The Status and Outlook for the Photovoltaics Industry

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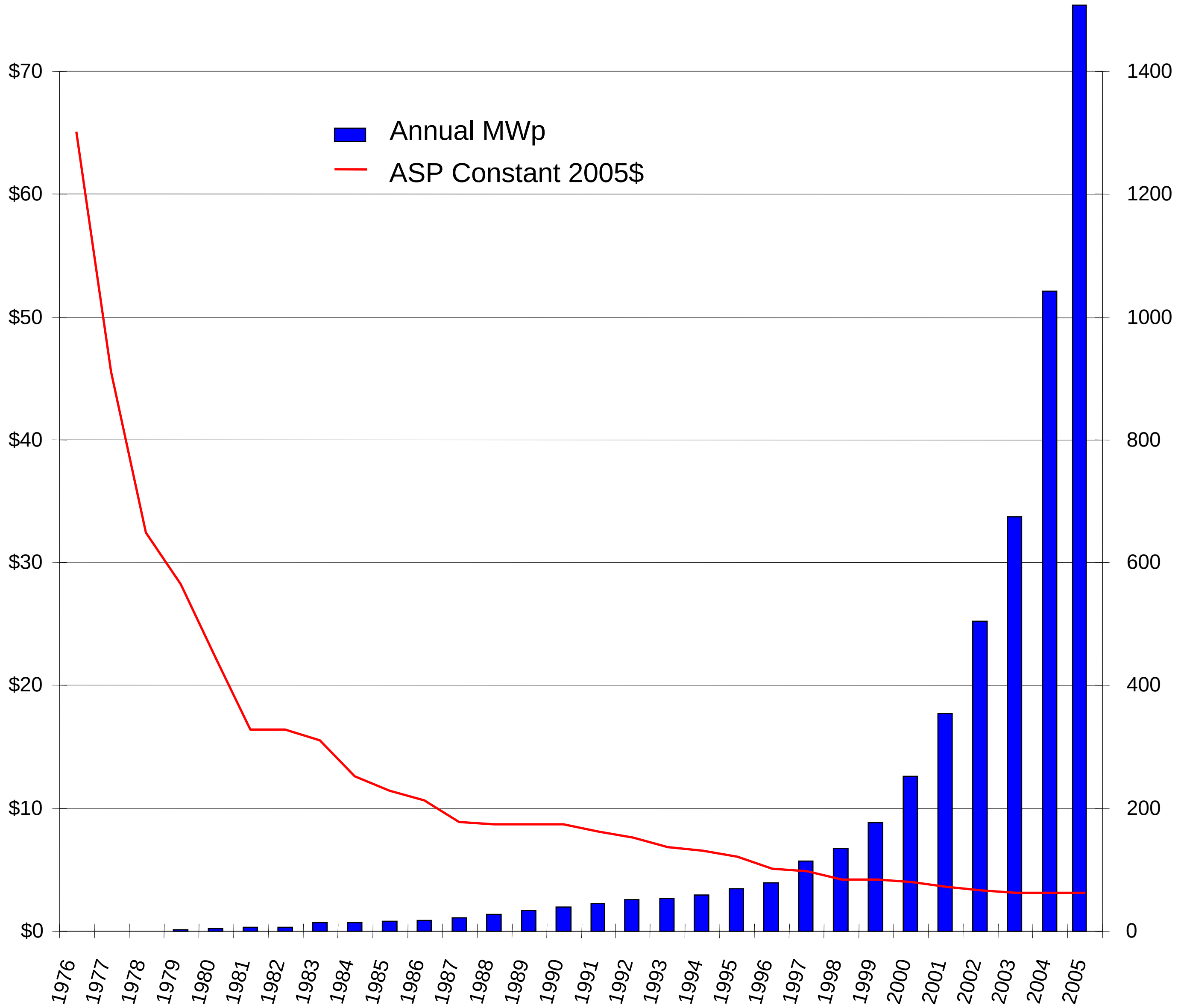
Outline of the Talk

- The PV Market
- The Major Players
- Different Types of Solar Cells
- Field Installations
- Performance and Cost
- Projections for the Future of Photovoltaics

Historical Average Selling Price and Volume



PV Shipments for Different Technologies

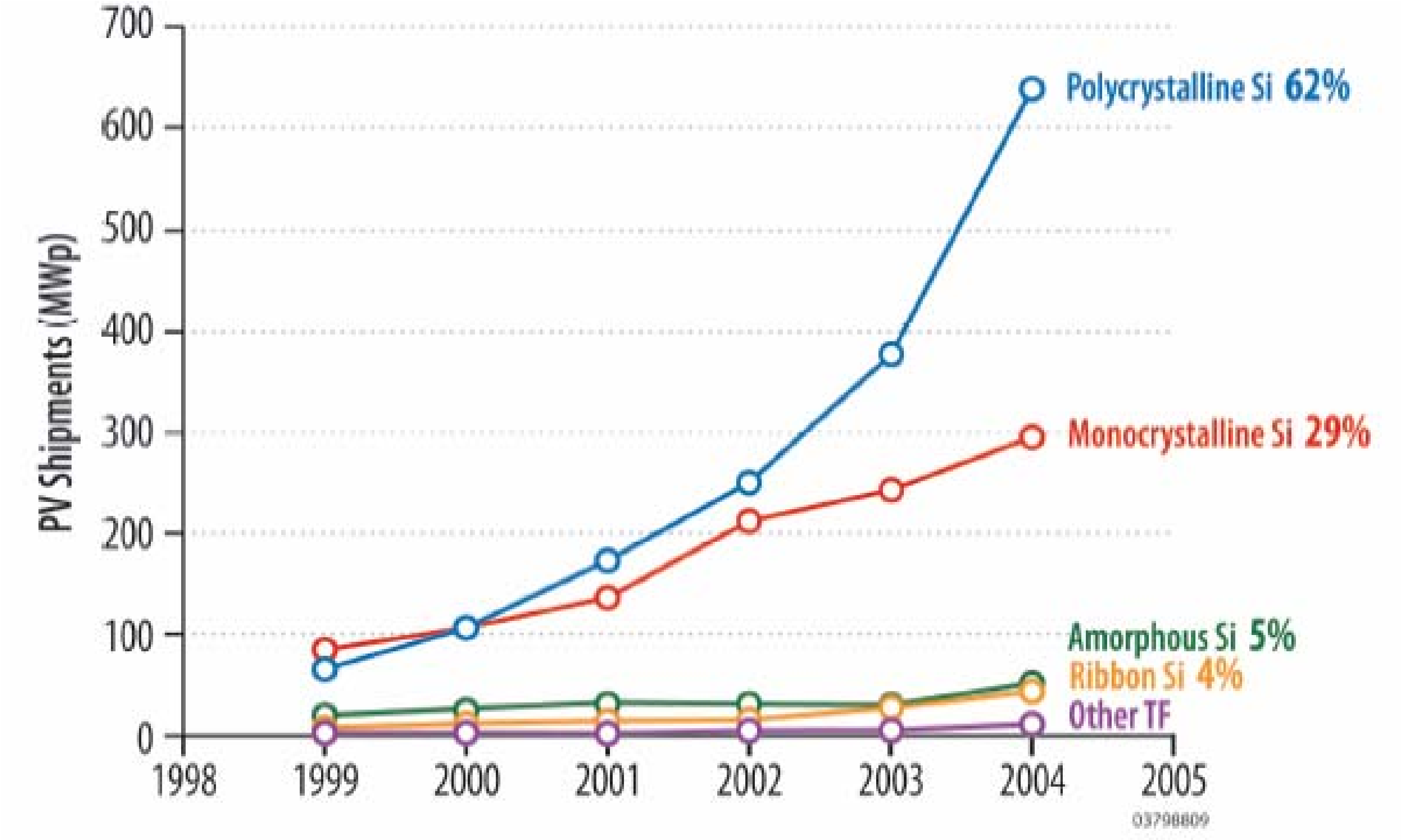


Fig. 3.1.1-2 Historic and current market share of crystalline and thin-film PV technologies. (Strategies Unlimited, 2005)

The Major Players

Crystalline Si

- Sharp
- Kyocera
- BP Solar
- Q-Cells
- Mitsubishi
- SolarWorld
- Sanyo
- Schott Solar
- Isofoton
- Motech
- Suntech

Amorphous Si

- United Solar
- Kaneka
- Fuji Electric
- Sharp
- Mitsubisihi
- Schott Solar

CIGS

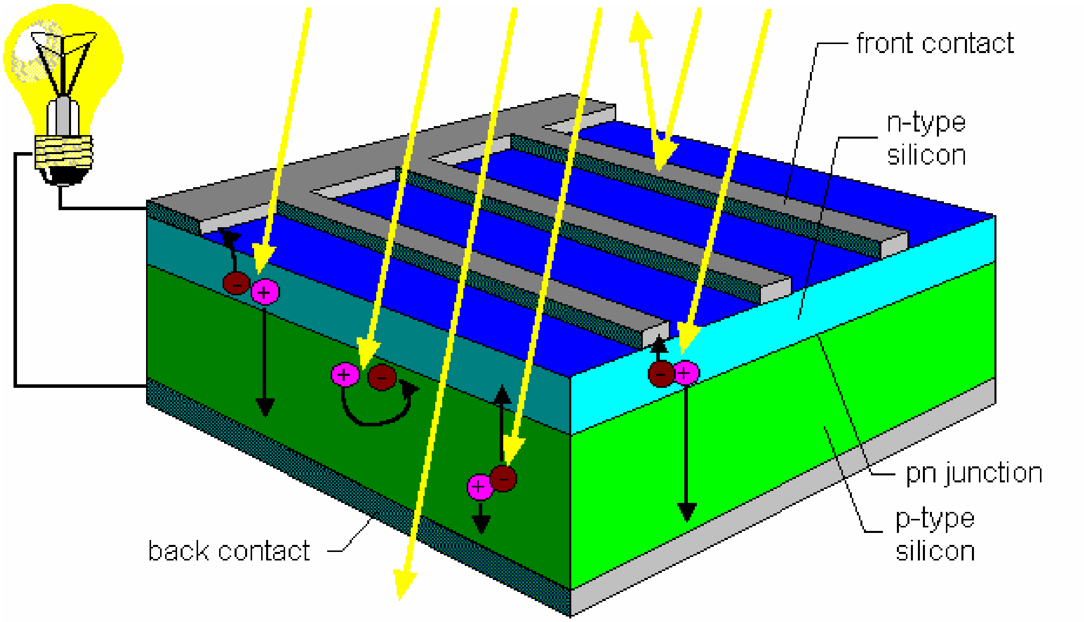
- Shell Solar
- Showa Shell
- Wurth Solar
- DayStar

