PV Basics
and
Global Scenario

Dr. Sudhir Kumar
Chief Executive
Green Energy Solutions, Pune

Mob: +91 96650 20206
drsk22@gmail.com

Solar Photovoltaic: Basics and Energetics

Common Terms

- Energy, Power, kW, MW, kWh, MWh, PLF, kCal, downtime, CUF, Outage, performance ratio, availability factor, grid availability, specific prodn. (kWh/kWp/yr), ….
- Sunlight as energy? IR, Visible, UV
- 100----400----800----2500 (nm)
- Wavelength vs Energy
- $E = hc/\lambda$ (where, $hc = 1240$ eV·nm)
  - h is planks constant 6.626×10^{-34} j.s.
  - c is speed of light 3×10^{8} m/s
  - λ is wavelength of light in nm

Useful Solar Radiation

- Electromagnetic radiation emitted by the sun as Heat, Light & Disinfectant
- 1367.7 W/m² outer space, 1000 W/m² on earth surface
- Direct radiation
- Diffuse radiation
- Two together referred as global radiation

Solar Radiation Measurements

- Global horizontal irradiance (GHI): Pyranometer
- Total: Direct + Diffuse
- Useful for PV

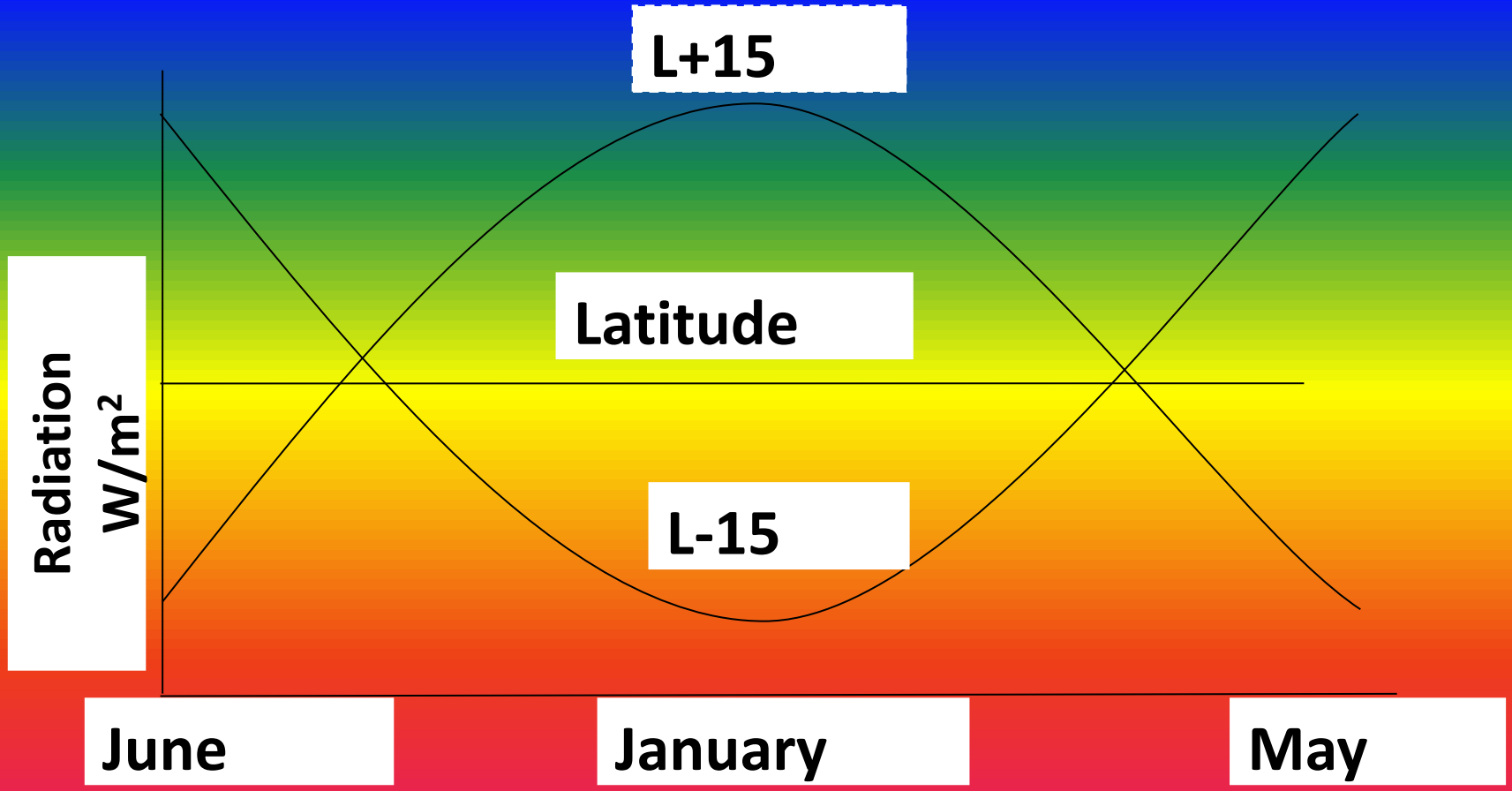
Solar Radiation Measurements

- Direct Normal Irradiance (DNI): Pyrheliometer
- Direct on perpendicular surface
- Useful for Reflectors, CSP

Solar Radiation Measurements

- Solar radiation Unit - kWh/m^2/day
- Power project :
  - CSP min. DNI-1800 kWh/m^2/yr (Reported)
  - SPV min. GHI-1500 kWh/m^2/yr (Suggested)
- Rooftop solar: No standard
- Radiation of site needed for designing
- Actual ground data: Not always available
- Derived data: NASA, METONORM, GeoModel

