NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Solar Heat & Electric : Technology & Cost Trends

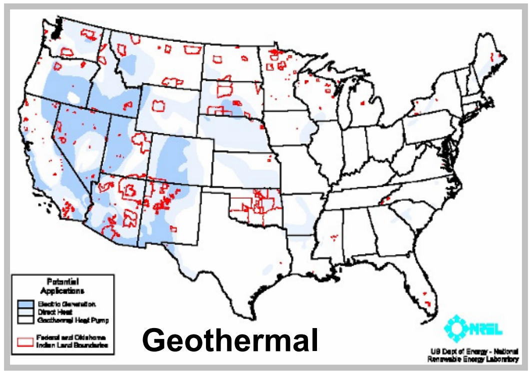
Kansas Corporation Commission Solar Roundtable

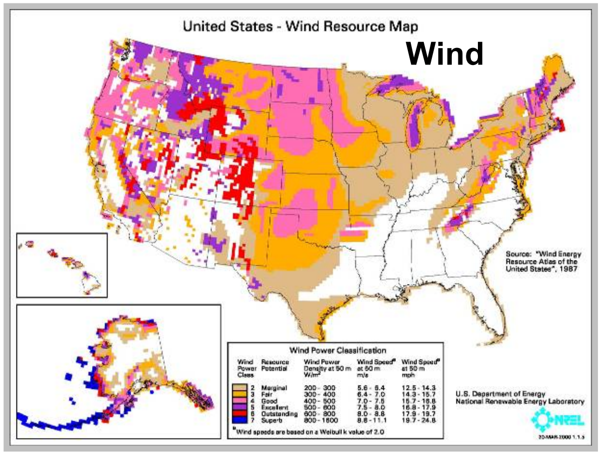
Roger Taylor

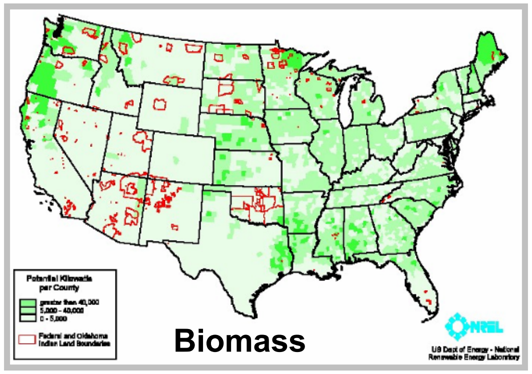
March 3, 2009

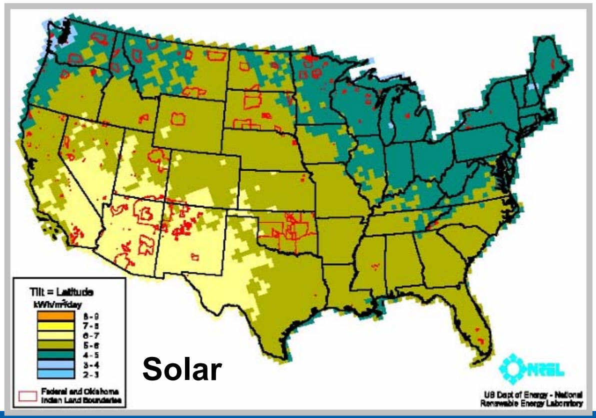
Major DOE National Laboratories

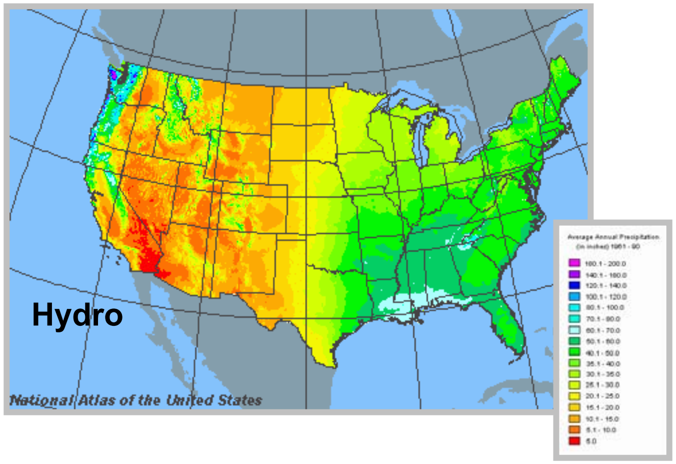
Renewable Resource Options





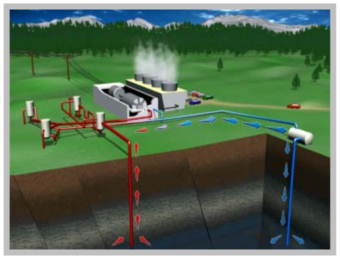






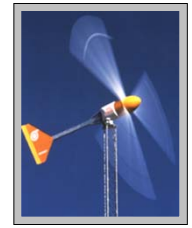
Renewable Technology Options

Power

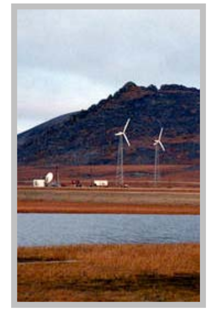


Small Modular Power

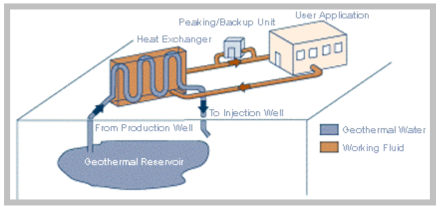
Small Wind



Diesel Hybrids



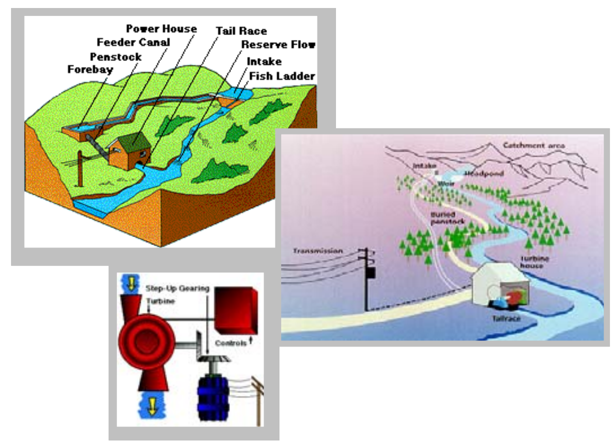
Direct Use



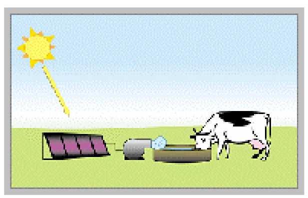
Big Wind

PV - Remote Homes

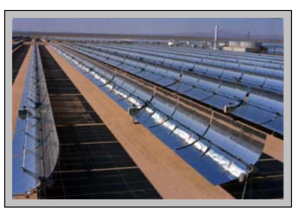
Small Hydro



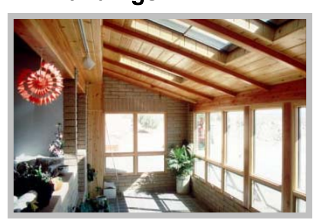
Stock Watering



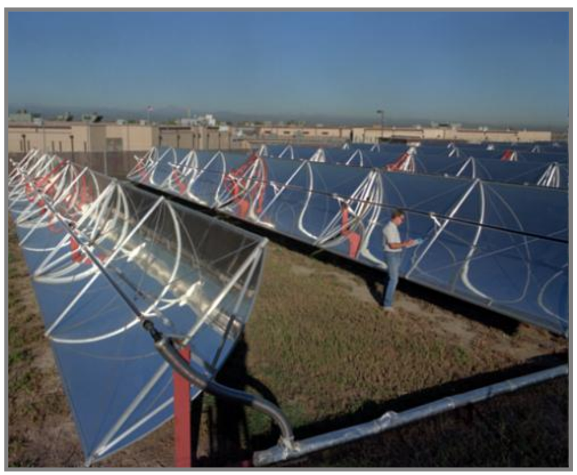
Process Heat



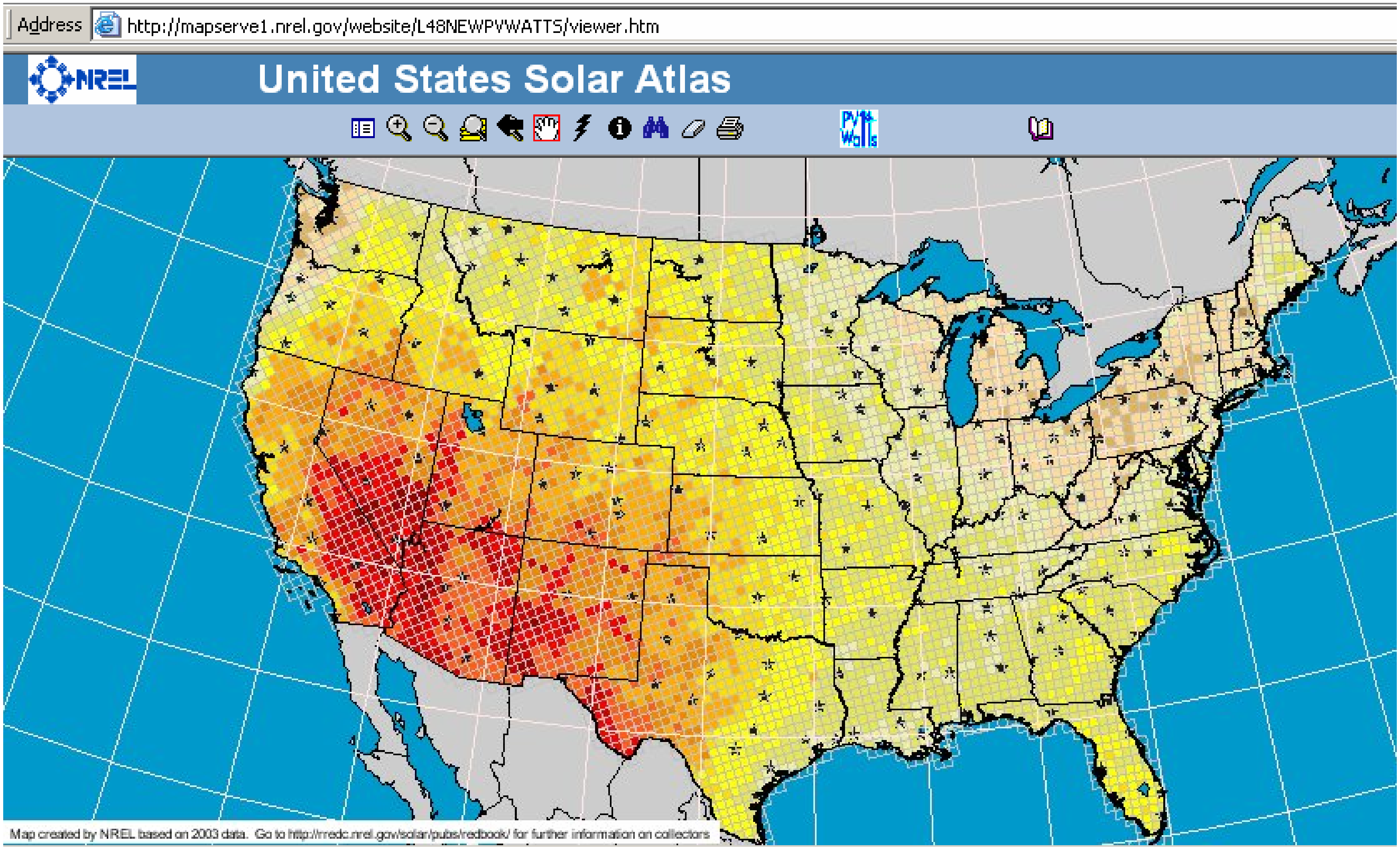
Buildings



Solar-based Technologies

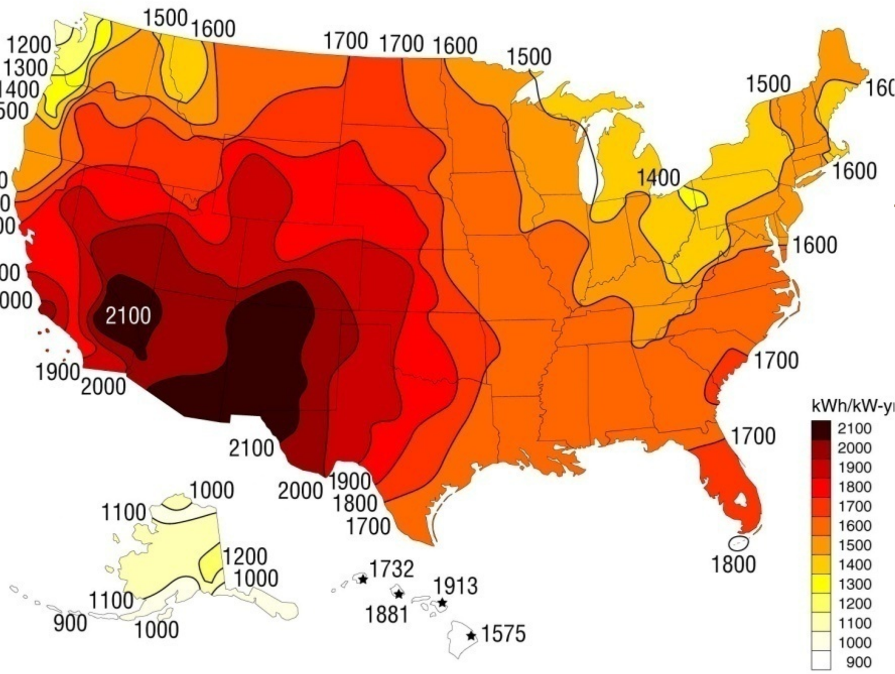


Kansas Solar Resource is Very Good

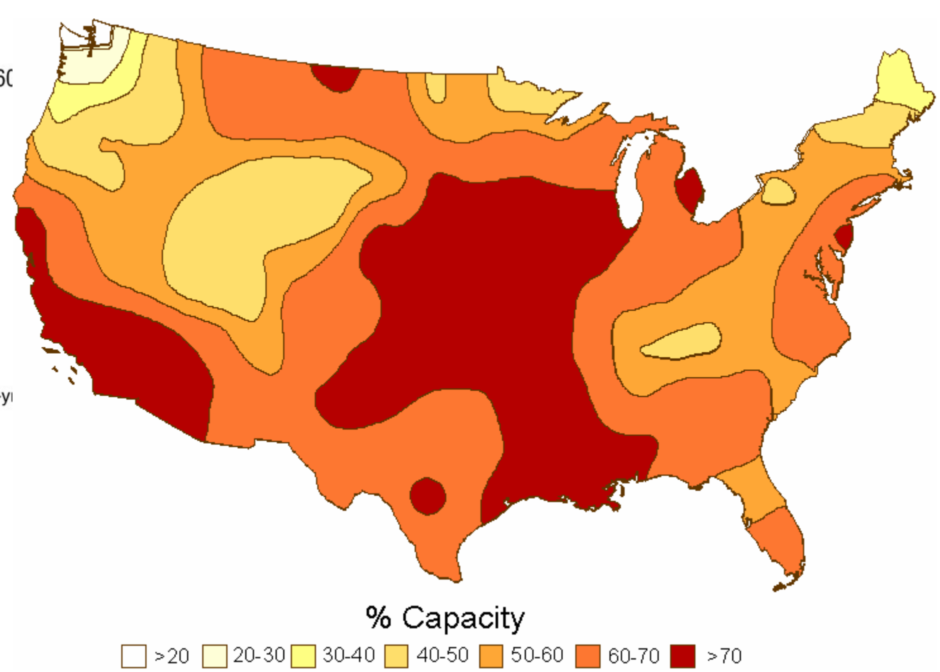


Solar can provide peak shaving in Kansas

PV Energy kWh/kW-yr



Effective Load Carrying Capacity



Source: Christy Herig (NREL) and Richard Perez (SUNY/Albany)

Solar Water Heating Is Not New!

