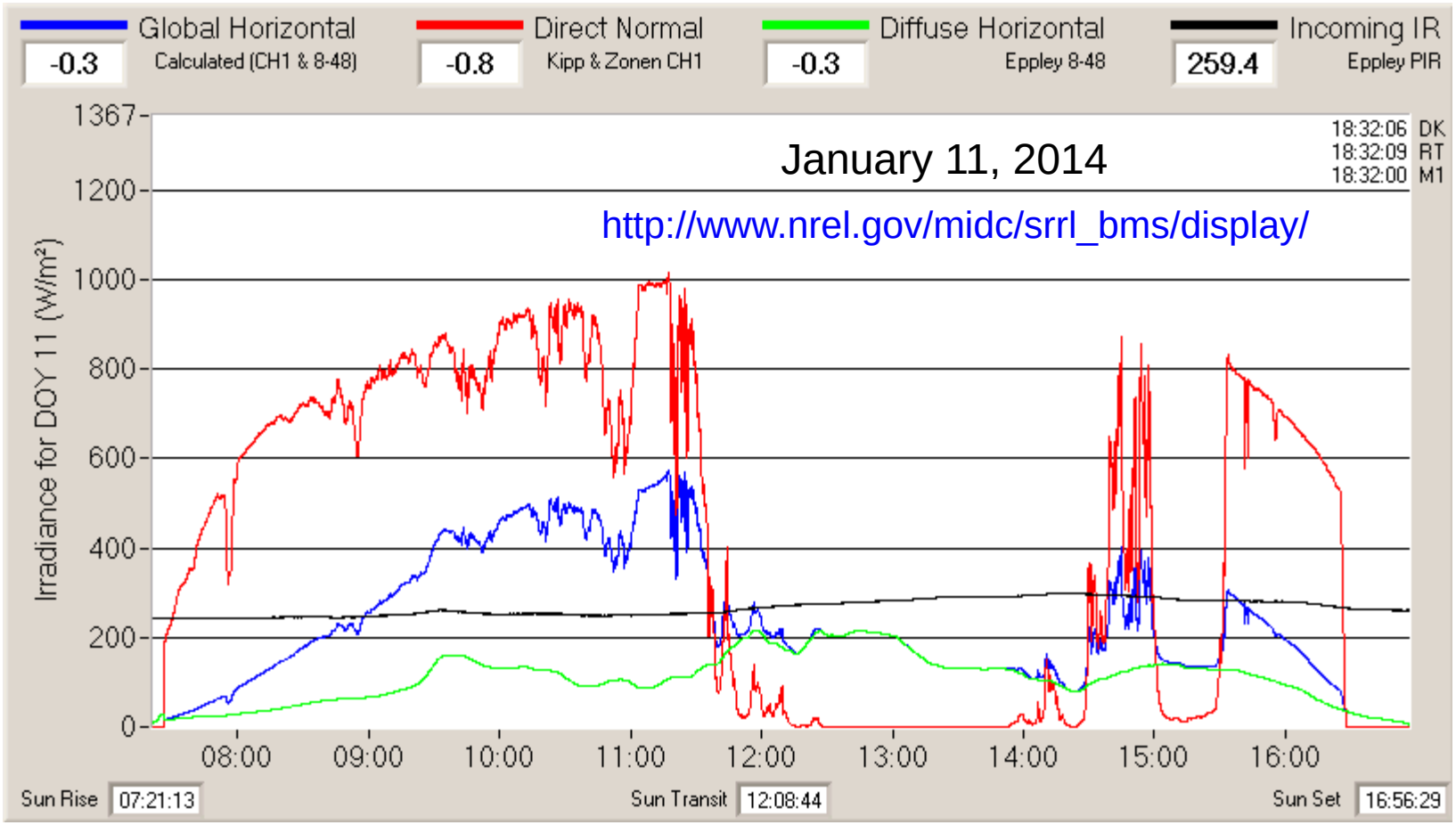
# The Solar Resource

Solar irradiation [W/m$^2$] measured at the NREL Solar Radiation Research Laboratory, Golden, CO



# Average Solar Irradiance Data

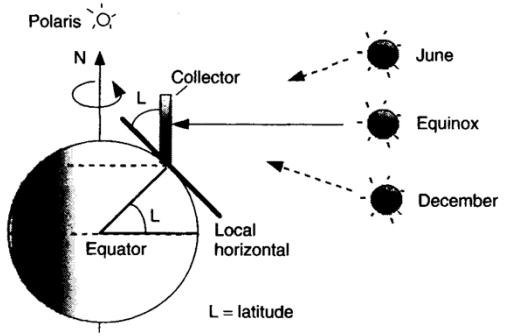
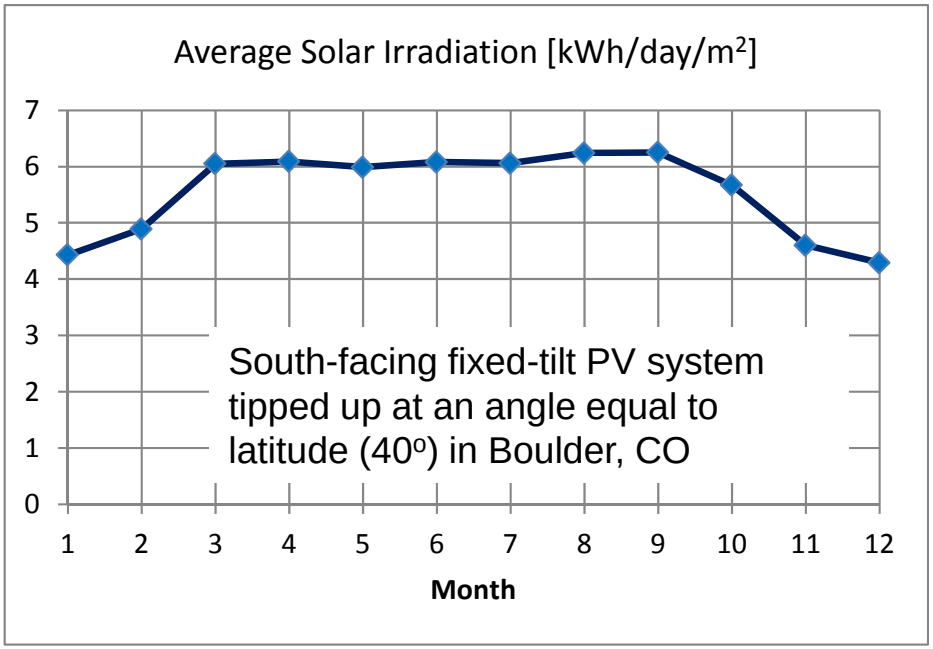



**Figure 7.8** A south-facing collector tipped up to an angle equal to its latitude is perpendicular to the sun's rays at solar noon during the equinoxes.