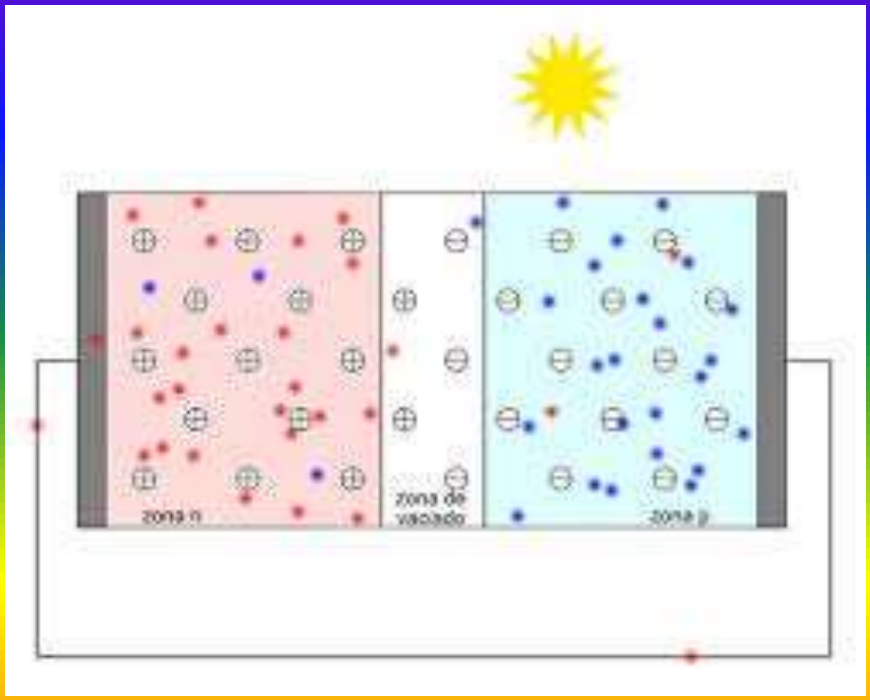
Winter or Summer Optimization

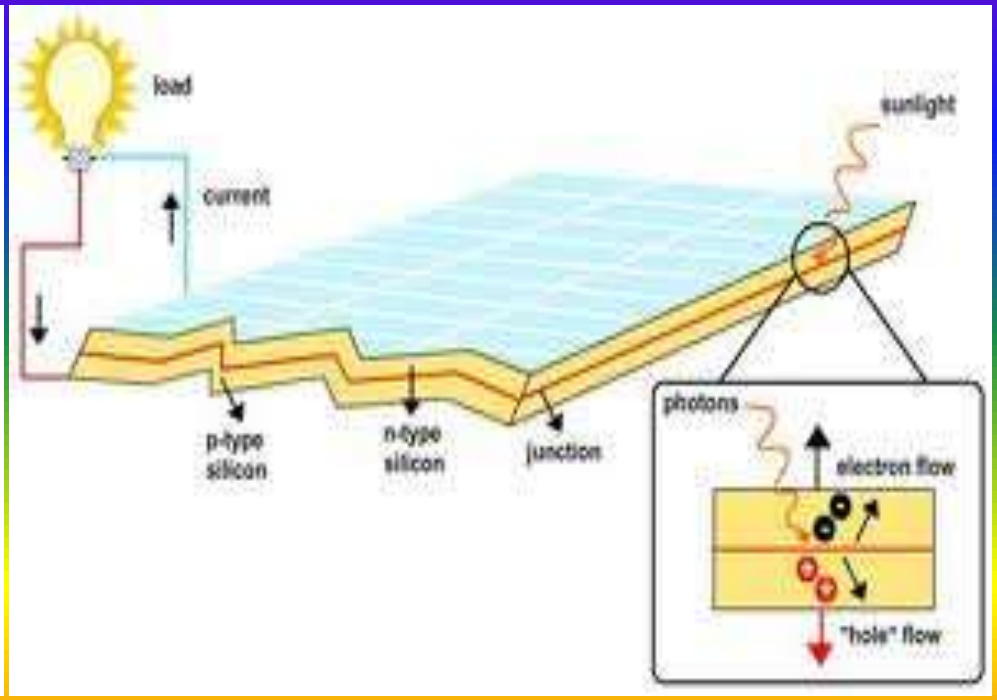


Photovoltaic cell

- Silicon n-type film on p-type chip (0.3 mm)
- Top metal grid + bus bar (photolithography)
- Bottom full metal cover e.g. Silver
- Positive (bottom) & Negative (top) connections

Photovoltaic Effect





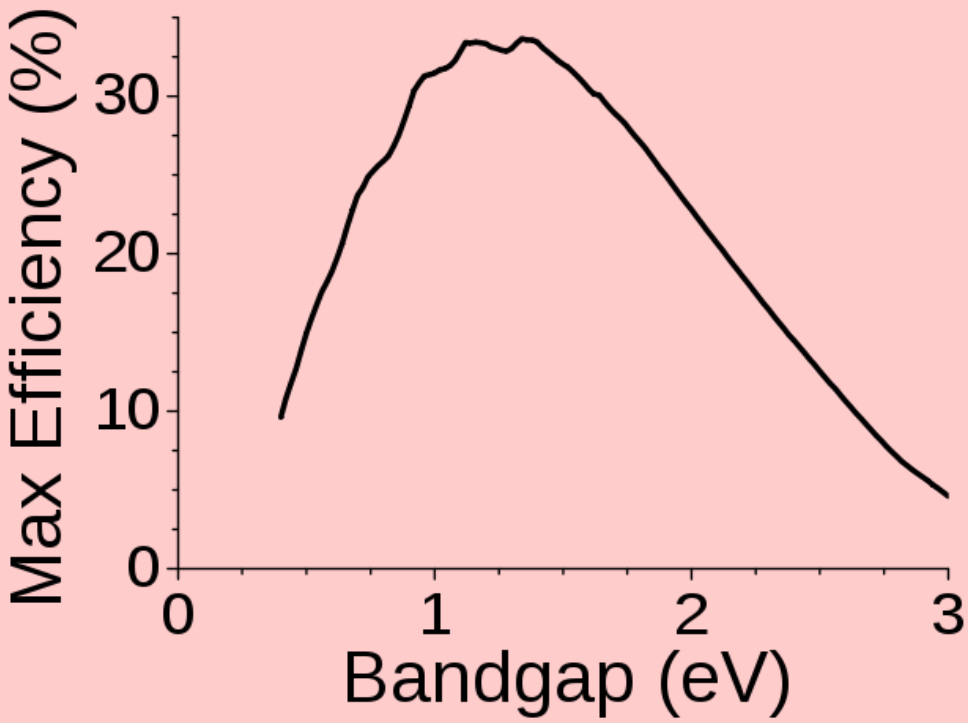
- Light energy strikes juction
- Electrons flow: inside from p- to n-
- Outer curcuit: from n- to p-
- Suitable load attached for use

Solar cell material

Ideal solar cell material:

- Must be a solid semiconductor
- Must have suitable band gap
- Responsive to visible range
- Stable under outdoor use
- Should have affordable cost
- Abundant availability in nature

