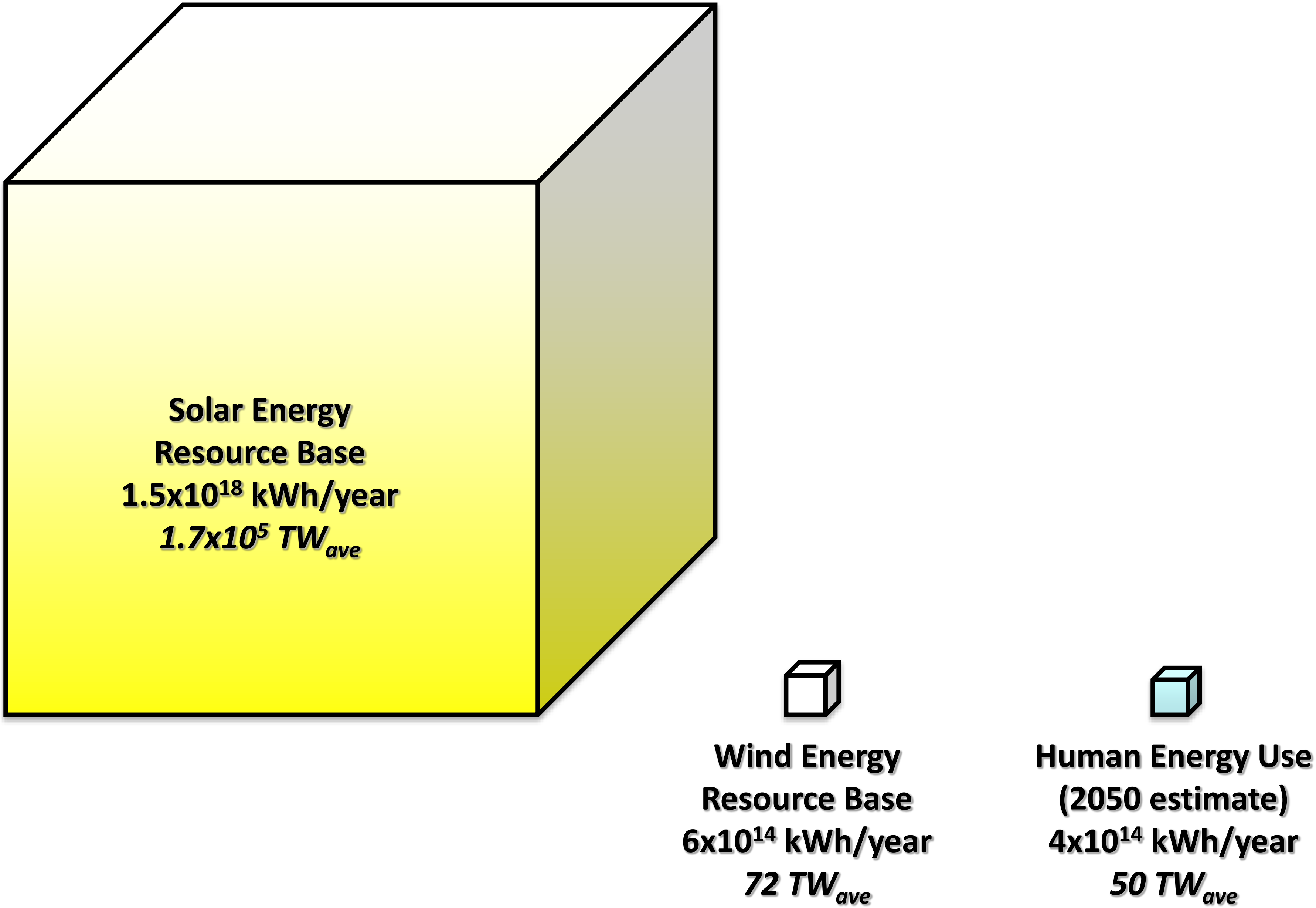
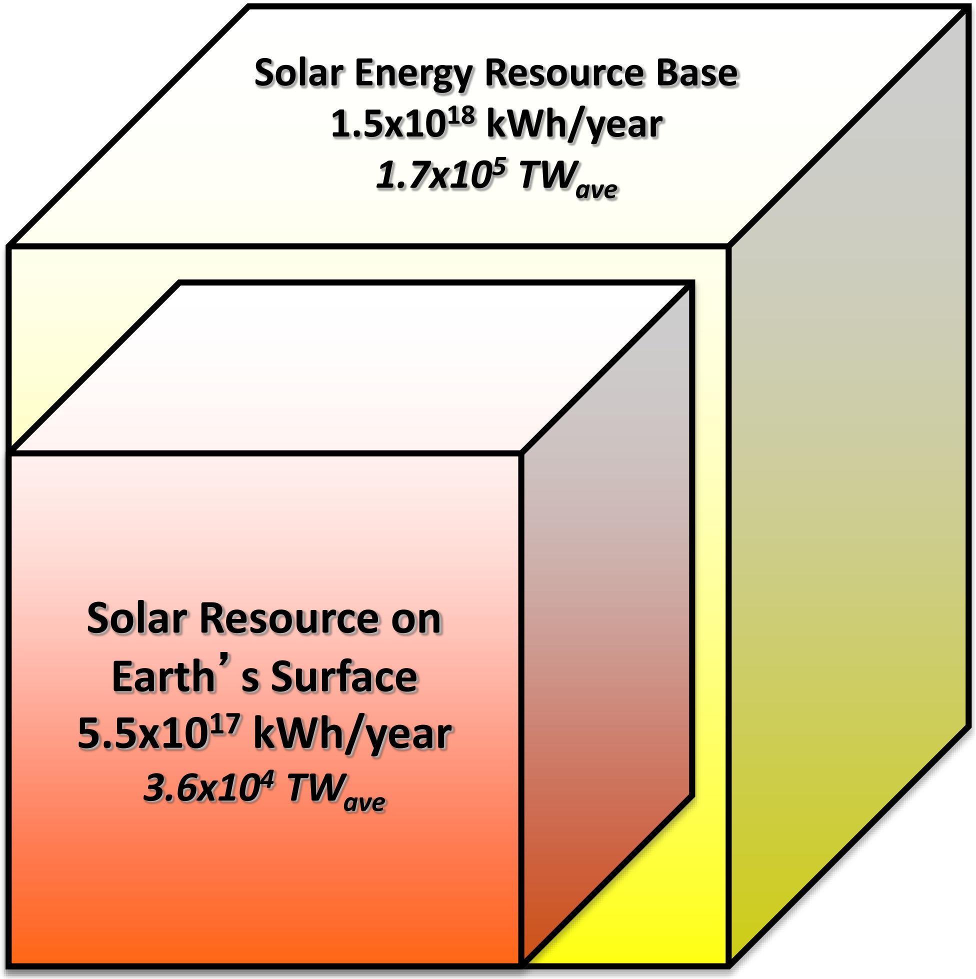
The Terrestrial Solar Resource



Solar Resource is VAST!



Solar constant: 1368 W/m^2

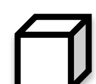
Surface, 30 – 50% less

Solar constant: 1 kW/m^2

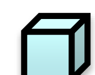
x 0 – 8 hours/day, or

An average of

4 $kWh/m^2/day$

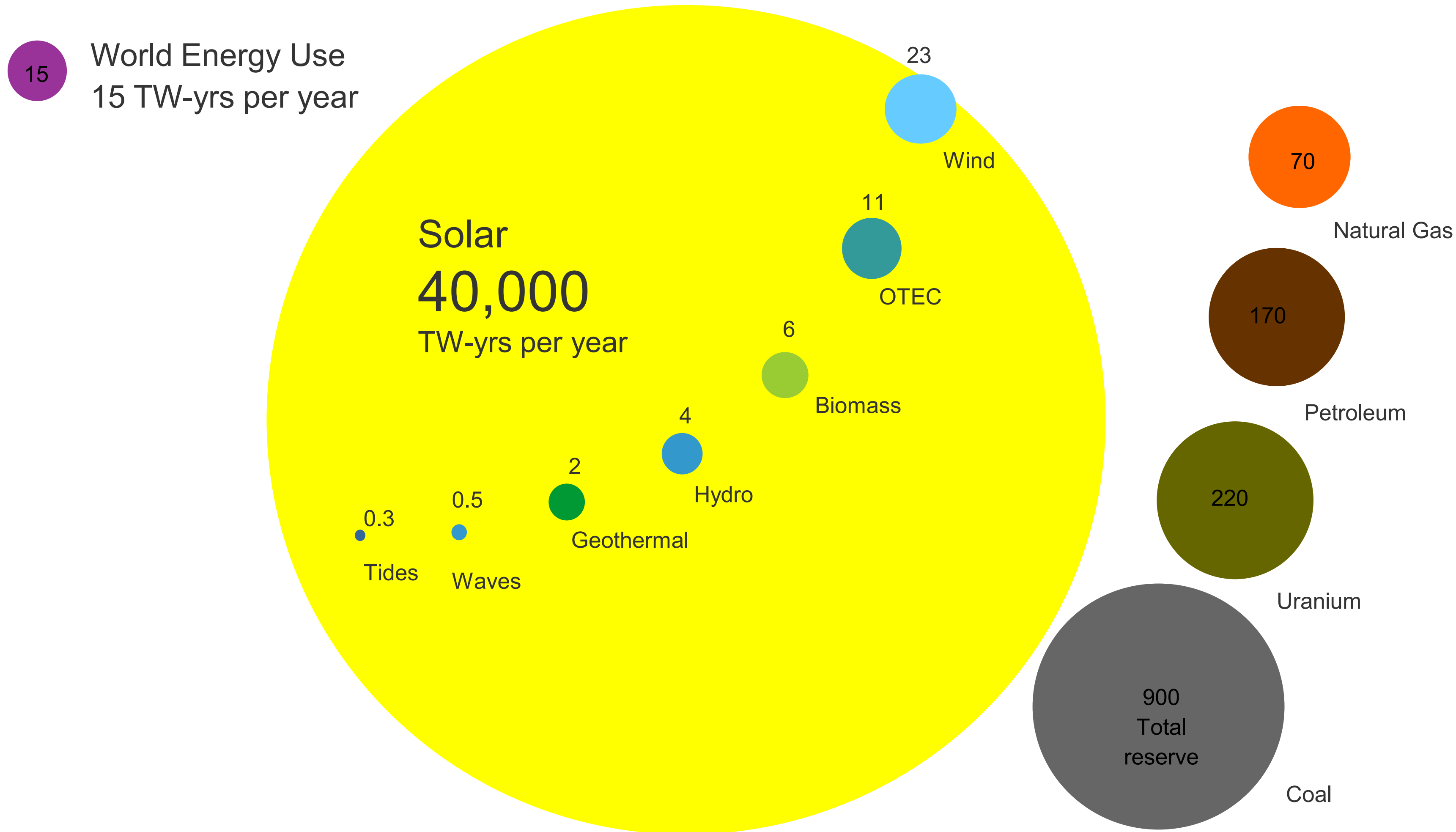


Wind Energy Resource Base
6×10^{14} kWh/year
72 TW_{ave}



Human Energy Use (mid- to late-century)
4×10^{14} kWh/year
50 TW_{ave}

Energy resources compared



PV Land Area Requirements

6 Boxes at 3.3 TW Each

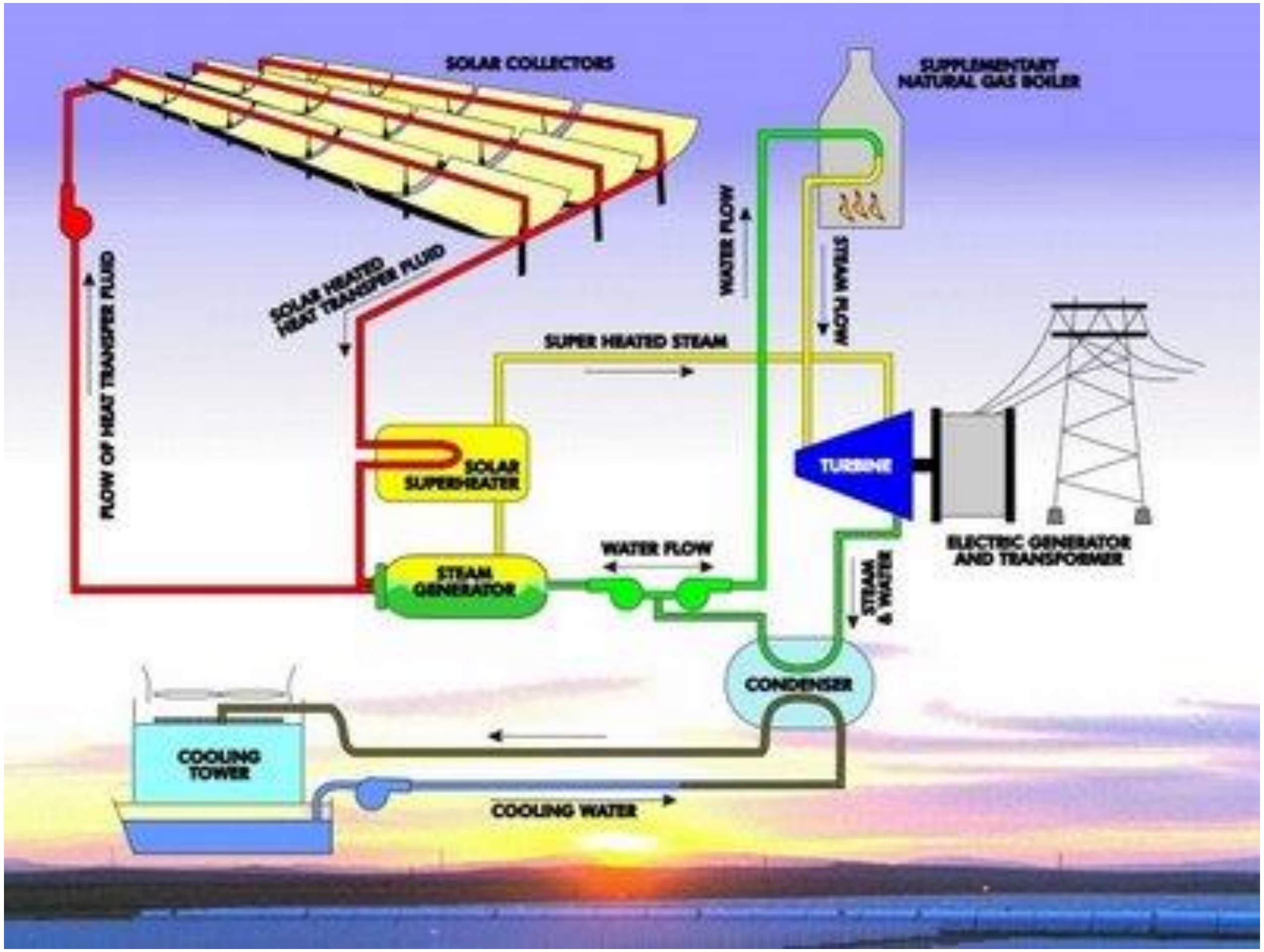
7

Evolution of U. S. deployment

SOLAR AMERICA CITY
2007

8

Solar Thermal



The World's Largest Solar Thermal Power Plant (Parabolic Trough)

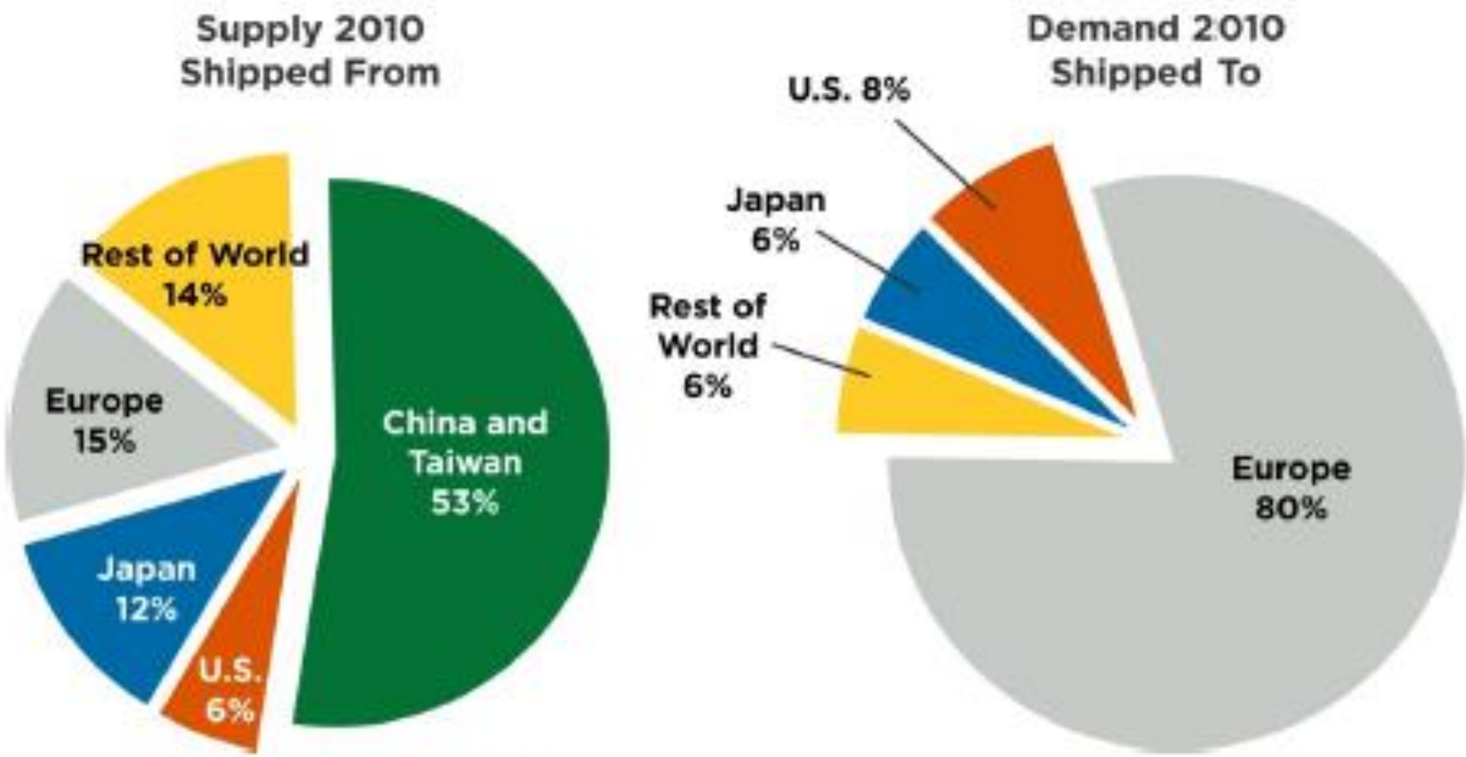
Solar Energy Generating System (SEGS)
310 MW
San Bernadino County, CA

The World's Largest Solar Thermal Power Plant (To

Ivanpah Solar Thermal Project
370MW
San Bernardino County, CA

PV Supply and Demand

Figure 2-2. 2010 Global PV Supply and Demand



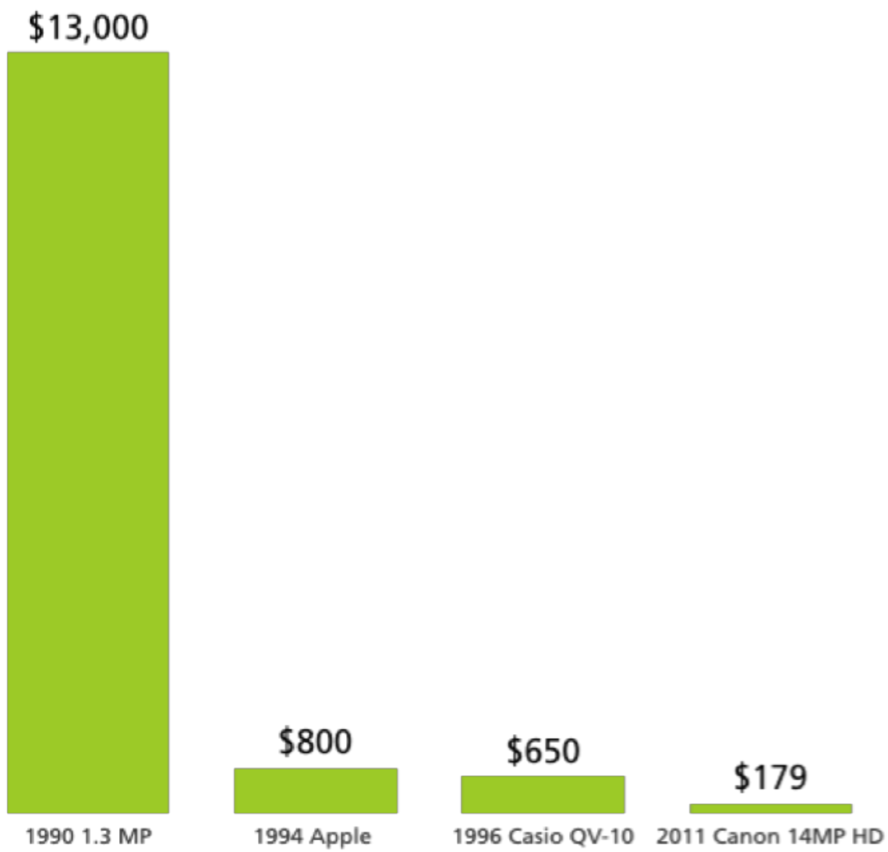
Source: Mints (2011a) and Mints (2011b)