CdTe

- First Solar
- Antec Solar

Operation of a Solar Cell

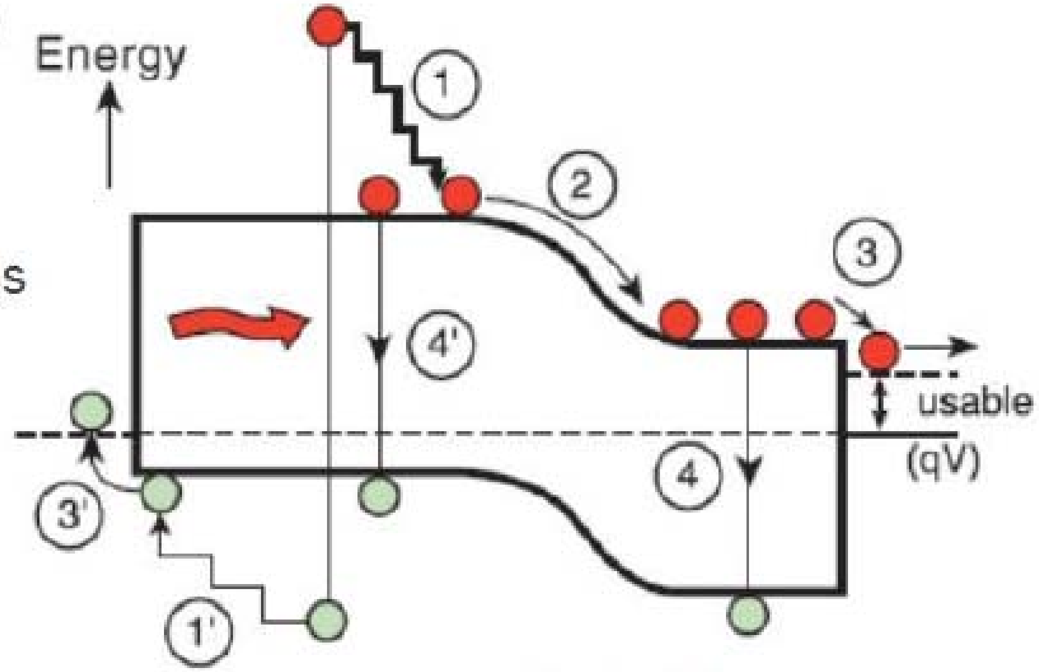
- Photons are absorbed in the semiconductor resulting in the creation of electron-hole pairs
- The photo-generated electron-hole pairs are physically separated at the p/n junction
- The photogenerated carriers are collected by the contacts on the front and rear of the cell
- The photocurrent can be delivered to an external load at an applied voltage to perform useful work



Operation of a Solar Cell

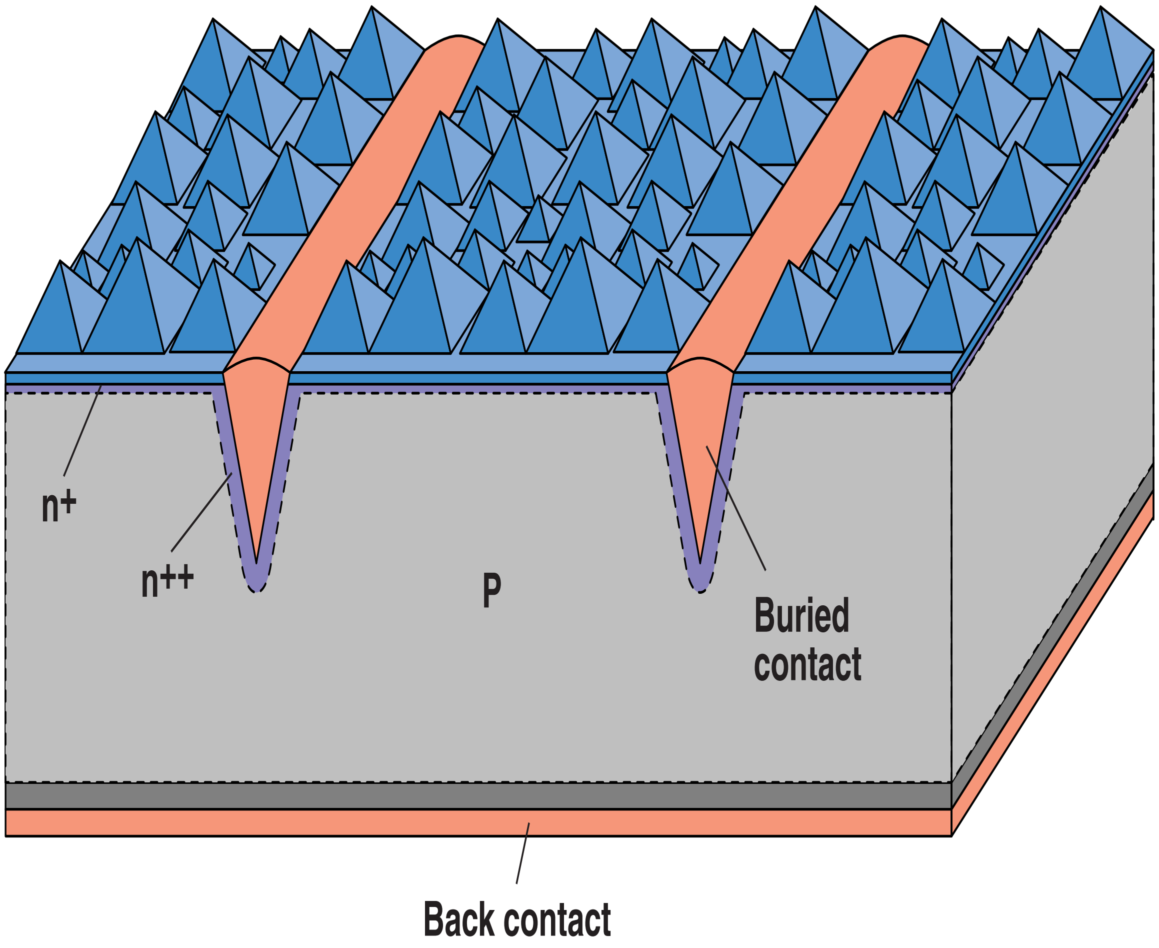
Sources of Standard PV-Cell Efficiency Loss

1) Lattice thermalization
2) Junction voltage drop
3) Contact voltage drop
4) Recombination
5) Non absorbed photons



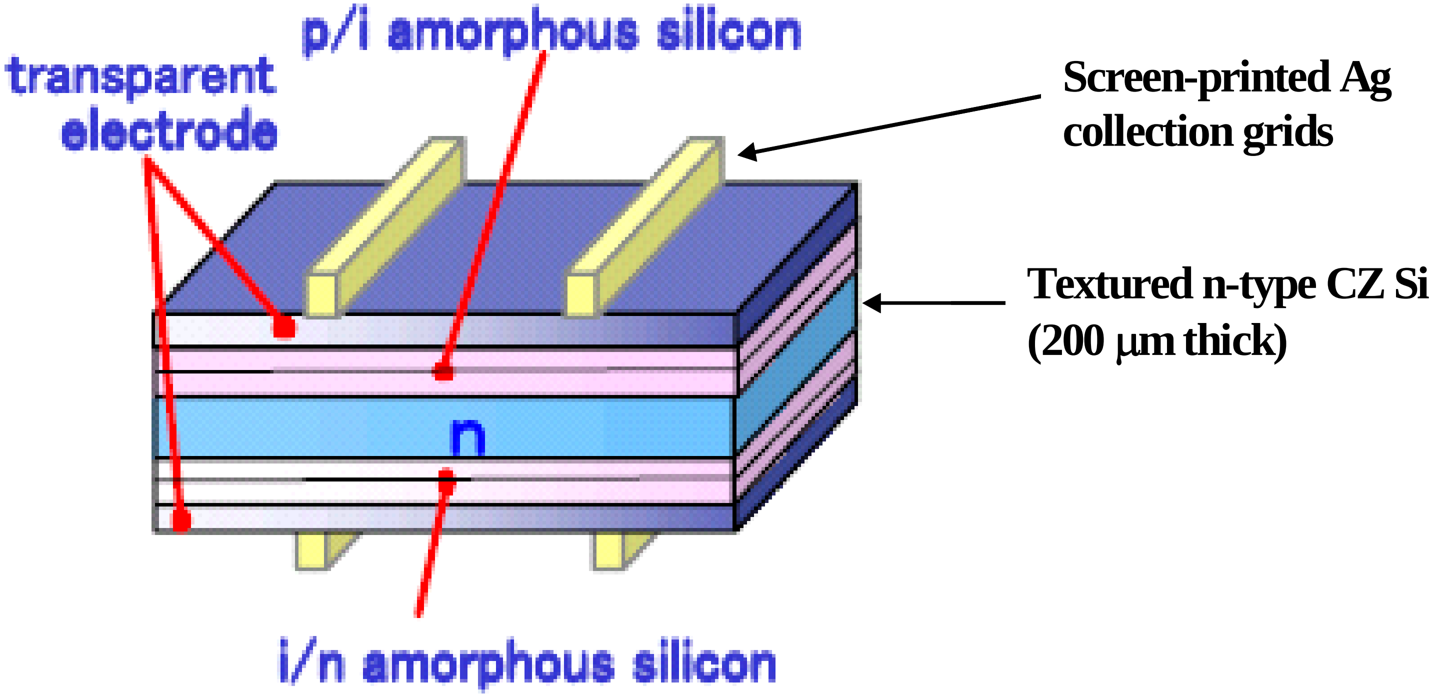
Source: M. Green et al., Univ. New South Wales