Efficiency vs. Band gap

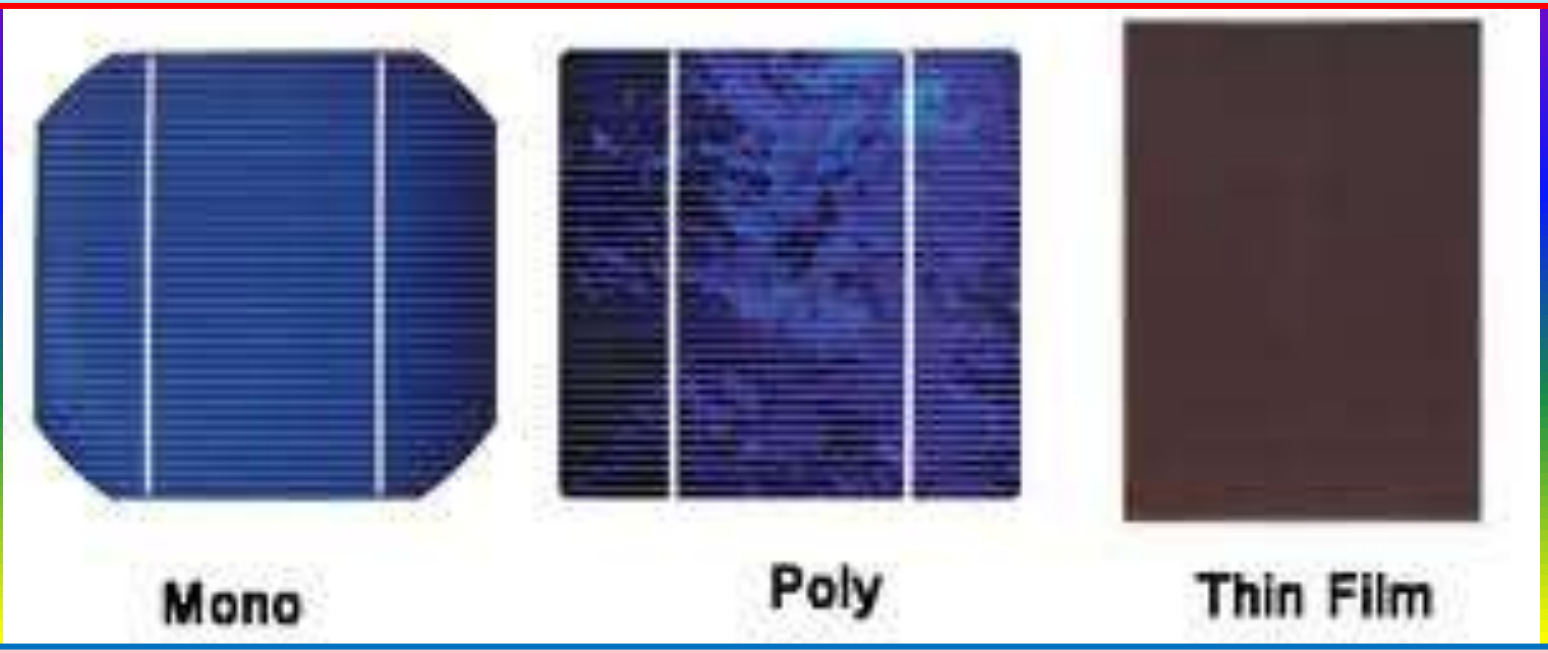


- **Ideal material close to 1.54 e.V.**
- **Corresponds to red wavelength**

Semiconductor Band Gaps: Examples

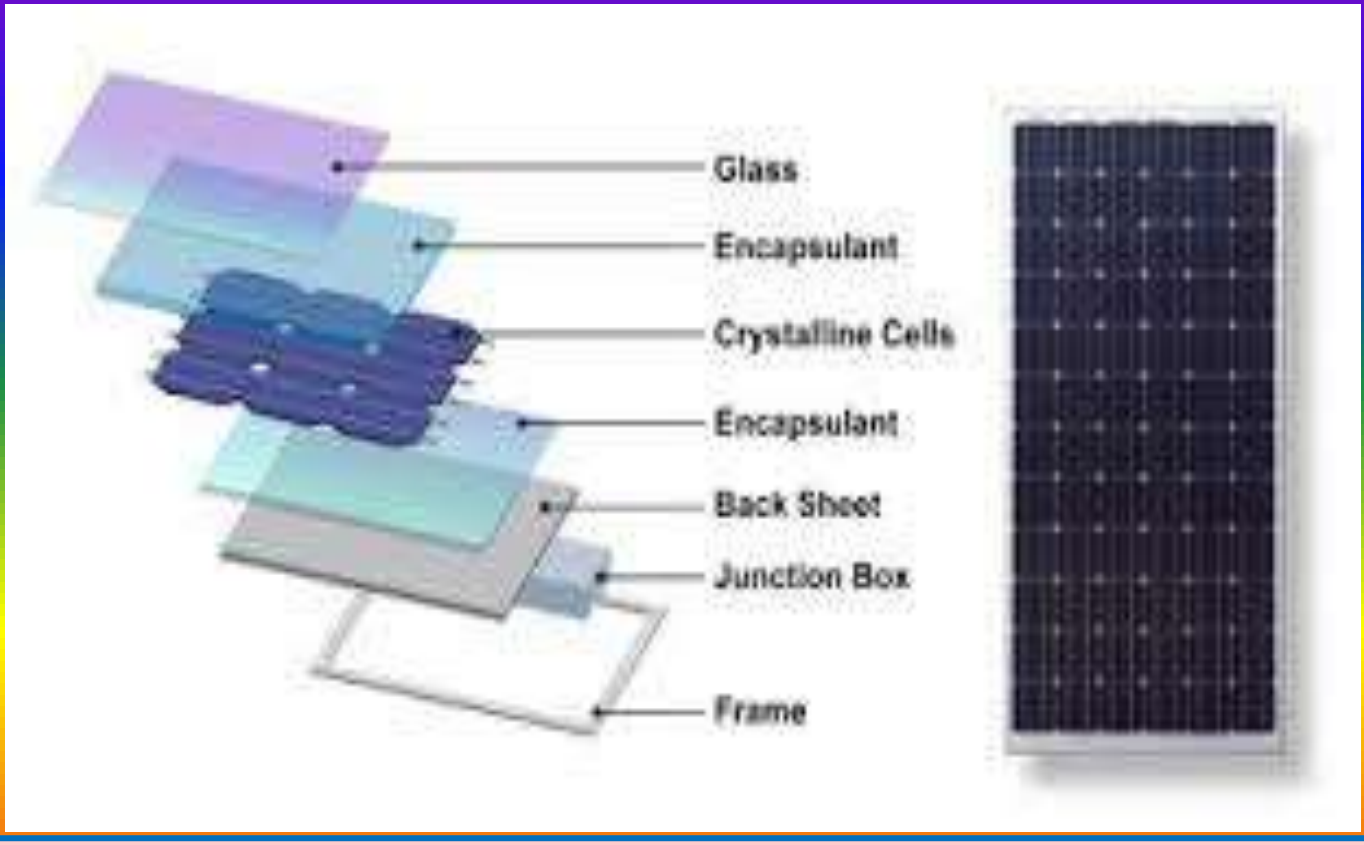
S.N.	Material	Chemical formula	Band Gap (e.V.) at 300K
1	Silicon	Si	1.11
2	Silicon dioxide	SiO_2	9
3	Germanium	Ge	0.67
4	Aluminium antimonide	AlSb	1.6
5	Diamond	C	5.5
6	Gallium(III) phosphide	GaP	2.26
7	Gallium(III) arsenide	GaAs	1.43
8	Gallium(II) sulfide	GaS	2.5
9	Indium(III) phosphide	InP	1.35
10	Zinc selenide	ZnSe	2.7
11	Cadmium sulfide	CdS	2.42
12	Cadmium selenide	CdSe	1.73
13	Cadmium telluride	CdTe	1.49
14	Copper(II) oxide	Cu2O	2.17

Types of PV Cells



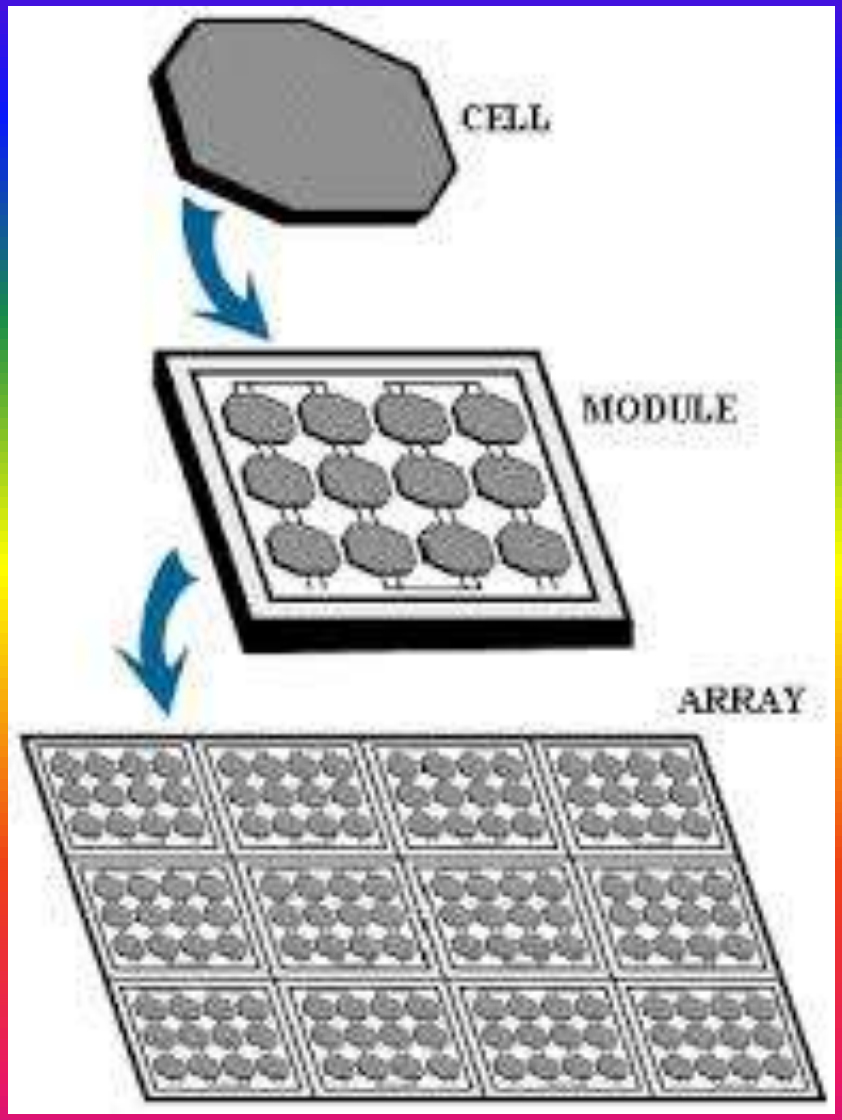
- Crystalline
  - Mono-crystalline silicon solar cells
  - Polycrystalline silicon solar cells
- Thin film
  - Amorphous silicon
  - Cadmium telluride
  - Copper indium di-selenide

Modules



- Hermetically sealed
- Two layers of ethylene vinyl acetate (EVA) encapsulant
- Support:
  - Top toughened glass
  - Bottom DuPont™ Tedlar® (PVF) polyvinyl fluoride sheet
- Sturdy, suitable for outdoor use