"Hours of full sun" $\frac{\text{kWh}}{\text{m}^2\ \text{day}}$

Examples of the yearly averages of "hours of full sun" for south-facing collectors at tilt angles equal to latitude

**Boulder, CO: 5.5**

San Diego, CA: 5.7

Phoenix, AZ: 6.5

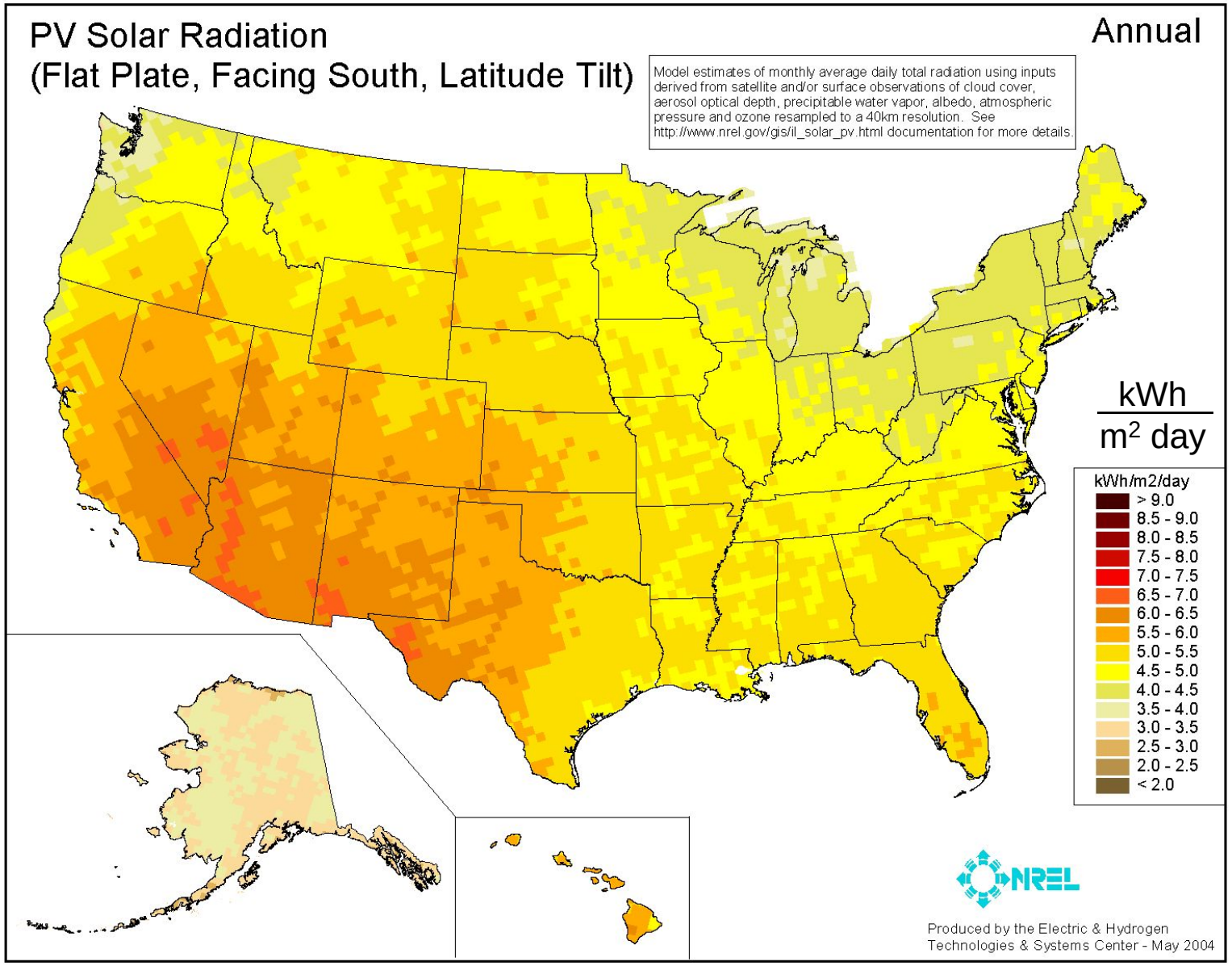
Seattle, WA: 3.7

Boston, MA: 4.6

Comprehensive solar irradiance data and performance calculators available at NREL PVWATTS site:

http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

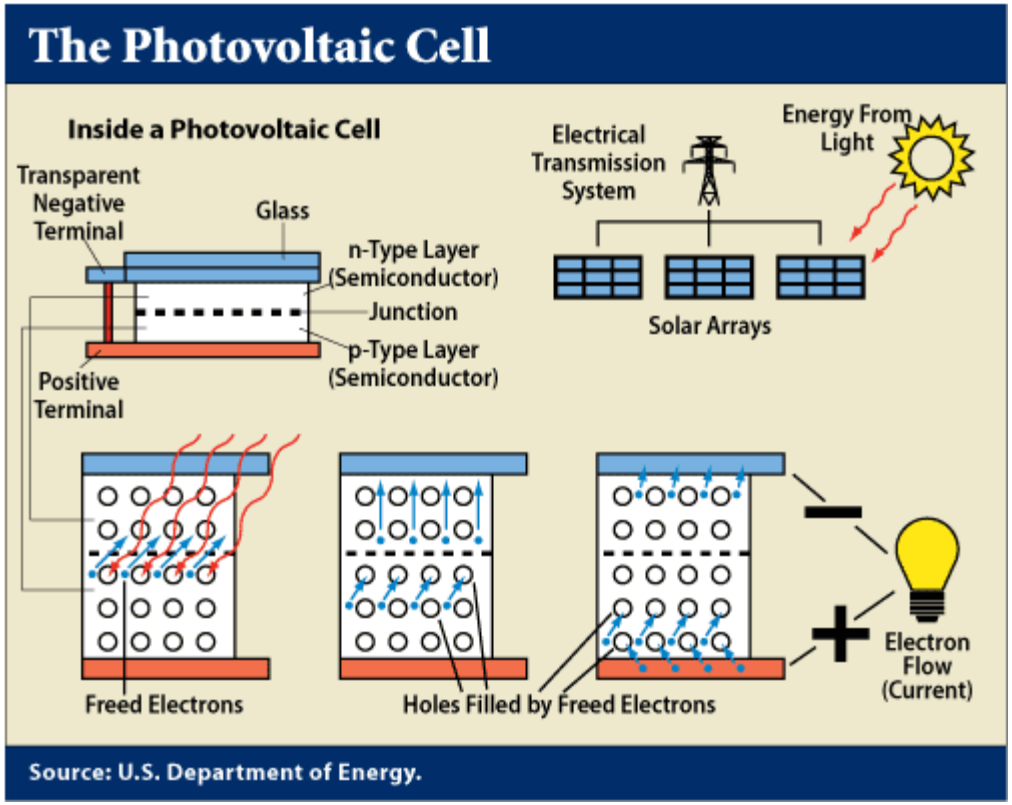
# US solar resource map



# Introduction to Photovoltaic (PV) Power Systems

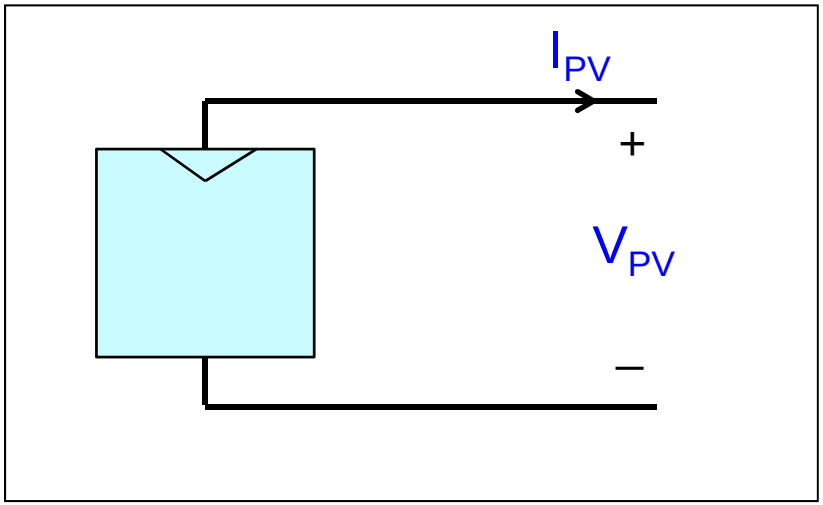
Standard crystalline silicon PV cell

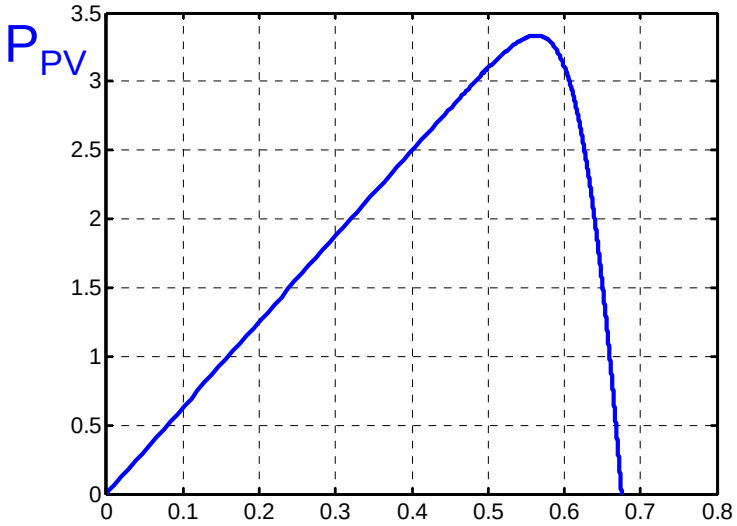
Typical cell size: 100-200 $cm^2$




- Commercial PV panel efficiency < 20%
- Clear-sky direct solar irradiation at the Earth surface: 1,000 $W/m^2$
- PV output power: < 200 $W/m^2$, < 4 W per PV cell

# PV cell characteristic

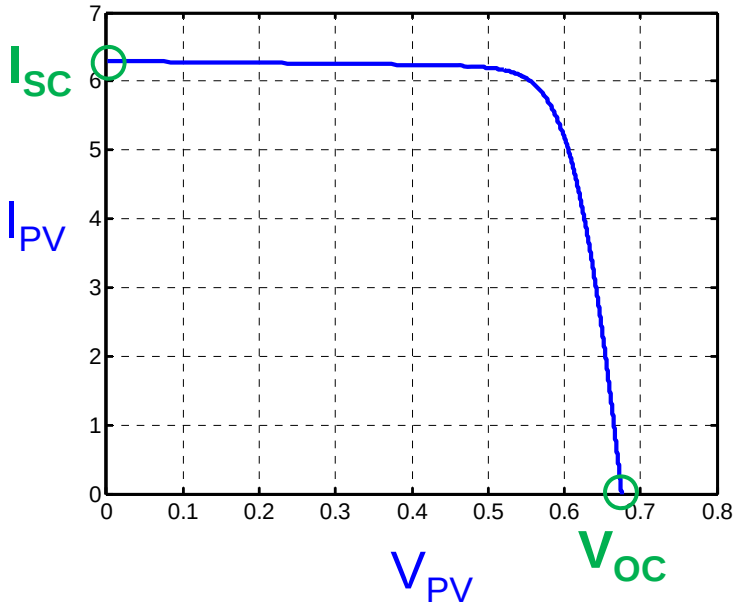


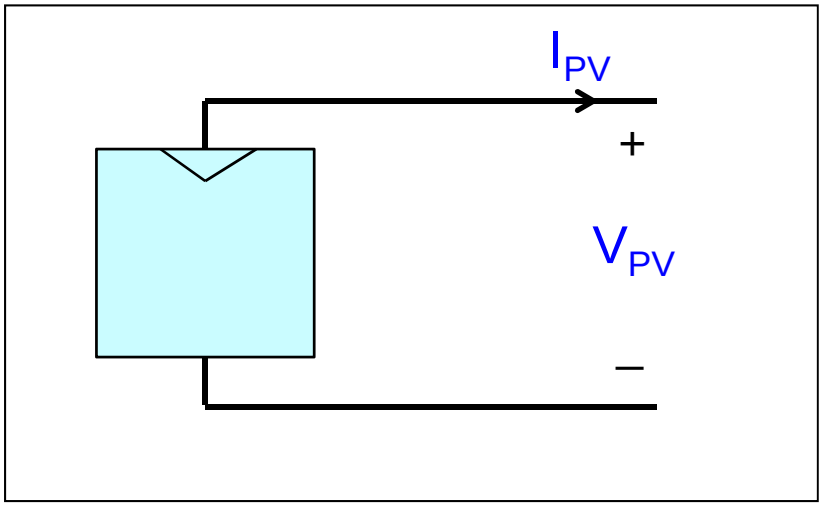

PV cell example:

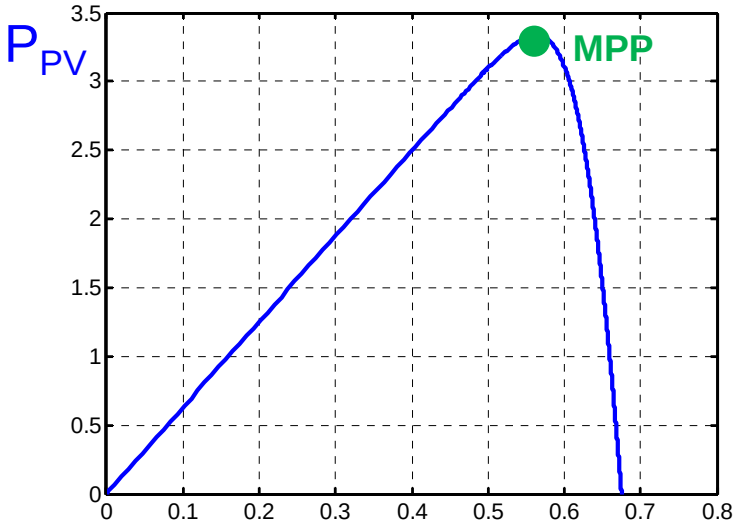
- Open-circuit voltage $V_{OC}$ = 0.675 V
- Short-circuit current $I_{SC}$ = 6.3 A

at Standard Test Conditions (STC):
1000 W/m$^2$, 25$^o$C, AM1.5 spectrum



# Maximum power point (MPP) [Wpk = “Watt peak”]

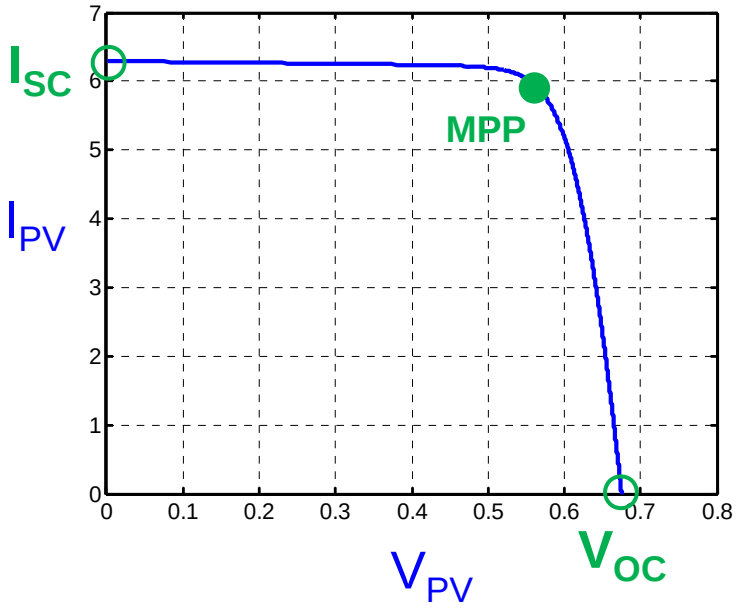


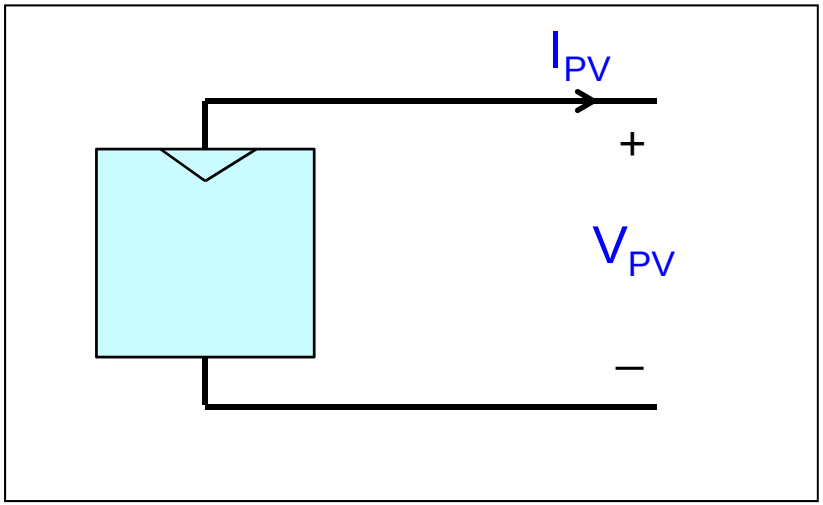

Maximum power point:

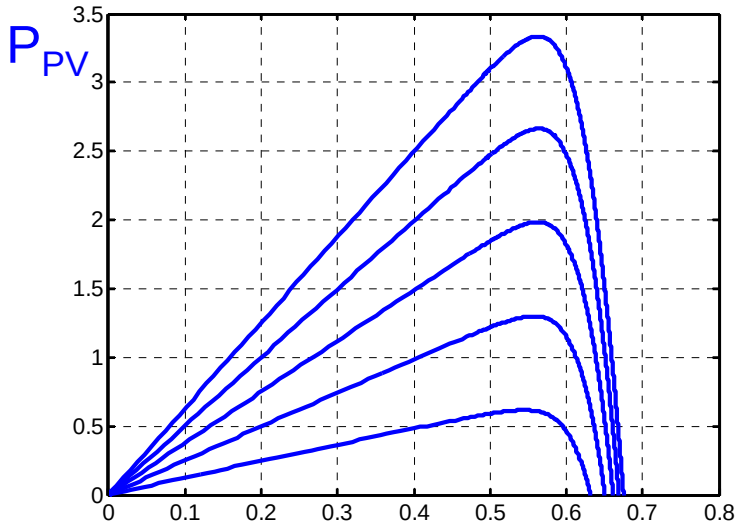
- Voltage $V_{mpp}$ = 0.56 V
- Current $I_{mpp}$ = 5.9 A
- Power $P_{mpp}$ = 3.34 Wpk