Goodrich, Margolis, et al, NREL

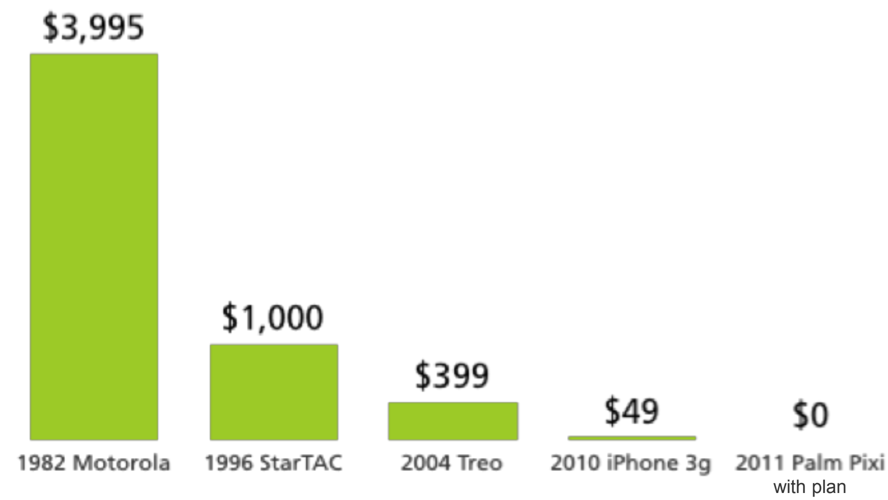
Solar Price Drops Mirror High Tech Consumer Goods

Driven by Innovation, Automation, and Scale

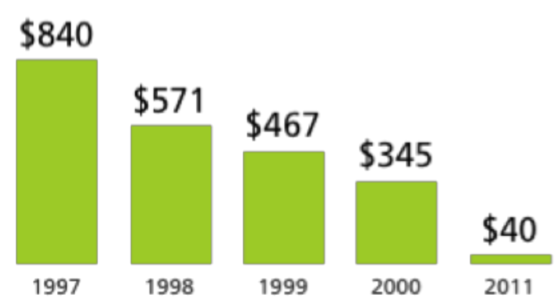
Digital Cameras



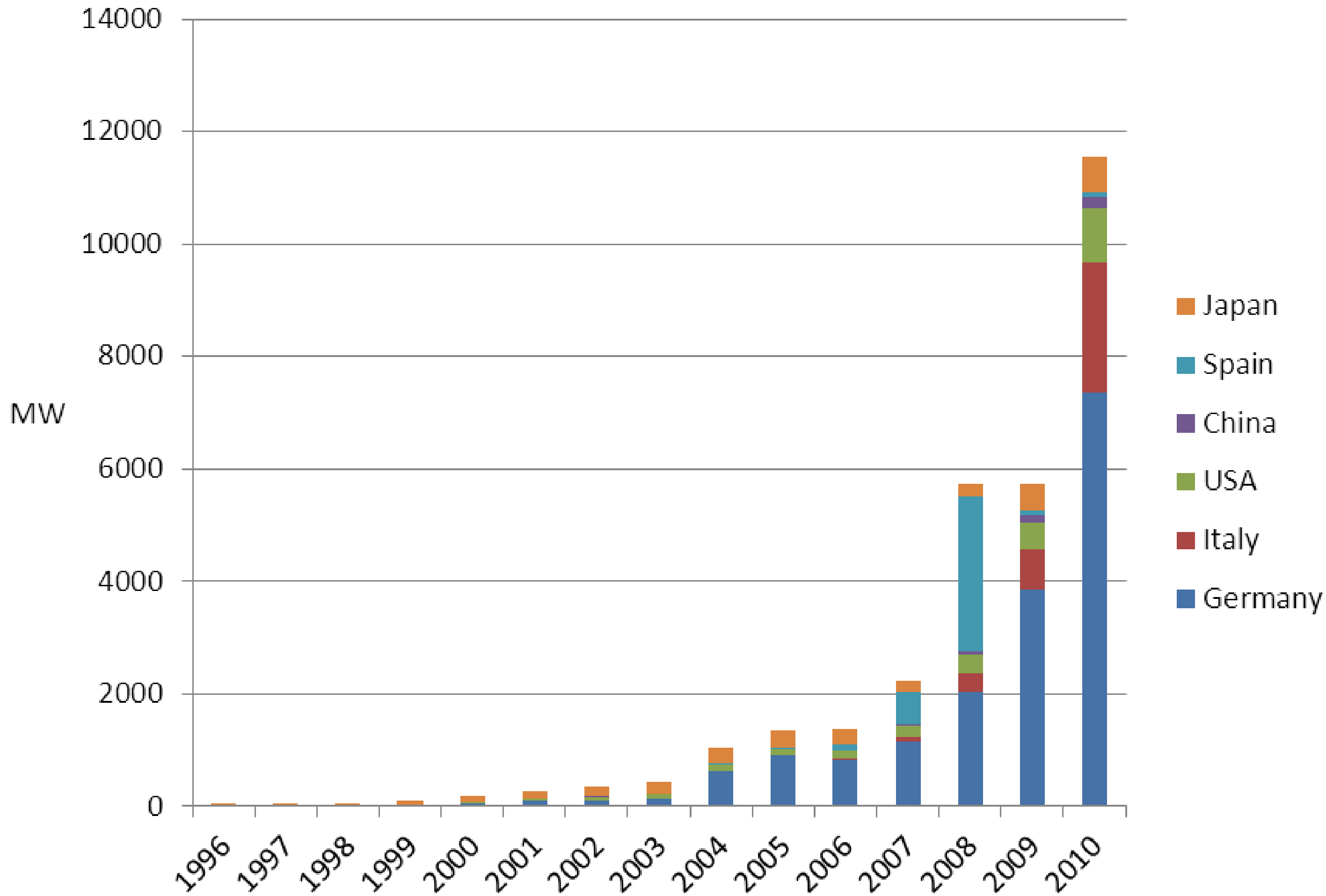
Cell Phones



DVD Players

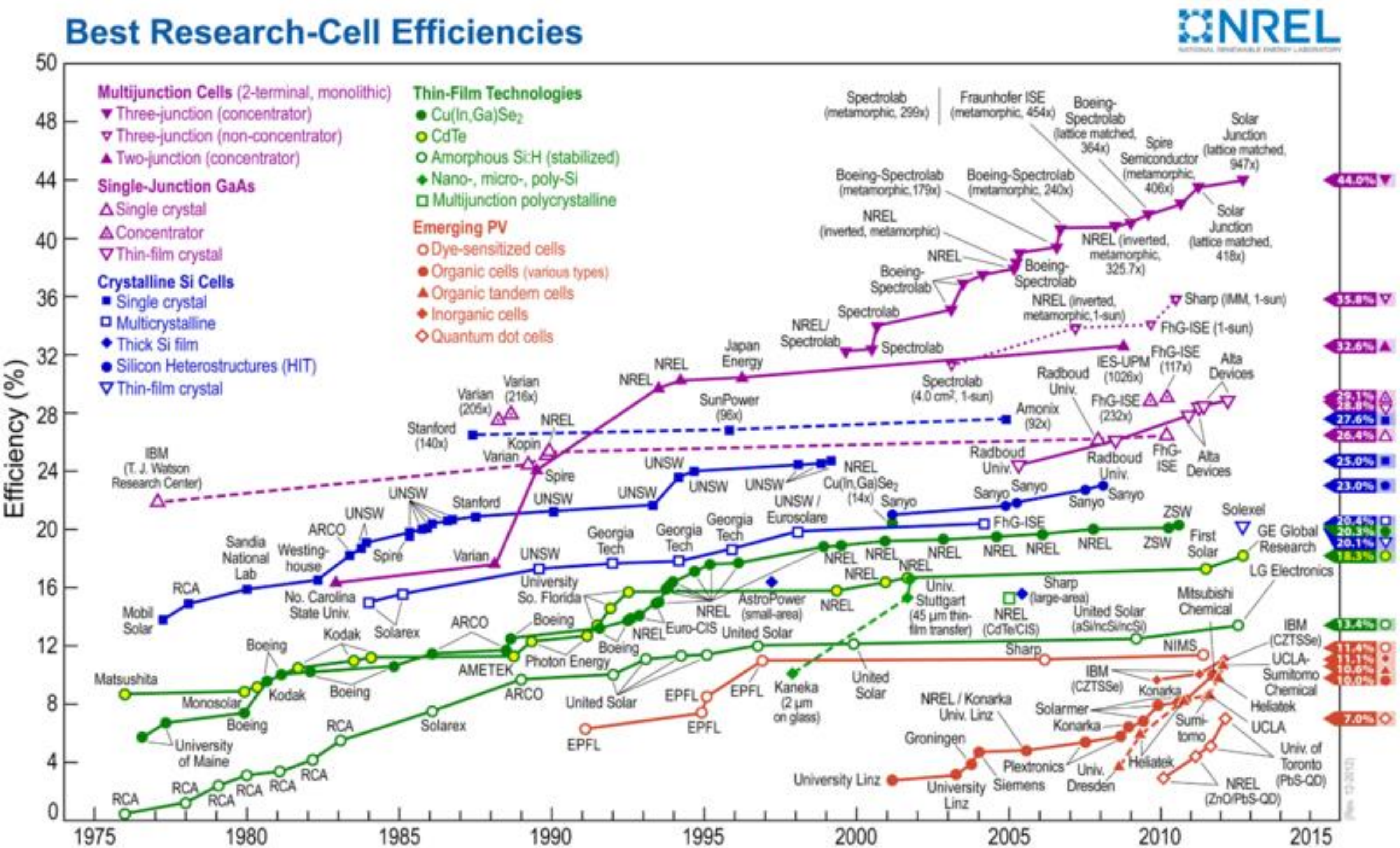


Annual installed PV power in key countries

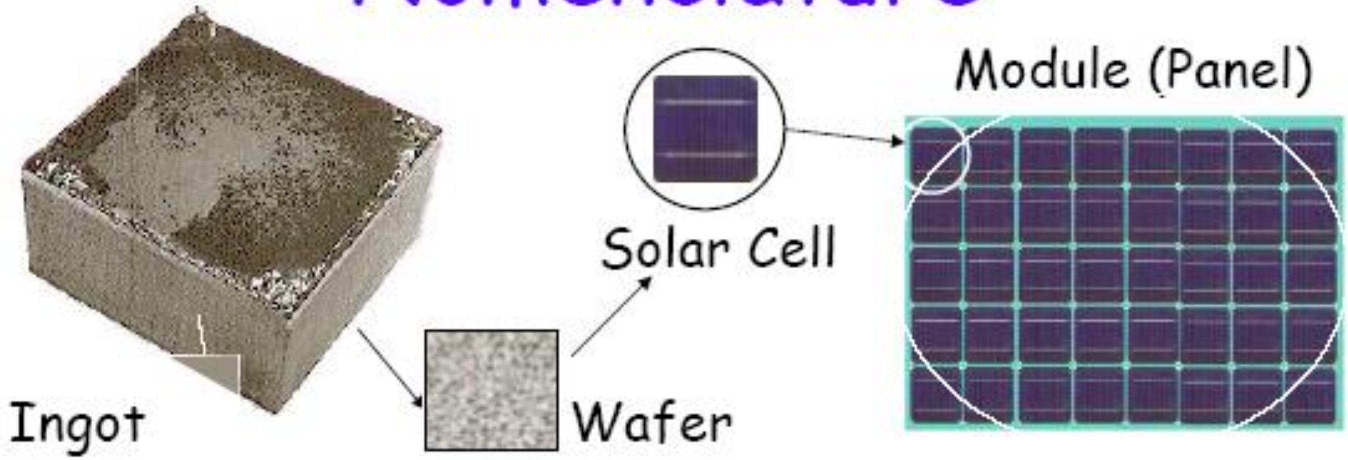


Based on data from IEA, EPIA, BSW-Solar, GSE, China PV Development Report, etc.

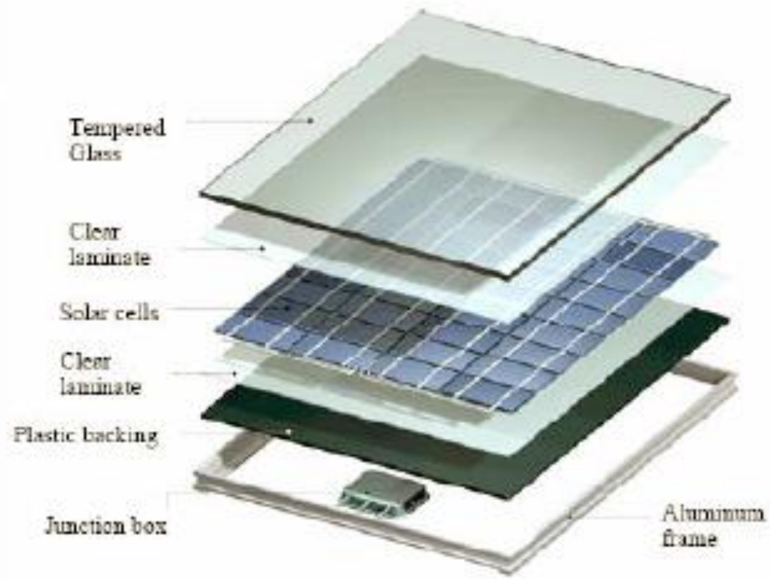
Best Research-Cell Efficiencies

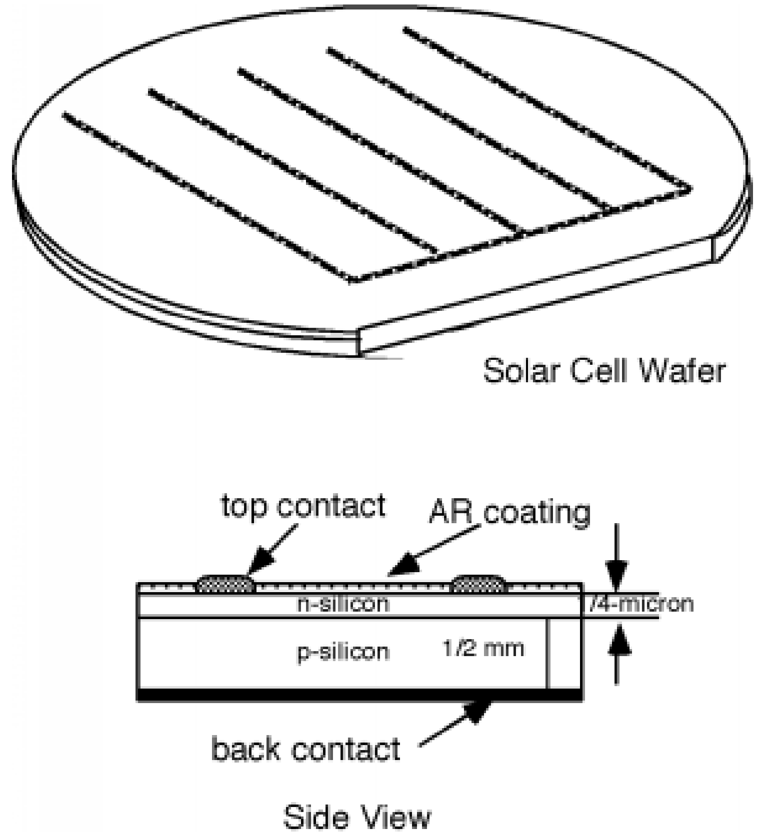


Nomenclature



Solar Array



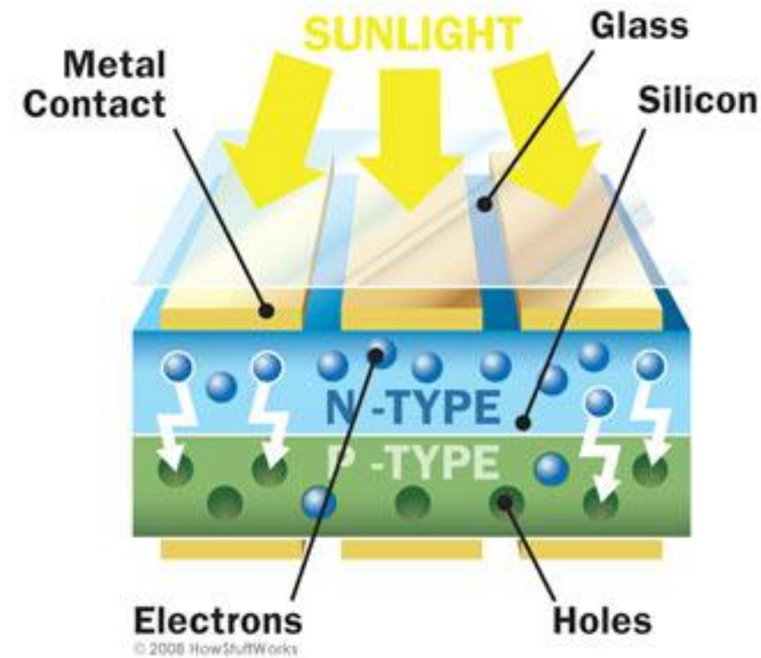

Solar Cell Wafer
top contact
AR coating
n-silicon
/4-micron
p-silicon
1/2 mm
back contact
Side View

17

P-N Junction

- The electric potential barrier between the two semiconductors of a solar cell
- Creates a low resistance path for excited electrons to flow through
- "Loose" electrons flow from the rich end to the poor one creating a direct current

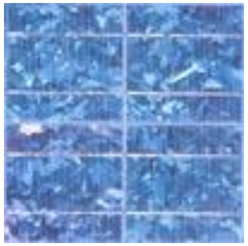
*This is called the photovoltaic effect and explains why the true name for solar cells are PV cells



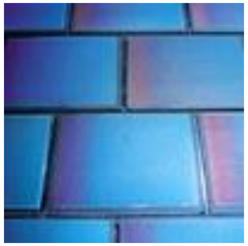
http://express.howstuffworks.com/exp-solar-power1.htm

PV Device Types

- Single-crystal silicon
  - 15+% efficient, typically
  - expensive to make (grown as big crystal)



- Poly-crystalline silicon
  - 10–12% efficient
  - cheaper to make (cast in ingots)



- Amorphous silicon (non-crystalline)
  - 4–6% efficient
  - cheapest per Watt
  - called "thin film", easily deposited on a wide range of surface types