Cell, Module, Array

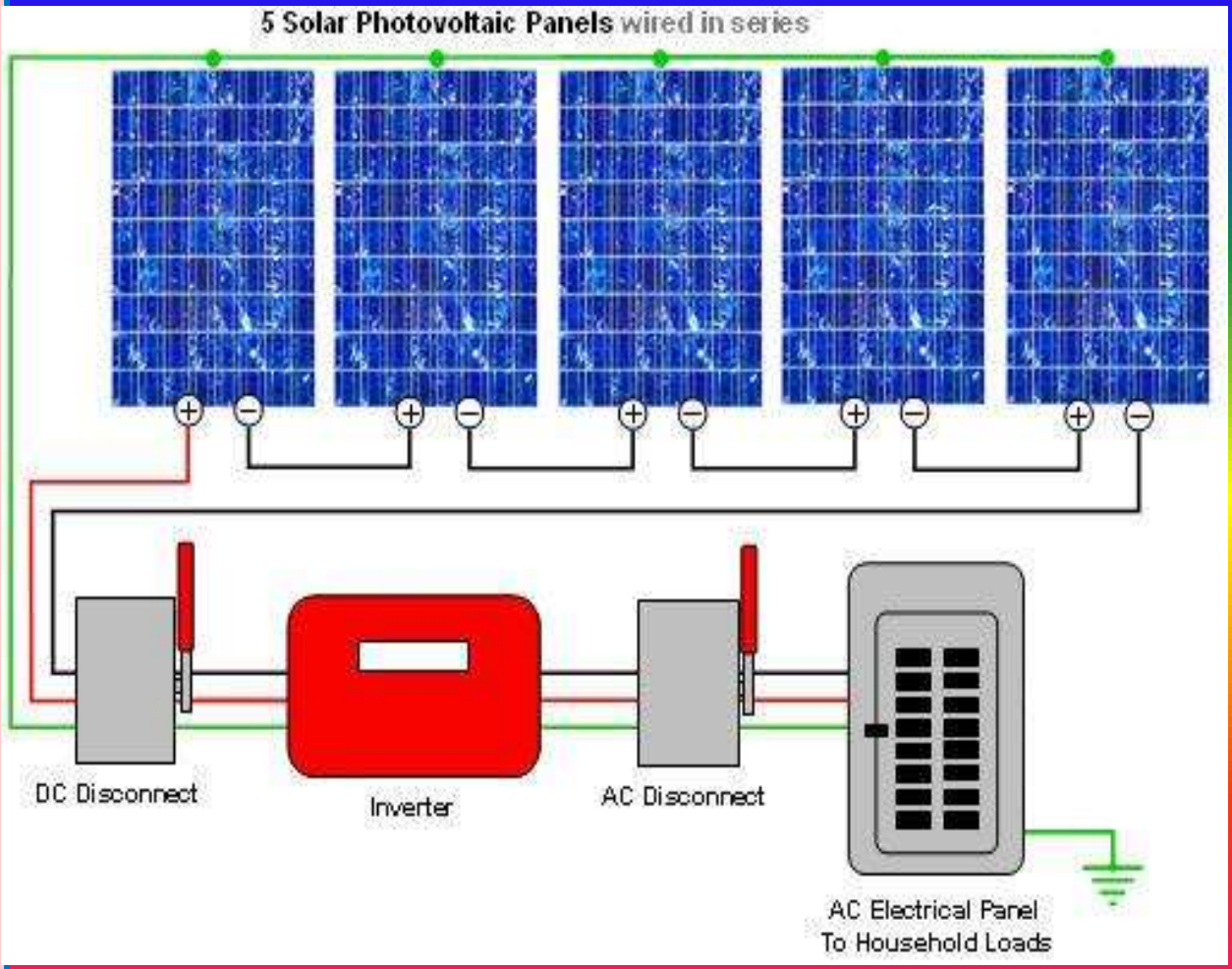


- Cells connected in series: Voltage added
- Cells connected parallel: Current added
- Parallel-series combination decides wattage, voltage
- Same logic with modules to form array
- Same logic with arrays to form solar field

Parameter	Crystalline	Thin Film
Types of Materials	Silicon	Amorphous Silicon, CdS, CdTe, CIGS etc.
Power Efficiency	12-19%	6-11%
Commercial maturity of the technology	Well Developed Long experience on Commercial plant	Under development Less experience on commercial plants
Output per MW installed	High	Varies as per sunlight condition
Cell cost	Slightly higher cost per Watt	Lower cost per Watt
Temperature Effects	Temperature variation affects the output	Lesser impact of temperature variations
Module Weight	Light weight modules	Heavier modules
Land Requirement	Lesser space required per MW	Largest space requirement
Availability	Easily available	Limited supply
Module quantity	Lesser nos. required due to high efficiency	More modules required
Plant Maintenance	Less maintenance required after installation so lower cost	Highest maintenance required, so highest maintenance cost
Health hazards	Made from non toxic material (Si)	Toxic materials used for thin films (CdS, CdTe)
De-rating	Very low de-rating with time	High de-rating factor

Suitability for Rooftop Applications

- Use the poly-crystalline modules solely because
- Slight cost advantage,
- Relatively easier availability with vendors
- Good efficiency
- Least degradation
- Local availability and
- Better life of cell



The Term: ROOFTOP

- **"Rooftop solar PV system" means the grid interactive solar photo voltaic power system installed on the rooftops/ground mounted or open land of consumer premises that uses sunlight for direct conversion into electricity through photo voltaic technology.**

- **"Net metering" means an arrangement for measurement of energy in a system under which rooftop solar PV system installed at eligible consumer premises delivers surplus electricity, if any, to the Distribution Licensee after off-setting the electricity supplied by Distribution Licensee during the applicable billing period.**

Rooftop Relevance Today

Evolution Period	Affordable to
1980 - 1989	Research laboratories, Space centers
1990-1999	Off-grid, Govt. Schemes, Remote area
2000-2009	Grid scale, Govt. supported, Institutes
2010-2019	Private, Commercial, Individual roofs√

Rooftop Concepts

CAPEX	OPEX*
Project owned by roof owner/consumer	Project owned by project developer/supplier
Roof owner/consumer responsible for O&M of system after initial 1-2 year period	Roof owner/consumer not responsible for O&M; O&M is responsibility of project developer
Can't be converted to OPEX model at a later date	Can be converted into CAPEX at a pre-decided date (option to buy back)
Power to be used for captive consumption; surplus power can be sold to distribution utility	Power can be sold to roof owner; Power can be sold to distribution utility; Power can be sold to third party**

**project developer is usually a Renewable Energy Service Company (RESCO)*

***some state regulations do not permit this mode of operation; should be checked at the time of project conception/planning*

Billing Sample

BSES

EBILL Customer

Date of Print Out: 24.07.2015

BSES Rajdhani Power Ltd.

Meter Details Annexure

Name : M/s. THE SECRETARY
Billing Address : NATIONAL PDODUCTIVITY COU LODHI ROAD NEW DELHI 110003

Supply Address : NATIONAL PDODUCTIVITY COU PLOT 5& INSTITUTIONAL AREA NEW DELHI 110003

Mobile / Tel. No. [redacted]
District / Division : Nizamuddin
Meter Reading Status : MR
Bill Month : JUL-15
Bill Date : 13-07-2015

Sanctioned Load : 224.00 (KW)
Contract Demand : 353.00 (KVA)
M D I : 192.00 (KVA)
Power Factor : .947
Pole No. : NA
Walking Sequence : NZ2KC0027A0AA
Cycle No. : KC
Tariff Category : Non-Domestic [HT]

CA No. : [redacted]
Energisation Date : 17.05.2002
Meter Type : 3PSK
Supply Type : HT(11KV)
Bill No. : [redacted]
Bill Basis : Actual

Customer Care Centre No. 39999707

Net Meter Consumption Details (Date of Reading : 30-06-2015)

B/F Units (If any)	Export Reading			Import Reading			Net Difference			Moderated Units			C/F Units (If any)
	Normal	Peak	Offpeak	Normal	Peak	Offpeak	Normal	Peak	Offpeak	Normal	Peak	Offpeak	
0	156	78	0	16020	8742	1134	15864	8664	1134	15864	10397	851	0

(Consumption in the above table are in KWH/KVAh, as applicable)