Before the advent of gas pipelines and electric utilities, the technology gained footholds in Florida and California before the 1920's

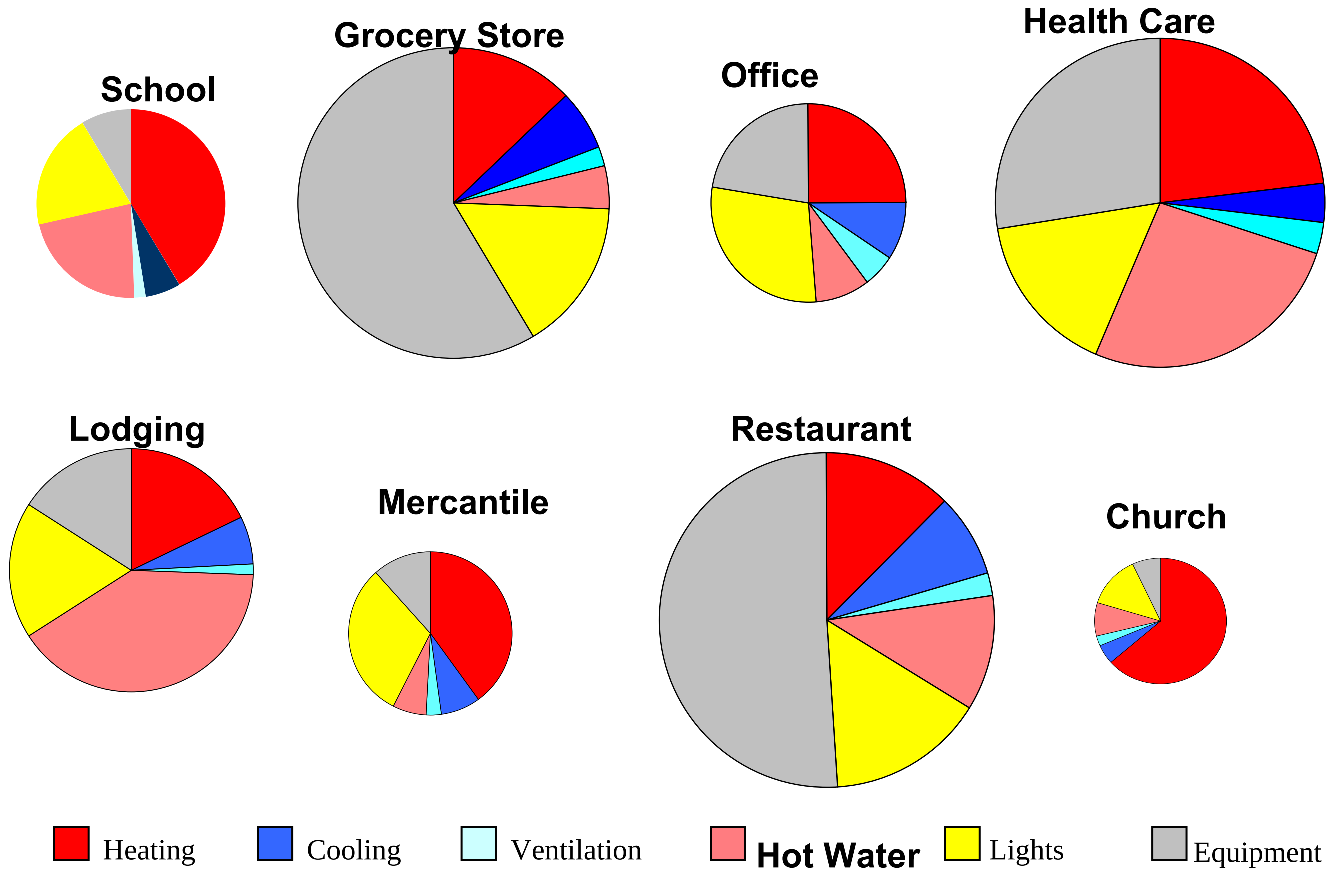
Over 1,000,000 systems are in use in American homes and business

The technology is in widespread use in:

- Caribbean basin
- China
- Israel
- Greece
- Japan
- Australia

Building Hot Water Energy Use

average 125 kbtu/sf/year



Energy for Water Heating

kBtu/sf/year

Office 8.7
Mercantile 5.1 Education
17.4 Health Care
63.0 Lodging
51.4 Pub Assembly
17.5 Food Service
27.5 Warehouse
2.0 Food sales
9.1
Public Safety 23.4 Other
15.3

All Buildings 13.8

Technical And Economic Viability Of A Solar Hot Water System Depends Upon:

Amount of annual sunshine

Capital cost of the solar system

Solar system annual O&M cost

Annual energy requirement and energy use profile

Temperature and amount of hot water

Prices of conventional fuels

Rate at which conventional fuels are escalating in price

Other (e.g. price of Carbon, tax incentives, RPS, local initiatives)

Solar Thermal Applications

Low Temperature (> 30C)

- Swimming pool heating
- Ventilation air preheating

Medium Temperature (30C – 100C)

- Domestic water and space heating
- Commercial cafeterias, laundries, hotels
- Industrial process heating

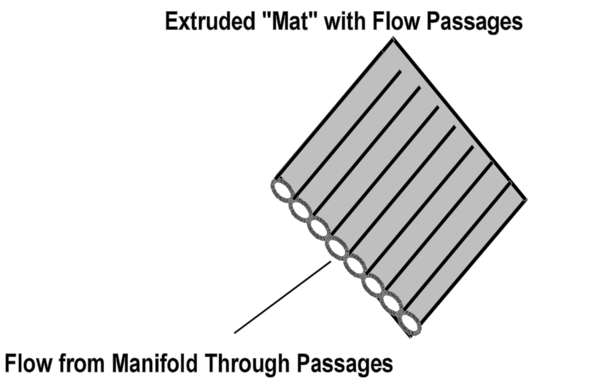
High Temperature (> 100C)

- Industrial process heating
- Electricity generation

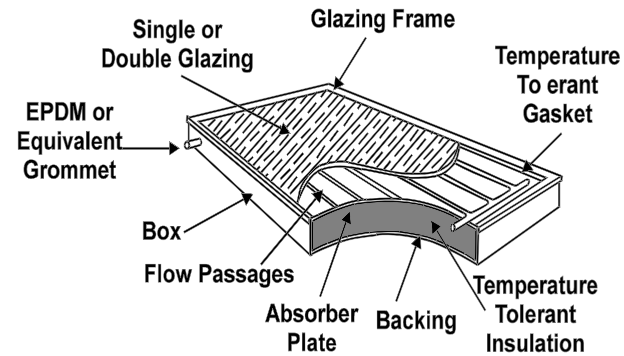
Solar thermal and photovoltaics working together