Crystalline Silicon Solar Cells



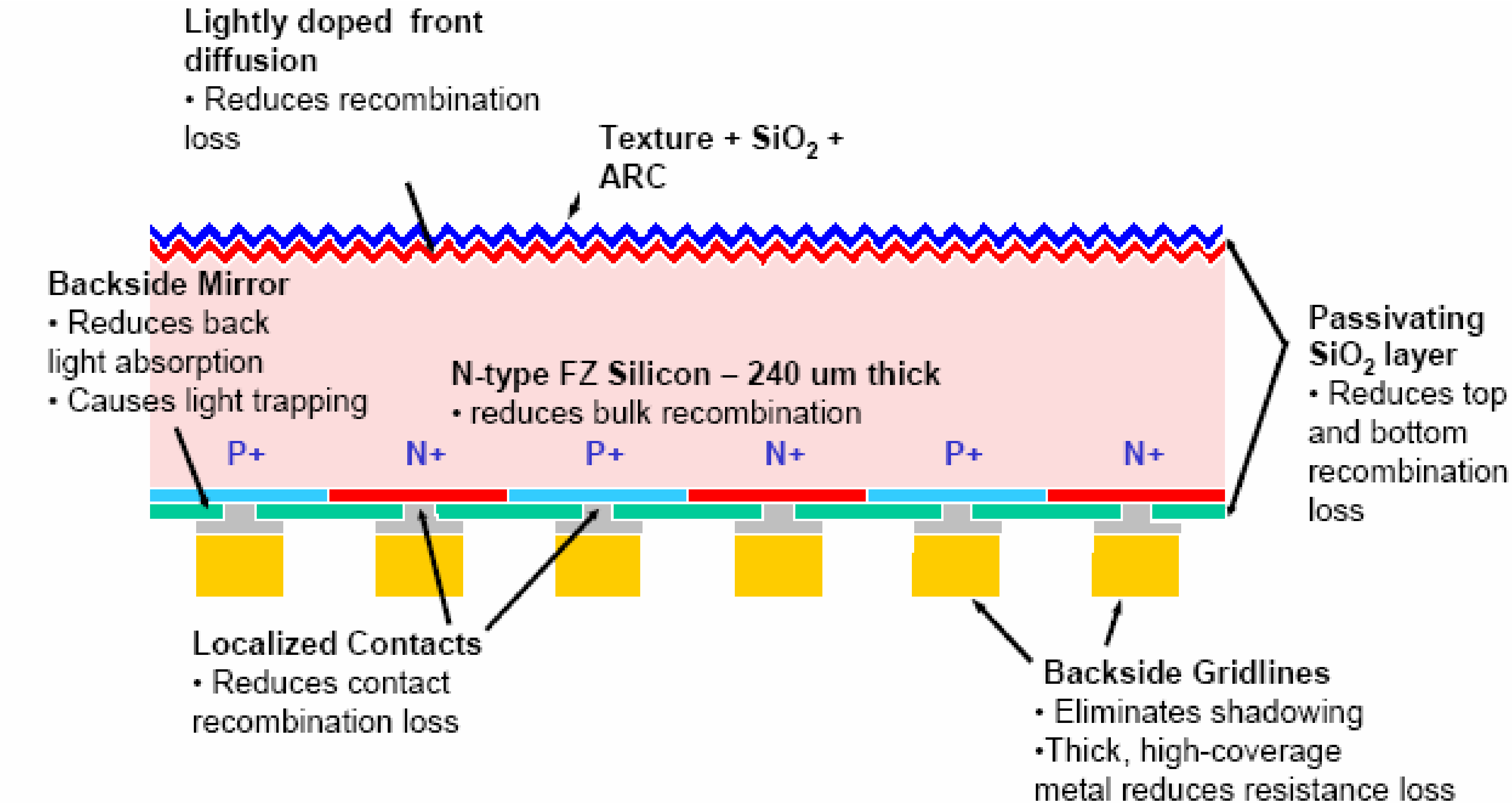
- The BP Solar Saturn solar cell utilizes a laser-grooved, buried front contact
- The aluminum back contact is heated to form a back surface field, which reduces surface recombination
- Best lab efficiency = 20.1%

Sanyo HIT Solar Cell



- The HIT cell utilizes amorphous Si intrinsic layers (~ 5 nm) as super-passivation layers. The cell is symmetric except for the a-Si p^+ emitter layer (~ 10 nm) on the front and the a-Si n^+ contact layer (~ 15 nm) on the rear. The transparent electrodes are sputter-deposited indium-tin-oxide (ITO)
- Best lab efficiency = 21.6% (open-circuit voltages > 700 mV)

SunPower Back Contact Solar Cell



Lightly doped front diffusion
- Reduces recombination loss

Texture + SiO_2 + ARC

Backside Mirror
- Reduces back light absorption
- Causes light trapping

N-type FZ Silicon – 240 um thick
- reduces bulk recombination

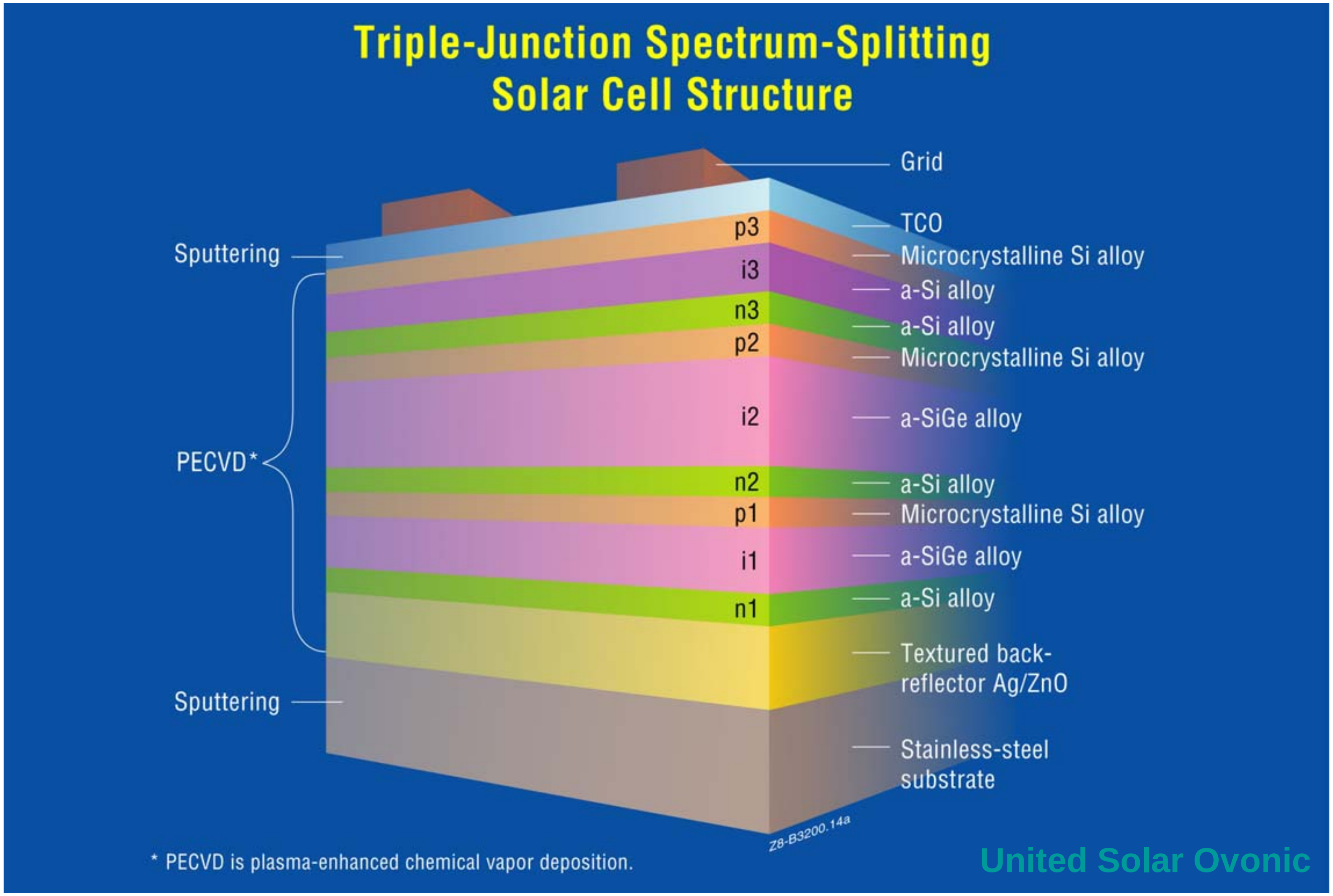
Passivating SiO_2 layer
- Reduces top and bottom recombination loss

Localized Contacts
- Reduces contact recombination loss

Backside Gridlines
- Eliminates shadowing
- Thick, high-coverage metal reduces resistance loss

- The SunPower cell has all its electrical contacts on the rear surface of the cell
- The diffusion lengths > twice the cell thickness
- Best lab efficiency = 21.6%

