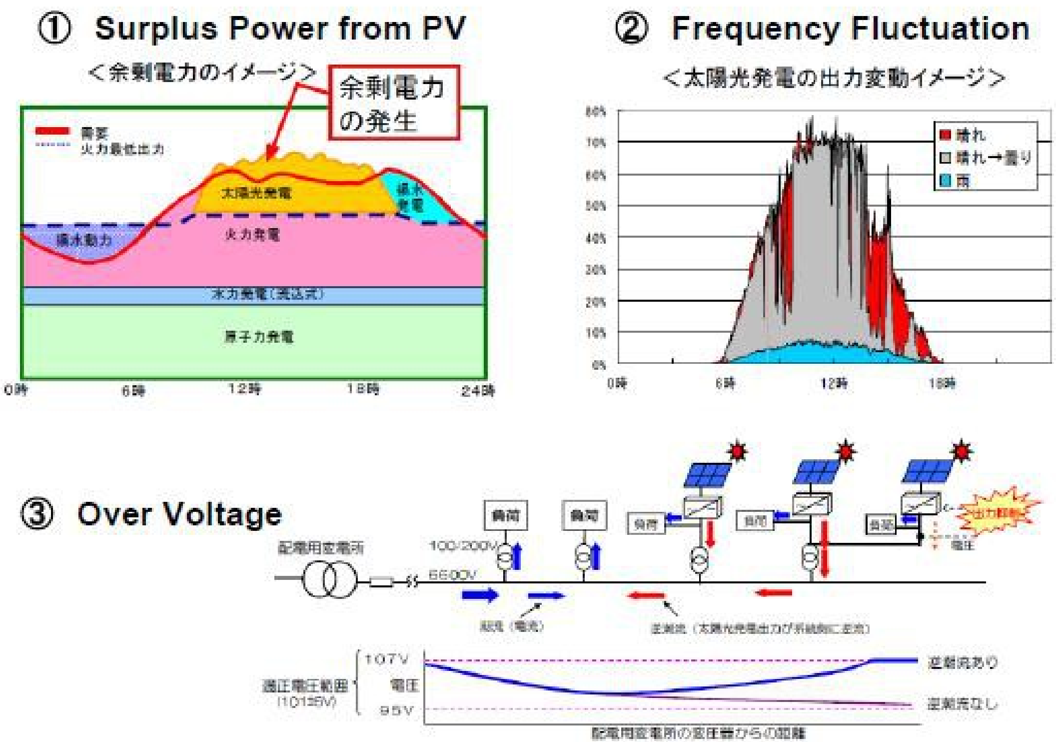
* System components
BOS such as inverter

*Forecasting technology

*Energy management

*Energy storage

Possible Negative Impact of Large amount of PV



Source: Ministry of Economy, Trade and Industry

Summary

1) Keys for technology development

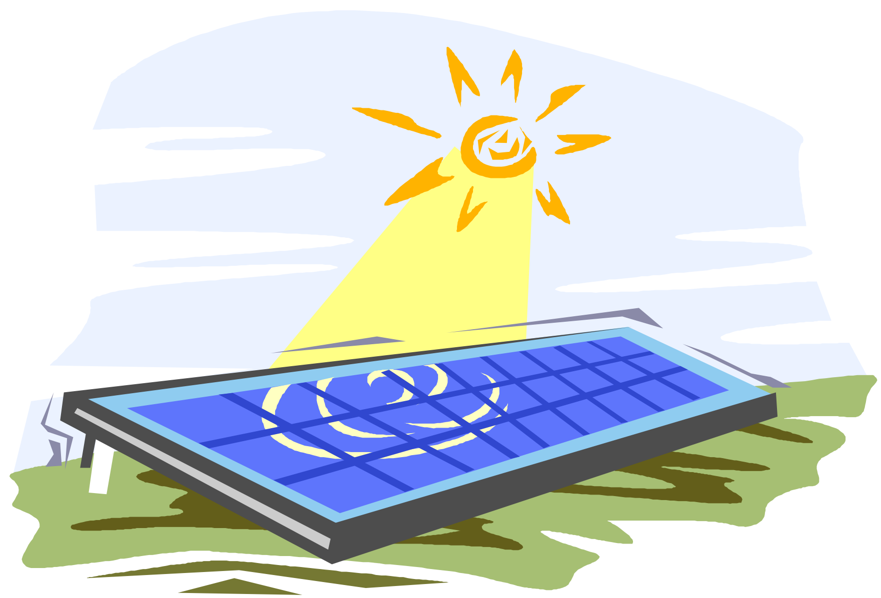
- **Better Efficiency**
- **Lower Cost**
- **Longer Operational Lifetime**
- **Shorter Energy-Pay-Back Time** (Lower energy consumption)

2) **Current technologies will co-exist with emerging technologies**. New technologies need time to prove performance and reliability.

3) **Technologies to support PV diffusion** such as forecasting technology, energy management and energy storage are important.

Thank you

HAVE A SUNSHINE DAY !



ห้องปฏิบัติการเทคโนโลยีพลังงานแสงอาทิตย์

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