Collector Types

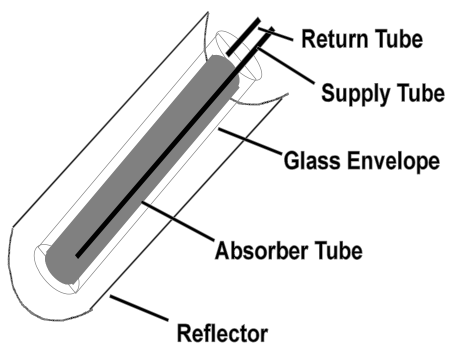
Unglazed EPDM Collector



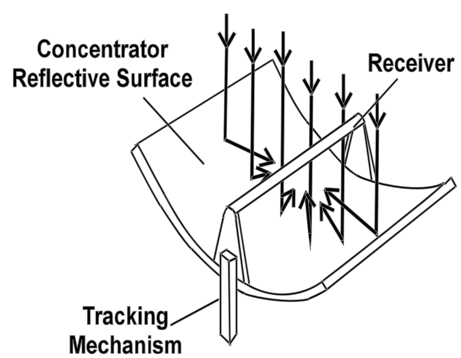
Flat Plate



Evacuated Tubes



Parabolic Trough



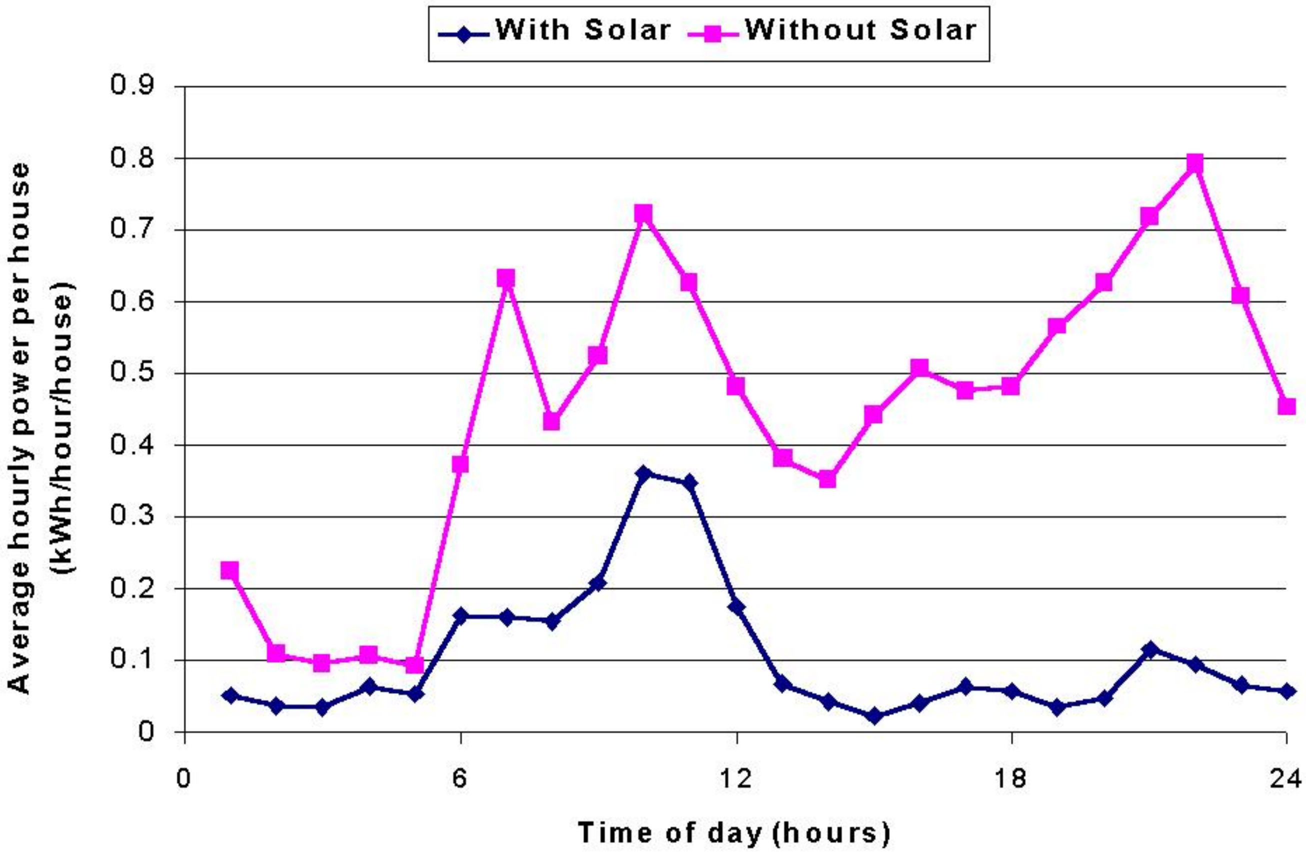
Typical Low Temperature Application

Mid Temperature Example:

USCG Kiai Kai Hale Housing Area, Honolulu HI

- 62 units installed 1998
- Active (pumped), Direct systems
- Average cost $4,000 per system
- 80 sf per system
- $800 per system HECO rebate
- Savings of 9,700 kWh/year and $822/year per system
- Simple Payback 4 years (with rebate)

USCG Housing, Honolulu HI



Concentrating Solar Power: Dispatchable Power

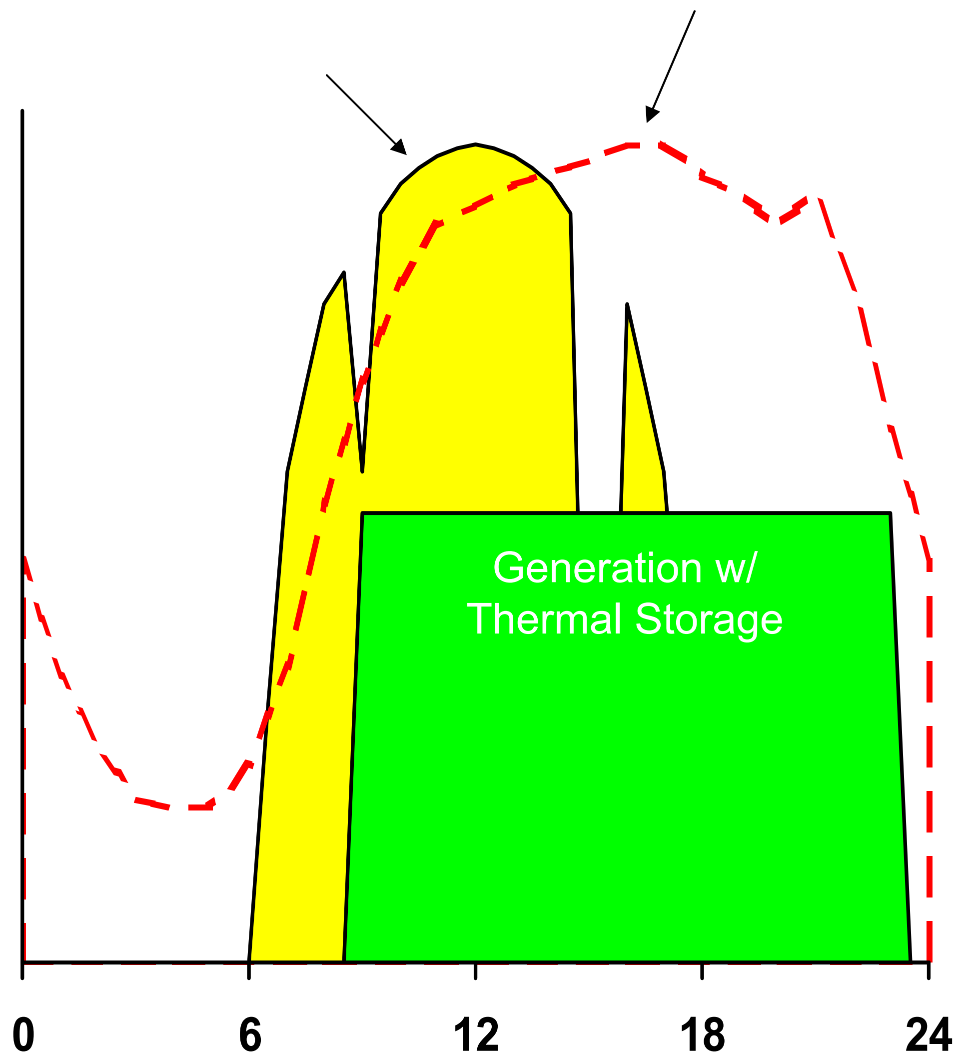
Parabolic Troughs: Commercial, utility-scale deployments

Central Receiver: Pre-commercial, pilot-scale deployments

- Up to 250MW plants (or multiple plants in power parks) for peaking and bulk power
- Moderate solar-to-electric efficiency
- Thermal storage offers load following and capacity factors up to 70%

Value of Dispatchable Power?

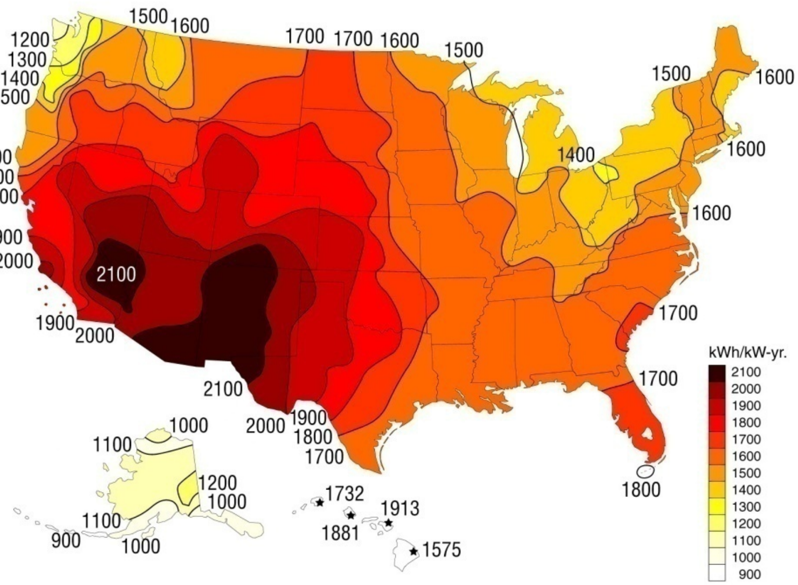
Meeting Utility Power Demands



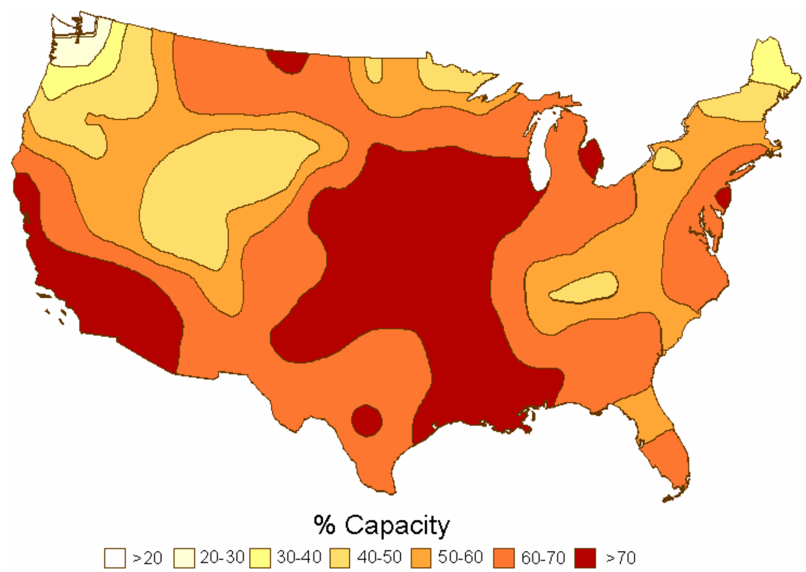
Storage provides
- higher value because power production can match utility needs
- lower costs because storage is cheaper than incremental turbine costs