Amorphous Silicon Triple-Junction Cell

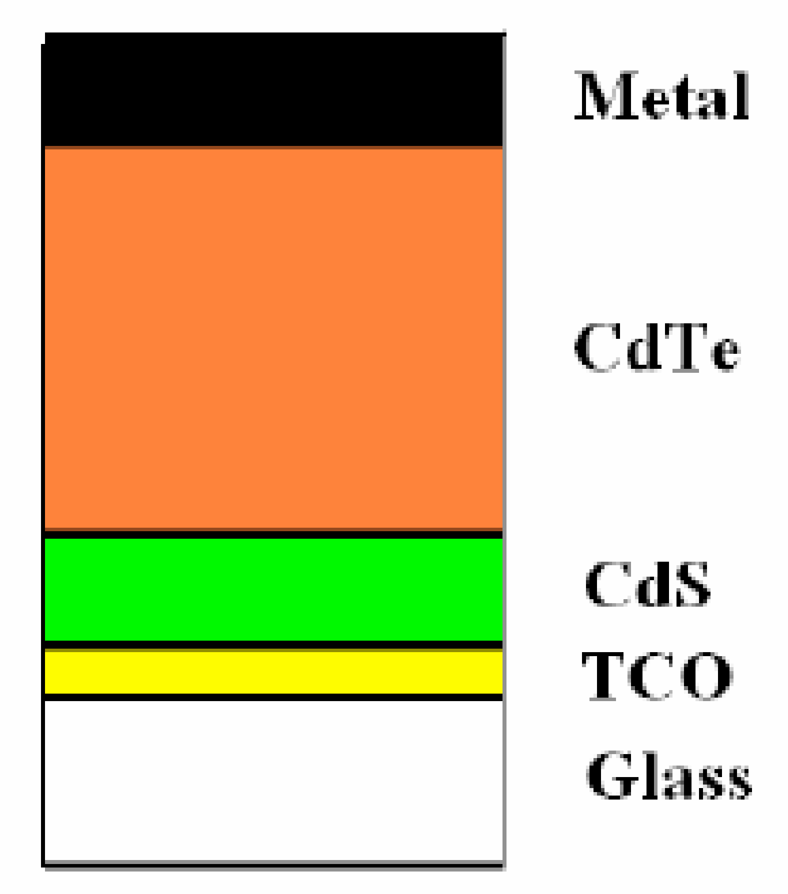

Triple-Junction Spectrum-Splitting Solar Cell Structure

* PECVD is plasma-enhanced chemical vapor deposition.

United Solar Ovonic

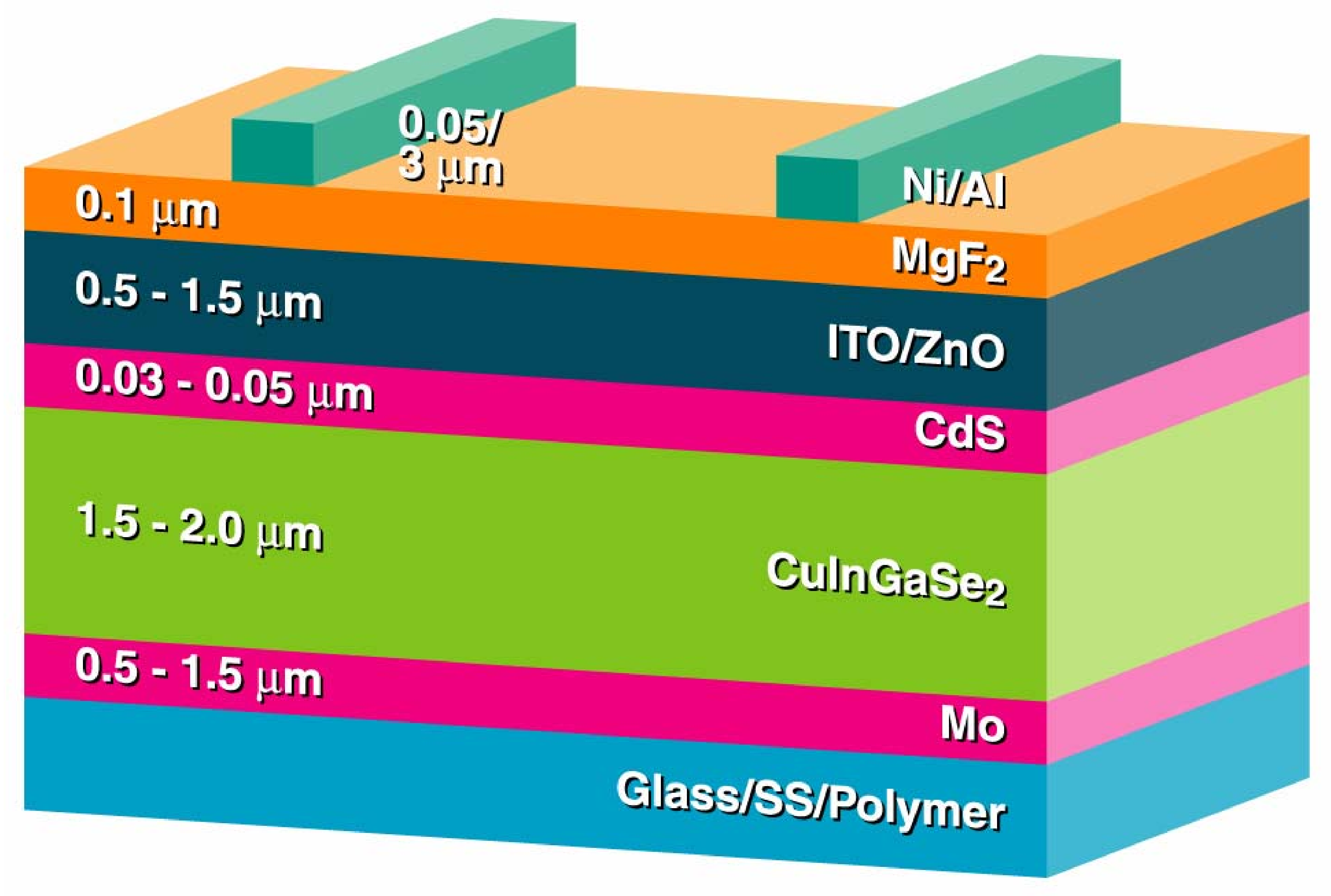
- United Solar has demonstrated a stable efficiency of 13% in the lab

Cadmium Telluride Solar Cells



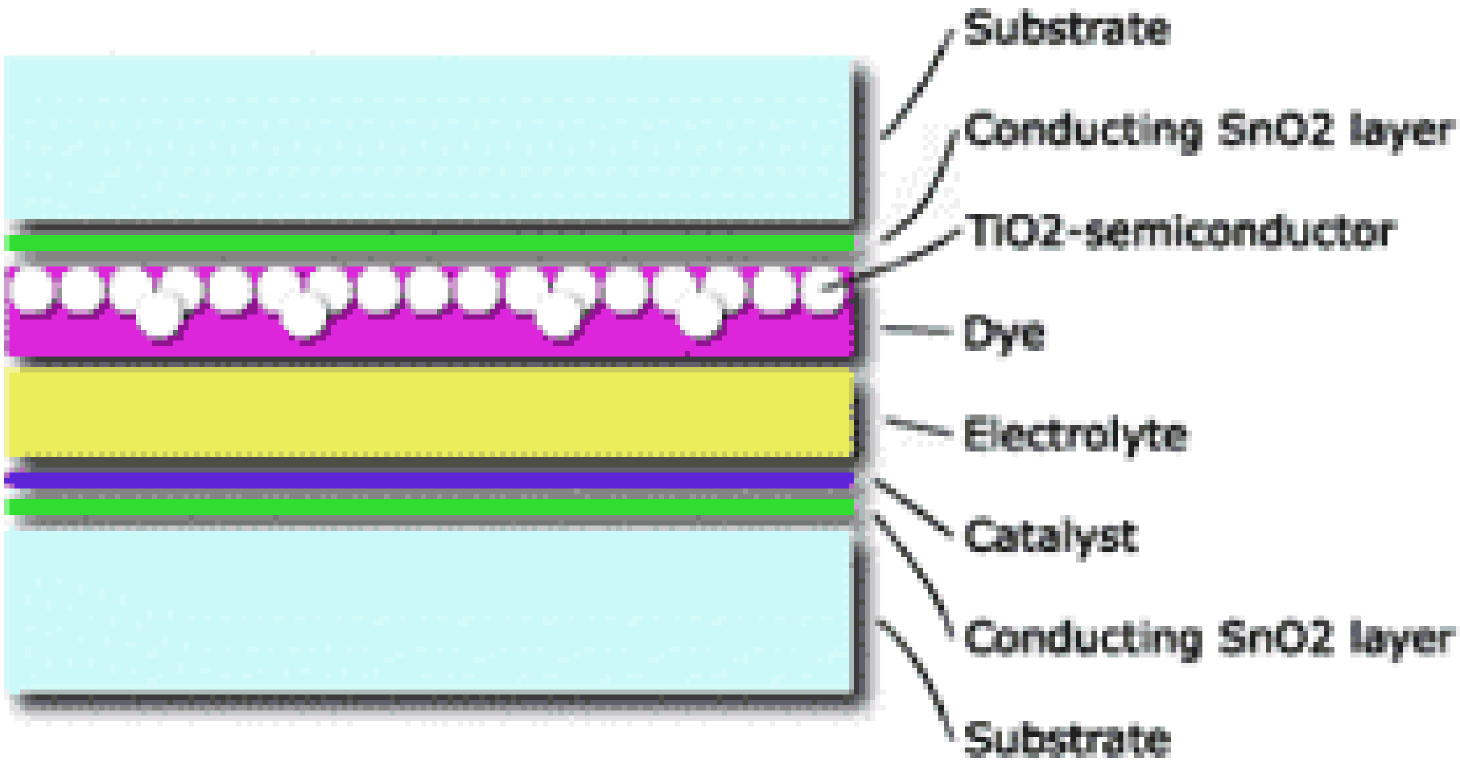
- The CdS/CdTe heterojunction solar cell is typically formed by using a chemical bath technique to deposit the CdS and close space vacuum sublimation to deposit the CdTe
- Toxicity of Cd is perceived by some to be an issue
- Best lab efficiency = 16.5%