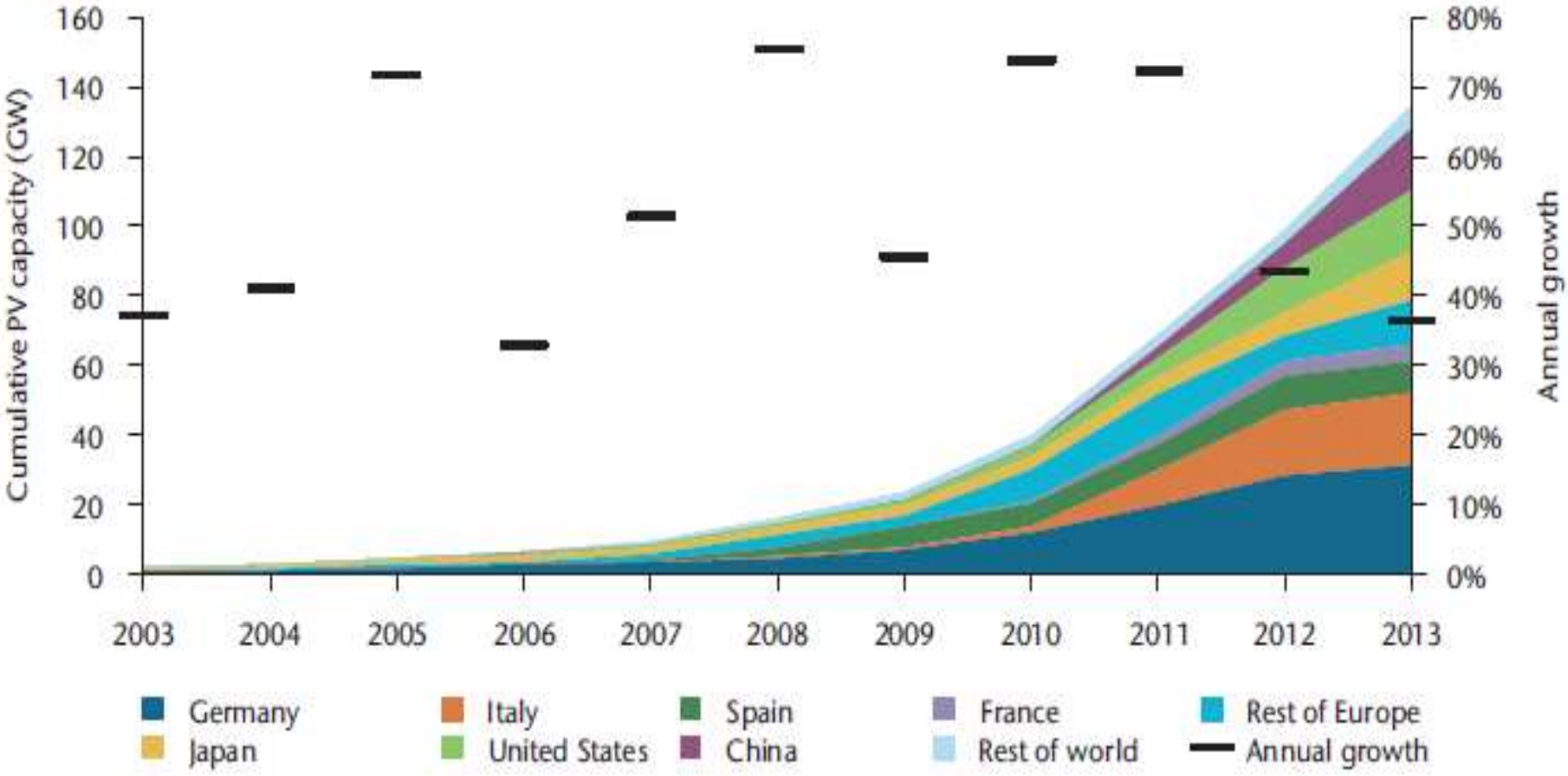
Moderated units: Peak units are increased by 20% and off-peak units decreased by 25%

Positives: Big Projections

- **Benefits:**
  - **Quick installation**
  - **Zero emission**
  - **Low noise**
  - **Very low maintenance**
  - **Reliable**
  - **Long life**
  - **On site production**
  - **Affordable**
- **MNRE rooftop target: 40,000MW (2022)**
- **2016-18: 2000, 4000,4000 MW**
- **Fiscal and financial incentives**

Let us look at the big pictures (IEA Report)

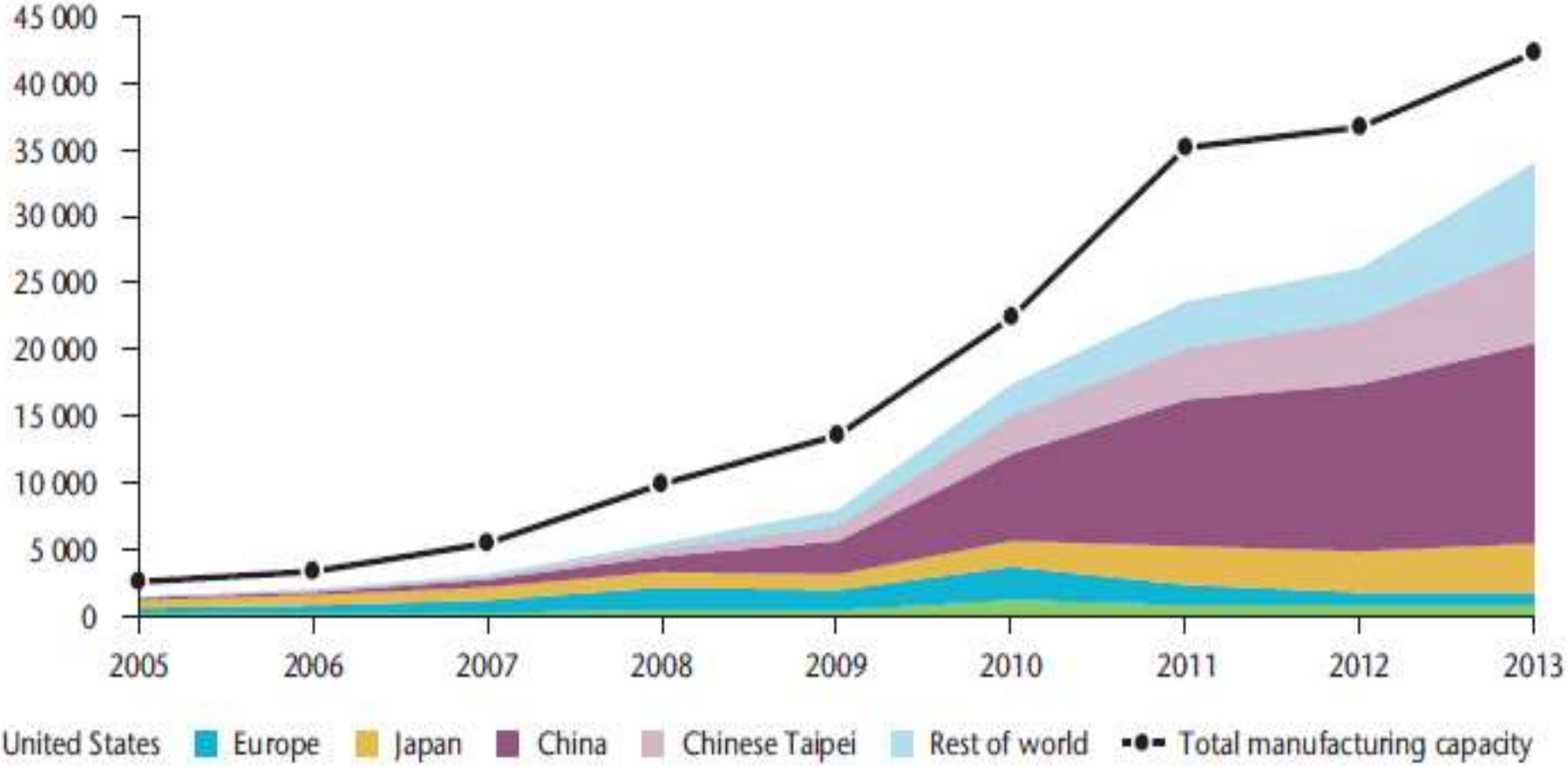
Figure 1: Global cumulative growth of PV capacity



Source: Unless otherwise indicated, all tables and figures derive from IEA data and analysis.

KEY POINT: Cumulative PV capacity grew at 49%/yr on average since 2003.

Figure 2: PV manufacturing by countries



Source: SPV Market Research (2014), *Photovoltaic manufacturer Shipments: Capacity, Price & Revenues 2013/2013*, Report SPV-Supply 2, April.