Solar can provide peak shaving in Kansas

PV Energy kWh/kW-yr



Effective Load Carrying Capacity

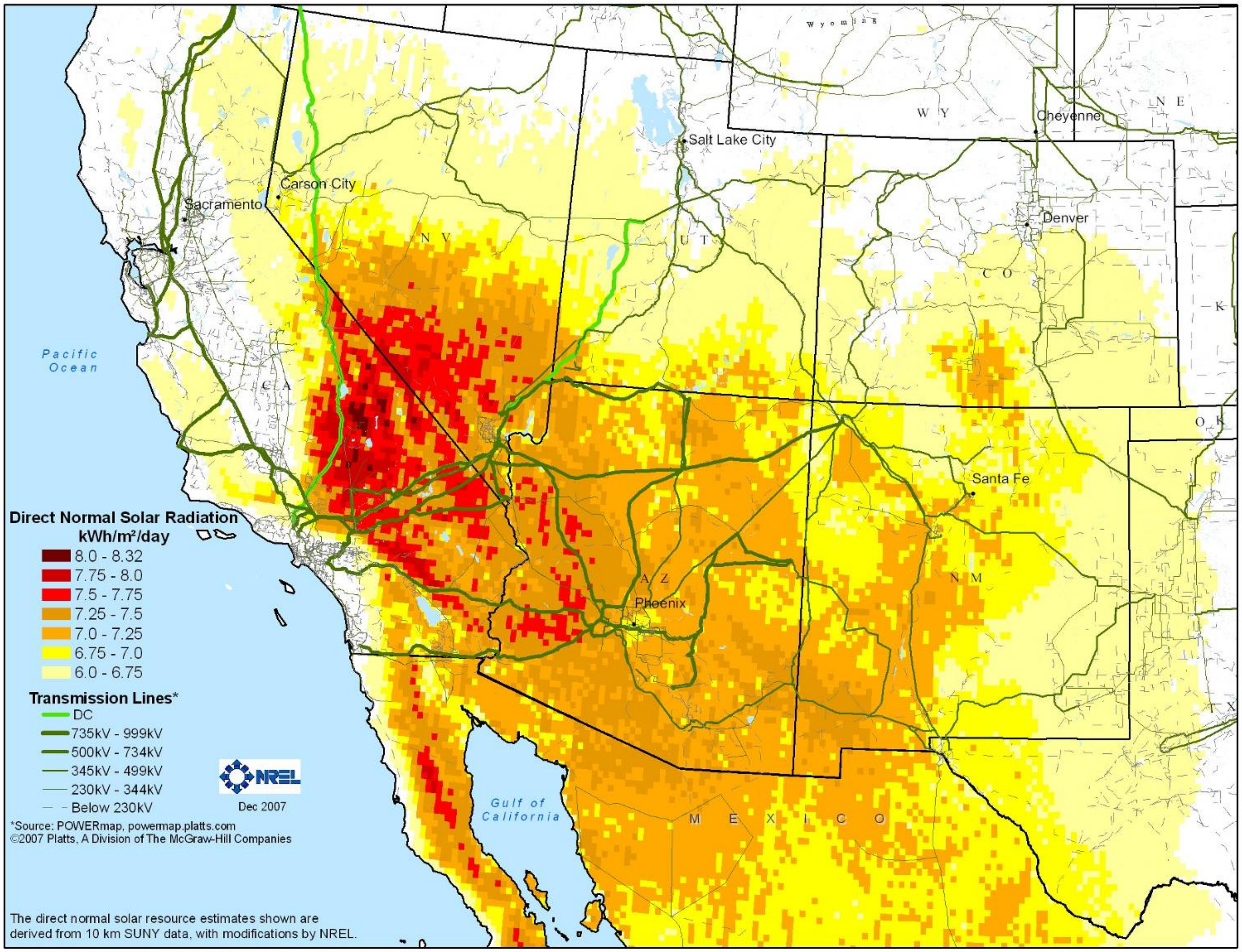


Source: Christy Herig (NREL) and Richard Perez (SUNY/Albany)

Operating Central Station Systems

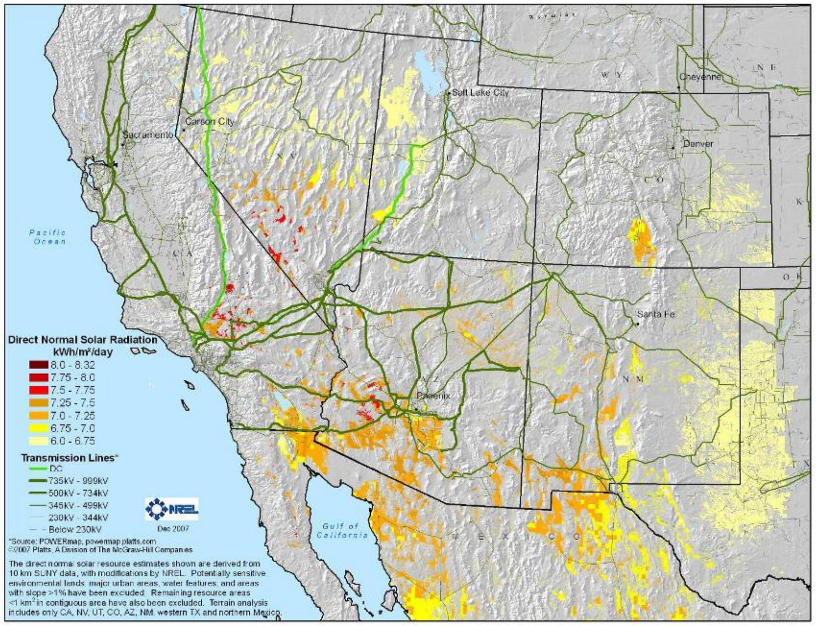
- The Solar Energy Generating Systems (SEGS) at Kramer Junction, CA (SEGS III-VII)
  - Five 30MW hybrid trough plants for a total of 150MW Capacity
  - Commissioned 1986-1988
  - Performance has increased with time
- Four additional SEGS plants located in two locations (Daggett, Harper Lake) for combined total of nine plants and 354 MW capacity

Southwest Solar Resources > 6.0 kWh/m^2/day



Resulting CSP Resource Potential

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	13,613	1,742,461	4,121,268
CA	6,278	803,647	1,900,786
CO	6,232	797,758	1,886,858
NV	11,090	1,419,480	3,357,355
NM	20,356	2,605,585	6,162,729
TX	6,374	815,880	1,929,719
UT	23,288	2,980,823	7,050,242
Total	87,232	**11,165,633**	**26,408,956**



Current total nameplate capacity in the U.S. is 1,000GW w/ resulting annual generation of 4,000,000 GWh

CSP Projects Early 2008

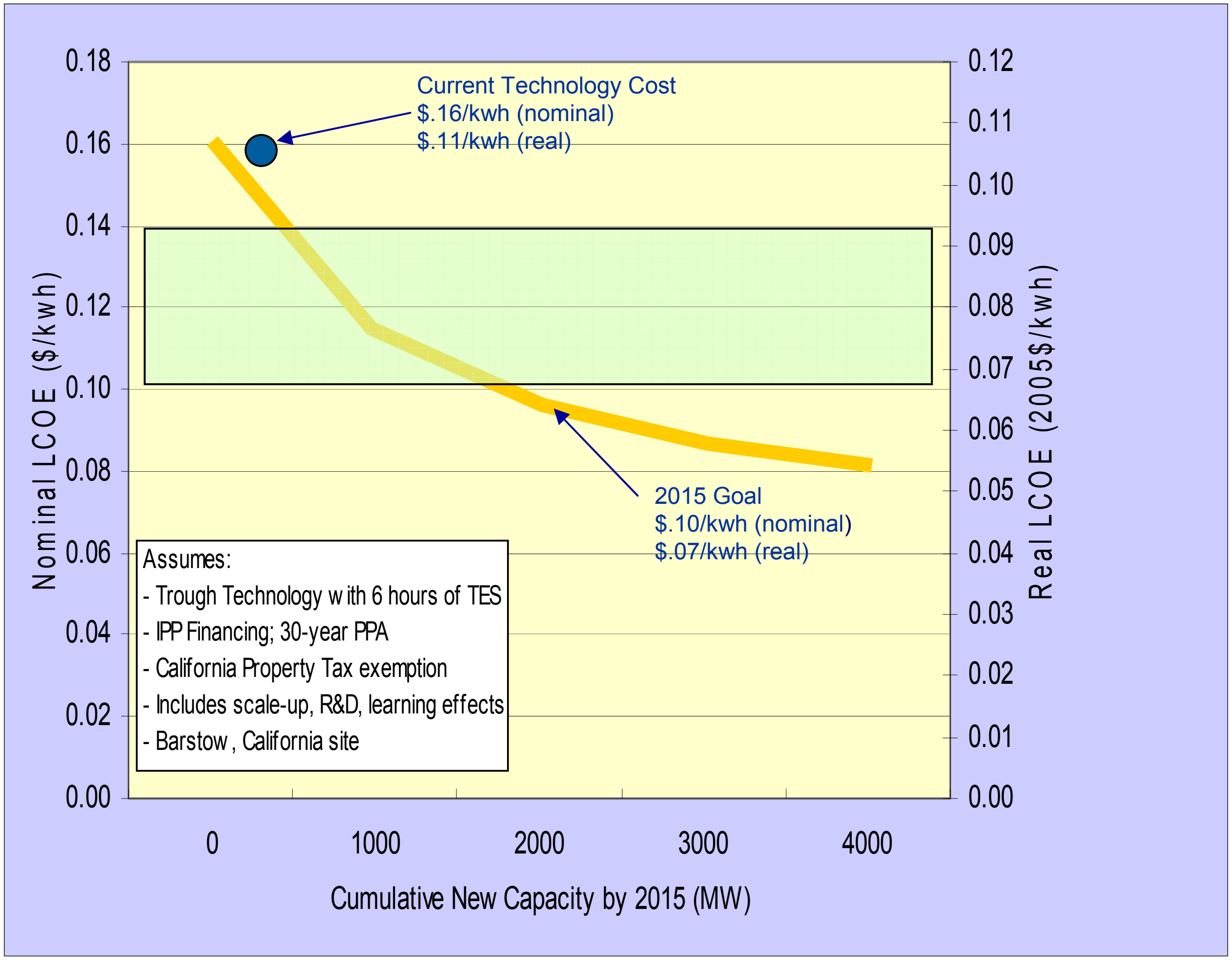
U.S. projects: enabled by 30% investment tax credit and State renewable portfolio standards

State	RPS Requirement
Arizona	15% by 2025
California	20% by 2010
Colorado	20% by 2020
Nevada	20% by 2015, 5% Solar
New Mexico	20% by 2015
Texas	5,880MW (~4.2%) by 2015

Utility/State	Capacity (MW)	Technology -Status
Arizona Public Service (APS)	1	Trough – completed and in operation 2006 (Acciona)
Nevada Power	64	Trough – completed and in operation June 2007 (Acciona)
Southern Cal Edison and San Diego Gas and Electric	500/300	Dish – signed power purchase agreement (SES)
Pacific Gas & Electric	550	Trough – signed power purchase agreement for four plants (Solel)
Pacific Gas & Electric	170	CLFR – signed power purchase agreement (Ausra)
Pacific Gas & Electric	500	Tower – MOU signed (Bright Source)
Florida Power and Light	300	CLFR or Trough
Arizona Public Service	280	Trough – signed power purchase agreement (Abengoa)
SW Utility joint venture (APS)	Est. 250	TBD – multiple expressions of interest submitted
New Mexico Utility Joint Venture	50-500	TBD – initial stages

Barrier:

Bridging the Cost Gap



Source: WGA Solar Task Force Summary Report

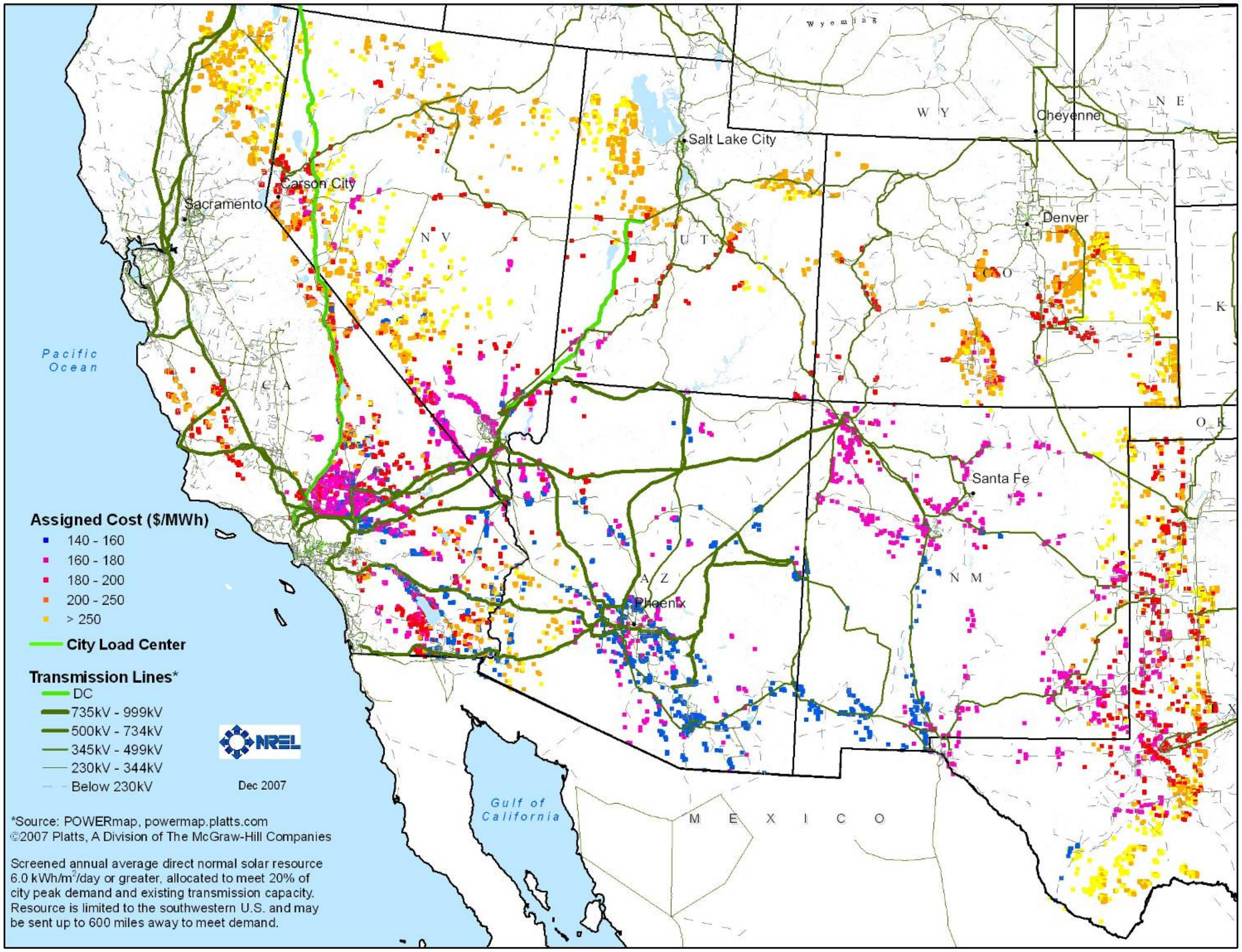
Cost Reductions to Bridge the Gap

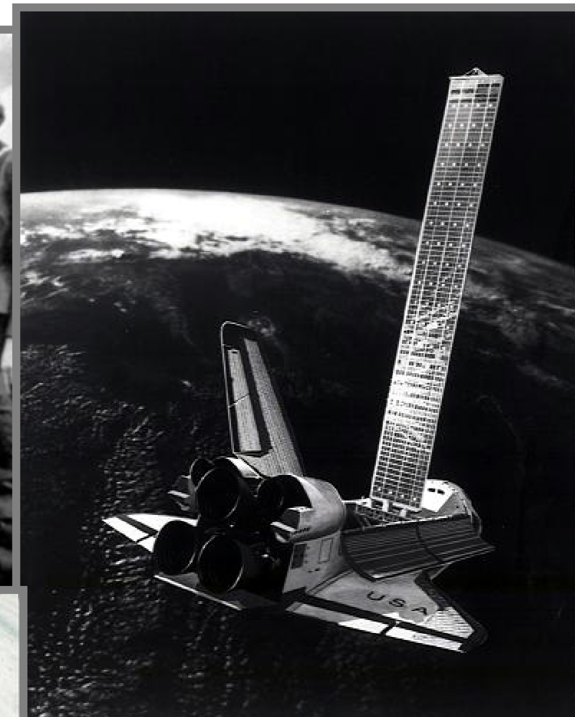
- Deployment
- Plant Size
- Financing
- R&D

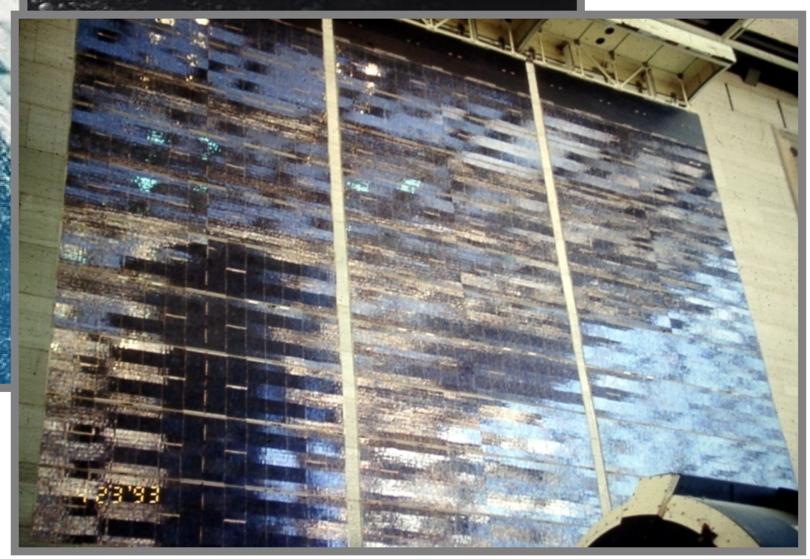
Analysis does not include current 30% investment tax credit

Barrier: Transmission

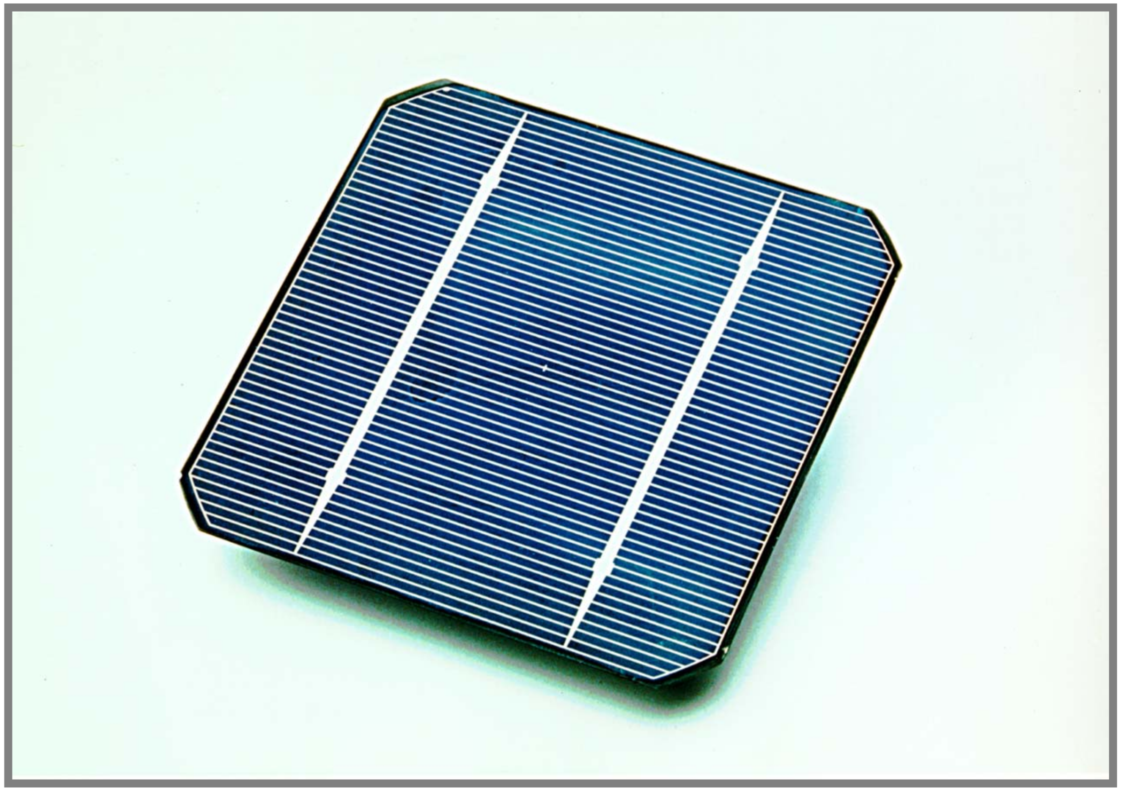
Optimal CSP Sites from CSP Capacity Supply Curves



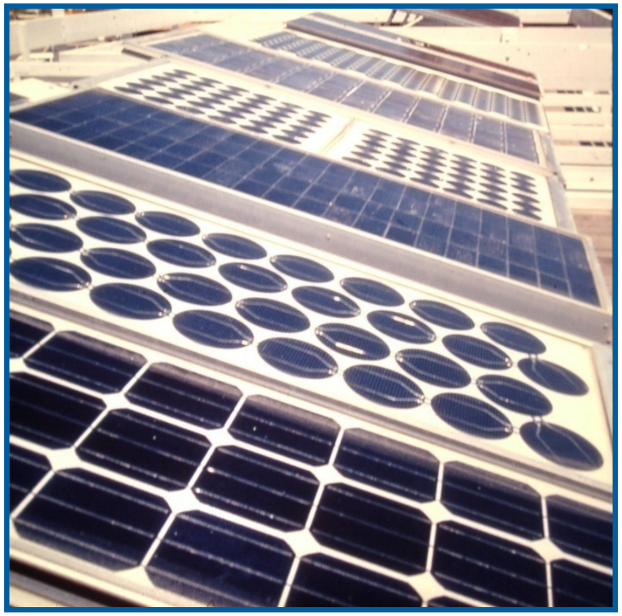

USA

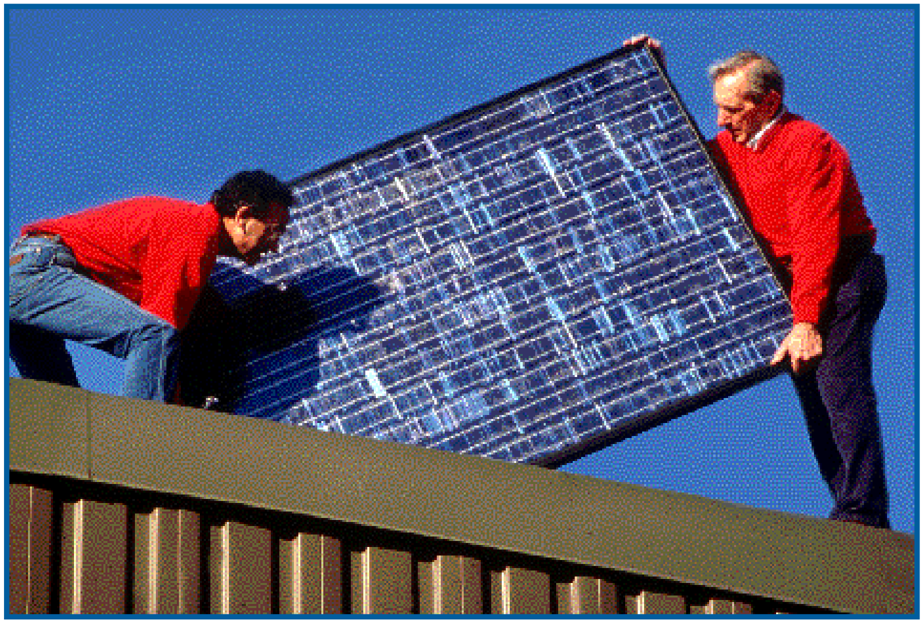


A typical solar cell (10cm x 10cm) generates about 1W at about 0.5V.