at Standard Test Conditions (STC), 1000 W/m$^2$, 25$^o$C, AM 1.5

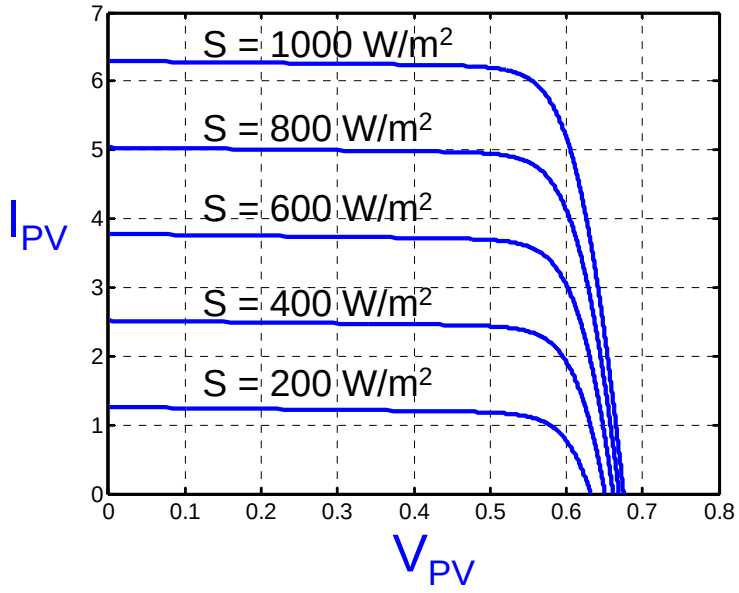


# PV cell characteristics: irradiation

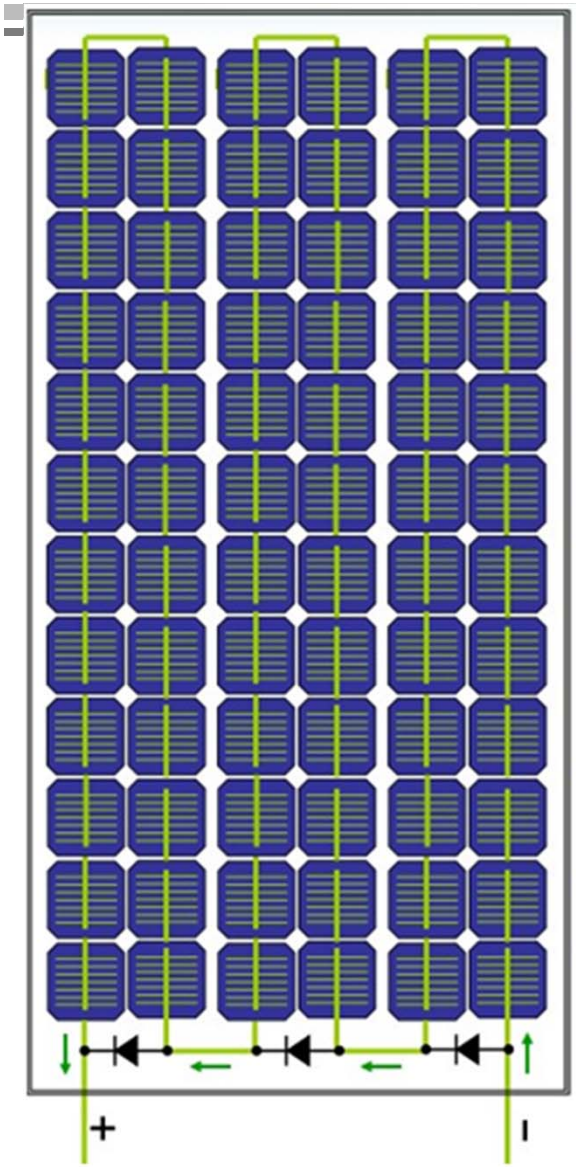



- Short-circuit current proportional to irradiation *S*
- Open-circuit voltage and MPP voltage do not change much with irradiation
- Maximum output power decreases with temperature (example: –0.4%/ºC)

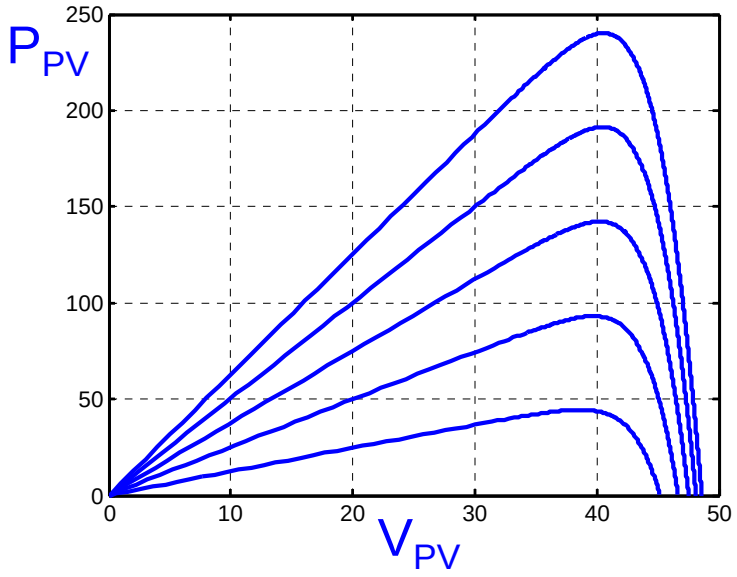


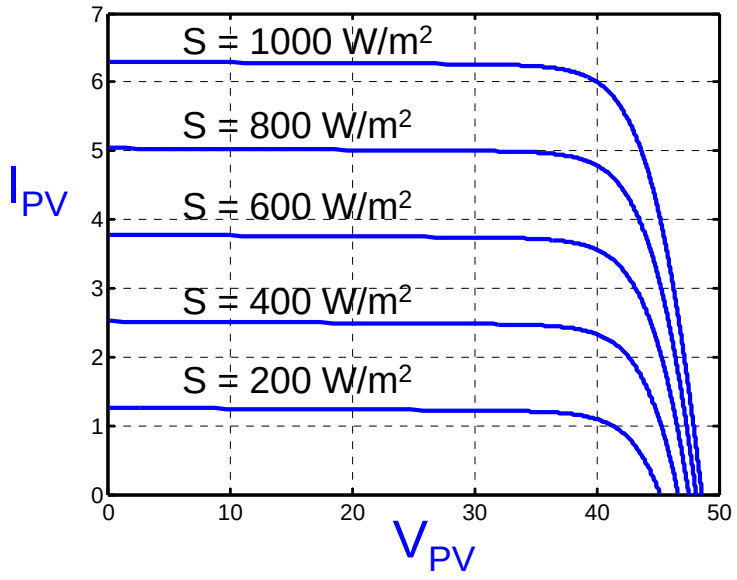
# PV panel example




Example: 72-cells in series, at STC:

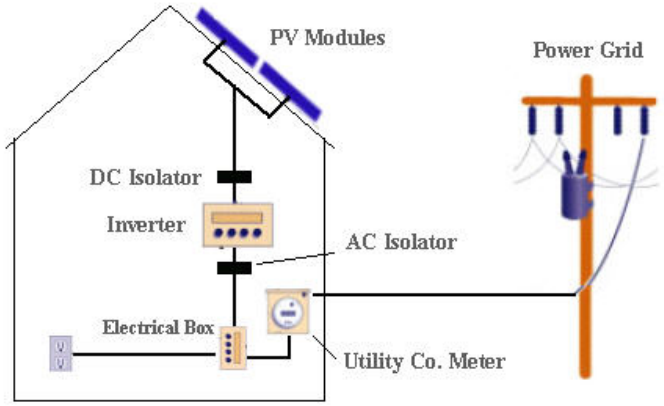
- $V_{OC}$ = 48.6 V
- $I_{SC}$ = 6.3 A
- $V_{mpp}$ = 40.5 V
- $I_{mpp}$ = 5.9 A
- $P_{mpp}$ = 240 Wpk = dc peak power rating of the panel under STC
- Area: 0.8 m x1.56 m = 1.24 $m^2$

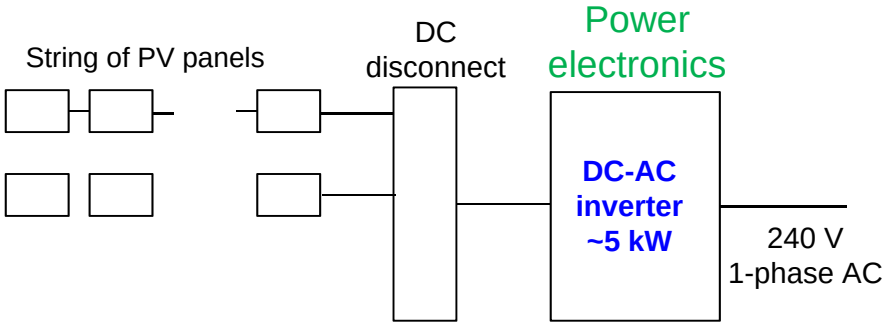


# Grid-Tied PV Systems

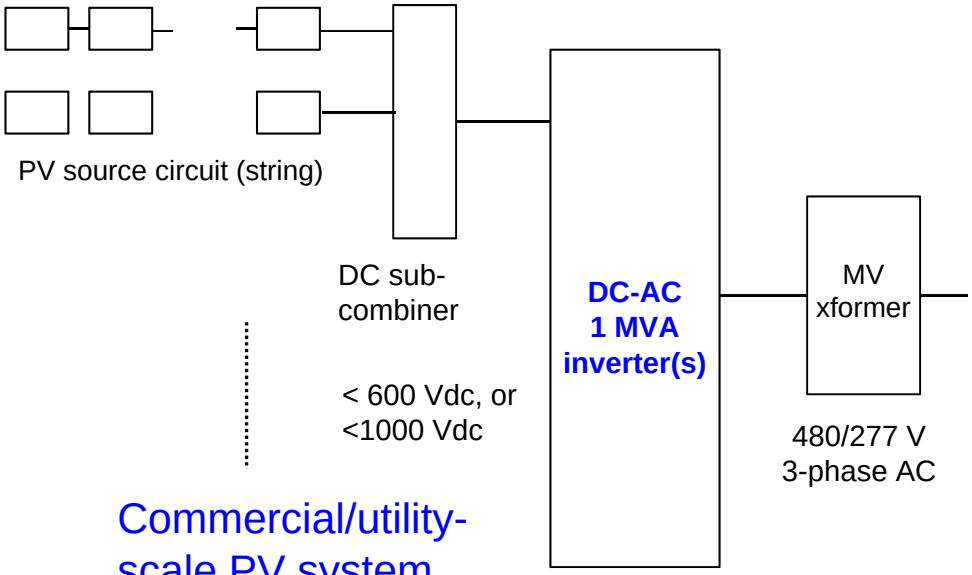
## Rooftop PV system




ECEE rooftop PV system, PV panels tied to our power lab