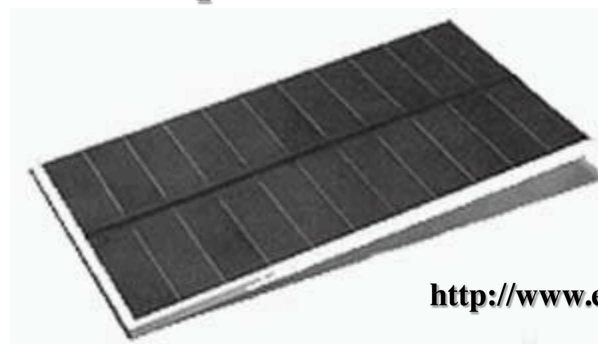
25

PV Device Types

Monocrystalline PV

http://www.arisetech.com/

Amorphous Silicon PV

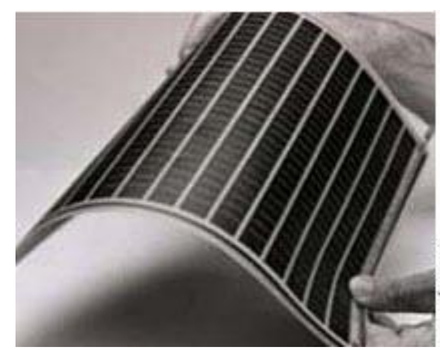


http://www.energyalternatives.ca/

Polycrystalline PV

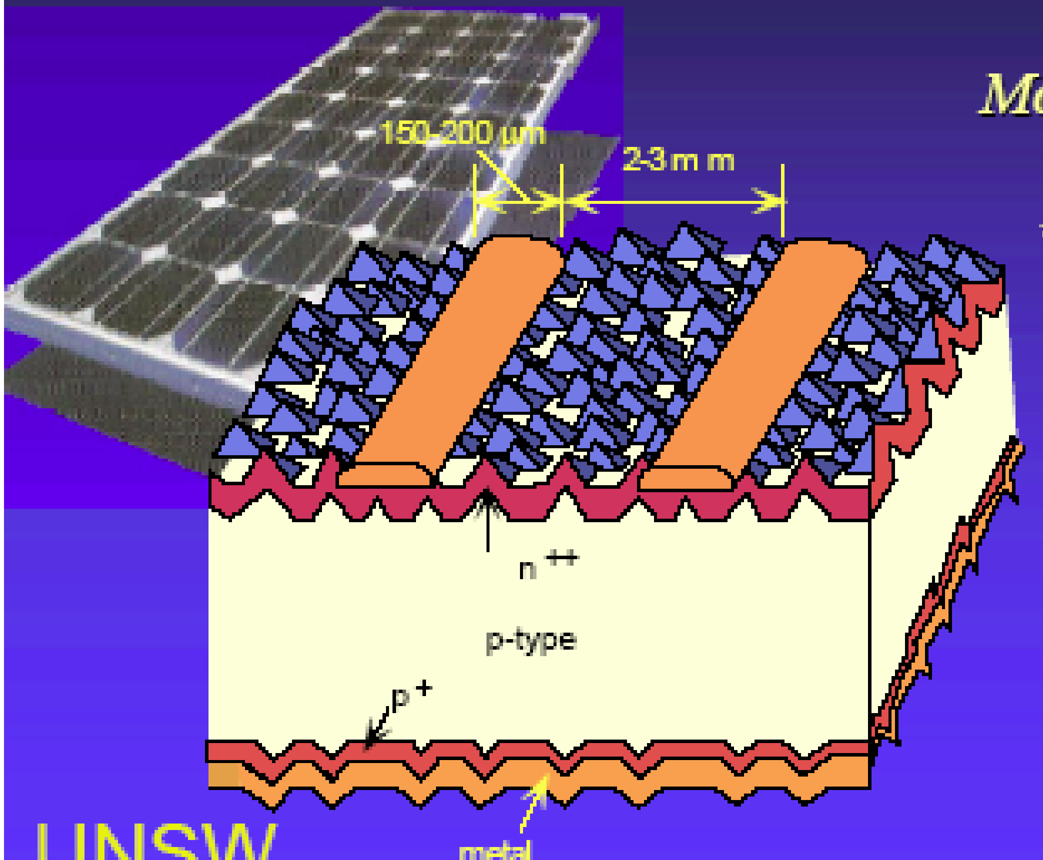
26**http://img.alibaba.com/**

CIGS Thin Film PV



http://www.cnn.com/

First generation cells



More Si than for ICs

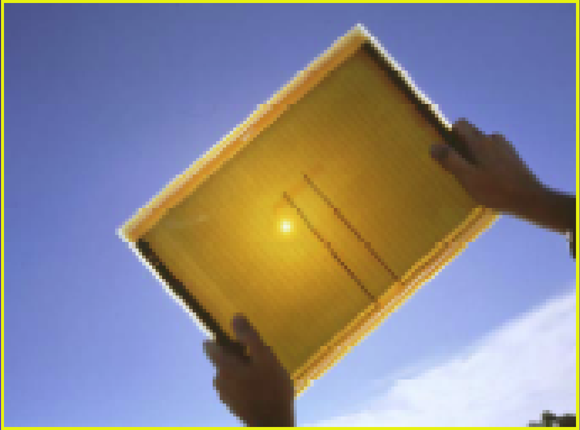
<u>Materials Issues</u>

. thinner cells

. simpler Si purification

27

Second Generation: thin-film



Advantages

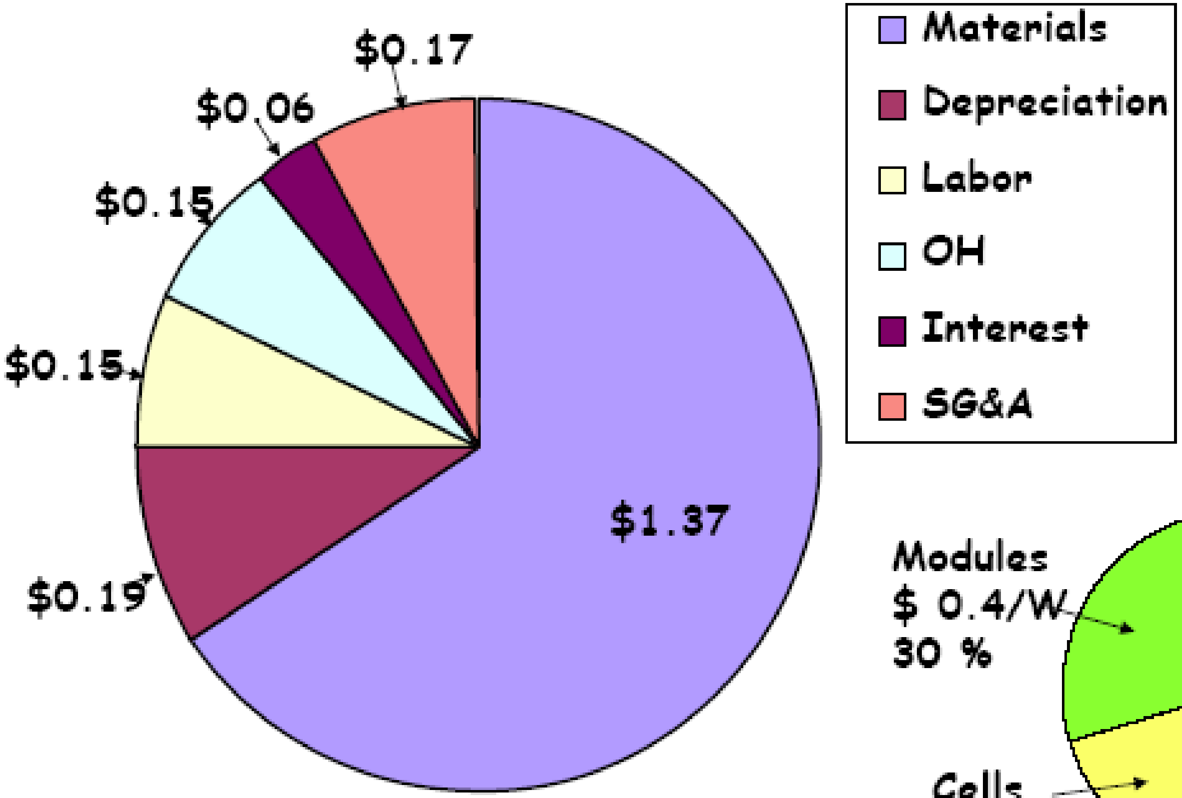
- *low materials cost*
- *large manufacturing unit*
- *fully integrated modules*
- *aesthetics, ruggedness?*

Thin-film Technologies

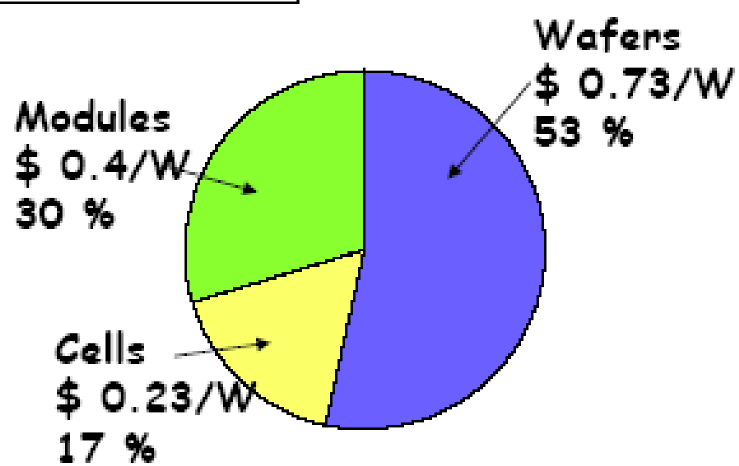
- **Silicon**
  - *amorphous*
  - *microcrystalline*
  - *polycrystalline*
- **Chalcogenide** *(polycrystalline)*
  - *CIS, CIGS [Cu (In,Ga) $(Se,S)_2$]*
  - *CdTe*
- **Dye sensitised, Organics**

UNSW

Module cost breakdown - $/W based on Multi crystalline silicon technology (30 MW factory)

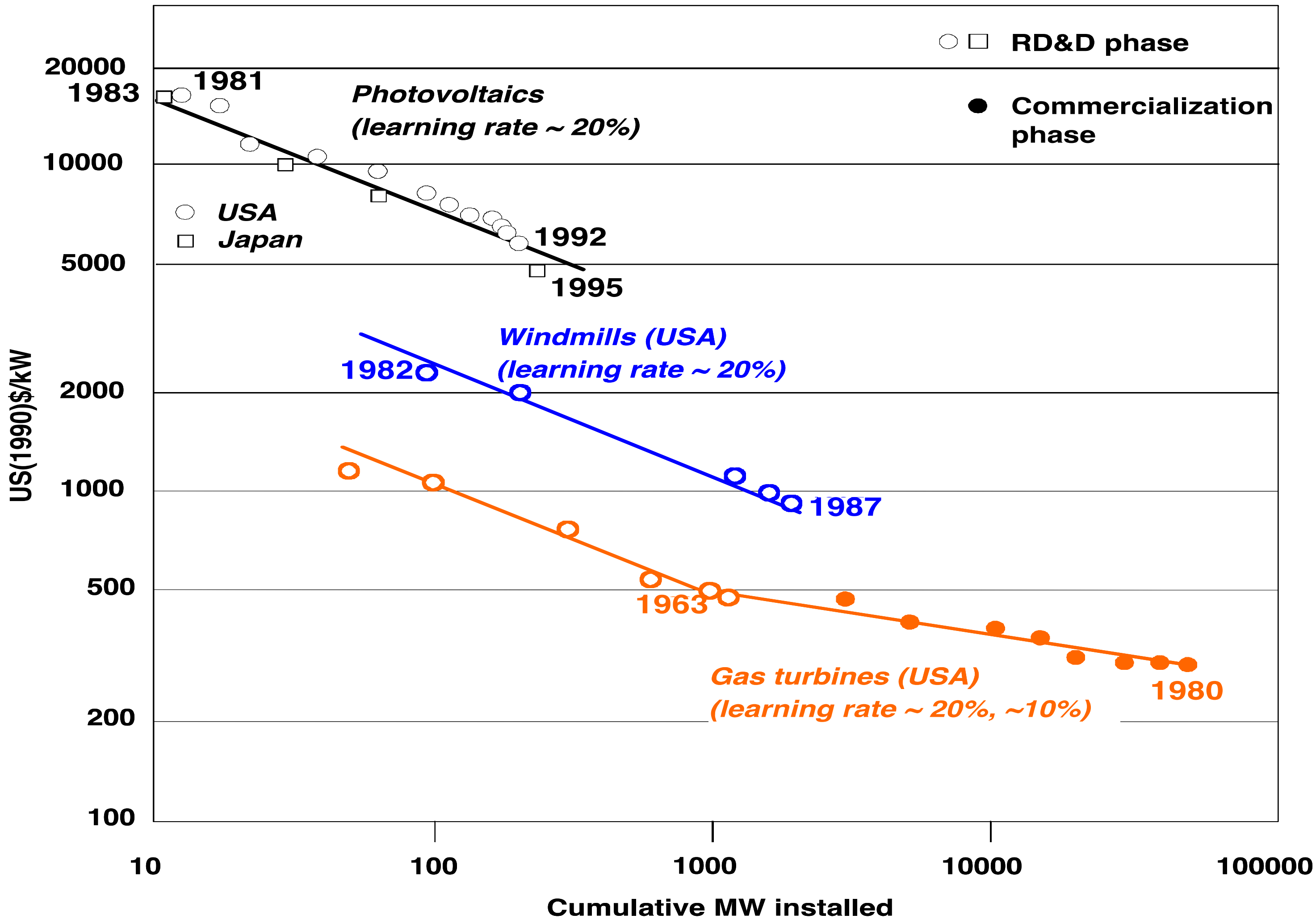


Total cost - $ 2.09/W



Materials cost breakdown

The Learning Curve … again



30

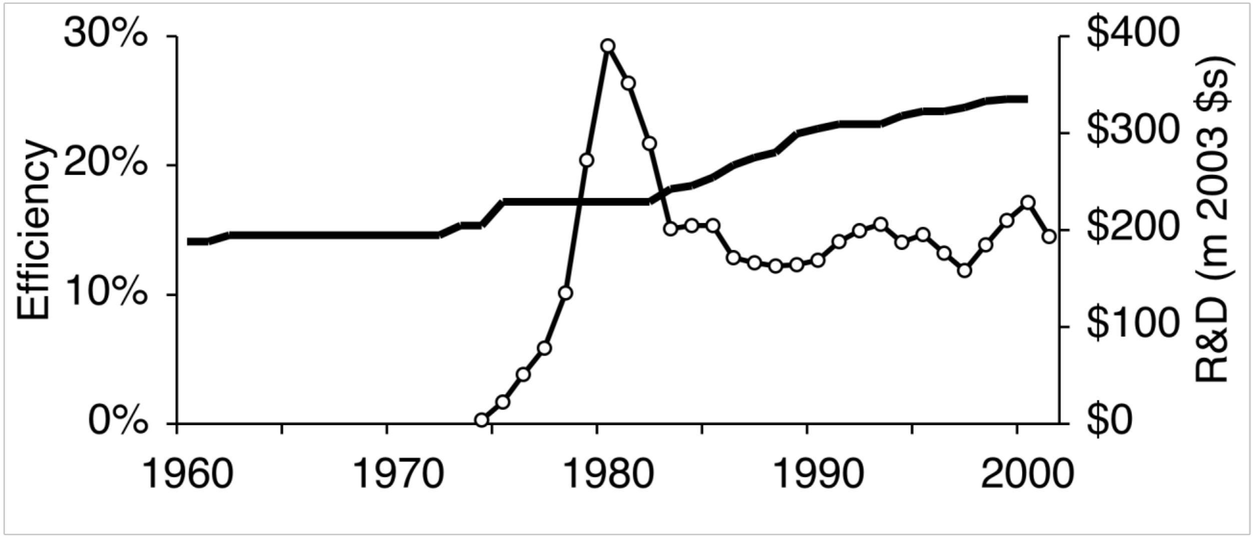
Factors Driving Past Cost Reduction

- Poly silicon price: \$300/kg → \$30/kg
- Wire sawing: now < \$0.25/W
- Larger wafers: 3” → 6”
- Thinner wafers: 15 mil → 10 mil
- Improved efficiency: 10% → 16%
- Volume manufacturing: 1MW → 1000MW
- Increased automation: none → some
- Improved manufacturing processes

31

Quantifying the benefits of R&D

R&D Funding → Technological change → (



50% increase in PV efficiency occurs immediately after unprecedented >$1b global investment in PV R&D (1978-85)…

33

Nemet, G. F. (2006) *Energy Policy* **34(17)**: 3218 - 3232.

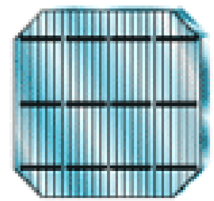
Si-based PV Production: From Sand to Systems

Module Fab

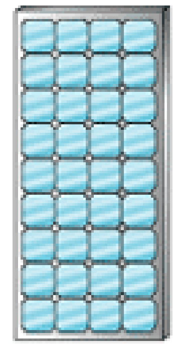
Raw Materials

Si Feedstock

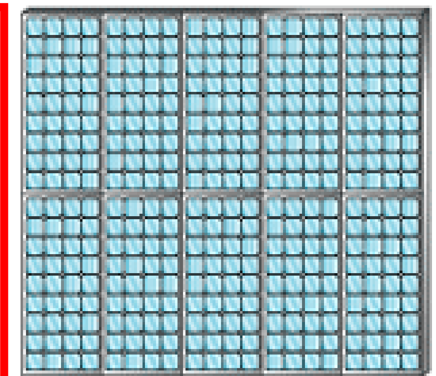
Wafer



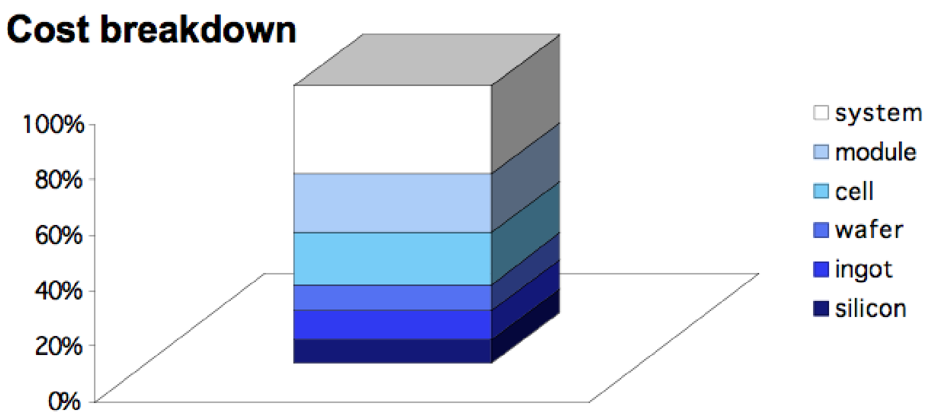
Cell



Module

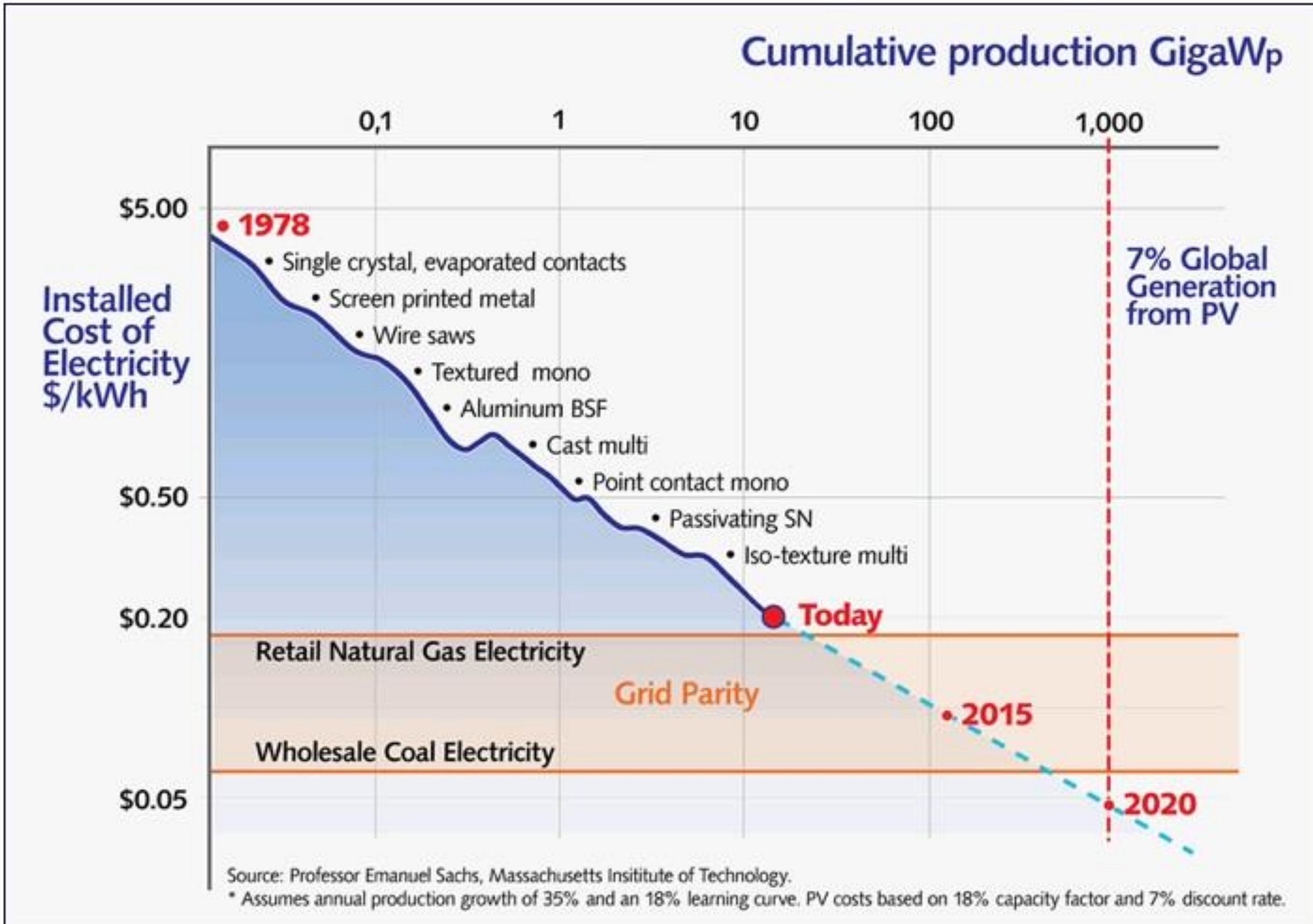


System



Source: H. Aulich, PV Crystalox Solar, 2007

Solar cost decreases 10% per year



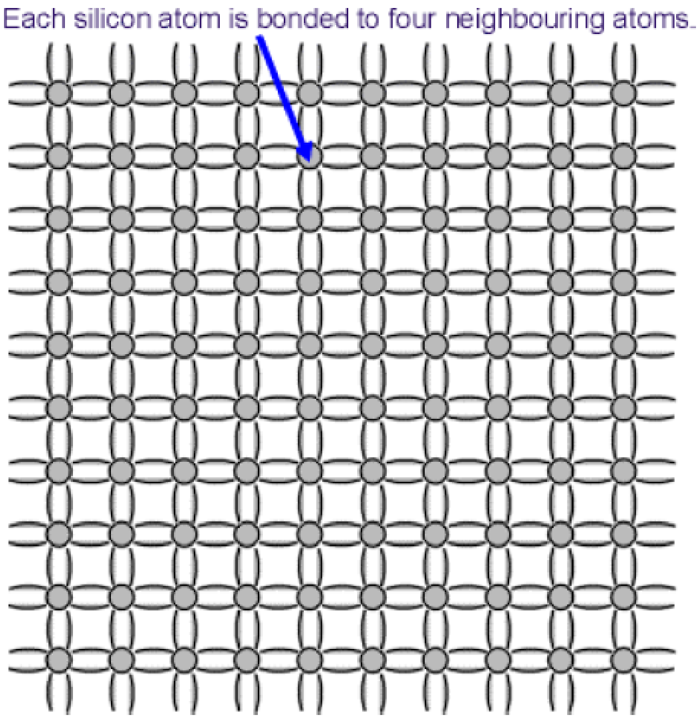
Source: Professor Emanuel Sachs, Massachusetts Insititute of Technology.

*Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 18% capacity factor and 7% discount rate.

Crystalline silicon

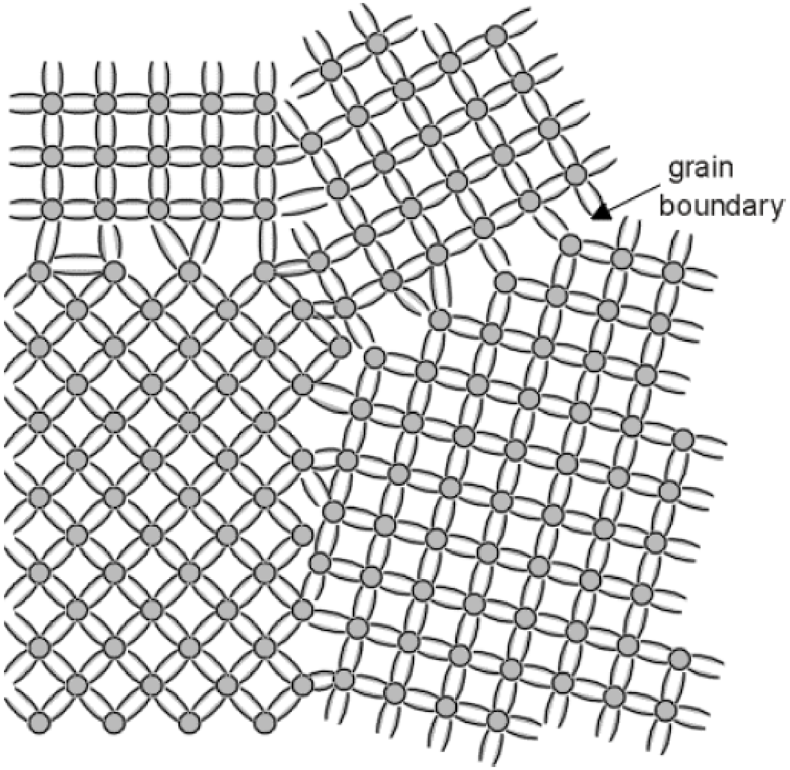
Single crystalline silicon

FZ, CZ



Multicrystalline silicon

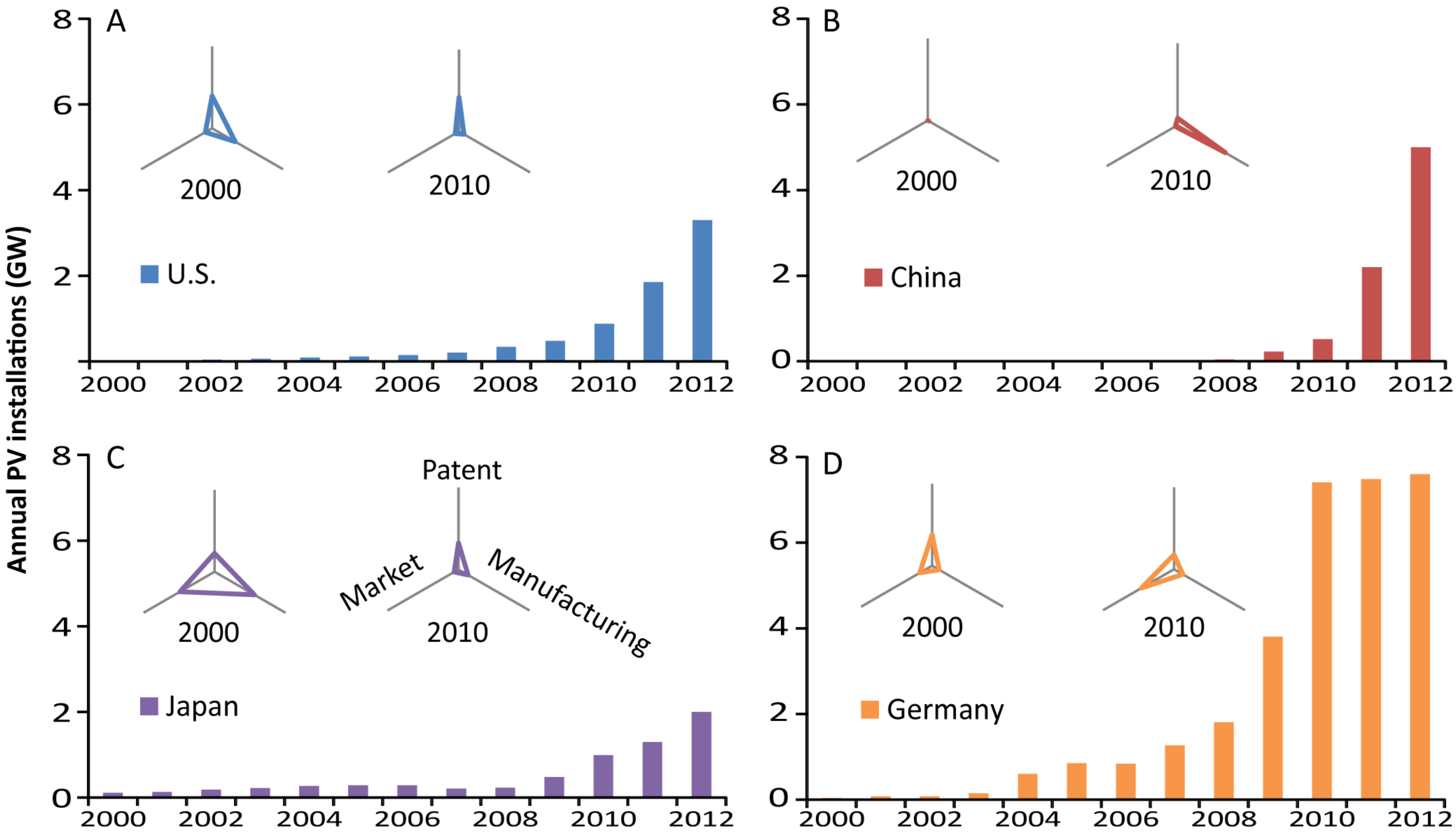
Cast, ribbon, sheet techniques



The grain size in multicrystalline silicon is from several microns to several millimeters or even centimeters. The fundamental physical properties such as bandgap and absorption properties are similar. The difference between c-Si and mc-Si is primarily the density of defects and impurities – and **cost, cost, cost**.

Slide from A.A. Istratov, Siltronic

The Evolving Solar Energy Economy



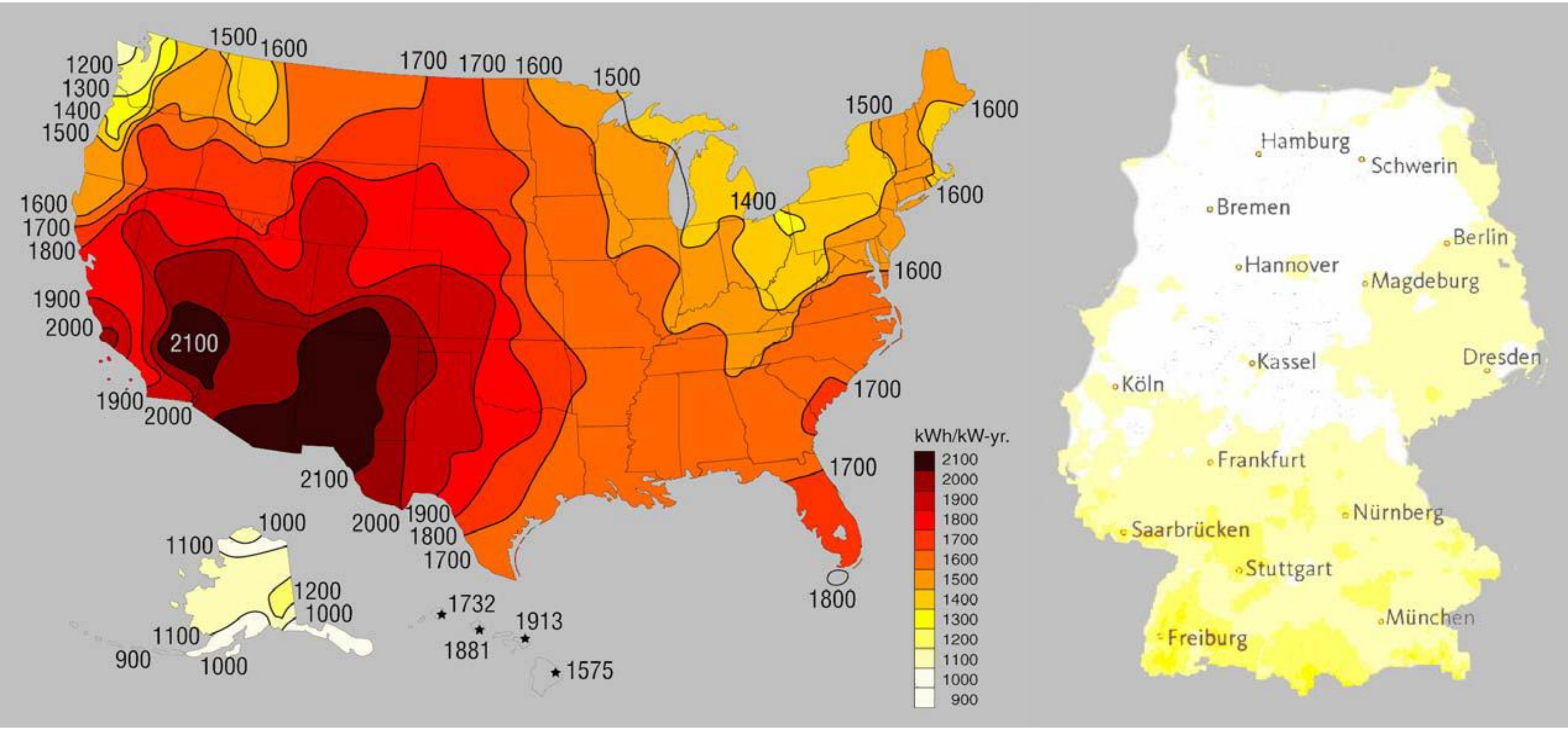
The New York Times

China Racing Ahead of U.S. in the Drive to Go Solar

By KEITH BRADSHER

Published: August 24, 2009

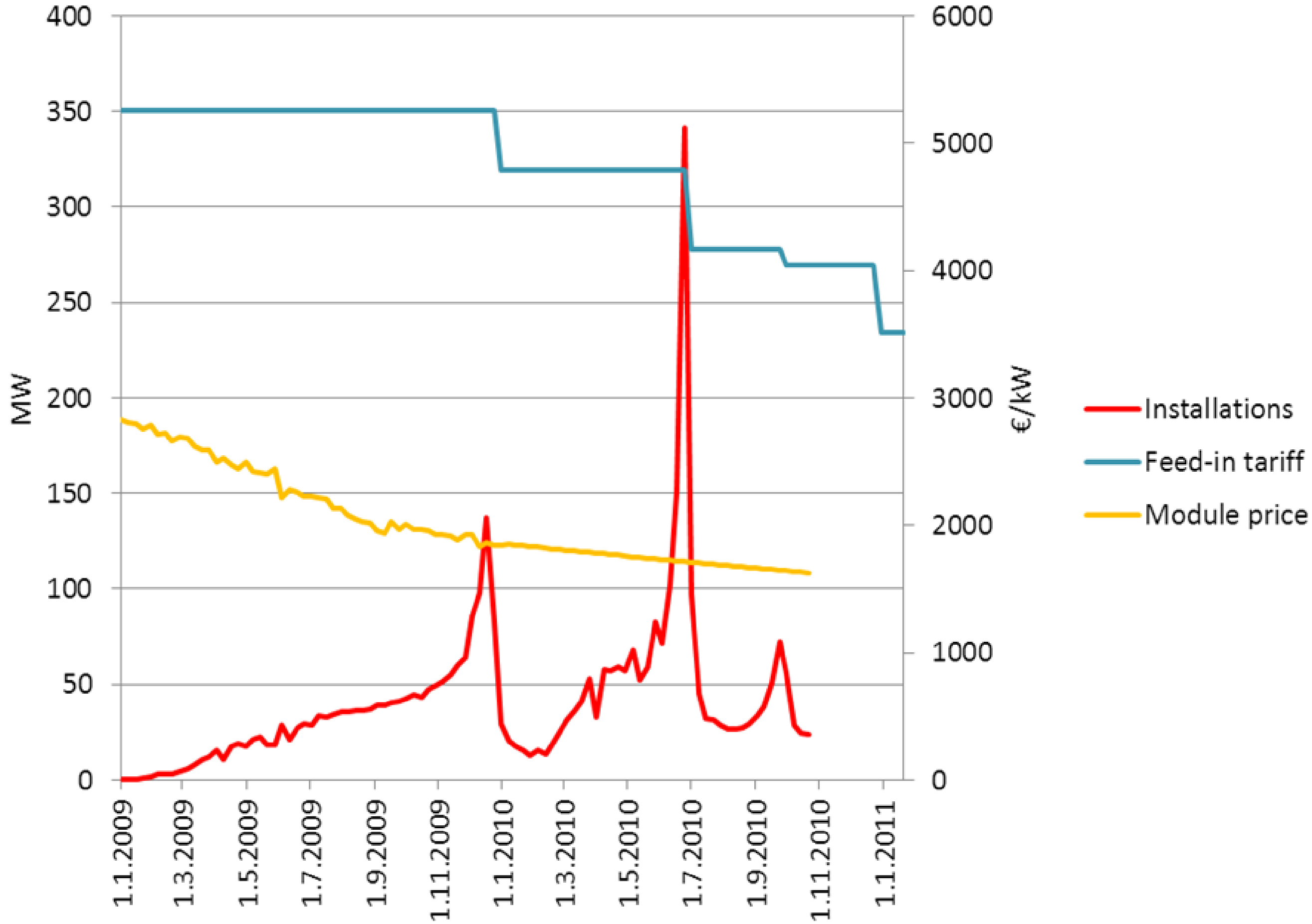
US has twice the German solar insolation resource



German FIT

Strong demand in periods before the feed-in tariff was reduced

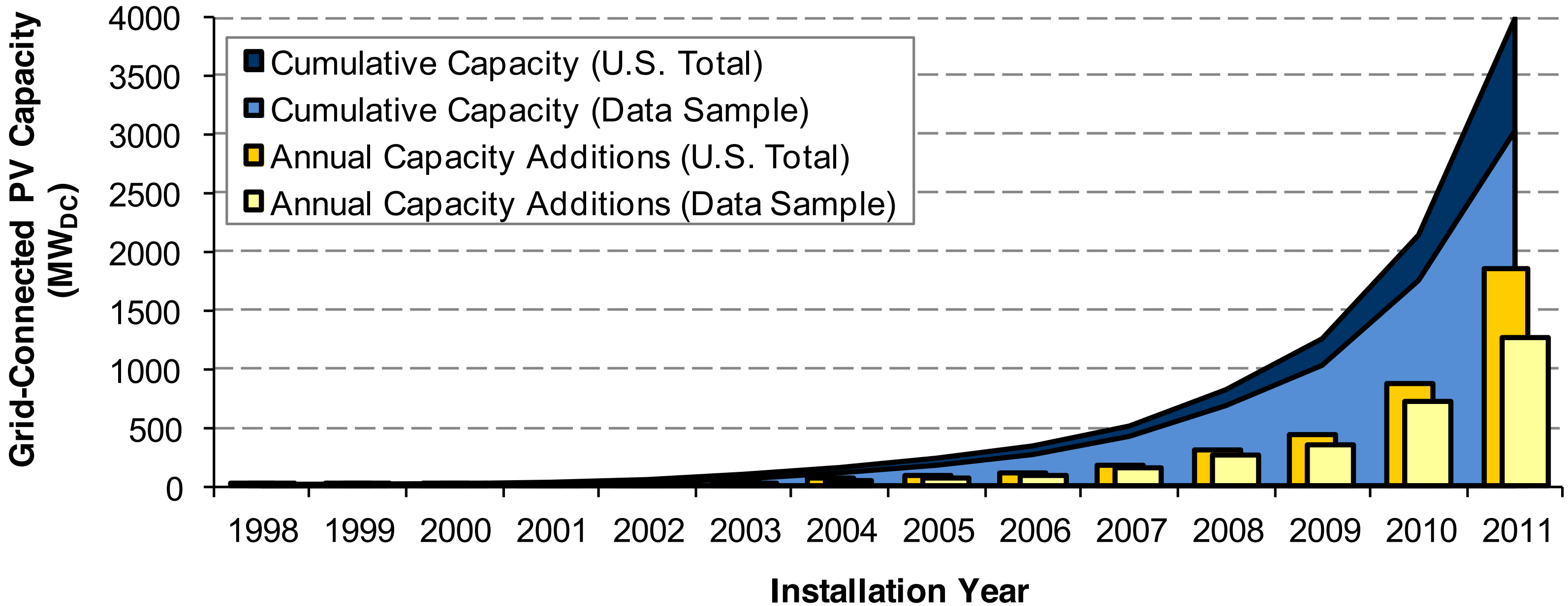
PV feed-in tariff for modules ≤ 30 kW, module prices and weekly installations for systems ≤ 30 kW



Modules ≤ 30 kW have accounted for 44% and 38% of total installations in 2009 and 2010 respectively

The Sample Represents a Large Fraction of All U.S. PV Capacity through 2011

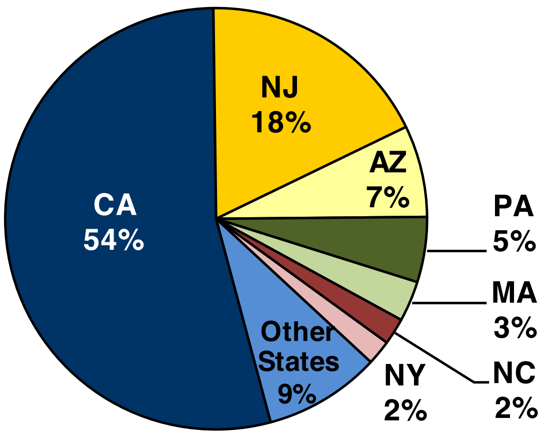
- DoE federal data, after all data cleaning was completed, consists of 152,311 PV systems totaling 3,022 MW, including 2,224 MW of residential and commercial PV and 798 MW of utility-scale PV
- The sample represents approximately 76% of cumulative grid-connected PV capacity installed in the United States through 2011, and 69% of annual capacity additions in 2011