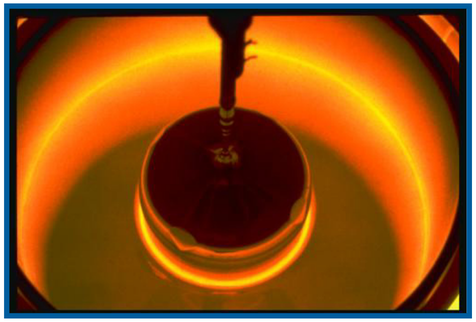


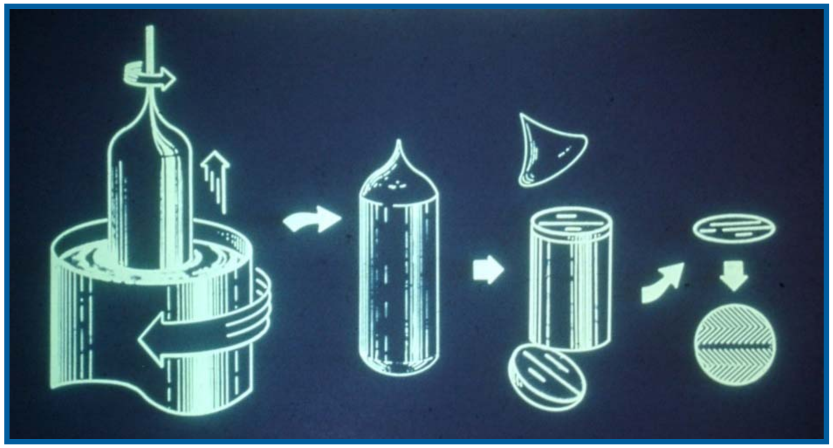
Individual cells are connected in series (increases the voltage) and in parallel (increases the current) into a module.