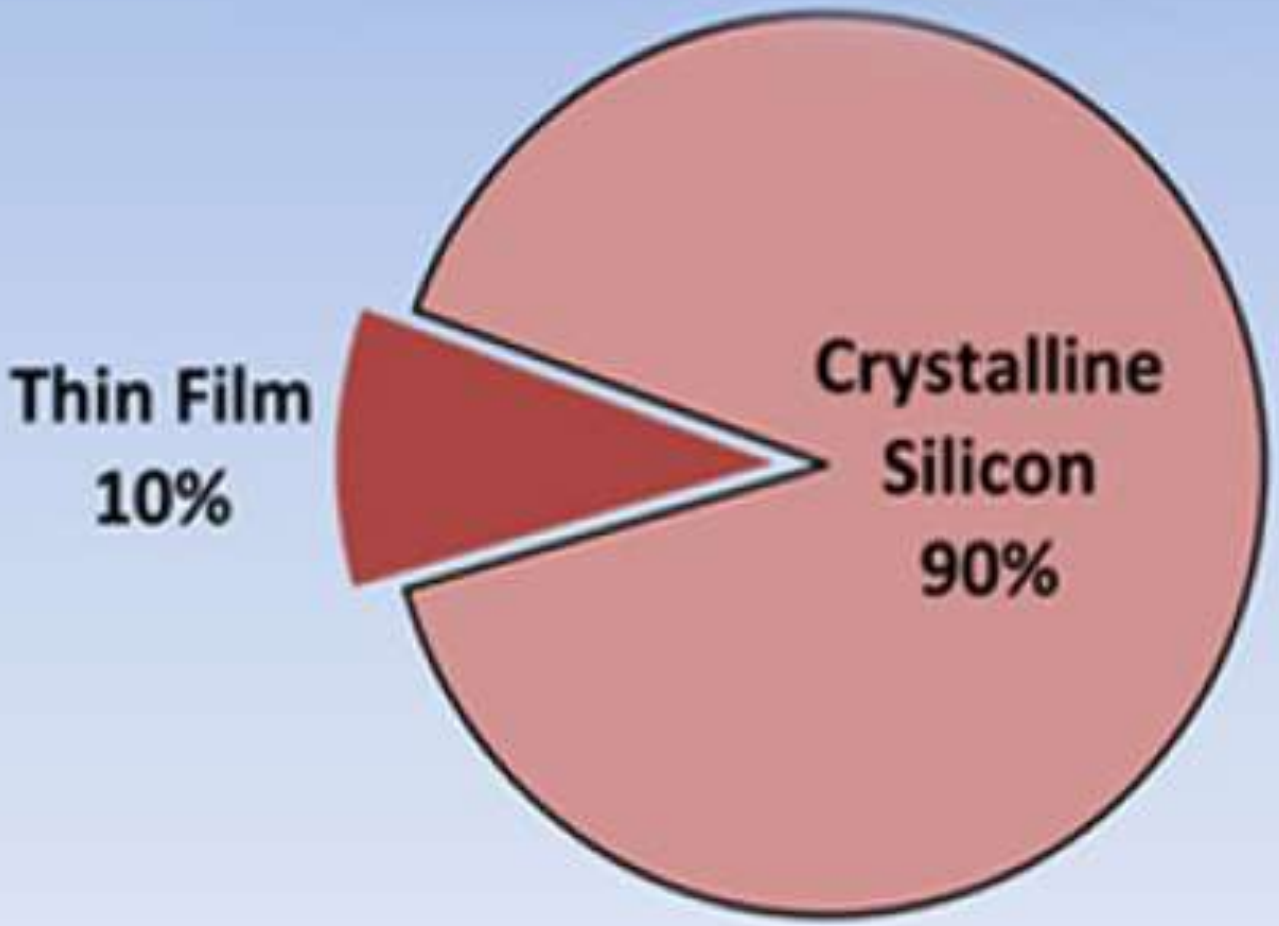
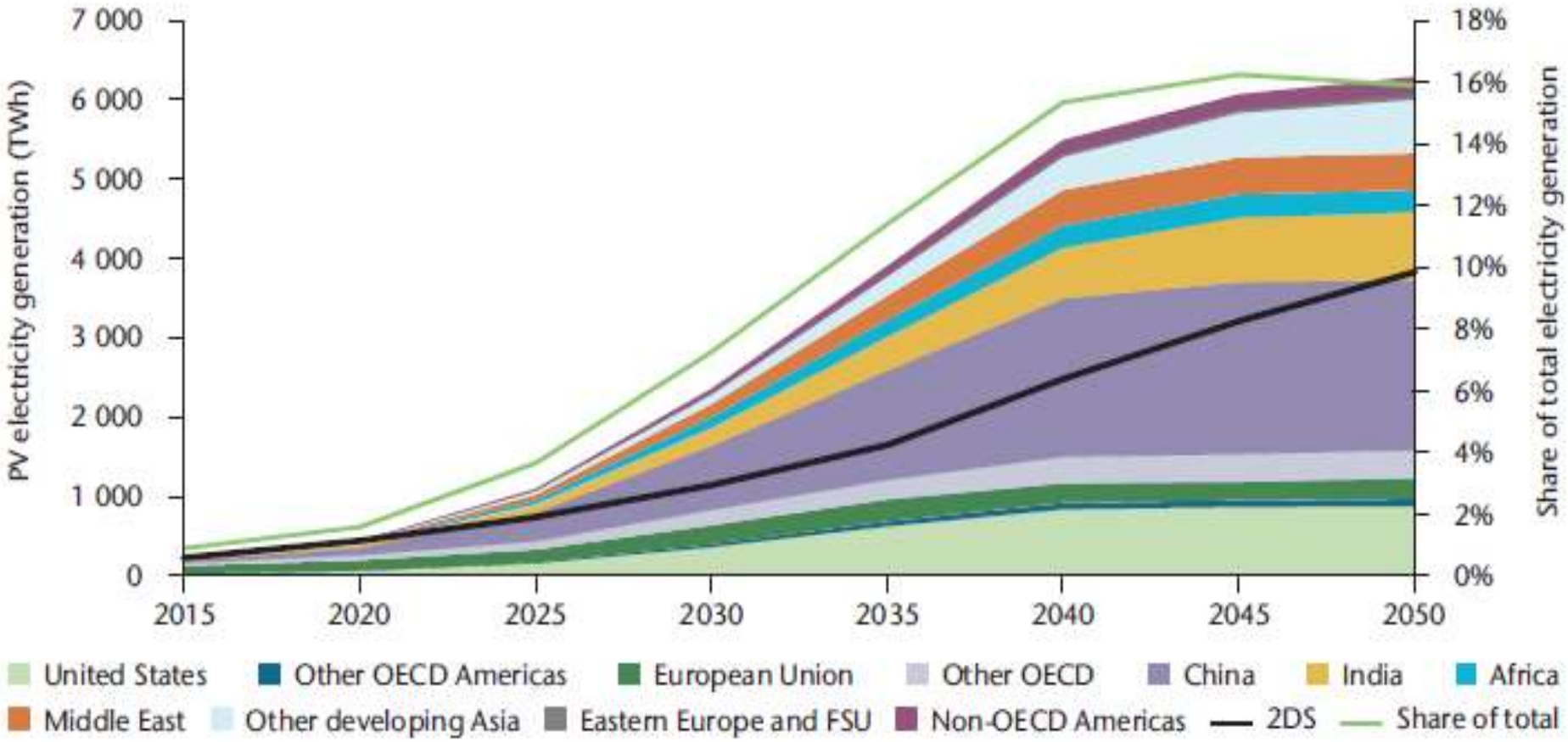
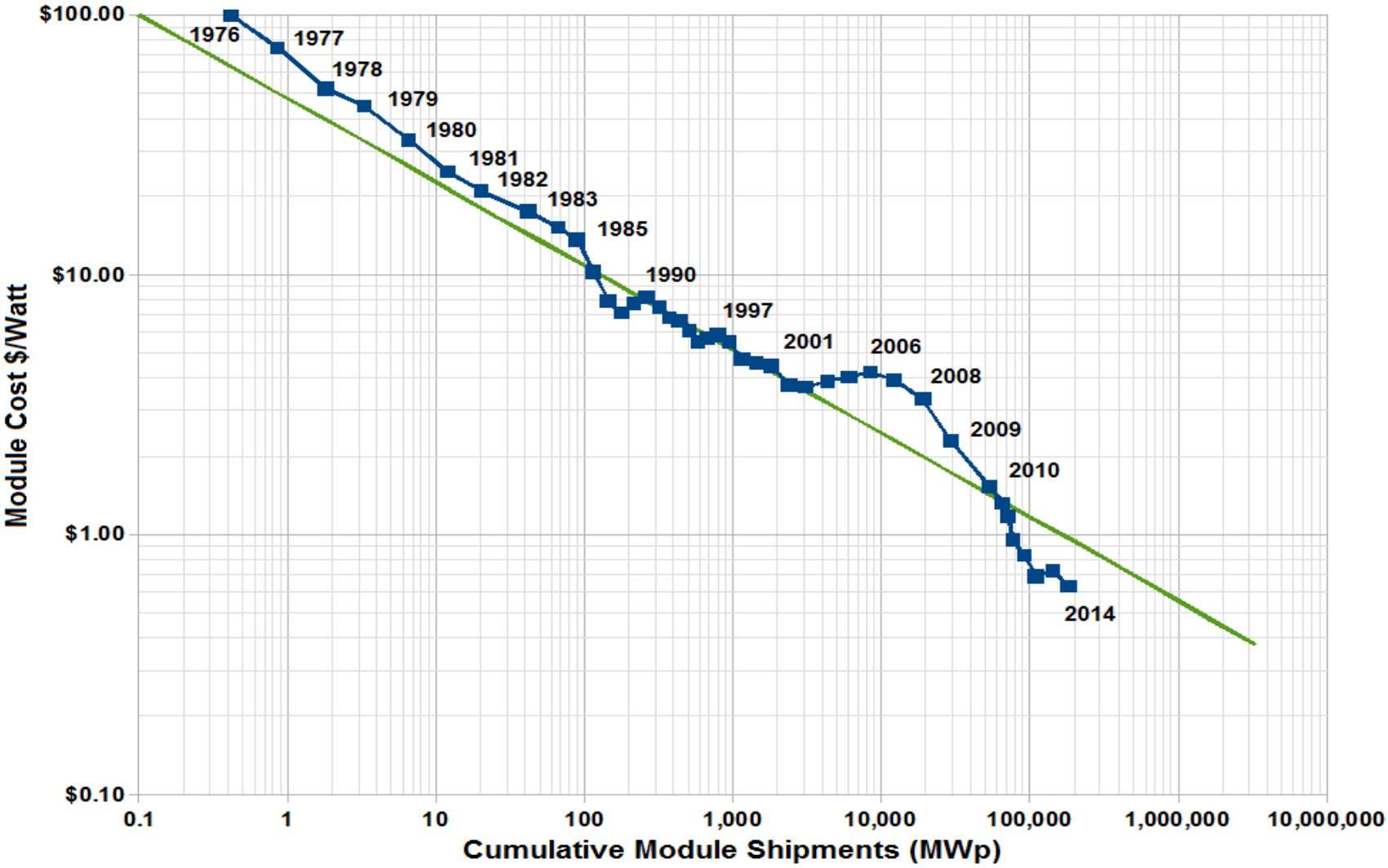