Copper-Indium-Gallium-Diselenide Cell



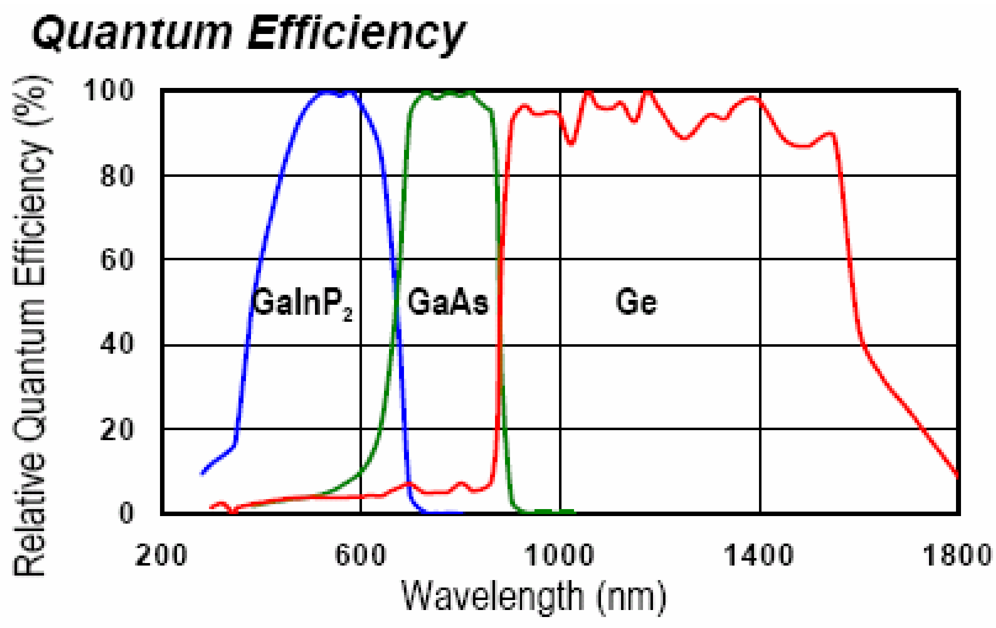
- NREL has obtained an efficiency of 19.5% in the lab

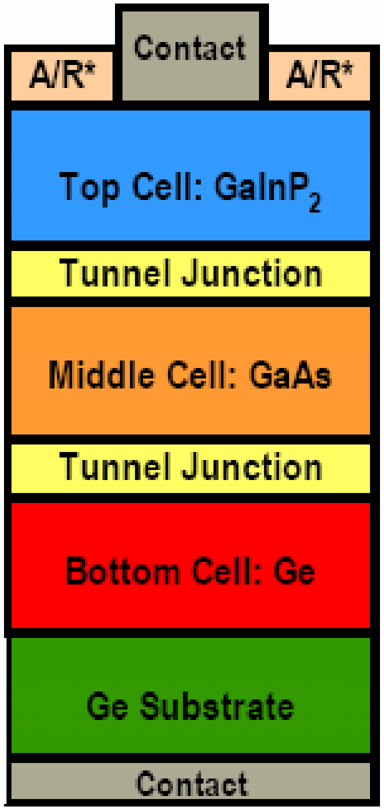
Dye-Sensitized Solar Cells



- Dye-sensitized solar cells utilize a few monolayers of ruthenium-based dye molecules on titanium oxide particles in an electrolyte
- Best lab efficiency = 11%

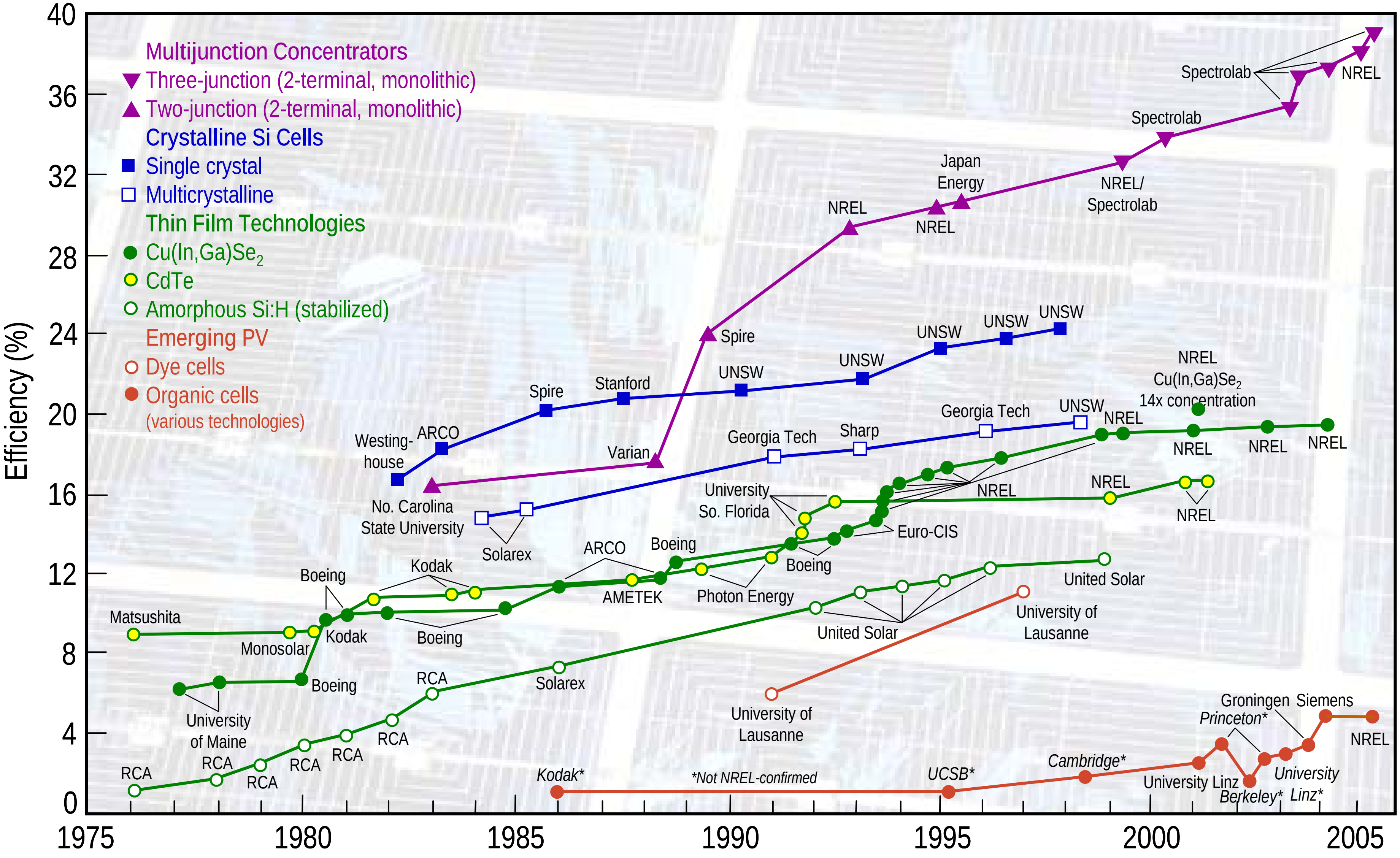
Spectrolab's Triple-Junction Solar Cell





- In July 2005, Spectrolab reported the highest efficiency solar cell to date, a 39.0% triple-junction cell operating at 236 suns

Conversion Efficiencies vs. Time (NREL)



bp solar

PV Module Conversion Efficiencies

	Modules	Lab
➢ Dye-sensitized solar cells	3 – 5%	11%
➢ Amorphous silicon (multijunction)	6 - 8%	13.2%
➢ Cadmium Telluride (CdTe) thin film	8 - 10%	16.5%
➢ Copper-Indium-Gallium-Selenium (CIGS)	9 - 11%	19.5%
➢ Multicrystalline or polycrystalline silicon	12 - 15%	20.3%
➢ Monocrystalline silicon	14 - 16%	21.6%
➢ High performance monocrystalline silicon	16 - 18%	24.7%
➢ Triple-junction (GaInP/GaAs/Ge) cell (236 suns)	-	39.0%

Paths to Ultra-High Conversion Efficiencies

- Multijunction solar cells
- Multiple absorption path solar cells (impact ionization, multiple exciton generation)
- Multiple energy level solar cells (localized levels or intermediate bands)
- Multiple spectrum solar cells (up and down conversion of photons)
- Multiple temperature solar cells (utilization of hot carriers)

- **All these approaches have theoretical efficiency limits > 60%.**
- **The theoretical efficiency limit is > 80% for multijunction cells utilizing other high efficiency approaches.**