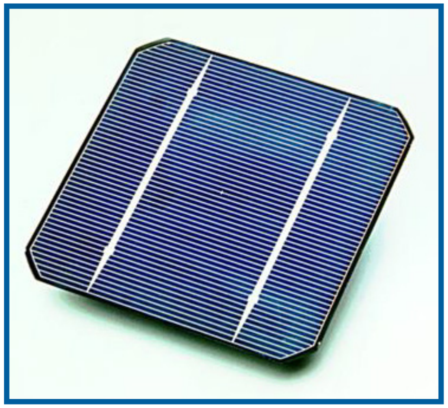


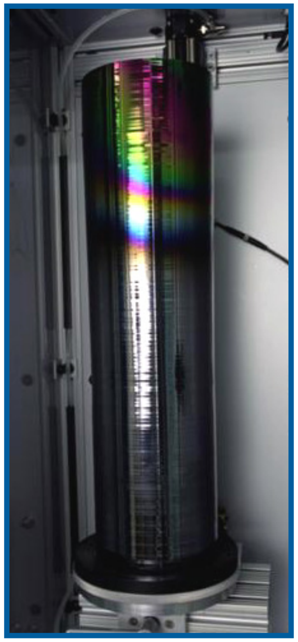


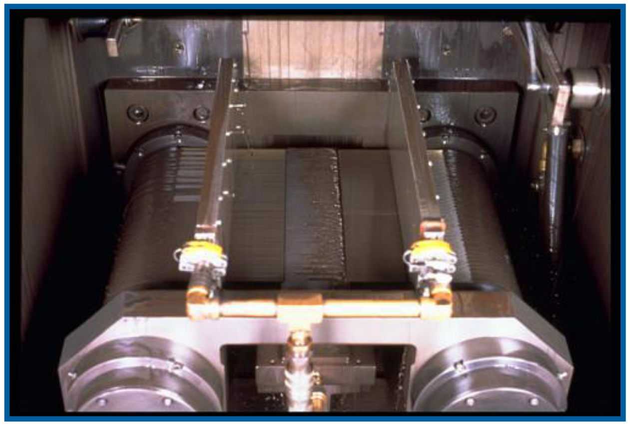
“Czochralski” Technology



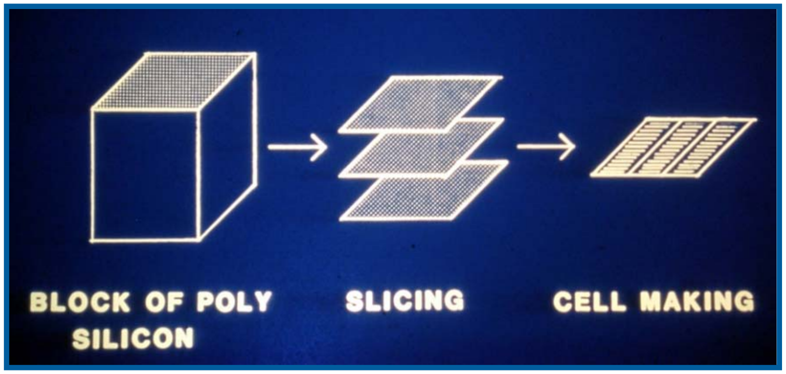


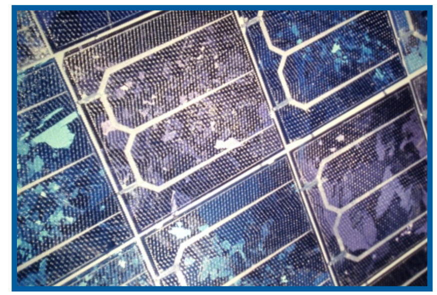


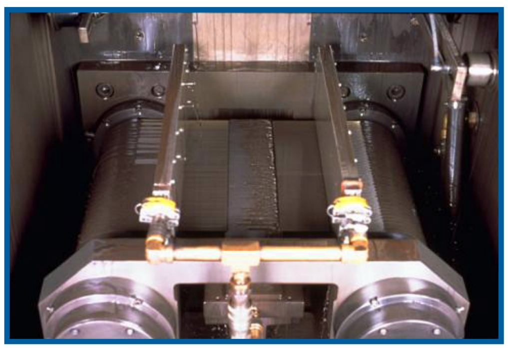




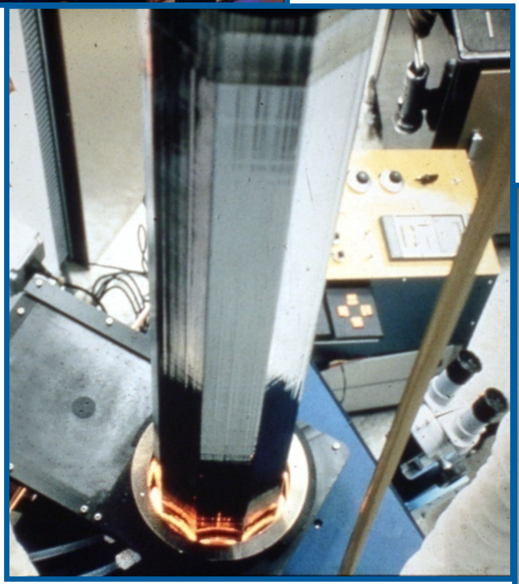
Cast Polycrystalline Technology

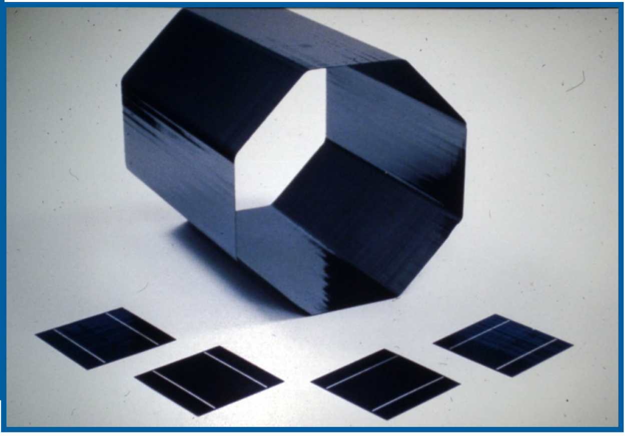




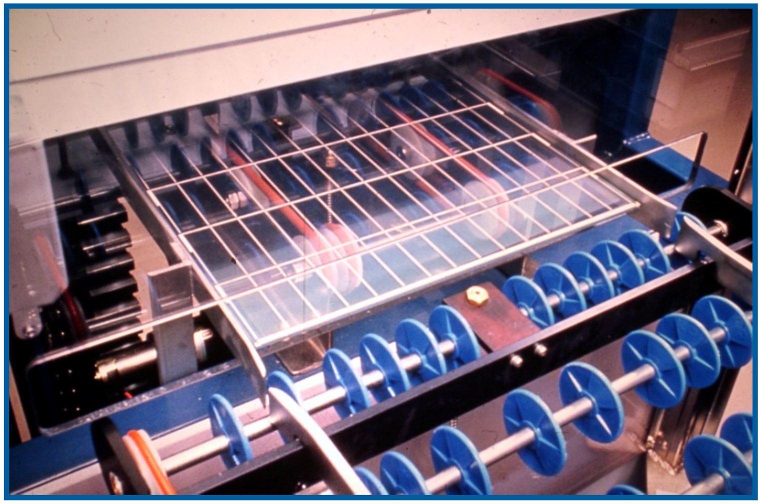


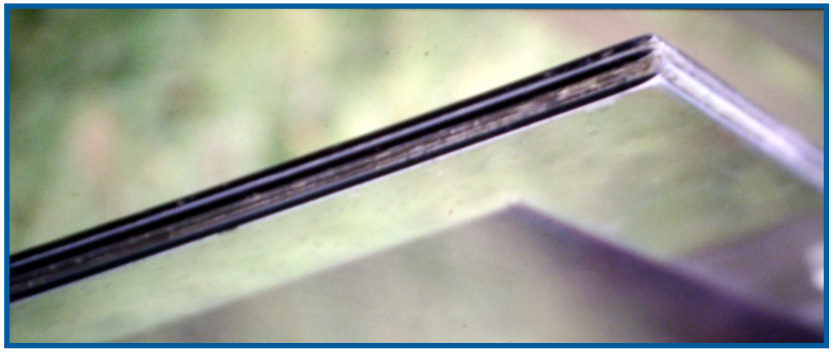
"Sheet" Technologies

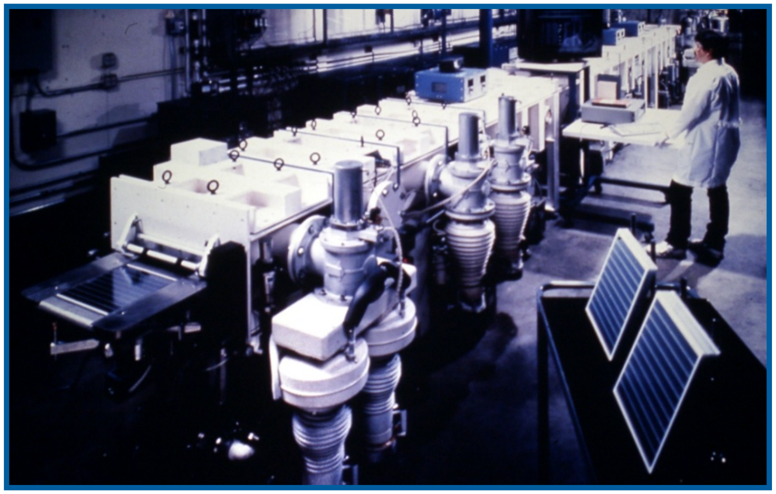


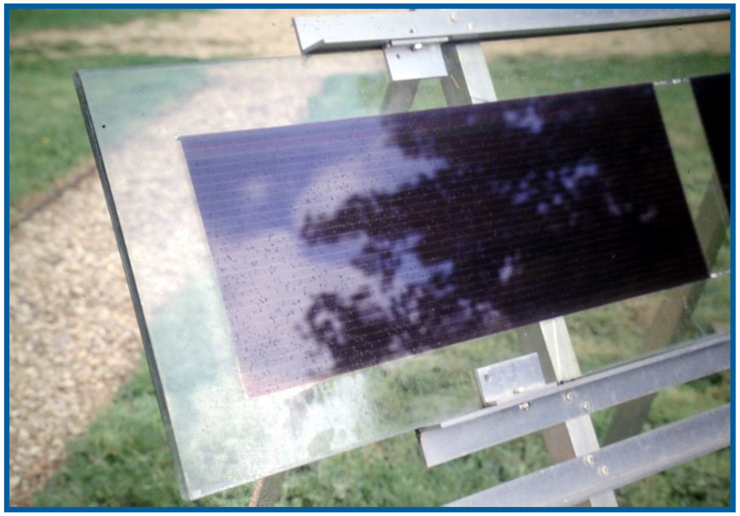


Thin Film Technologies On Glass

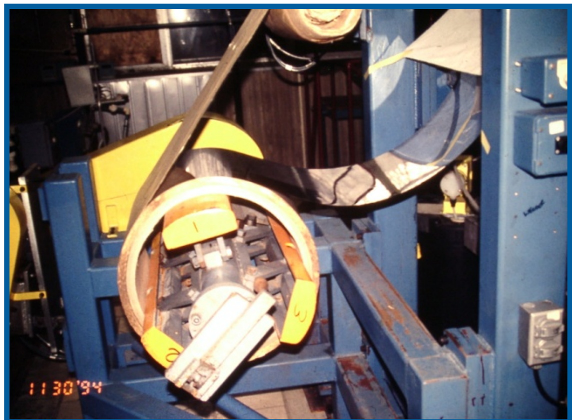




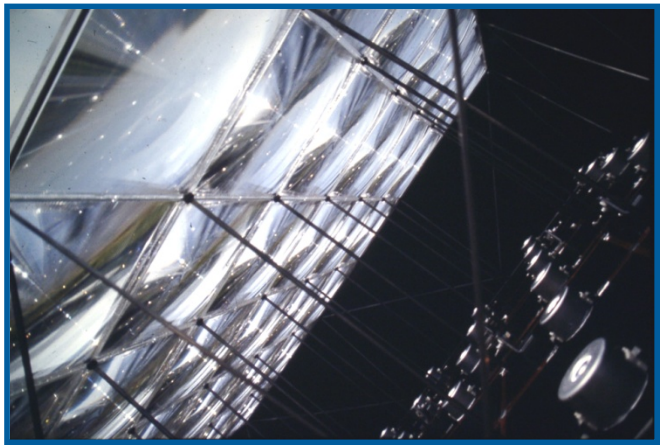


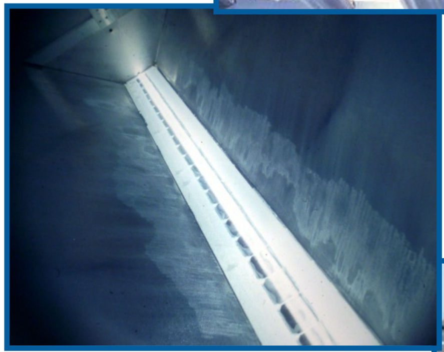


Thin Film Technologies
On Flexible Substrates



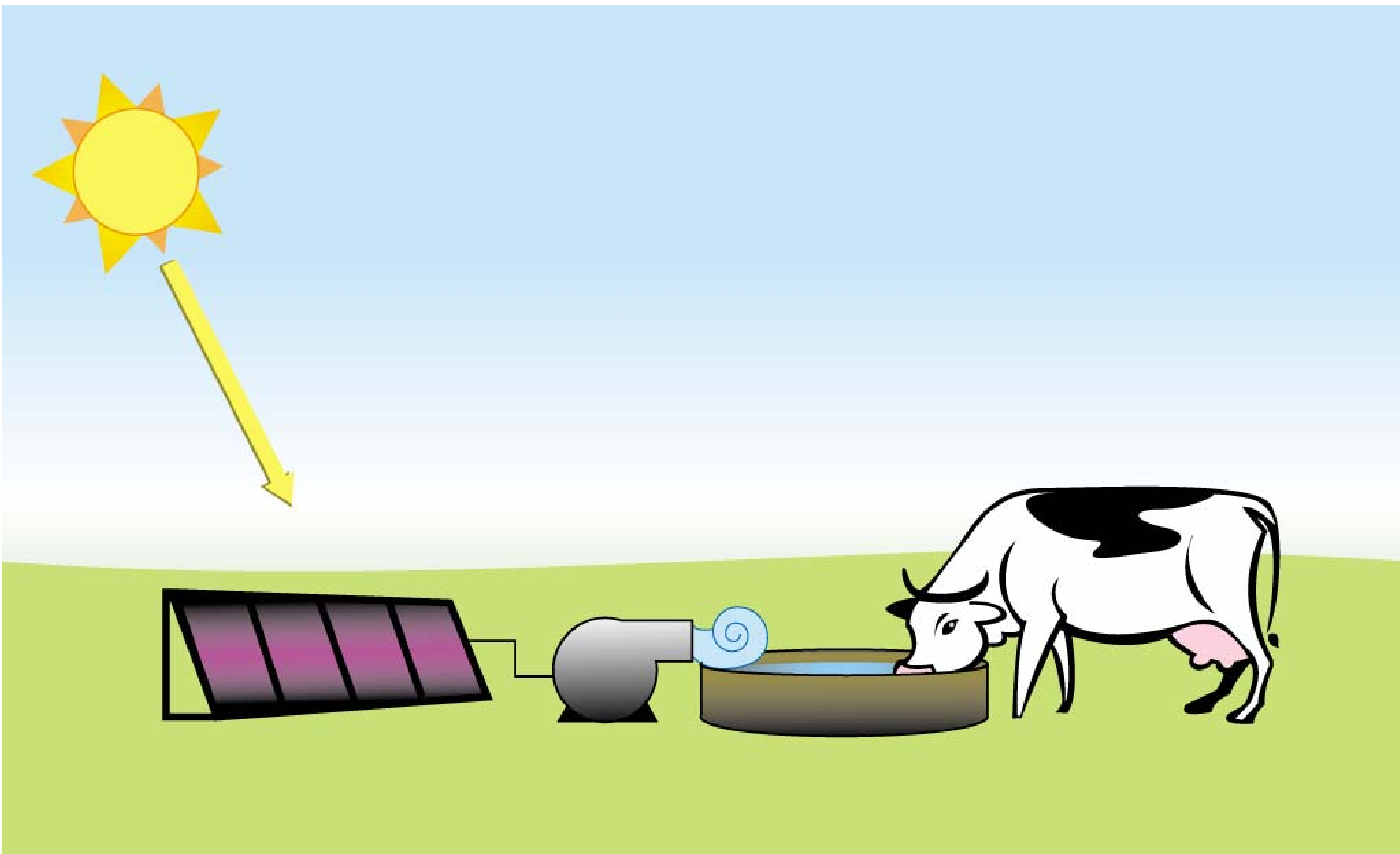
Concentrating PV Systems



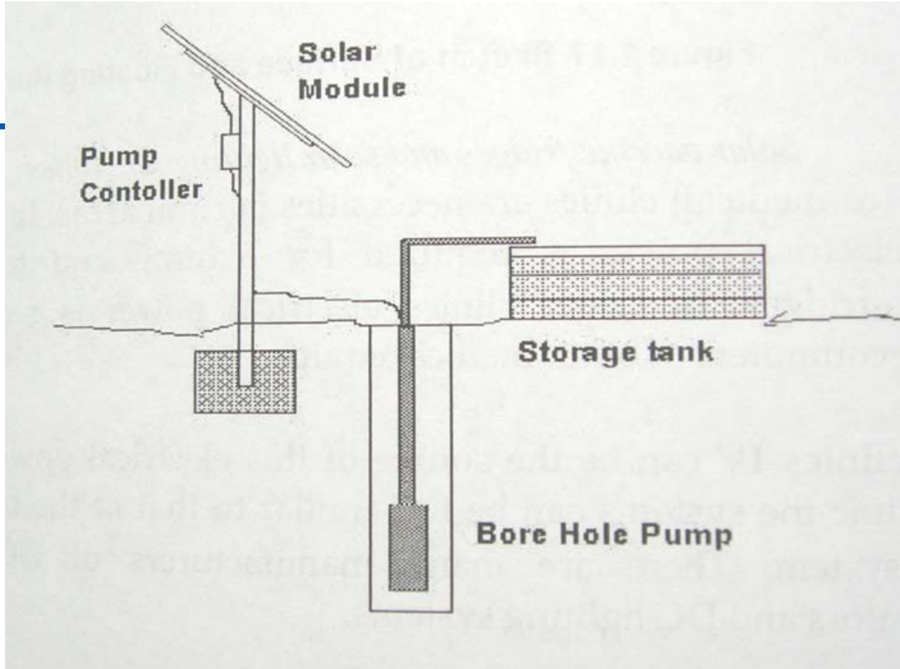


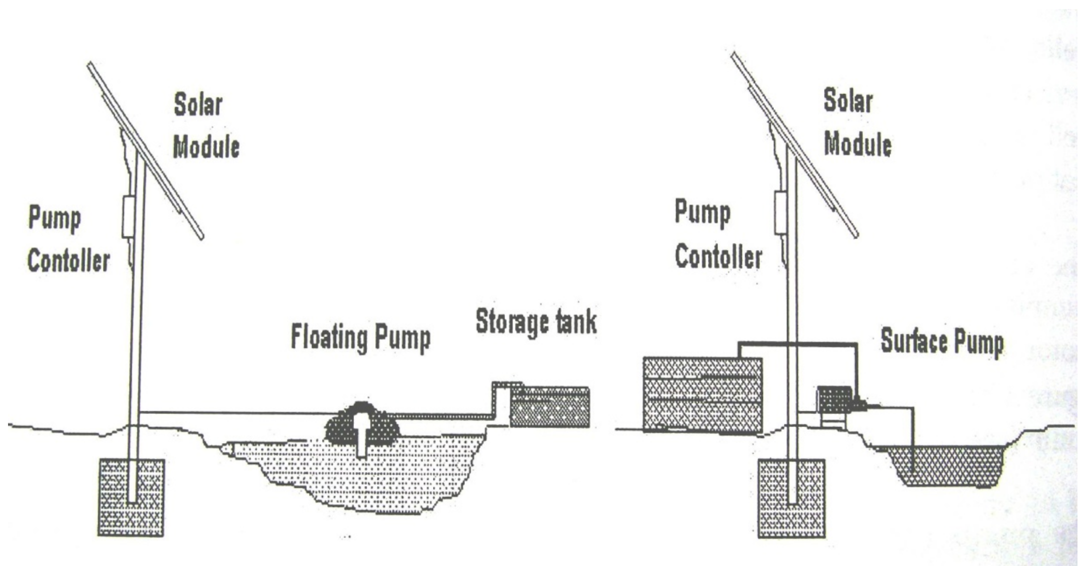
Collector Technology Considerations

- Flat plate, single crystal and polycrystalline Si most common and high acceptance
- Higher efficiencies usually mean less cost for wiring and structure
- Tracking can provide more power and energy in less space but fixed costs must be compared
- Long term performance essential.