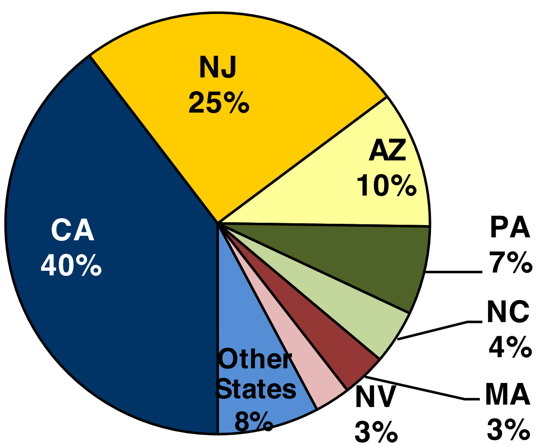
Data source for U.S. grid-connected PV capacity additions: Larry Sherwood (Interstate Renewable Energy Council)

Residential & Commercial PV Data Sample: Distribution Across States and by System Size

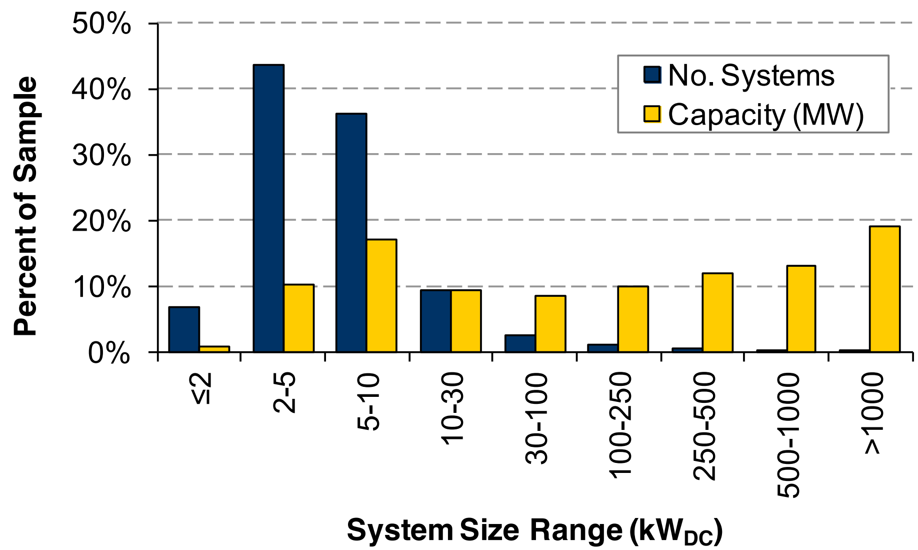
Distribution of Capacity Across States (1998-2011)



Distribution of Capacity Across States (2011)



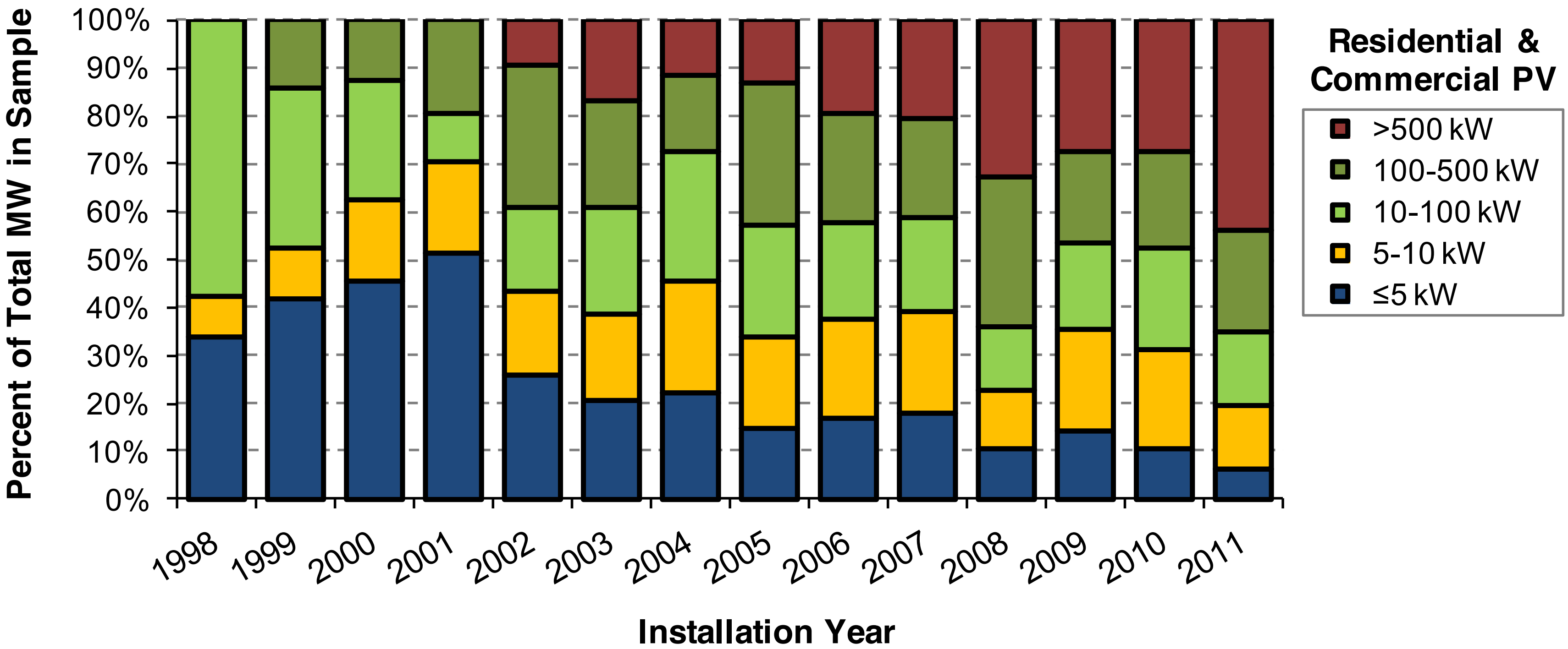
Sample Distribution by System Size



- CA represents the majority of cumulative installed capacity in the data sample, though 2011 capacity additions are more evenly distributed across states
- The vast majority of systems are relatively small (<10 kW), though the sample capacity is evenly distributed across system sizes

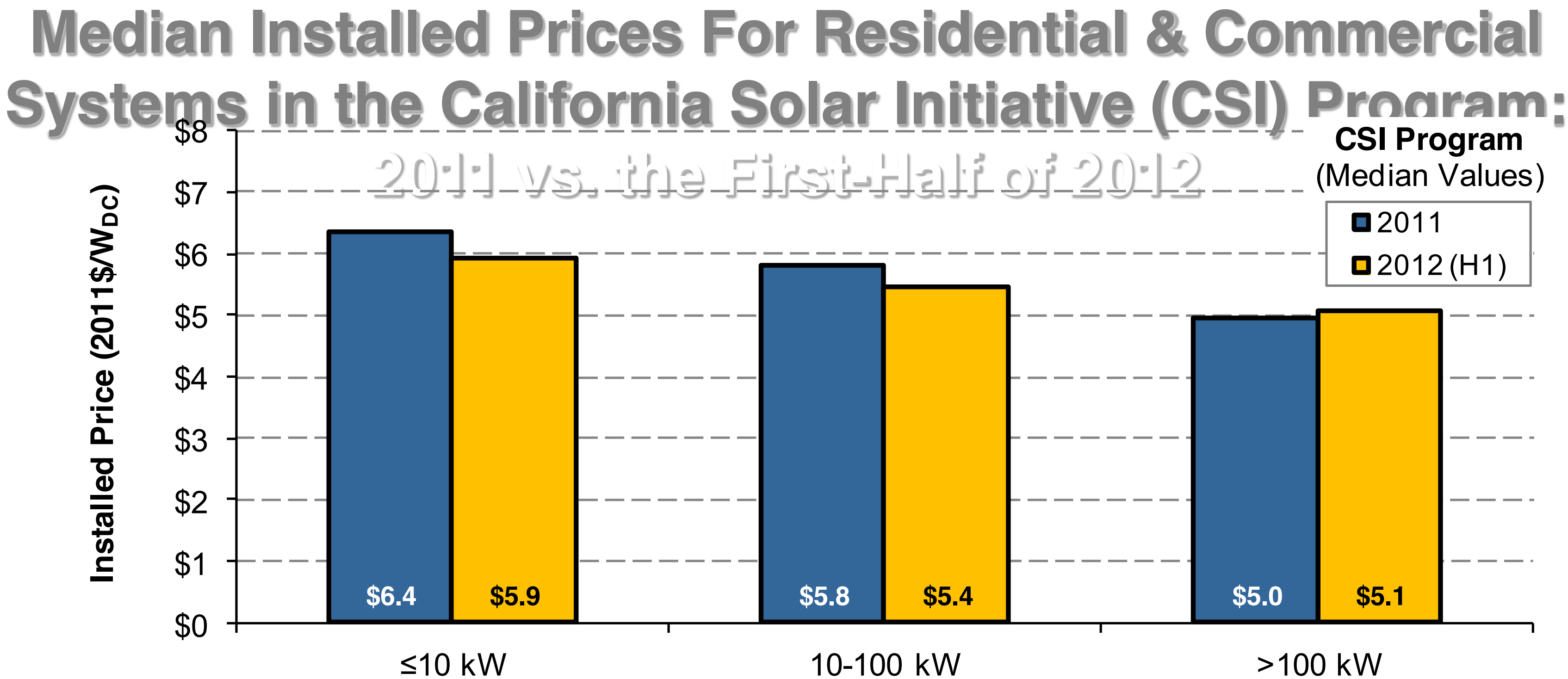
US: Residential & Commercial PV Data Sample: System Size Trend over Time

Over time, an increasing portion of residential and commercial PV capacity has consisted of relatively large systems



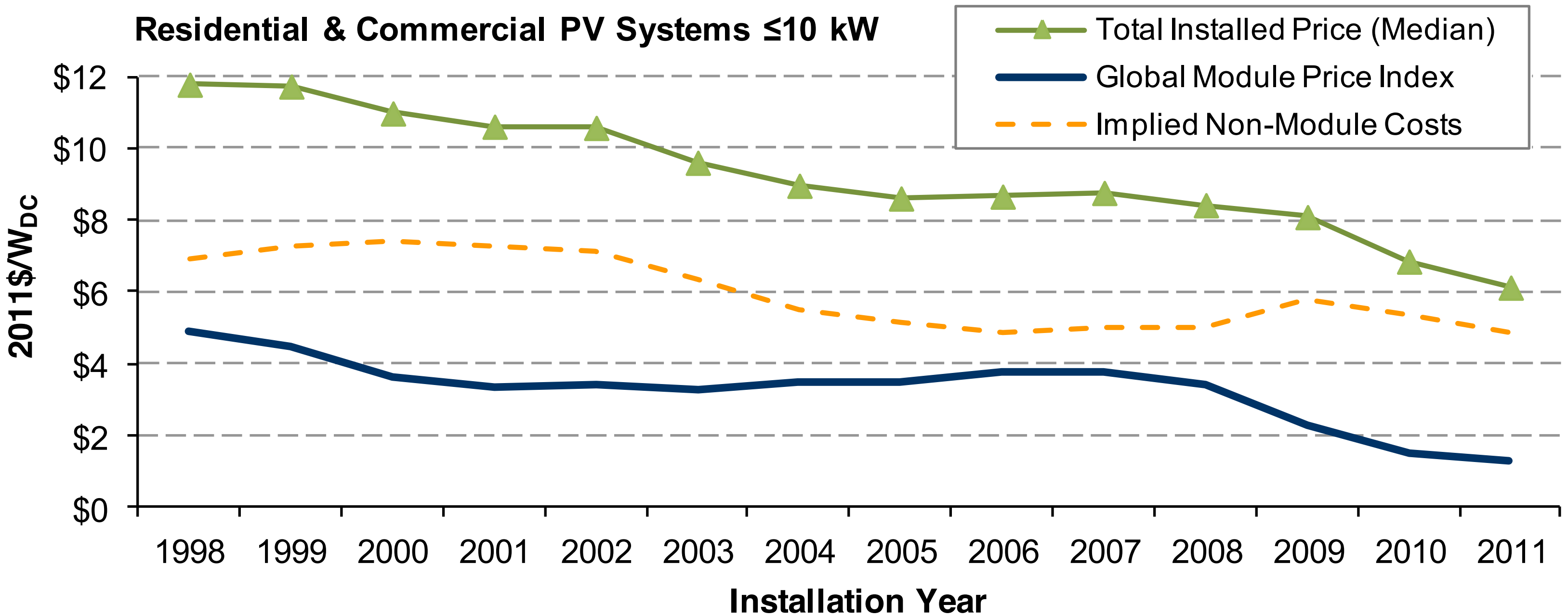
Data for California Show That Installed Prices Continued to Fall into 2012

Median installed prices for ≤10 kW and 10-100 kW systems fell by roughly $0.4/W (6-7%) in the CSI program during the first half of 2012, relative to 2011 (the slight increase for >100 kW systems is due to shift towards smaller systems within that size range from 2011 to H1 2012)



Recent Installed Price Declines Primarily Reflect Falling Module Prices

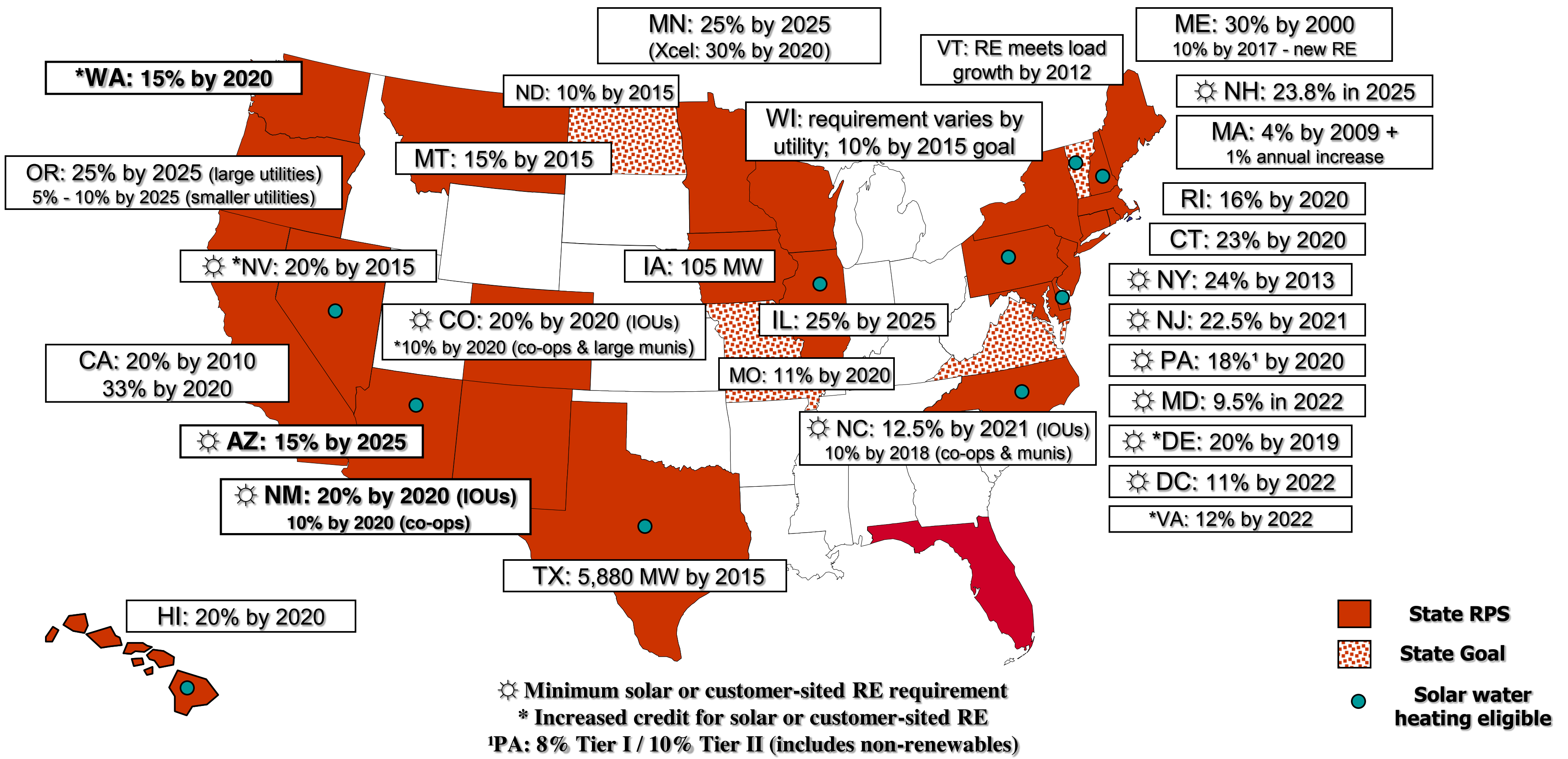
Global average module prices began a steep decline in 2008, falling by **$2.1/W** from 2008-2011, with movements in total installed price appearing to lag behind; implied non-module costs have fallen by **$2.0/W** since 1998, but have remained relatively flat in recent years



Notes: The Global Module Price Index is Navigant Consulting's module price index for large-quantity buyers (Mints, 2012). "Implied Non-Module Costs" are simply a residual term, equal to the Total Installed Price minus the Global Module Price Index.

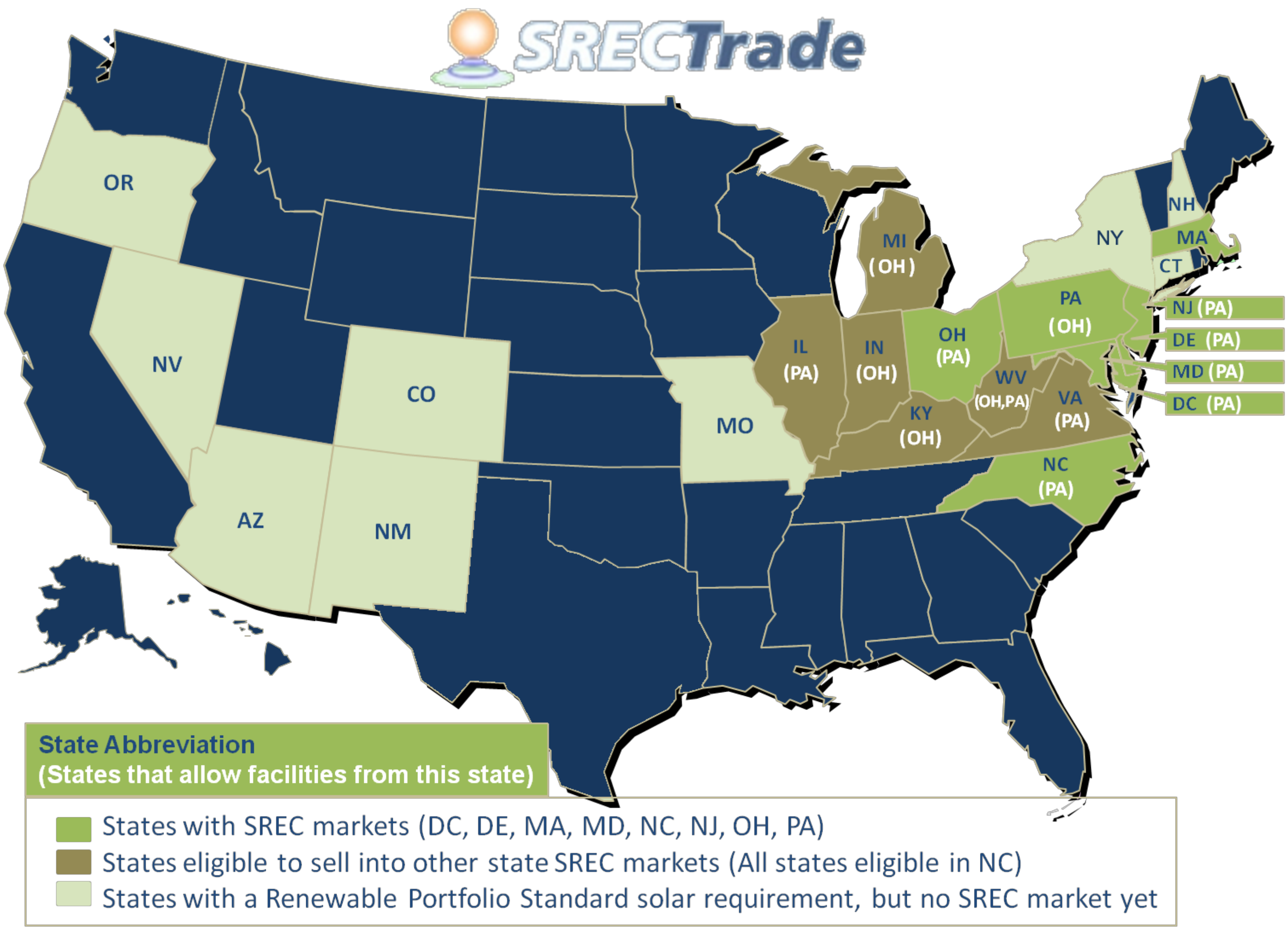
Renewable Energy Portfolio Standards

(30 states + Washington, DC)