Remote Telecommunication Site

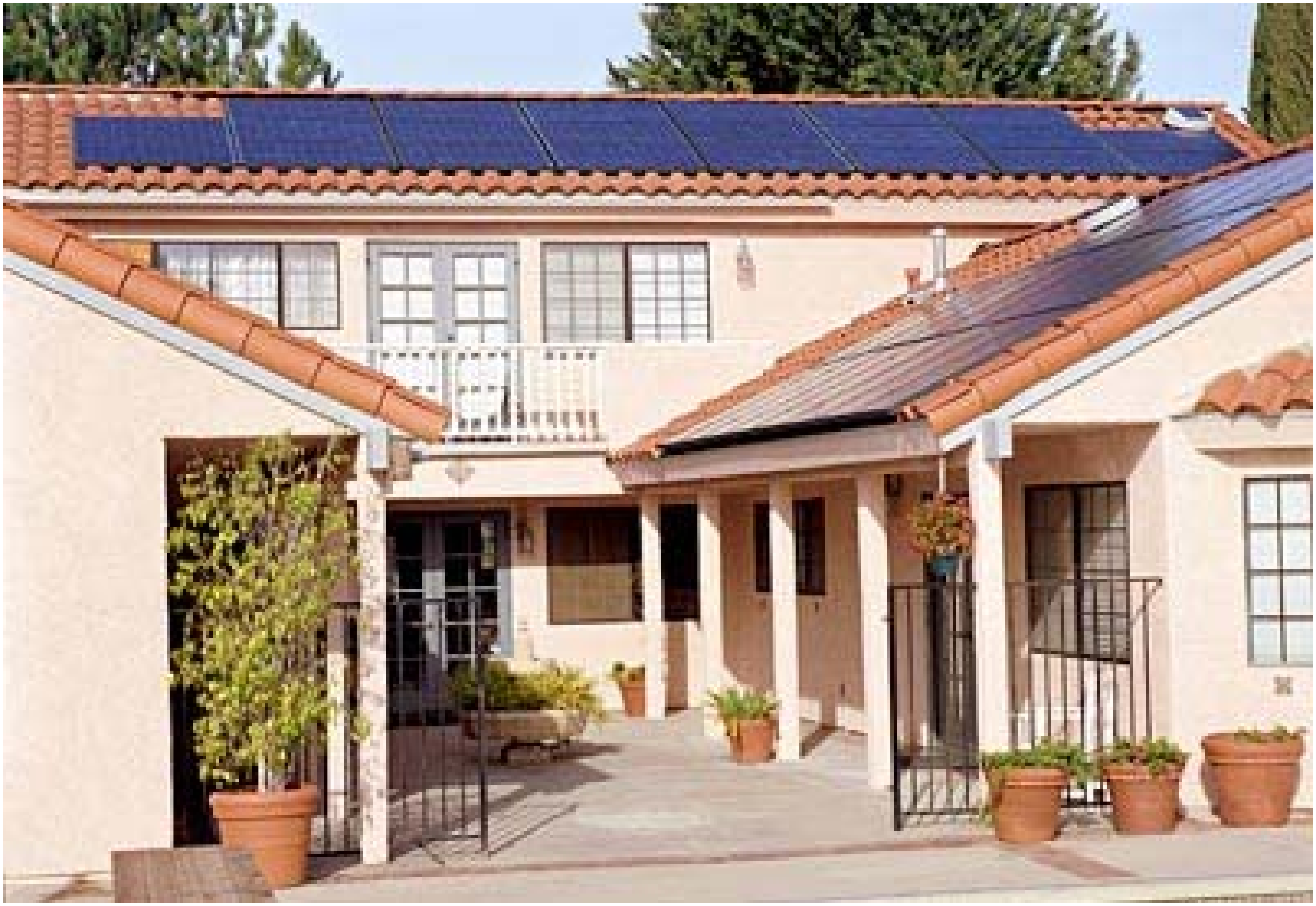
Remote Application: Village Power

Philippines Village

PV Concentrator System

A concentrator system using Fresnel lenses (Amonix)

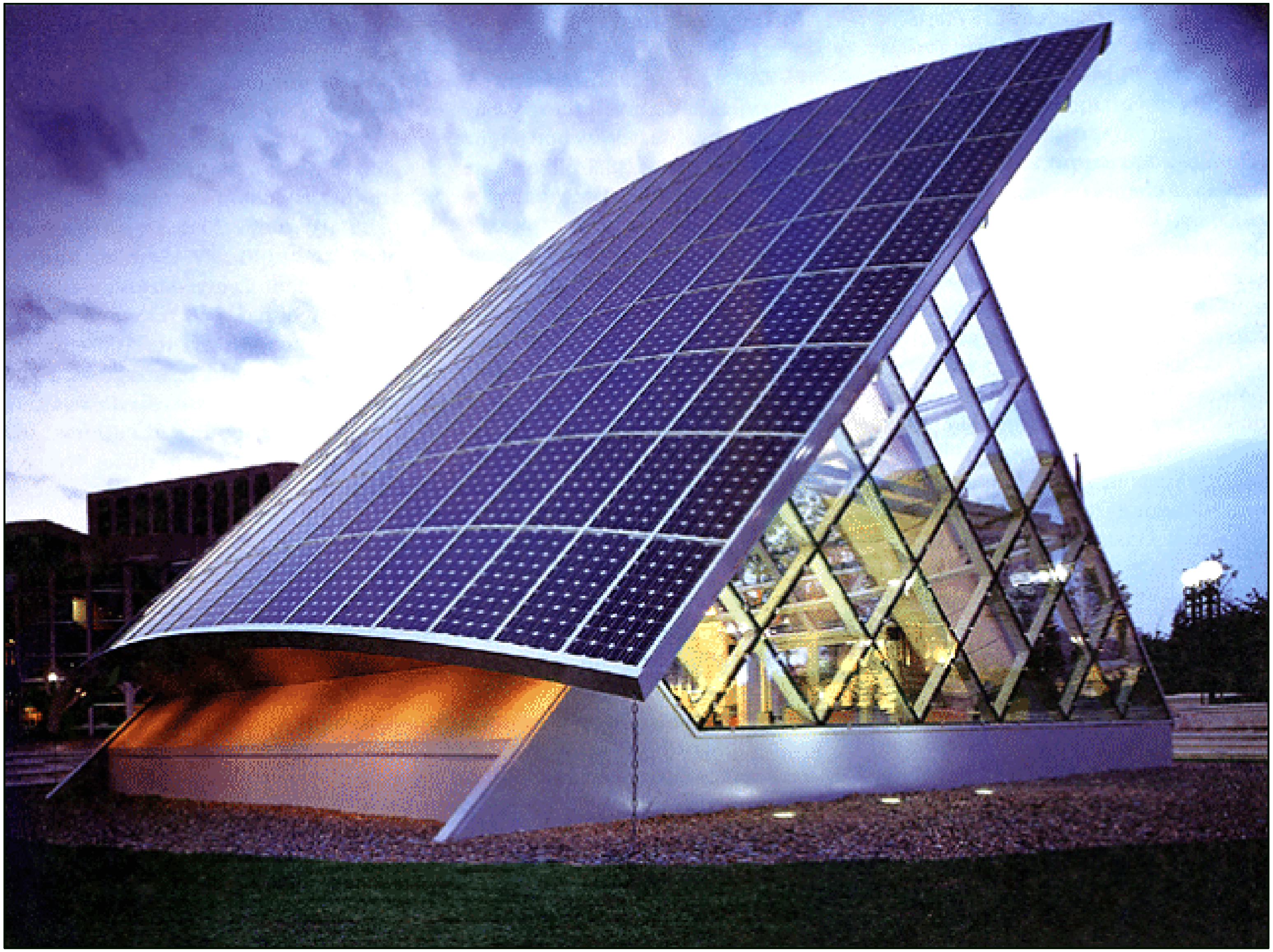
Roof-Mounted PV Arrays



United Solar – Coca Cola Bottling Plant (LA)