## Commercial/utility-scale PV system

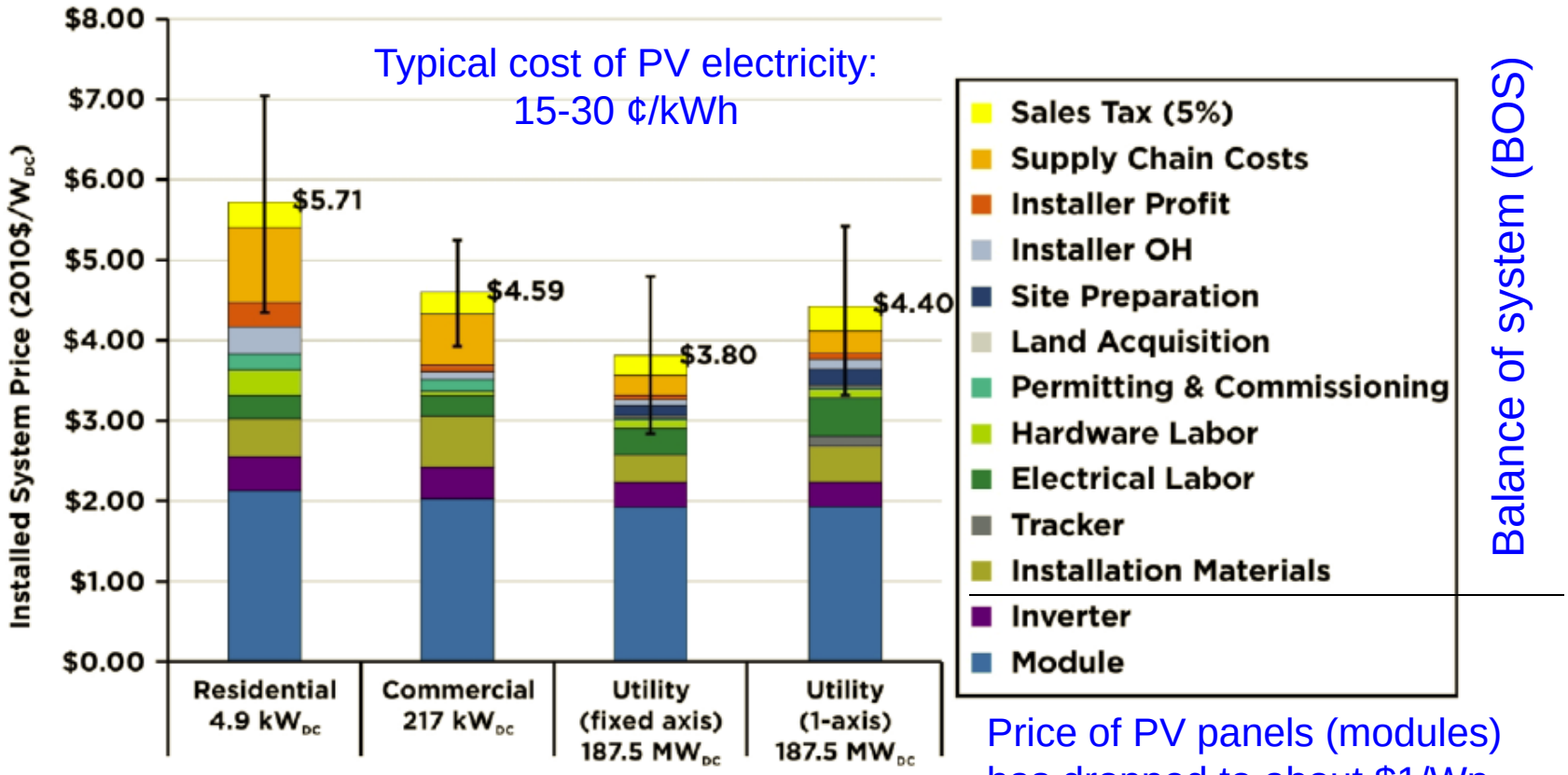



Power electronics

1.6 MW PV system at DIA

# PV system cost breakdown

**Figure 4-4. Benchmarked 2010 Installed PV System Prices with Uncertainty Ranges for Multiple Sectors and System Configurations with Three Standard Deviation Confidence Intervals Based on Monte Carlo Analysis[42]**



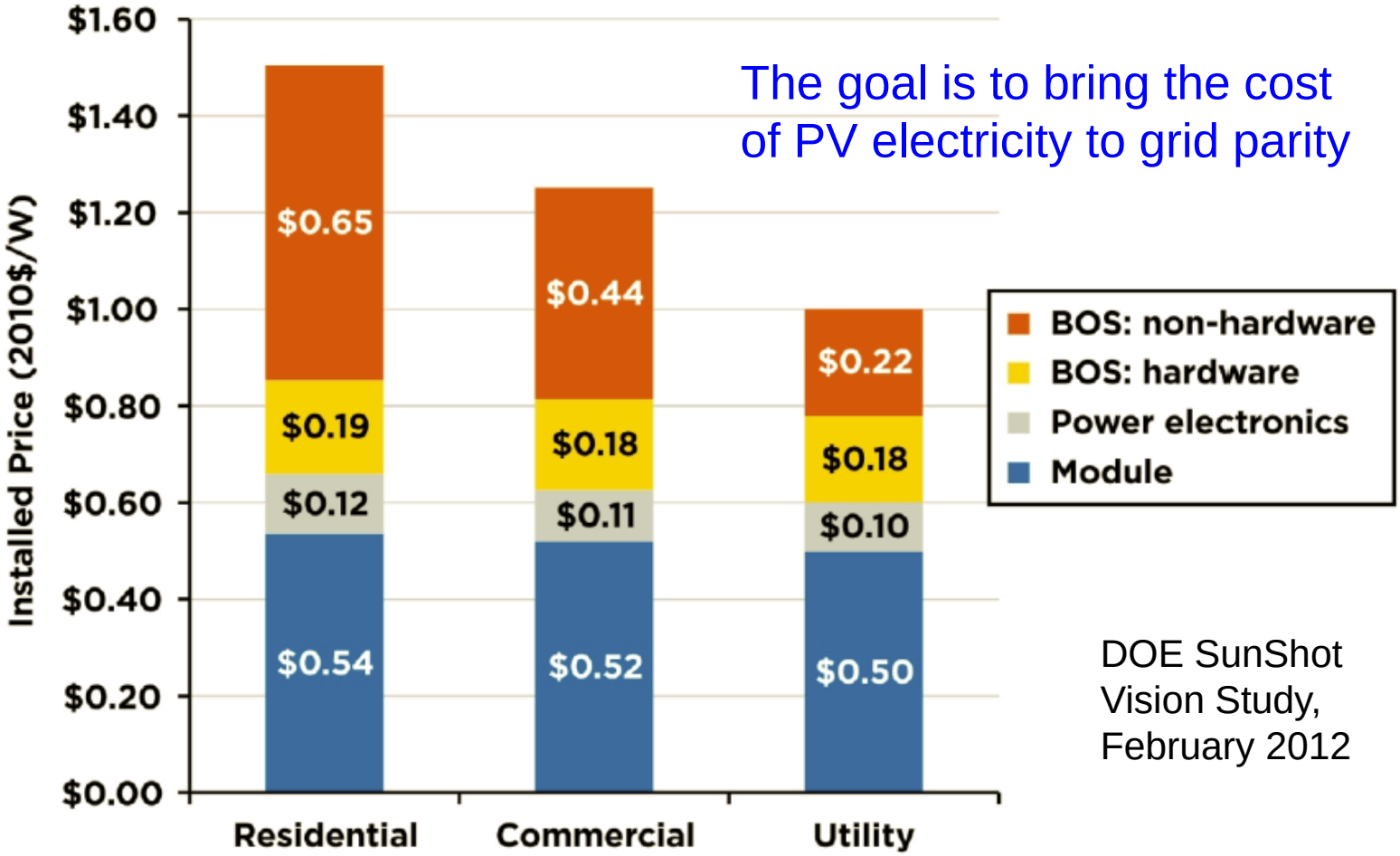

Price of PV panels (modules) has dropped to about $1/Wp in 2013!