Thin Film
10%
Crystalline
Silicon
90%

Figure 8: Regional production of PV electricity envisioned in this roadmap



KEY POINT: in the hi-Ren scenario, PV provides 16% of global electricity by 2050, and China has a 35% share of the total PV electricity production.

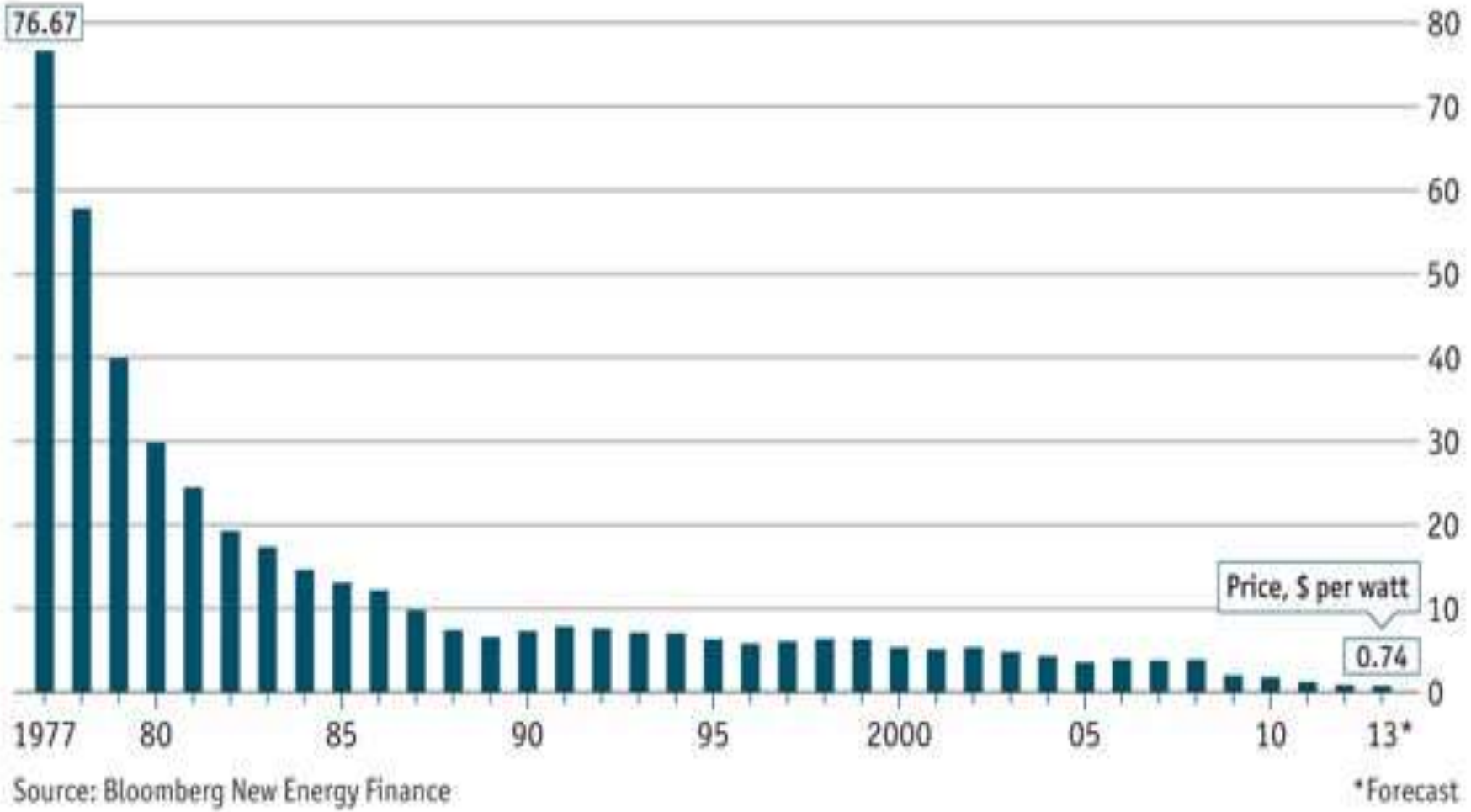
Swanson's Law



- Richard Swanson: Founder SunPower Corporation solar panel manuf. Module price drop 20 percent every doubling of cumulative shipment