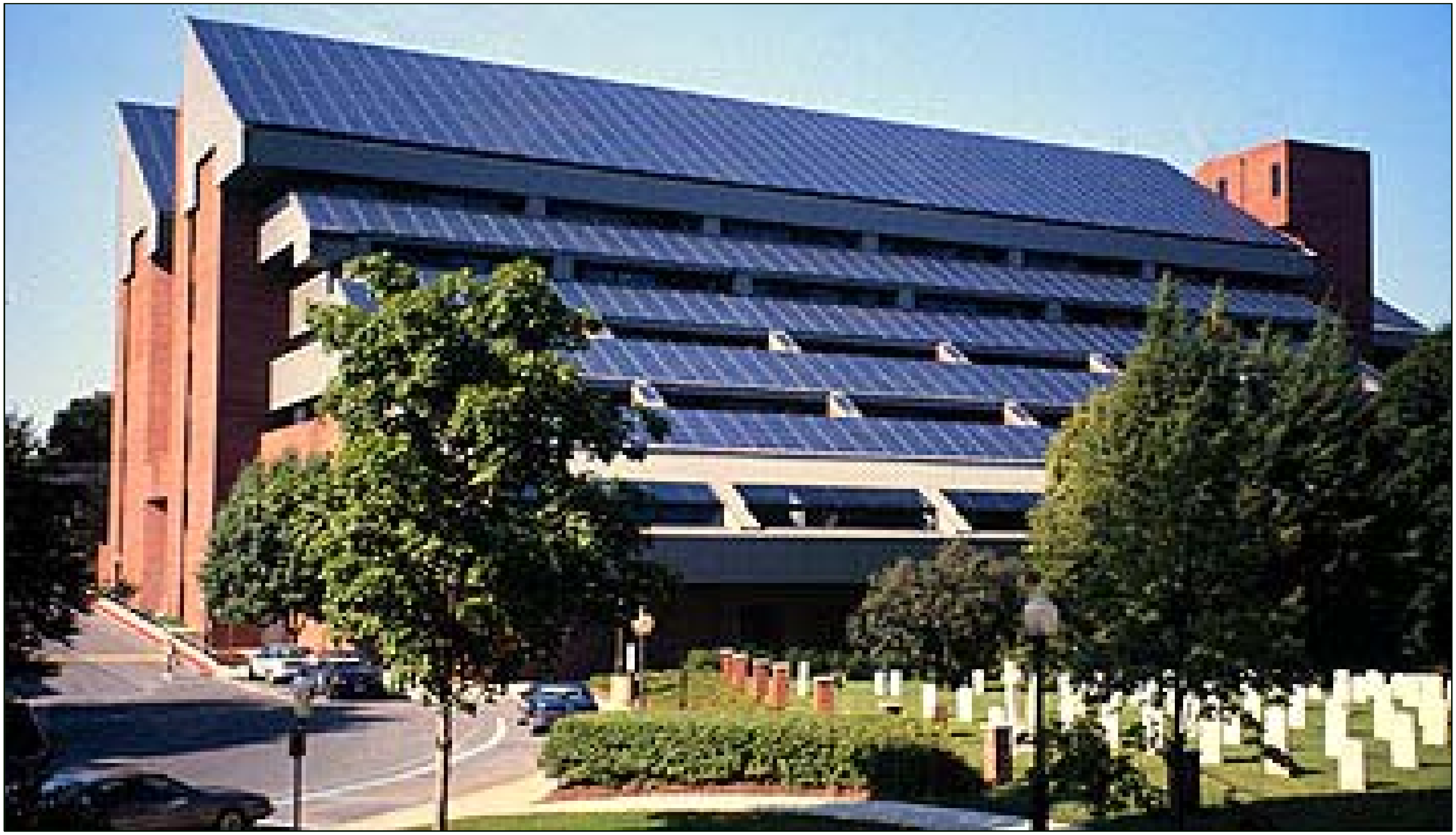
BP Solar Roof-Mounted PV Array

Building-Integrated PV



Building PV Curtain Wall

Building-Integrated PV



Georgetown University

Building-Integrated PV

BIPV and Plug-Power Hybrids

DOE Targets for PV System Costs

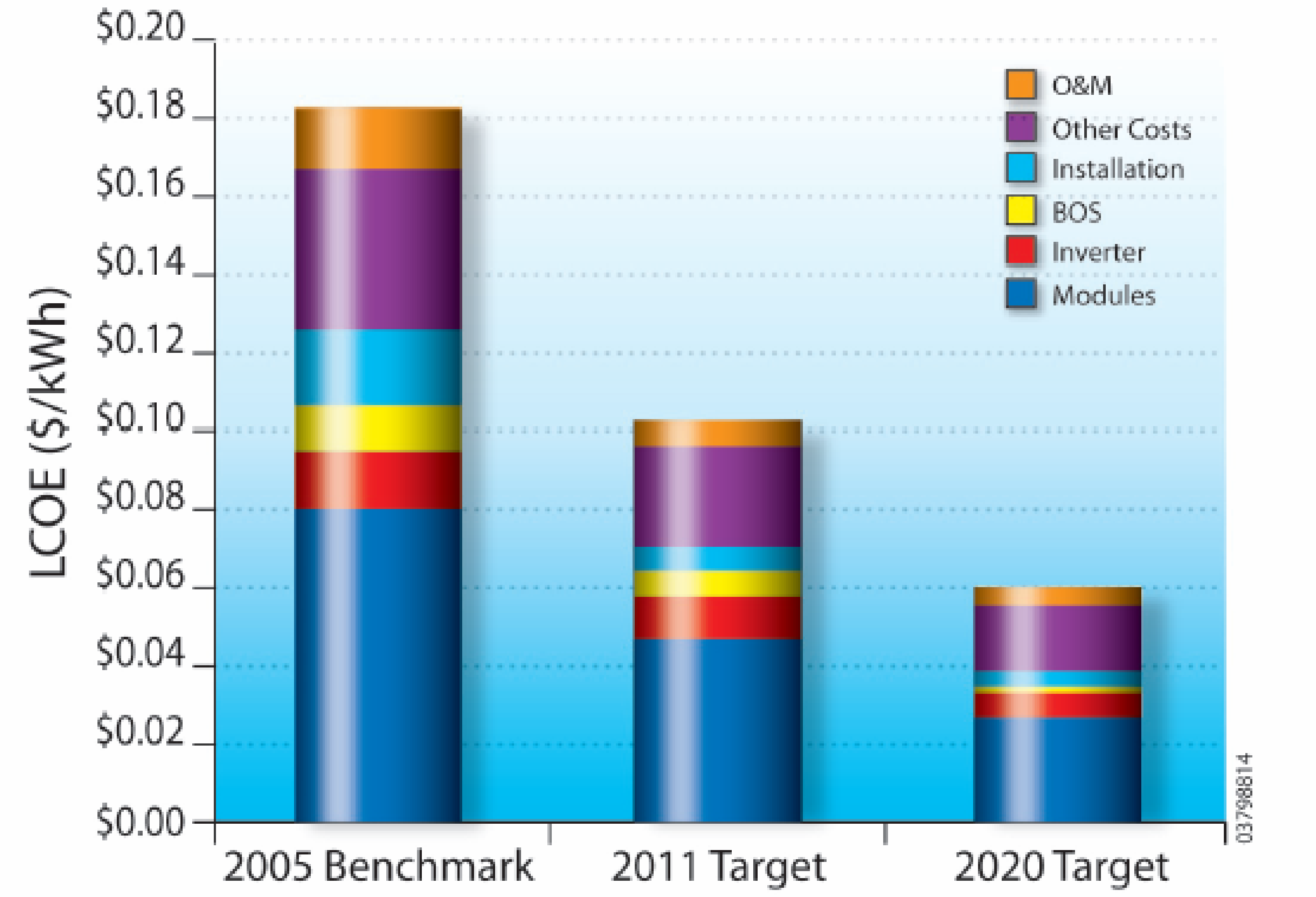


Fig. 3.1.6-6 Component contributions to LCOE for c-Si commercial reference system – shown for 2005 benchmark and 2011/2020 targets.

PV Electricity Costs in Europe

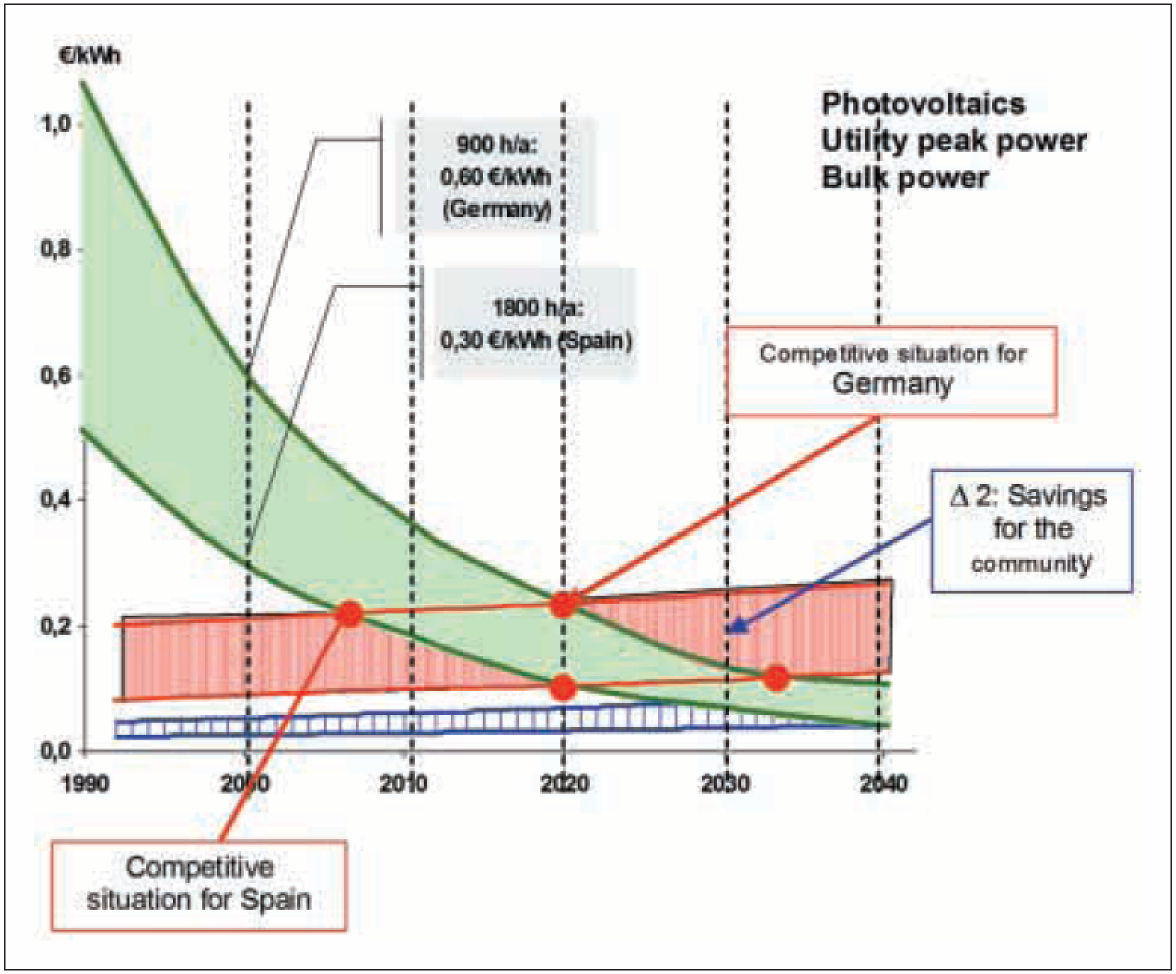
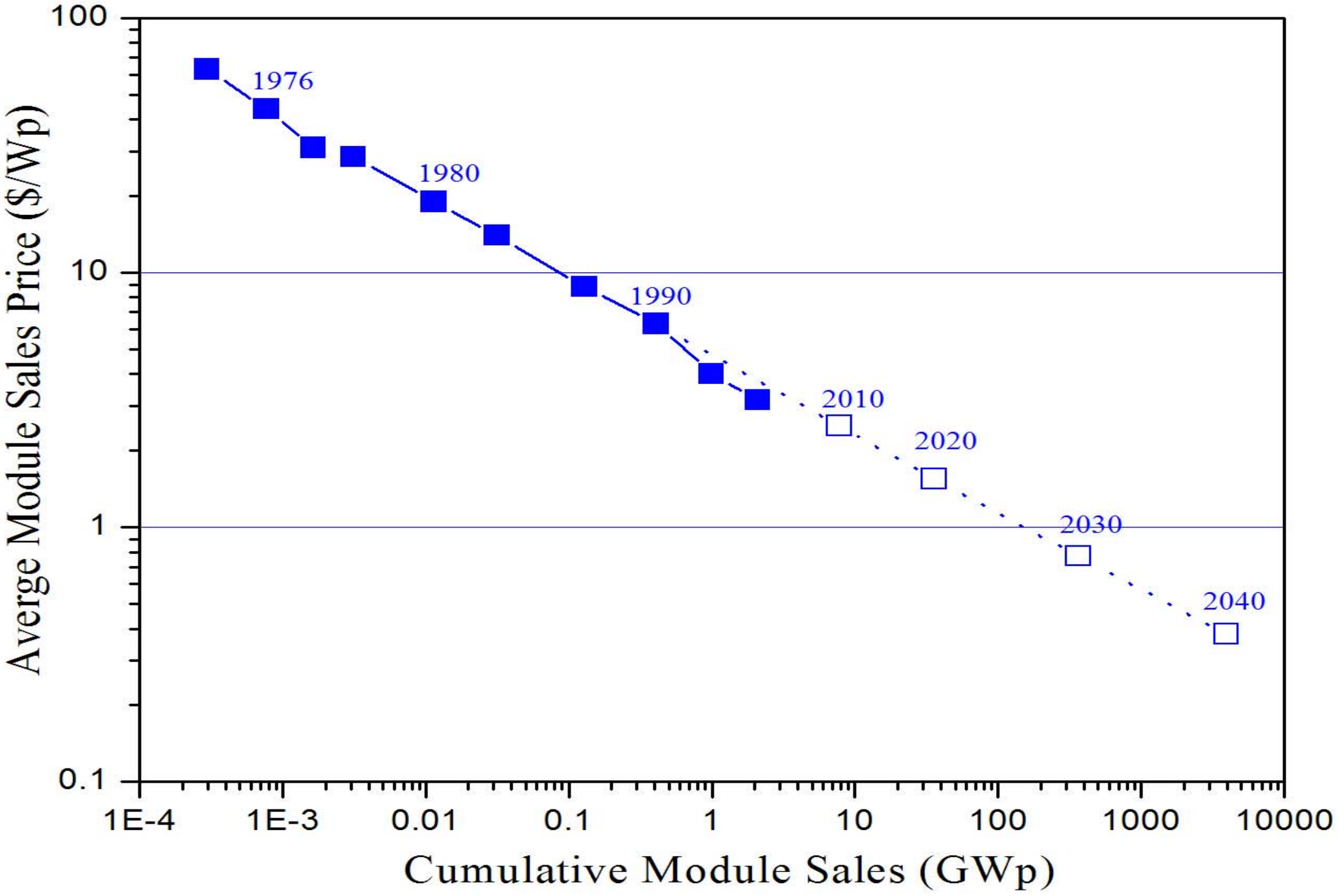