Source: Goodrich et al. (2012)

DOE SunShot Vision Study, February 2012

# DOE 2020 Sunshot targets

**Figure 4-6. Estimated Subsystem Prices Needed to Achieve 2020 SunShot Targets**



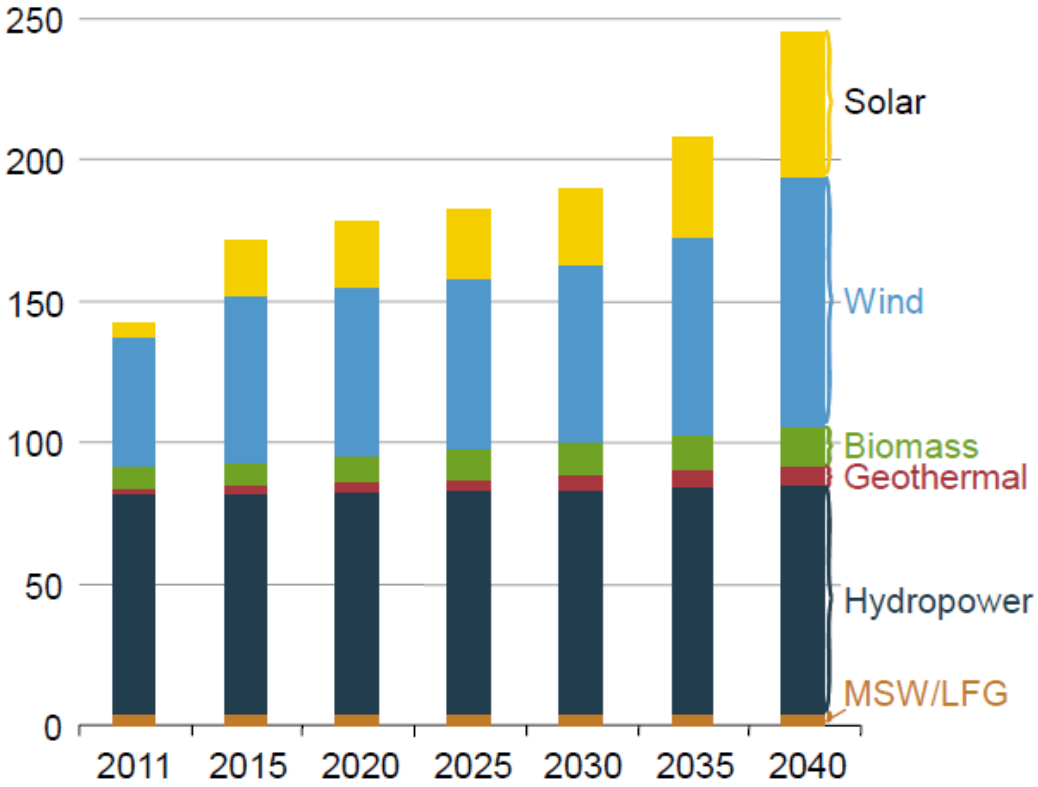

The goal is to bring the cost of PV electricity to grid parity

DOE SunShot Vision Study, February 2012

# Projected Growth of Renewable Generation

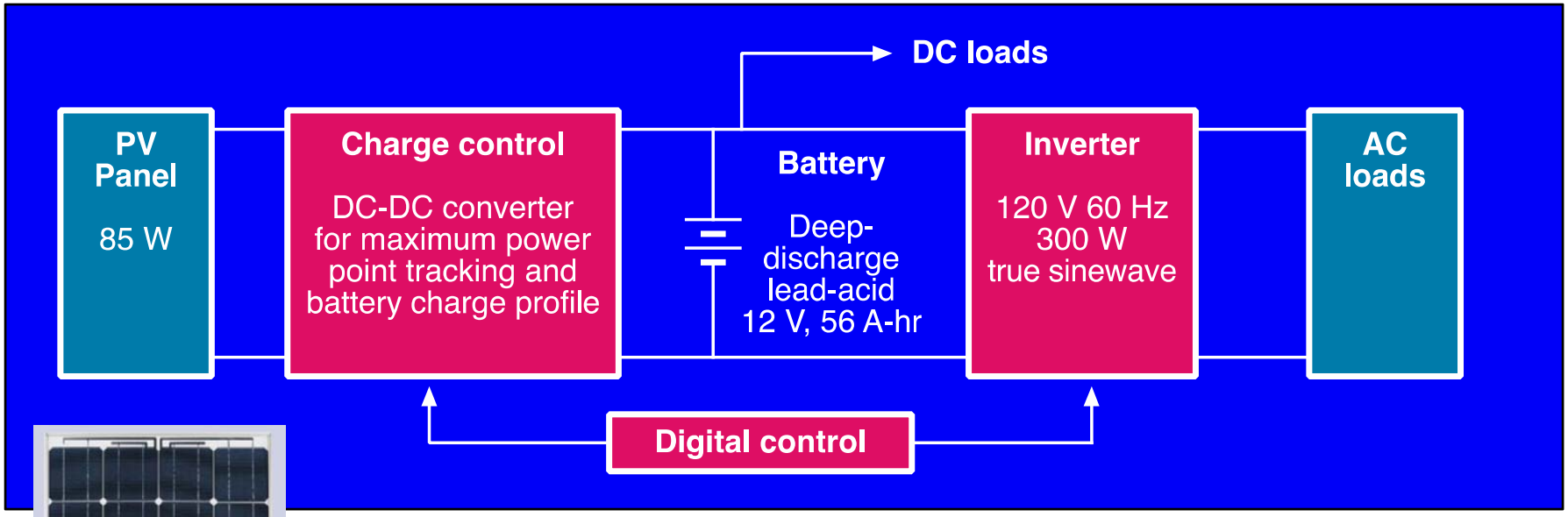
**Solar photovoltaics and wind dominate renewable capacity growth**

**Figure 82. Renewable electricity generation capacity by energy source, including end-use capacity, 2011-2040 (gigawatts)**




DOE/EIA Annual Energy Outlook 2013

# ECEN4517/5517 Lab: Stand-Alone PV System




- Sharp SQ85-P PV panel, 85Wpk peak dc rated power (MPP under STC)
- 36 PV cells in series
- Outside dimensions: 1.2m x 0.527m = 0.63 $m^2$