The Swanson effect

Price of crystalline silicon photovoltaic cells, $ per watt

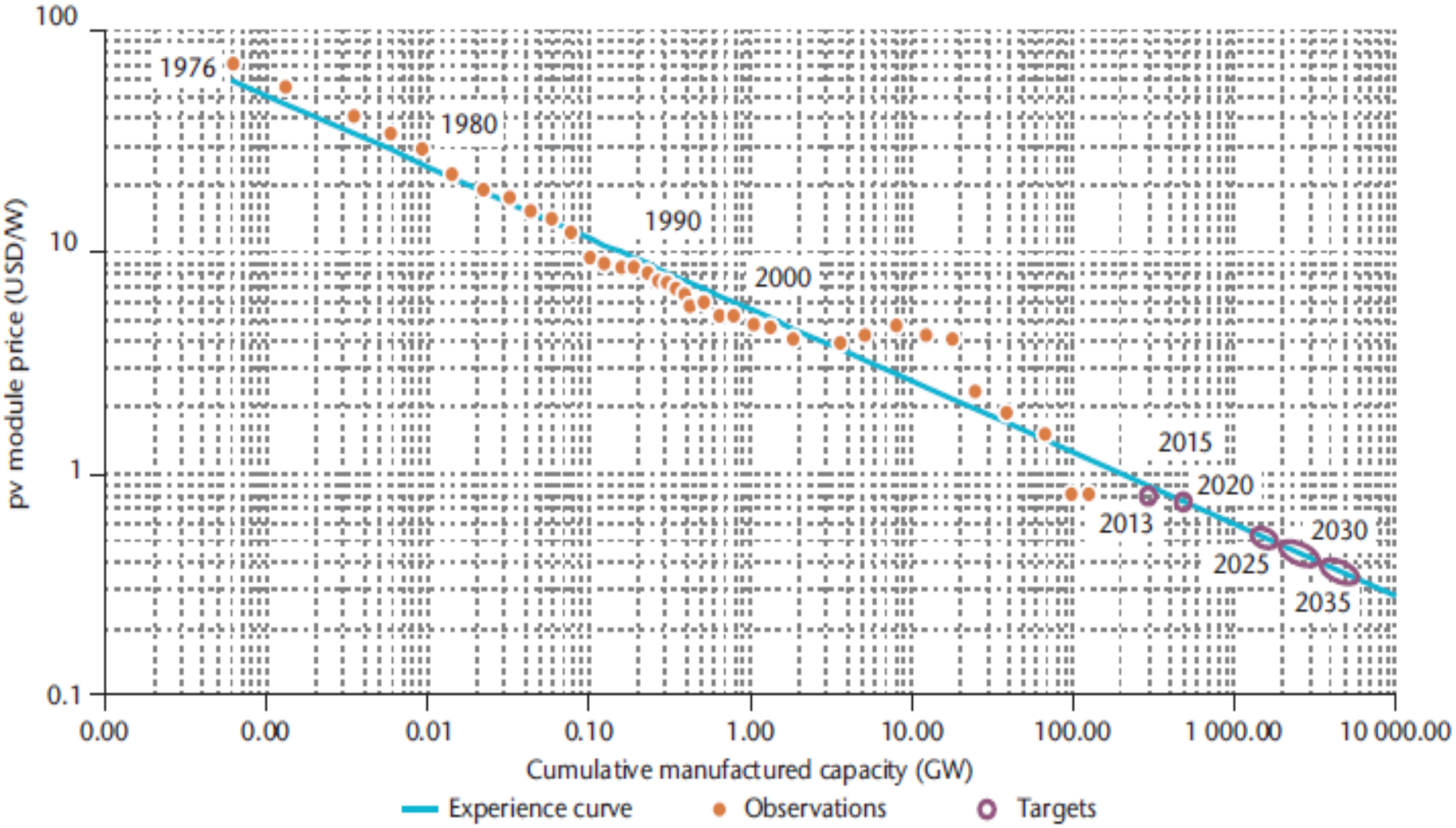


Source: Bloomberg New Energy Finance

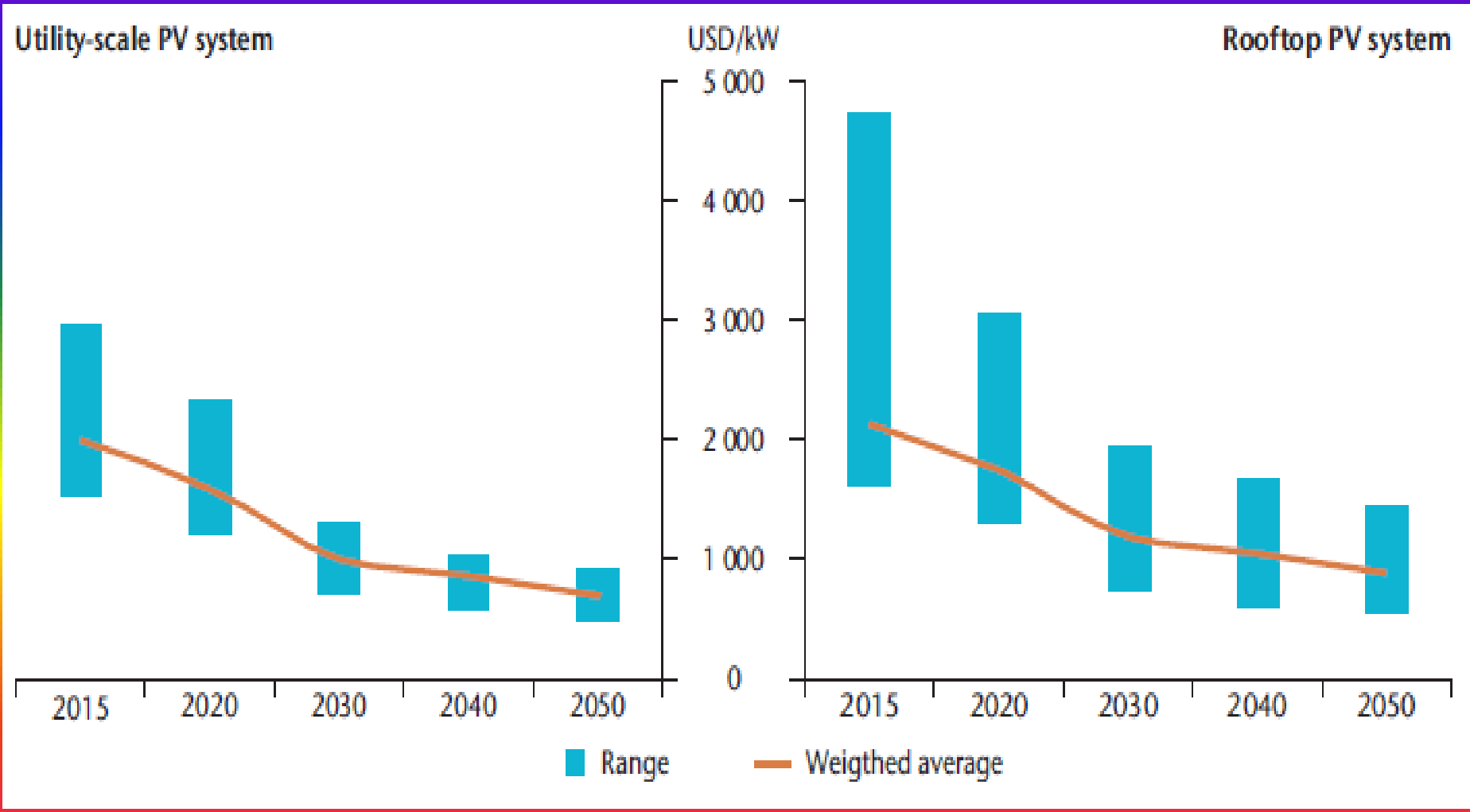
*Forecast

Economist.com/graphicdetail

Figure 10: Past modules prices and projection to 2035 based on learning curve



PV Investment Cost Projection



The Future Ahead

- Bright Future – Catalyzed by Efficient & Cheap Battery e.g. Lithium Ion, NiMH
- PV + Wind + Storage – Grid power cheaper
- Every house – Own power plant with storage – 100% free from grid
- Coal/Oil/Gas power project – only for industries/large commercial entities
- 100% cars/ Two wheelers – Battery operated – Charged by solar – No traffic pollution

The Future Ahead

- Oil – Only for heavy duty transportation
- Sea Wave/Tidal – Major source of power
- No need of green corridor of grid – saving
- 100% lighting – LED only – Great saving
- Solar passive architecture – Energy efficient buildings – Mandatory
- Solar supported Digital India – A reality – Even in rural/ remote areas

THANK YOU

Dr. Sudhir Kumar, Chief Executive,
Green Energy Solutions,
8/15, Mazda Deluxe Homes, Porwal Park, Tank Road,
Off: Alandi Road, Yerwada, Pune - 411006, India.
Cell No. +91-9665020206, E-mail: drsk22@gmail.com