March 2012

SREC Markets (2012)



SREC Markets (2012)

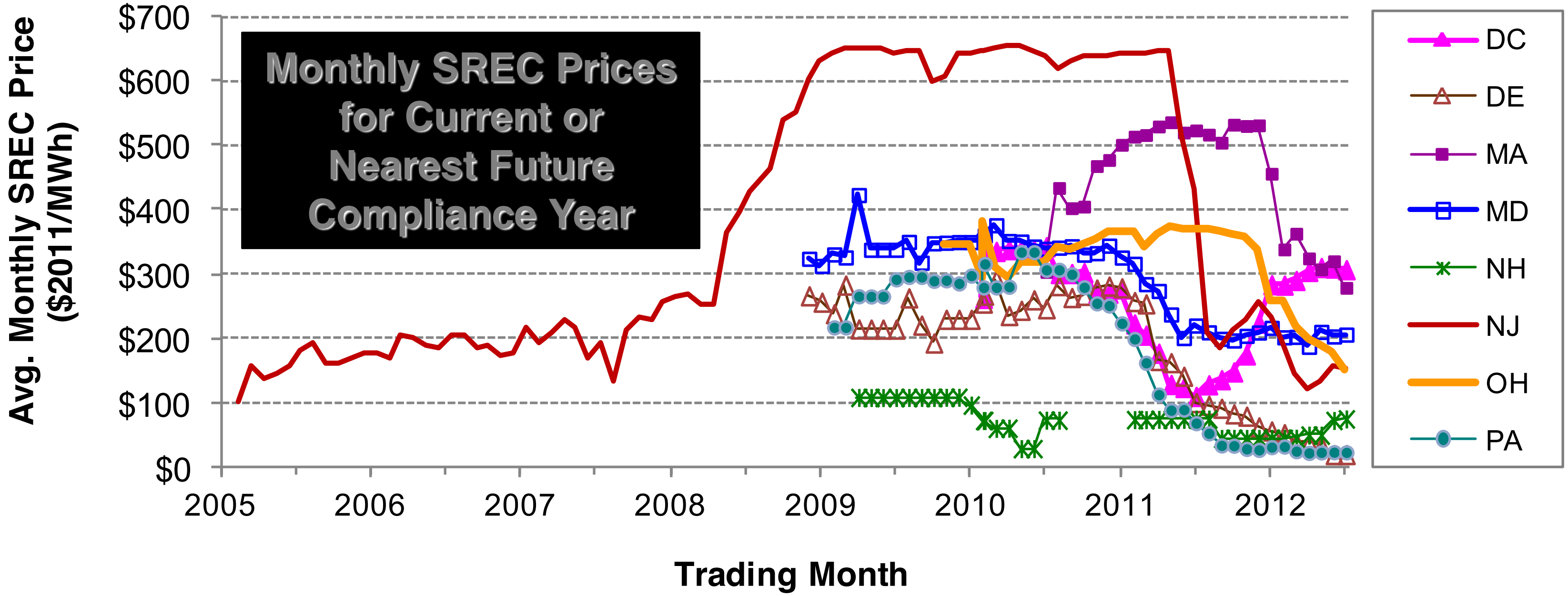
1 SREC 1,000 kWh of solar electricity = 1 MWh of solar electricity
Recall: 1 kWh/m^2 yields an average of 4 kWh/m^2/day x 365 days/yr = 1460 kWh/m^2/yr

So 10 kW solar capacity = ~14 SRECs per year

The SREC is sold separately and represents the "solar" aspect of the electricity. The value of an SREC is determined by the market subject to supply and demand constraints. SRECs can be sold to electricity suppliers needing to meet their solar RPS requirement. The market is typically capped by a fine or solar alternative compliance payment (SACP) paid by any electricity suppliers for every SREC they fall short of the requirement. The sale of SRECs is intended to promote the growth of distributed solar by shortening the time it takes to earn a return on the investment.

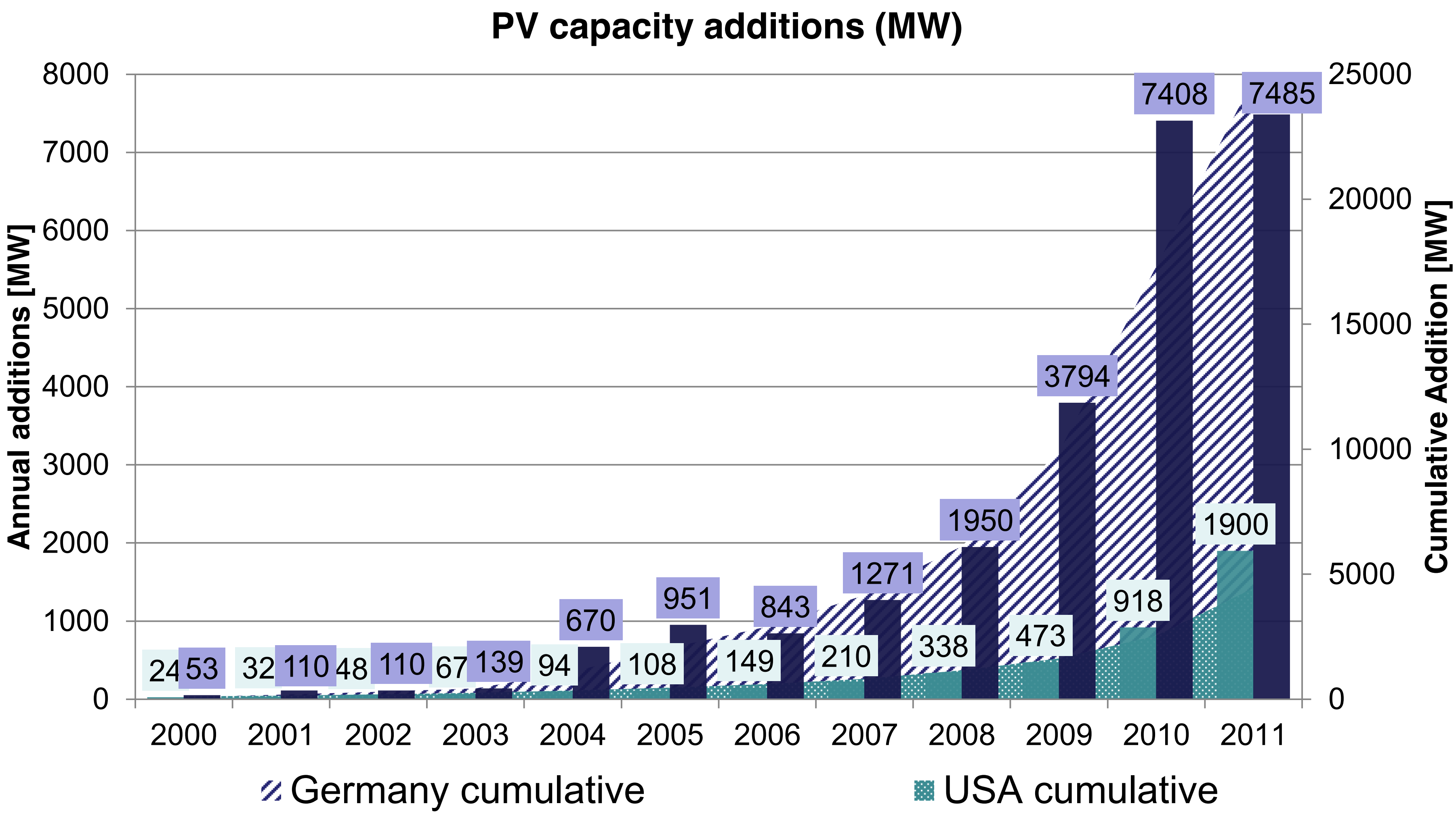
SREC Prices in Many Markets Have Also Declined Significantly

Solar renewable energy certificate (SREC) prices fell precipitously in most markets during 2011 and into 2012 as a result of oversupply in states with RPS solar set-asides, with spot prices and long-term contract prices in several major markets dropping to $100-$200/MWh (or lower)

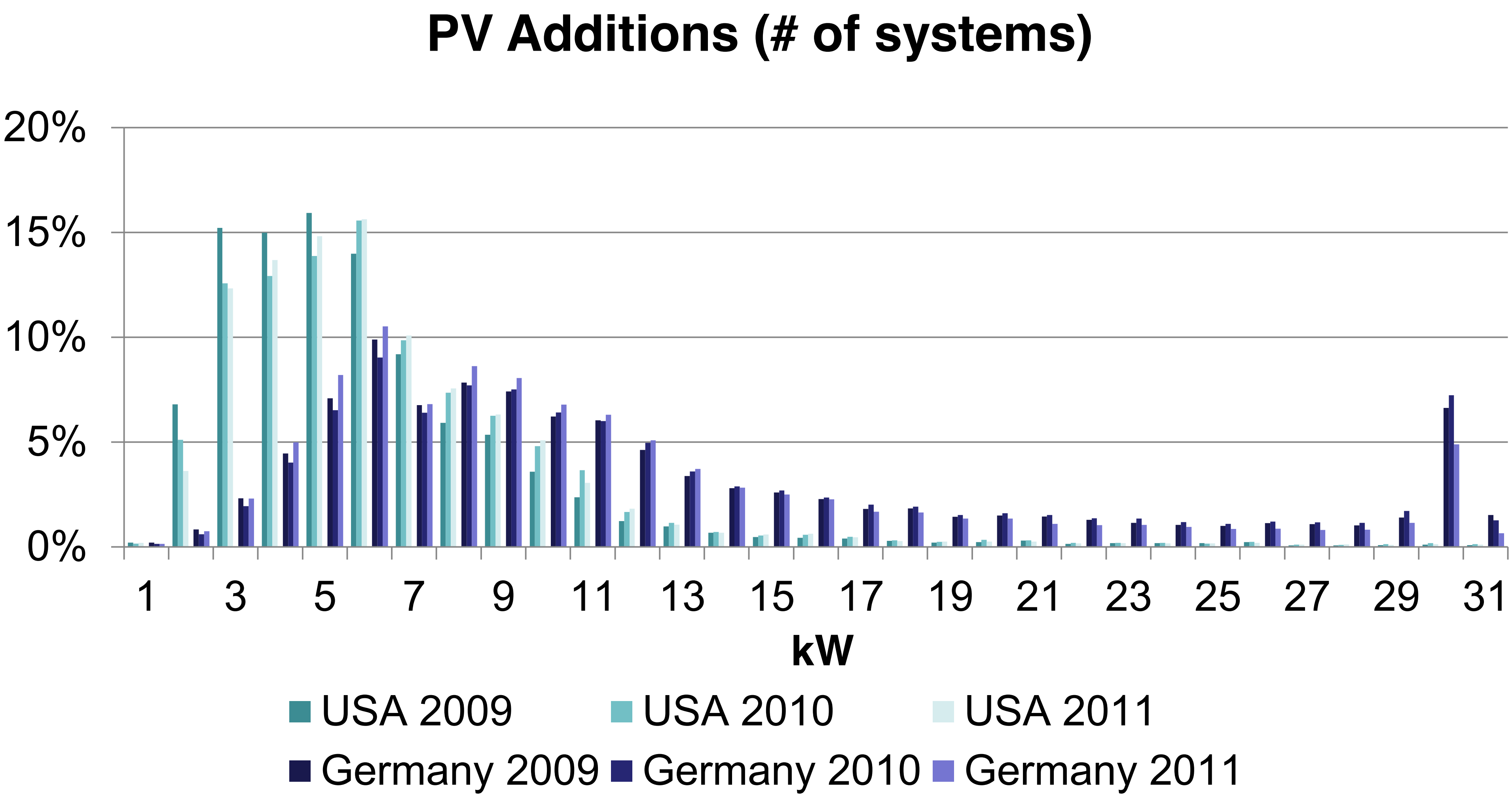


Sources: Spectron, SRECTrade, and Flett Exchange (data averaged across available sources). Plotted values represent SREC prices for the current or nearest future compliance year traded in each month. Long-term contract prices, if available, may be either higher or lower than contemporaneous spot-market prices, depending on the particular state.

German total additions more than 5x US
Germany's 2011 additions nearly 4x US market

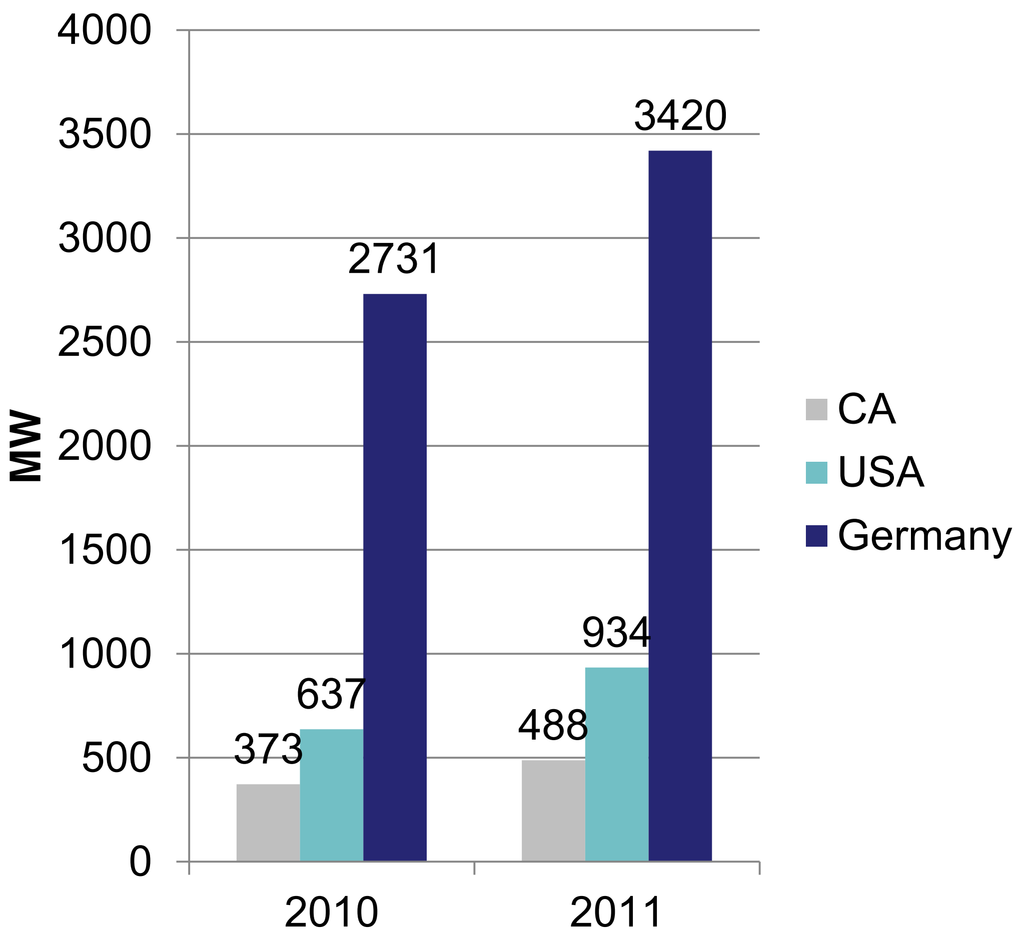


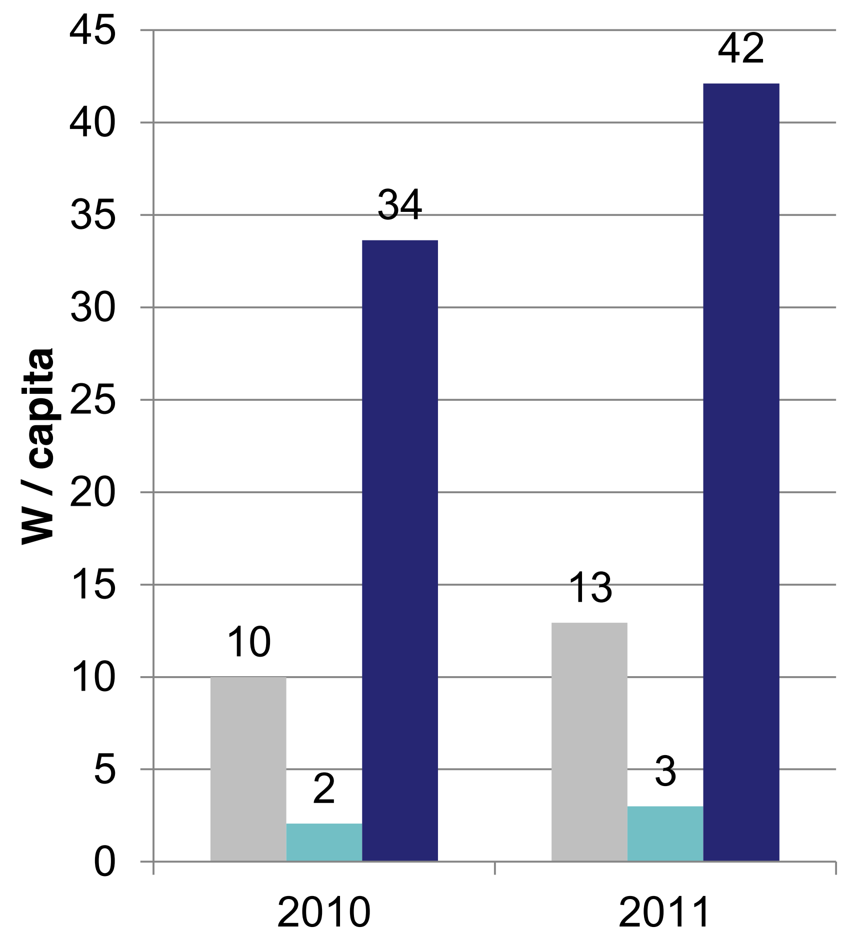
German residential market less defined than US residential market



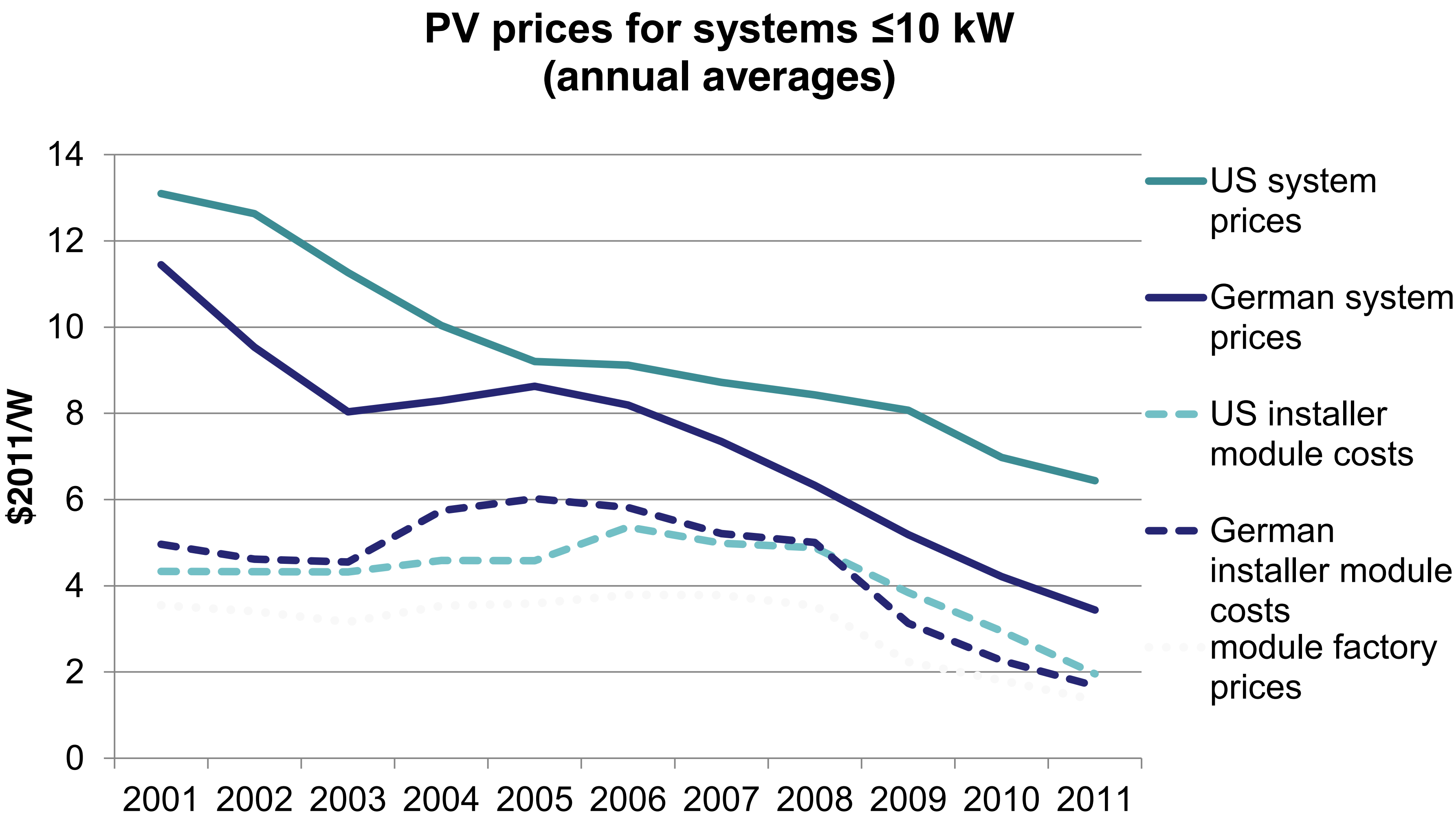
German cumulative installations 3.6x US
German cumulative installations/capita 14x US