Fig. 11: Cost development of PV generated electricity vs. conventional price of electricity
(Source: RWE Schott Solar)

- PV electricity is close to being competitive in Spain today
- PV electricity is also close to grid parity today in Japan
- In the next few decades PV should become cost competitive in many parts of the world

PV Module Price Experience Curve



- At current growth rates, PV module prices should fall below $1/Wp by 2027

Forecast for PV Electricity Production

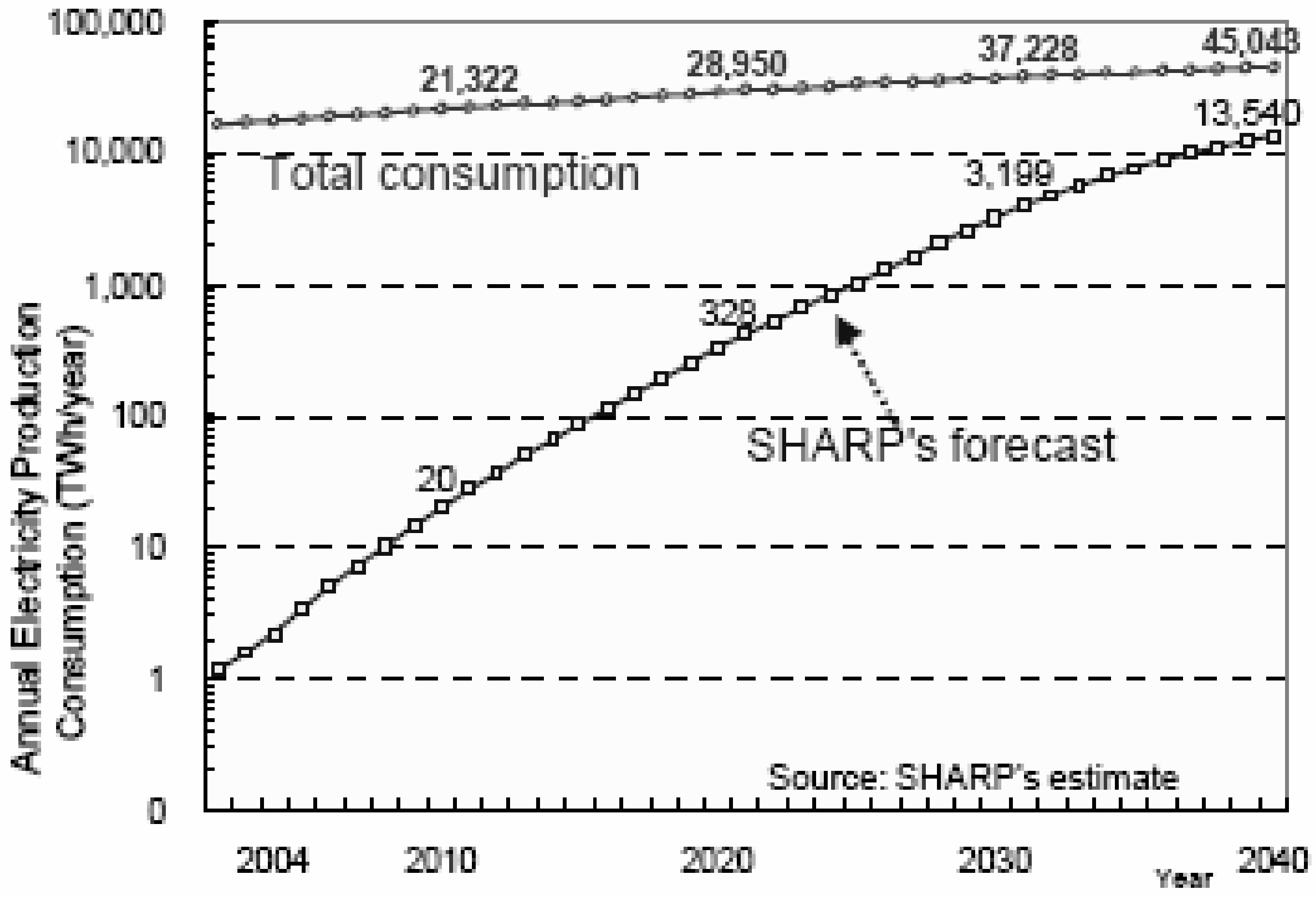
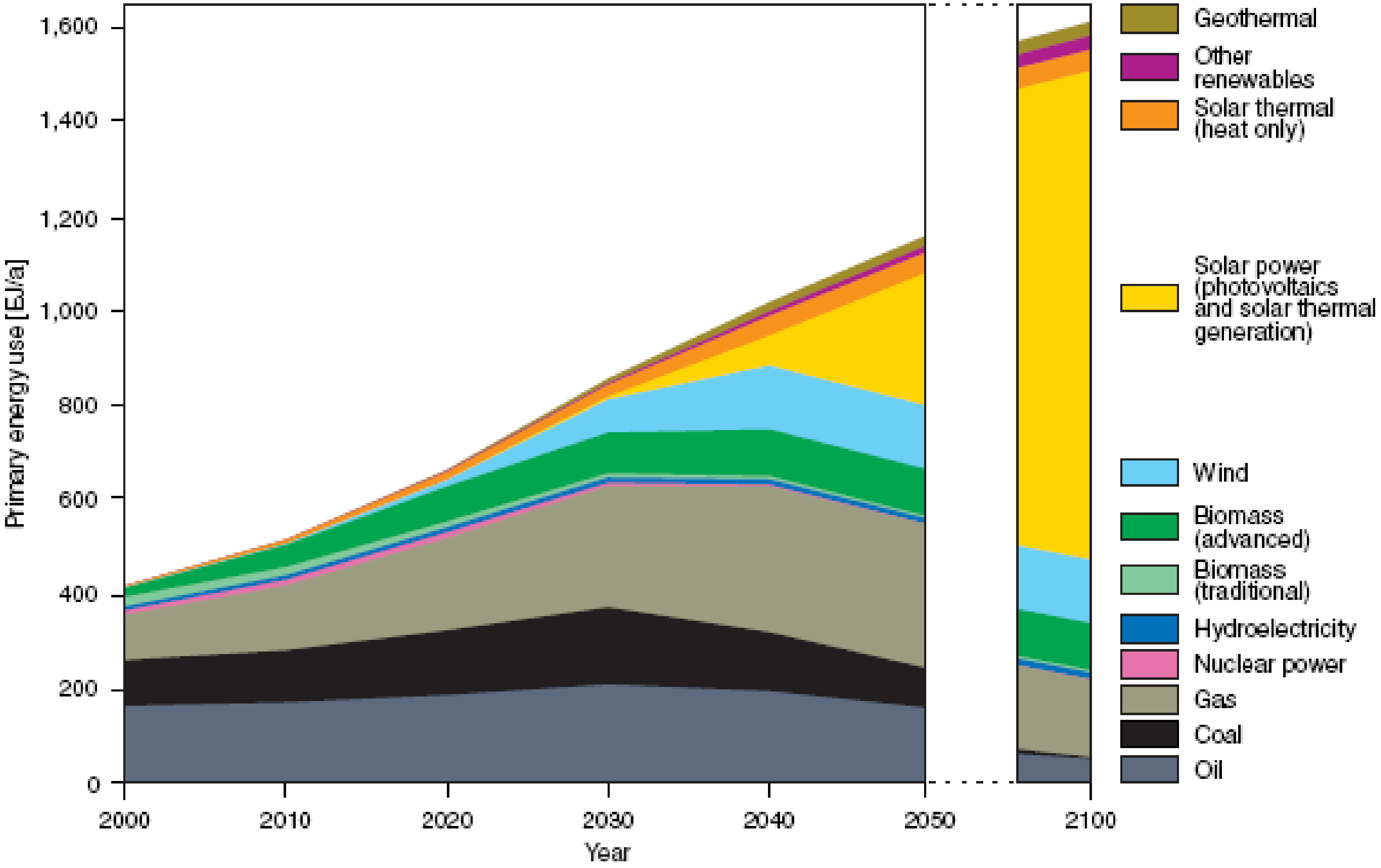


Fig.8 Forecast of world power supply by PV generation

Solar Energy – the Long-Term Solution?



Source: German Advisory Council on Global Change

Projections for the Future of PV

- Module efficiencies are likely to exceed 20% in the next decade
- The levelized cost of PV electricity may be about 6 ¢/kWh by 2020
- Disruptive technologies with theoretical limits of >60% may emerge in the next few decades
- At current growth rates, the cumulative PV production would be ~36 GWp by 2020 and 4 TWp by 2040
- 3 TWp of solar electricity will reduce carbon emissions by about 1 Gton per year (7 Gtons of carbon were emitted as CO_2 in 2000)
- Thus, by about 2035 PV could be producing about 10% of the world’s electricity and start to play a major role in reducing CO_2 emissions