Cumulative residential PV installations

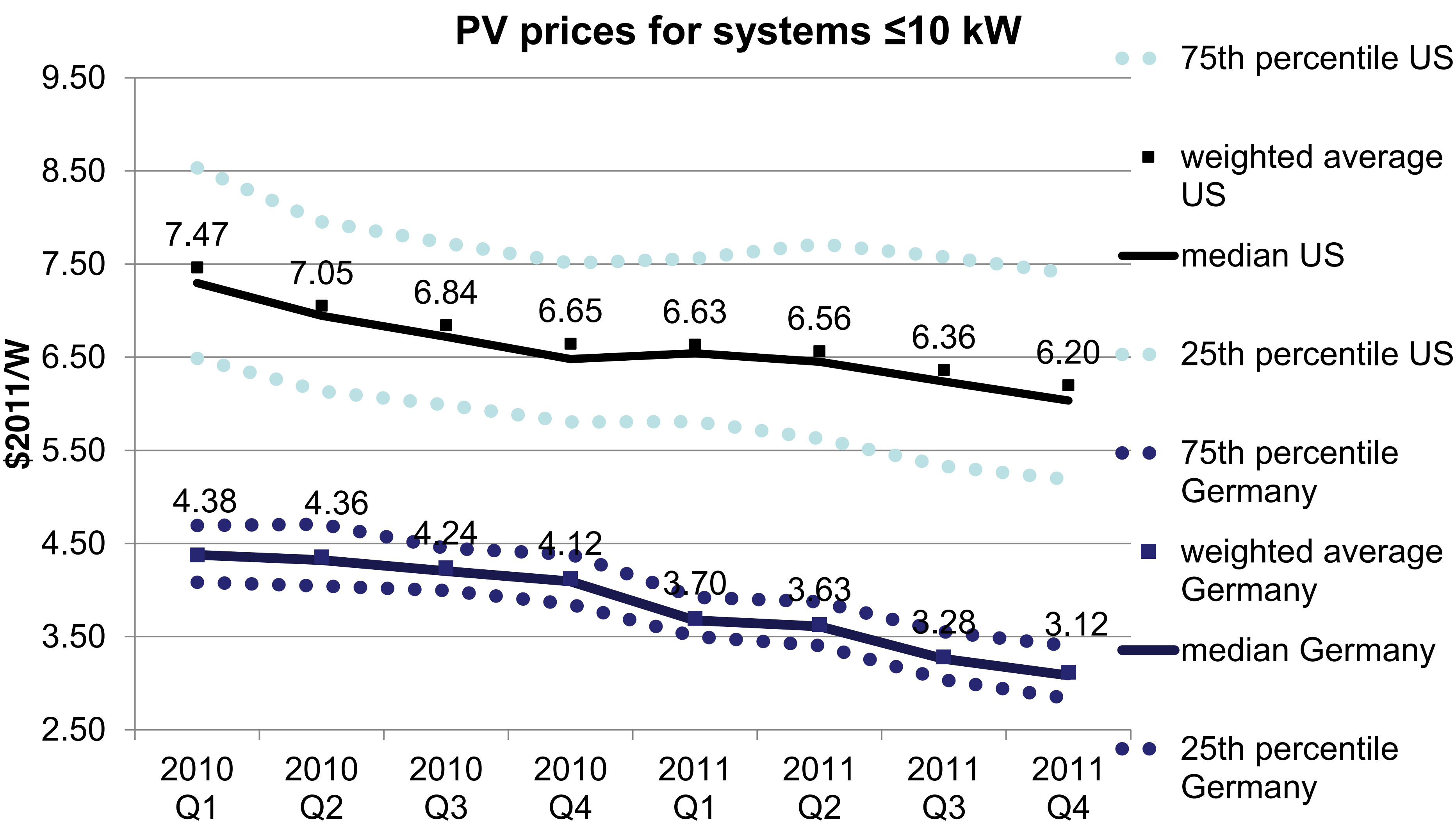




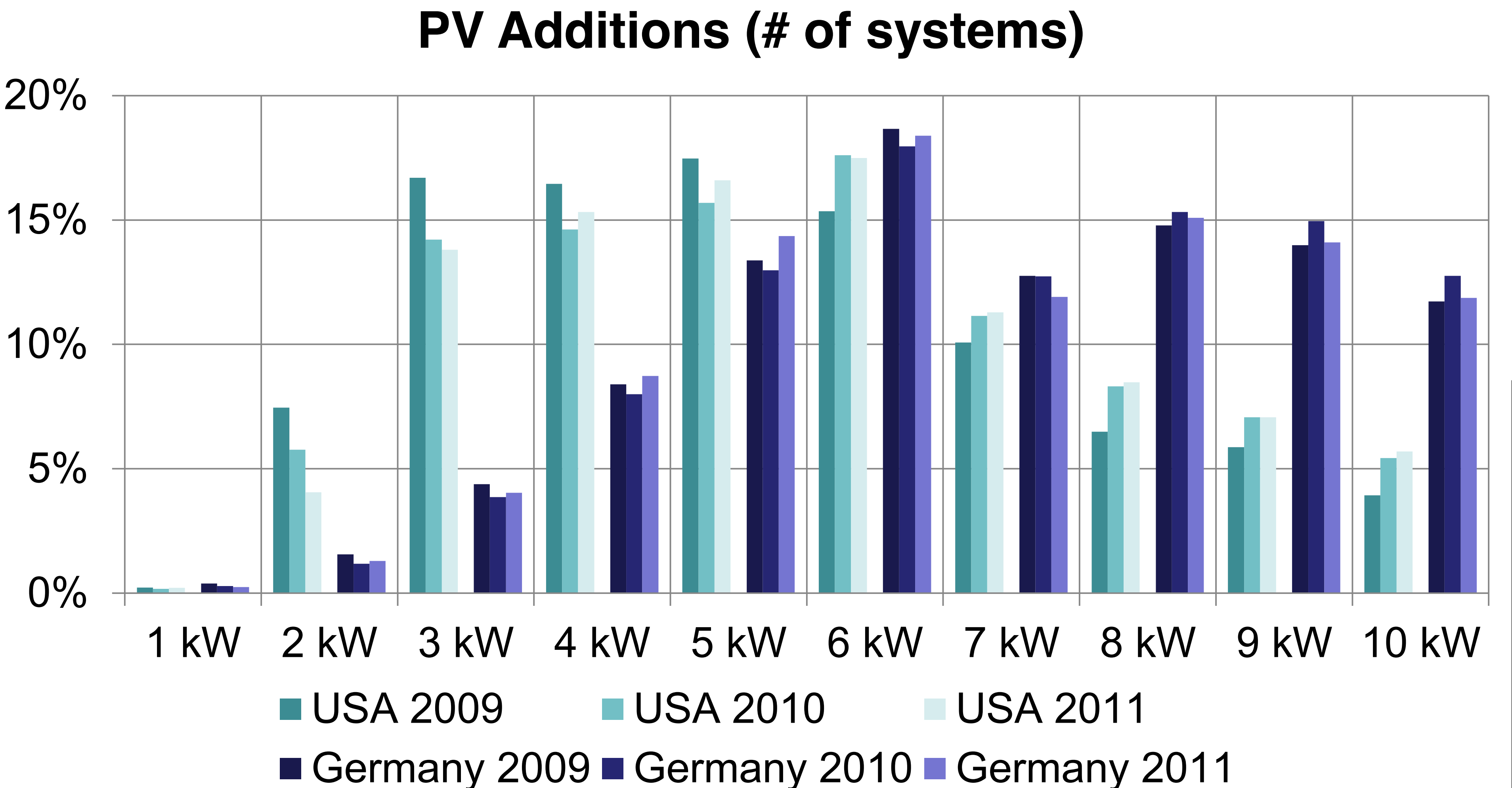
Price discrepancy growing since 2005



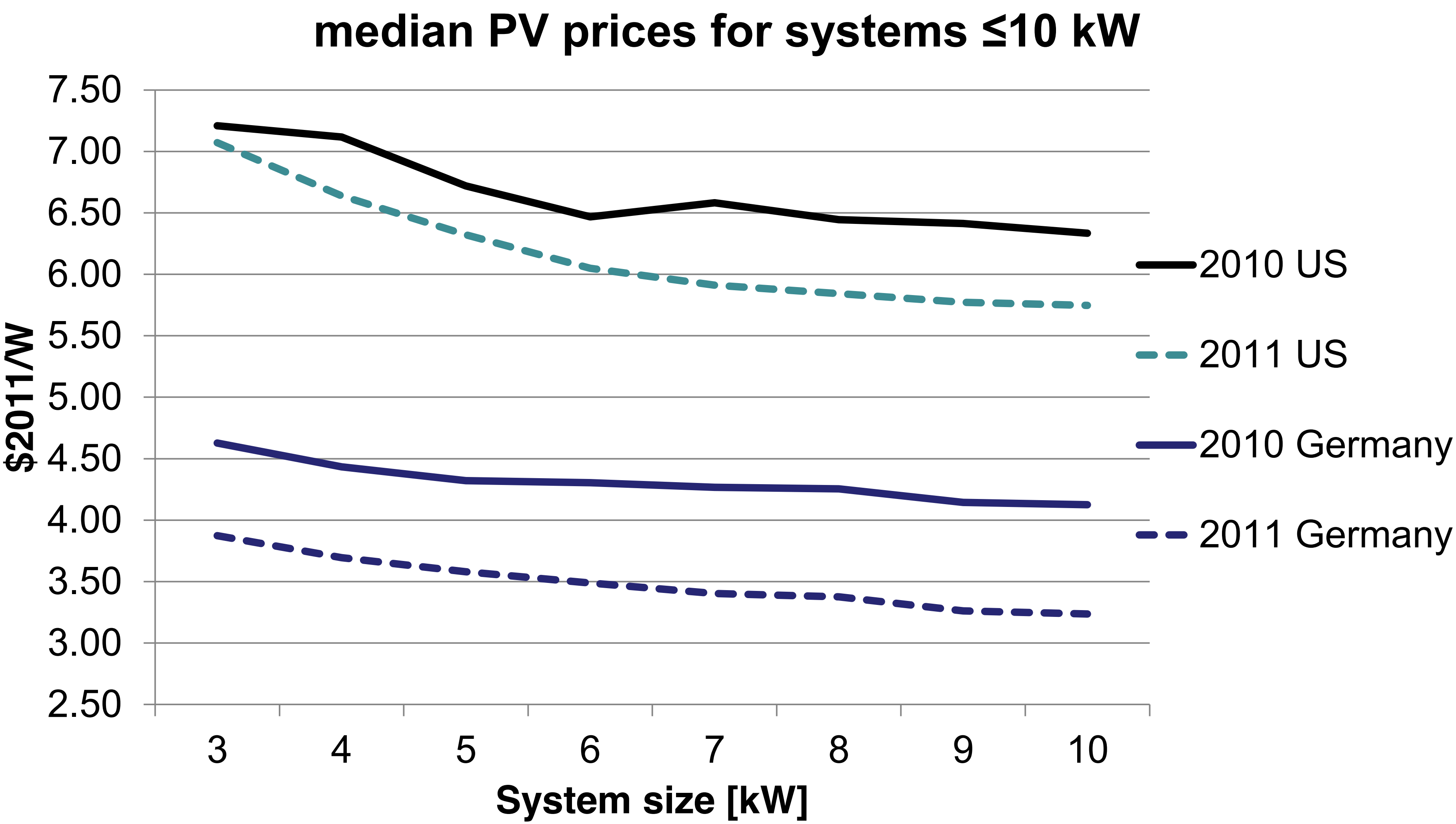
US vs. Germany: Prices drop in both markets by $1.3, but maintain their difference



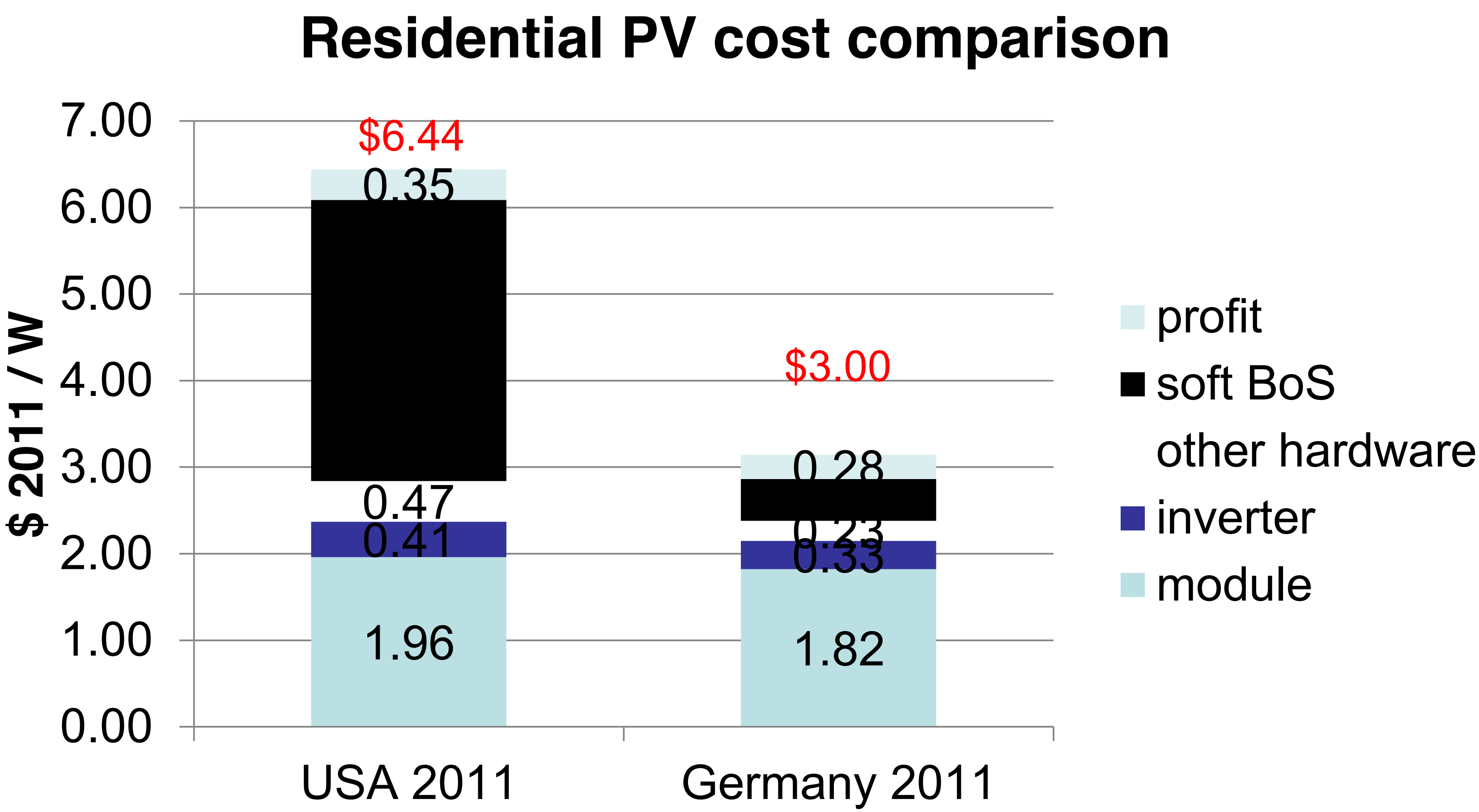
German residential systems are on average 1-2kW larger than US systems



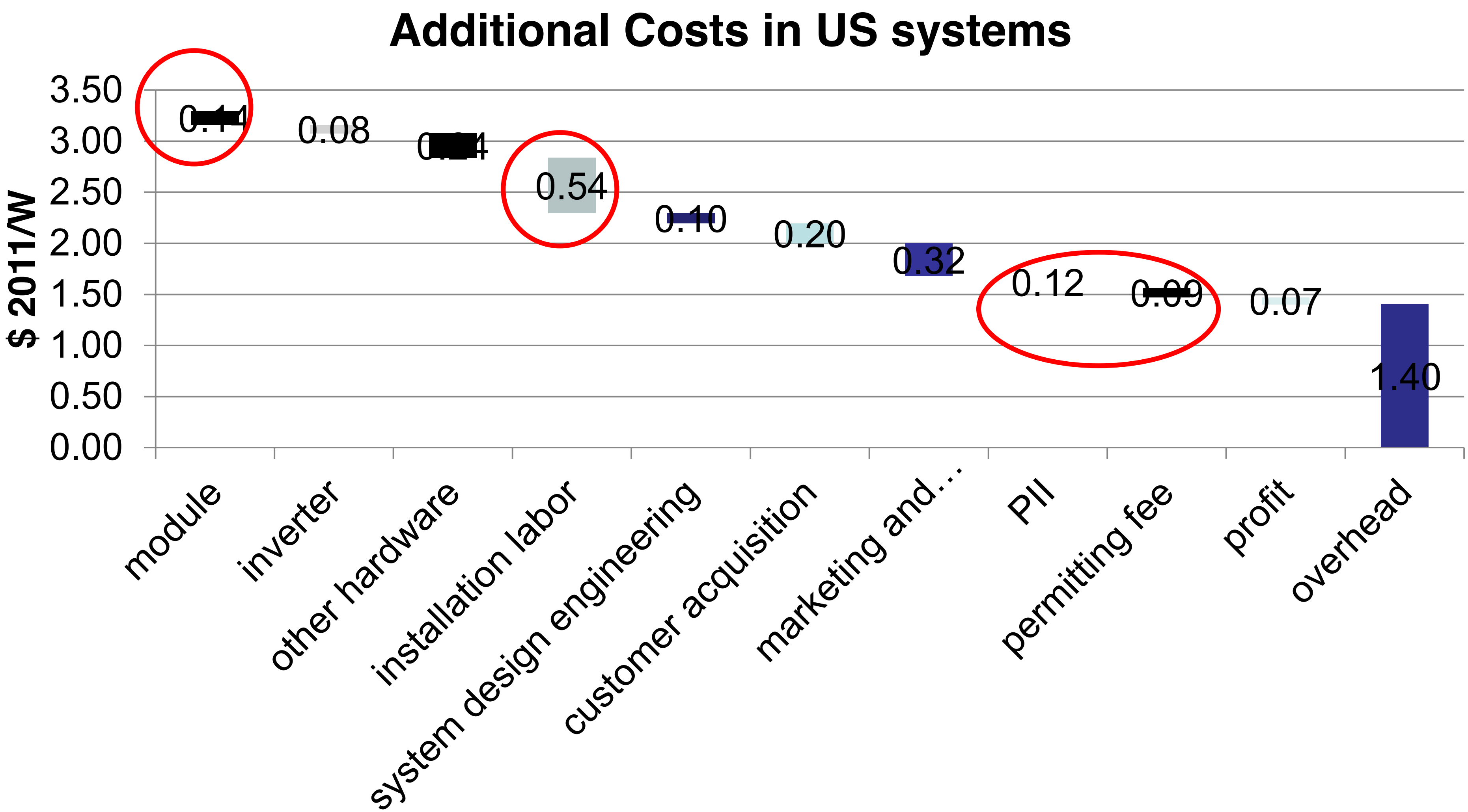
Shift of average size from 5 to 7kW would reduce US prices by $ .4/W



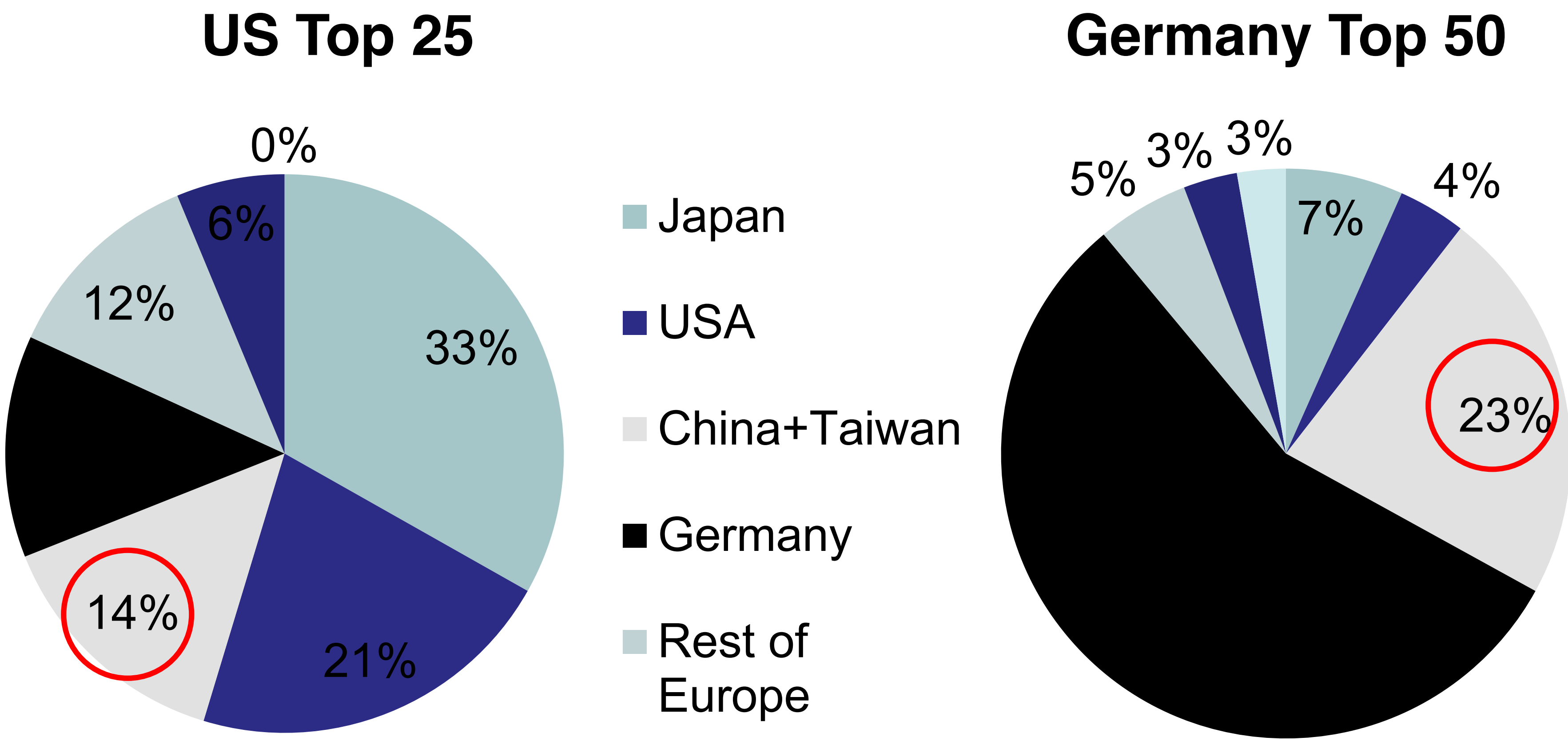
US soft costs make up most of the difference



Build-up of the $3.30 price difference



Share of module manufacturers for <10kW systems in 2010 by country of HQ



CA RE + Energy Efficiency Strategies

Residential New Construction

- All new residential construction in California will be zero net energy by 2020.

CA RE + EE Energy Efficiency Strategies

Commercial New Construction

- All new commercial construction in California will be zero net energy by 2030.
- Leverage opportunities from emerging technologies initiatives, incentive programs, and local initiatives targeting commercial building/ property developers.

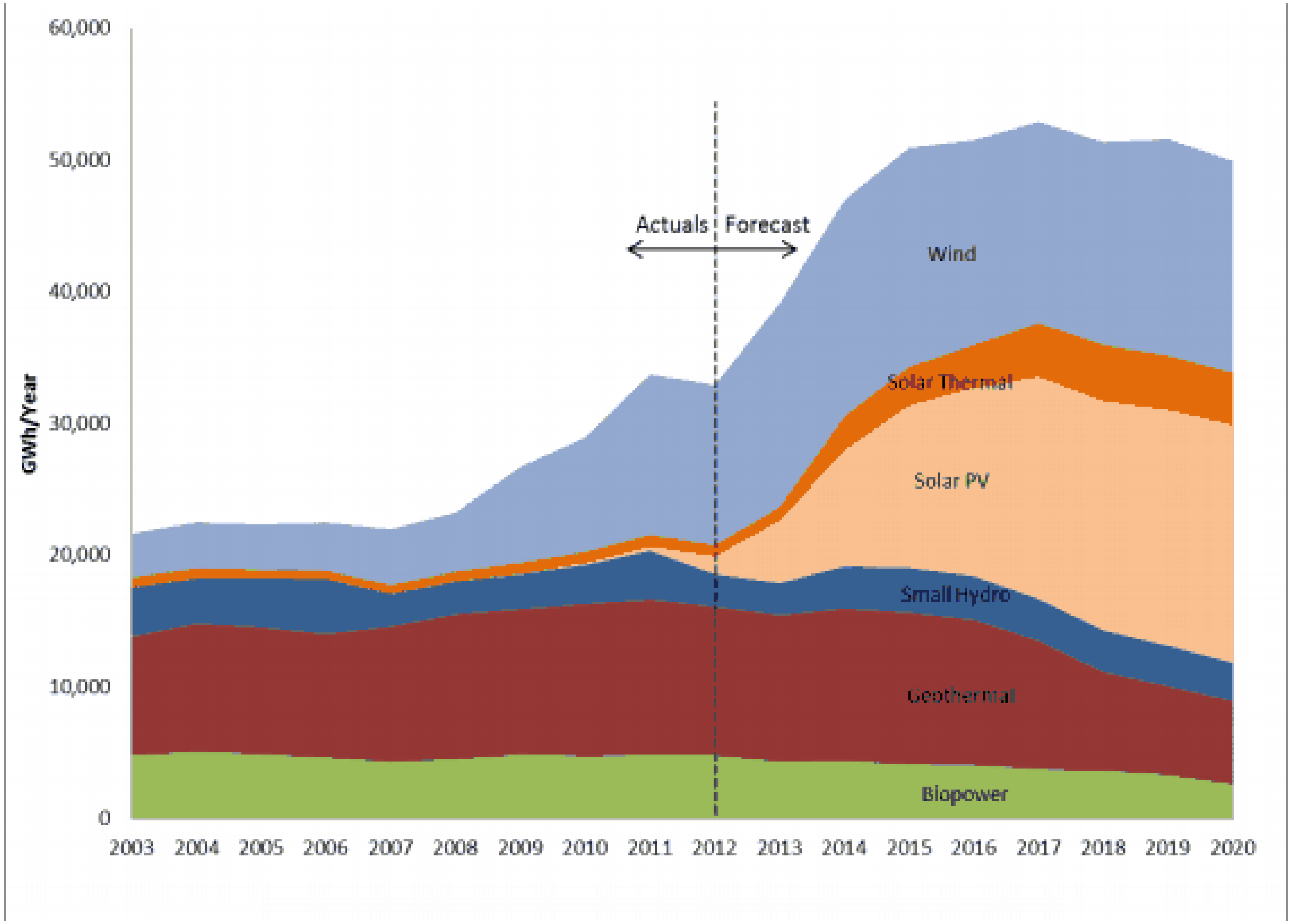
The World's Largest Silicon PV Project

Antelope Valley Solar Project

579 MW

San Luis Obisbo County, CA

Almost 80% of the California RPS is Projected to Be Met by Solar & Wind by 2020



Source: CPUC RPS Report

CA Leads in New Solar Home Construction

Rocklin Zero Energy Community

Over 8000 New Solar Homes Installed in CA. 12,000 more under way.

Future Applications

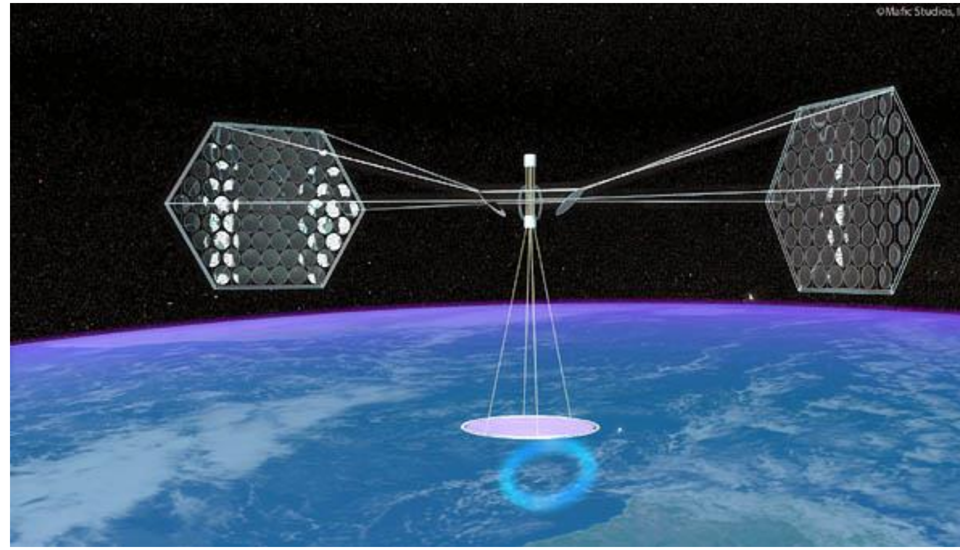
- Constant trend of increasing efficiencies across all forms of solar cells
- Inventive methods currently being considered include

  *solar panels on sattlelites which beam the energy back to earth in the form of microwaves

  *desert spanning solar farms

  *laser sunlight collectors to focus sun rays right at the solar cells

http://pneumaticaddict.wordpress.com/page/25/



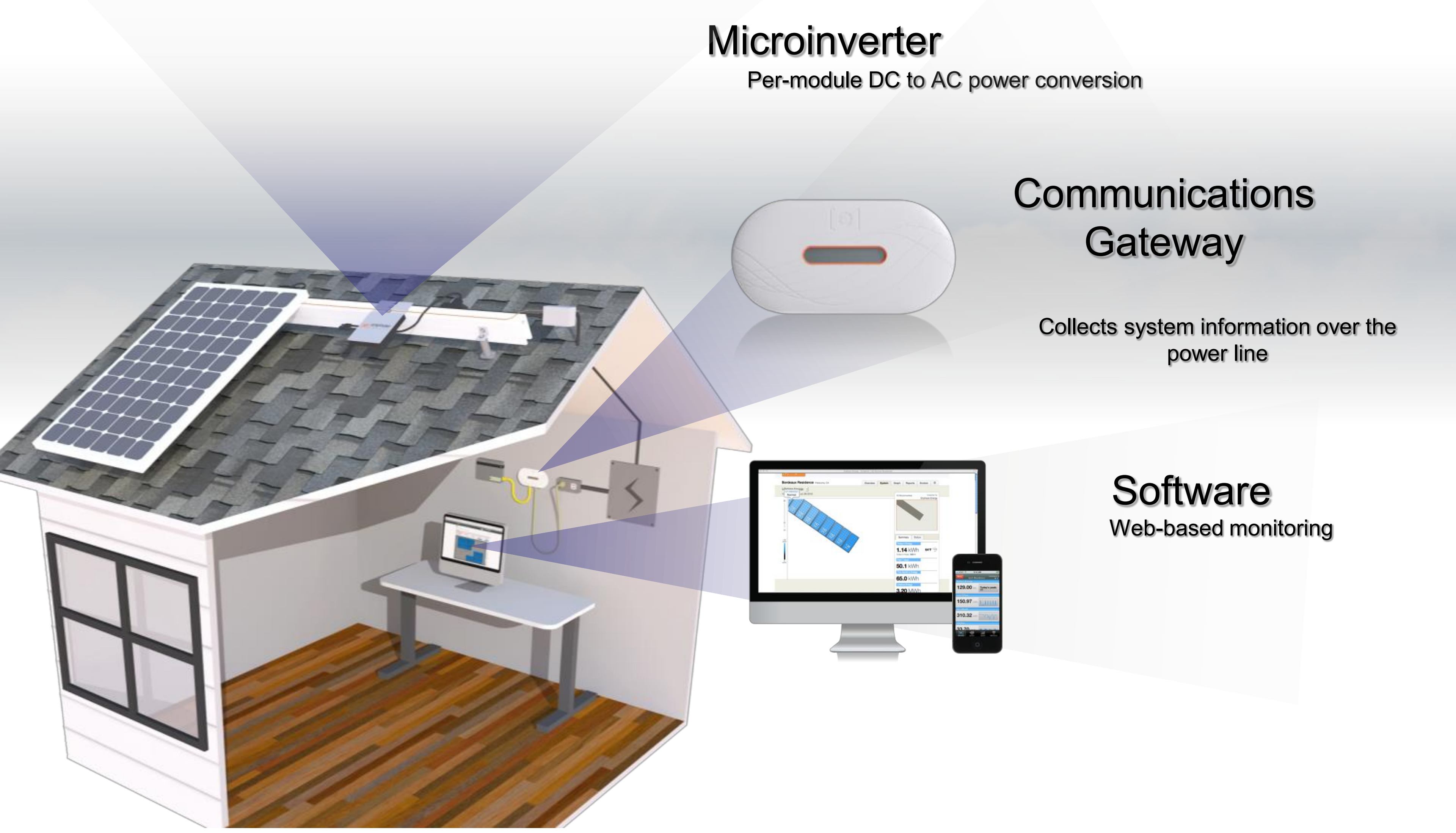
http://www.maximumpc.com/article/news/solaren_quench_pges_energy_thirst_with_spacebased_solar_power

Technological and Entrepreneurial Opportunity: Lighting Africa

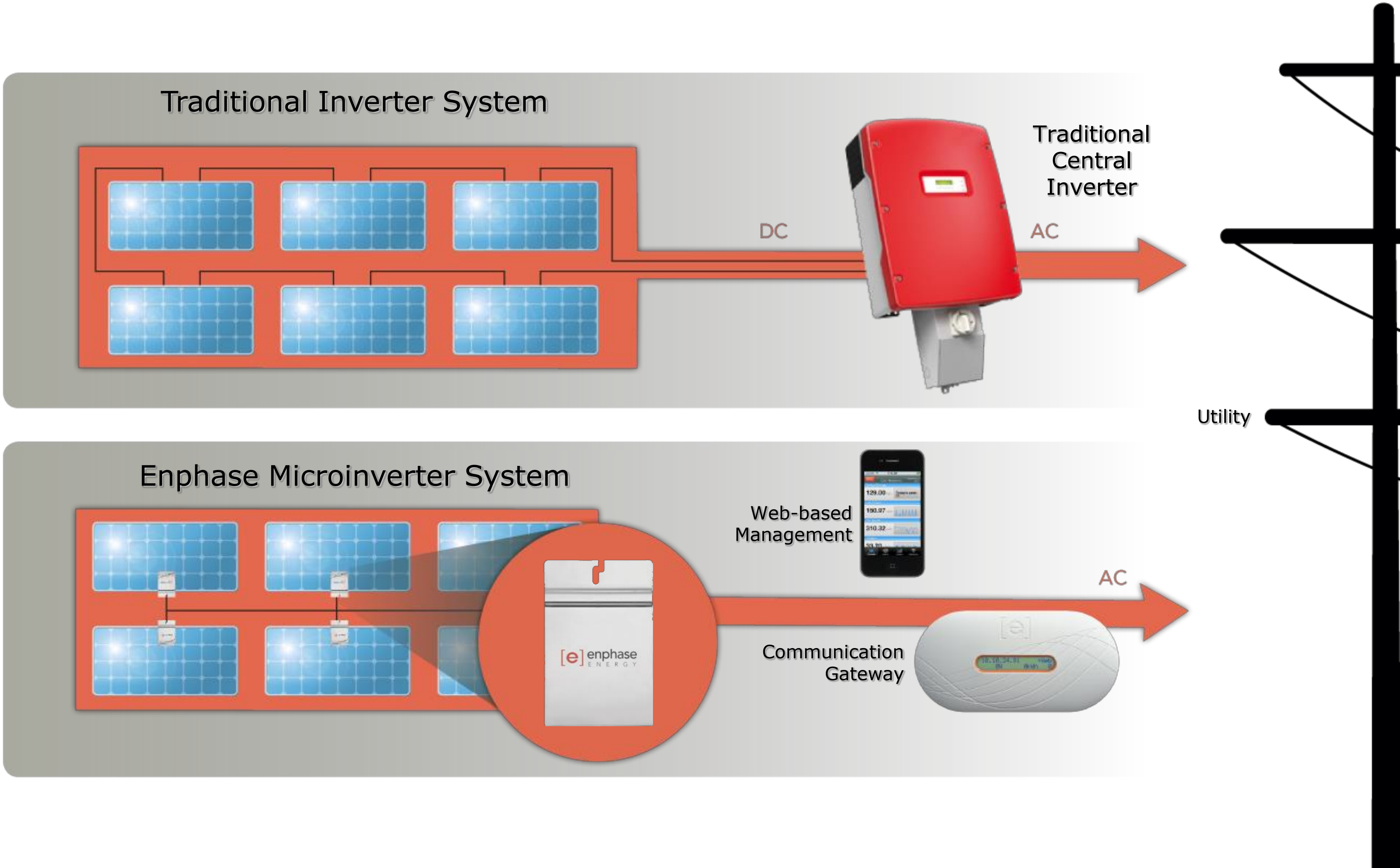
rael.berkeley.edu

Insights from what <u>technology can do</u>

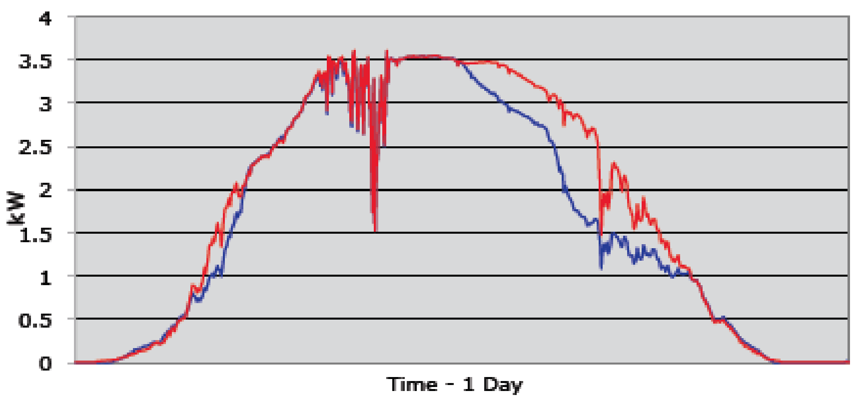
Systems Approach to Household Energy



Microinverters: A device-level subtle revolution

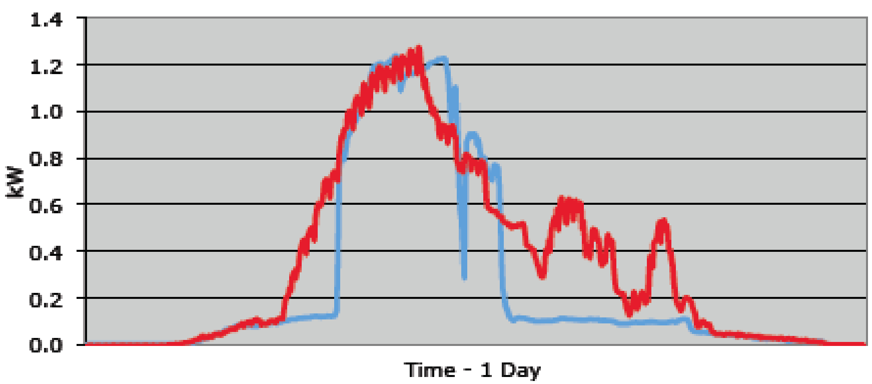


Micro-inverters versus traditional designs



Energy Advantage: 10.24%

- SMA SB6000US (95.5%) - Blue
- Enphase – Red
- Location: Petaluma, CA
- Date: November 2007



Energy Advantage: 33.63%

- Xantrex GT3 (94.5%) - Blue
- Enphase – Red
- Location: Grass Valley, CA
- Date: December 2007