Water Pumping Designs

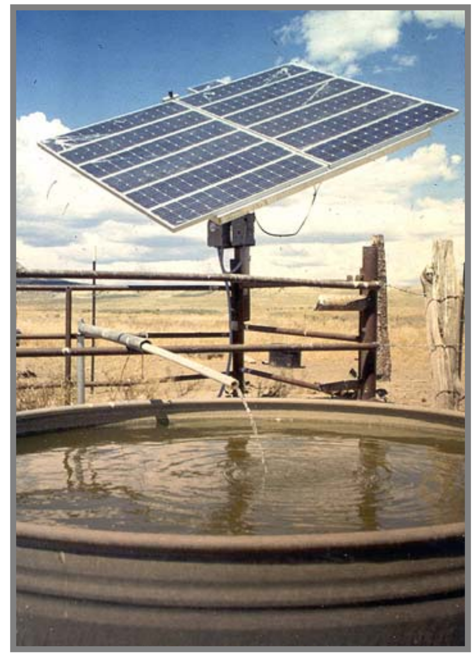


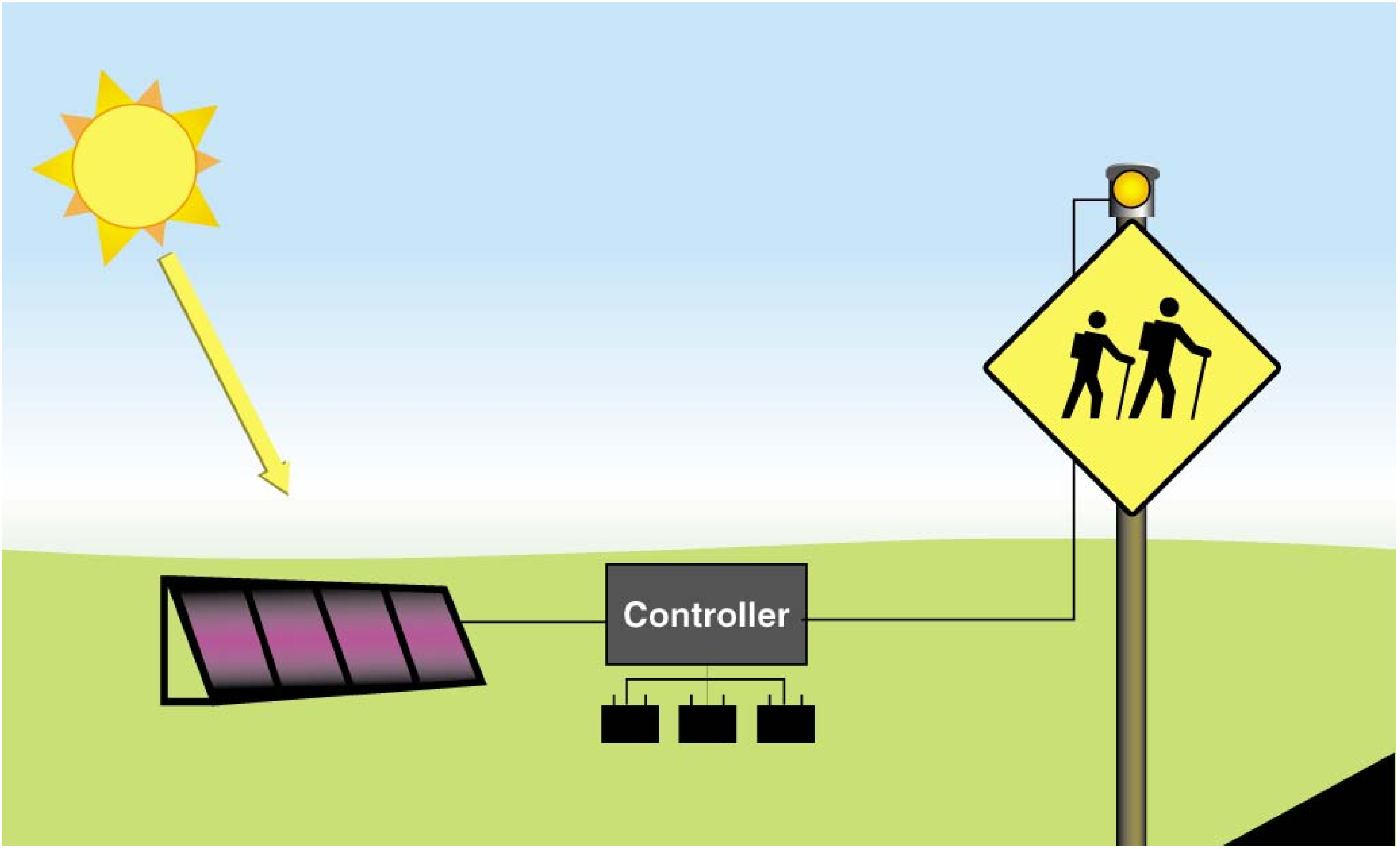


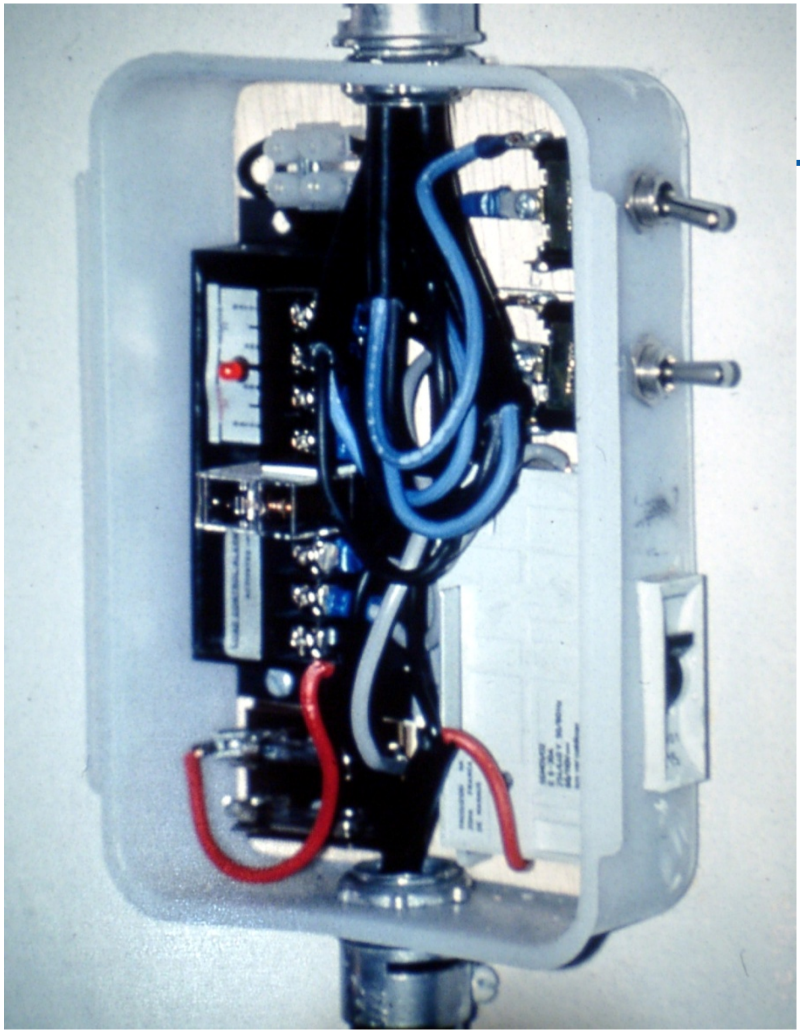
Rural Electrification: Classics

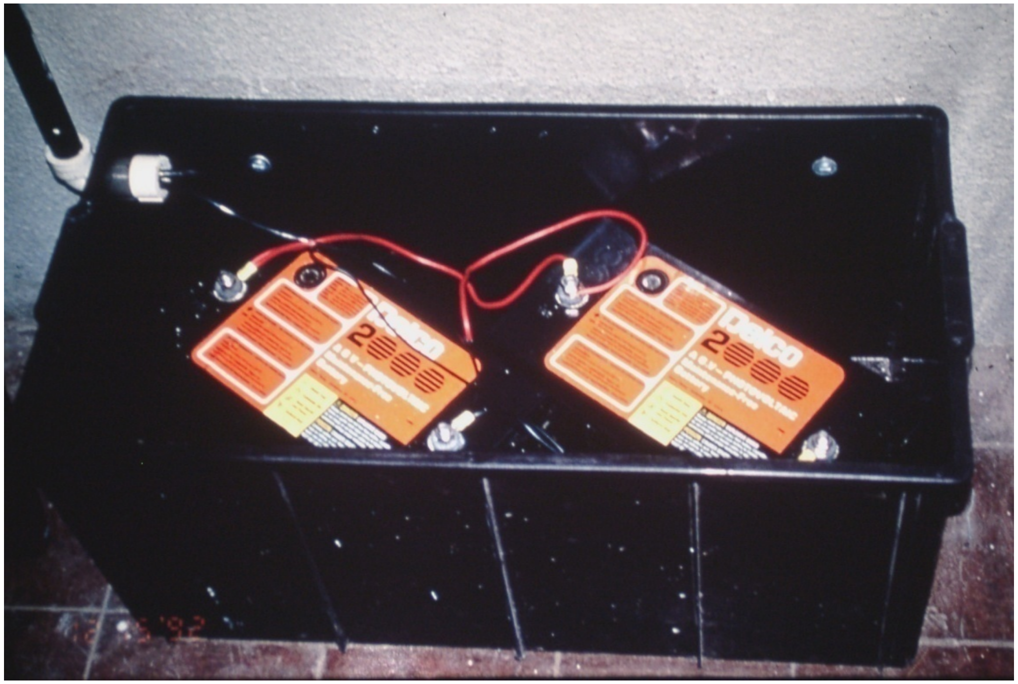
Historically, the primary means of providing power have been through grid extension and diesel generators.

- **Grid Extension:** Very high initial cost, poor cost recovery, time intensive (generation, transmission, distribution) and usually must be subsidized. Most often used.
- **Diesel Generators:** Inexpensive installation but expensive to operate, environmental damage/pollution, and subject to volatile fuel costs and availability.




Controller




Delco
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Delco
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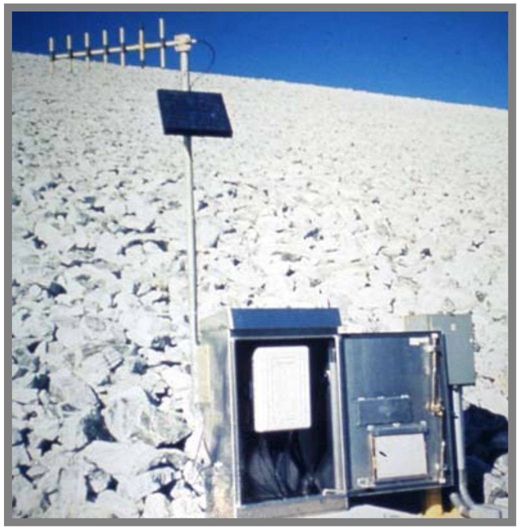
Energy Storage

- Deep cycle storage batteries are common
- Batteries require a temperature moderated enclosure and maintenance
- Storage size tied to electrical usage
- Technical issues are temperature & temperature
- Most systems with batteries use a charge control device





Typical PV - Battery Systems



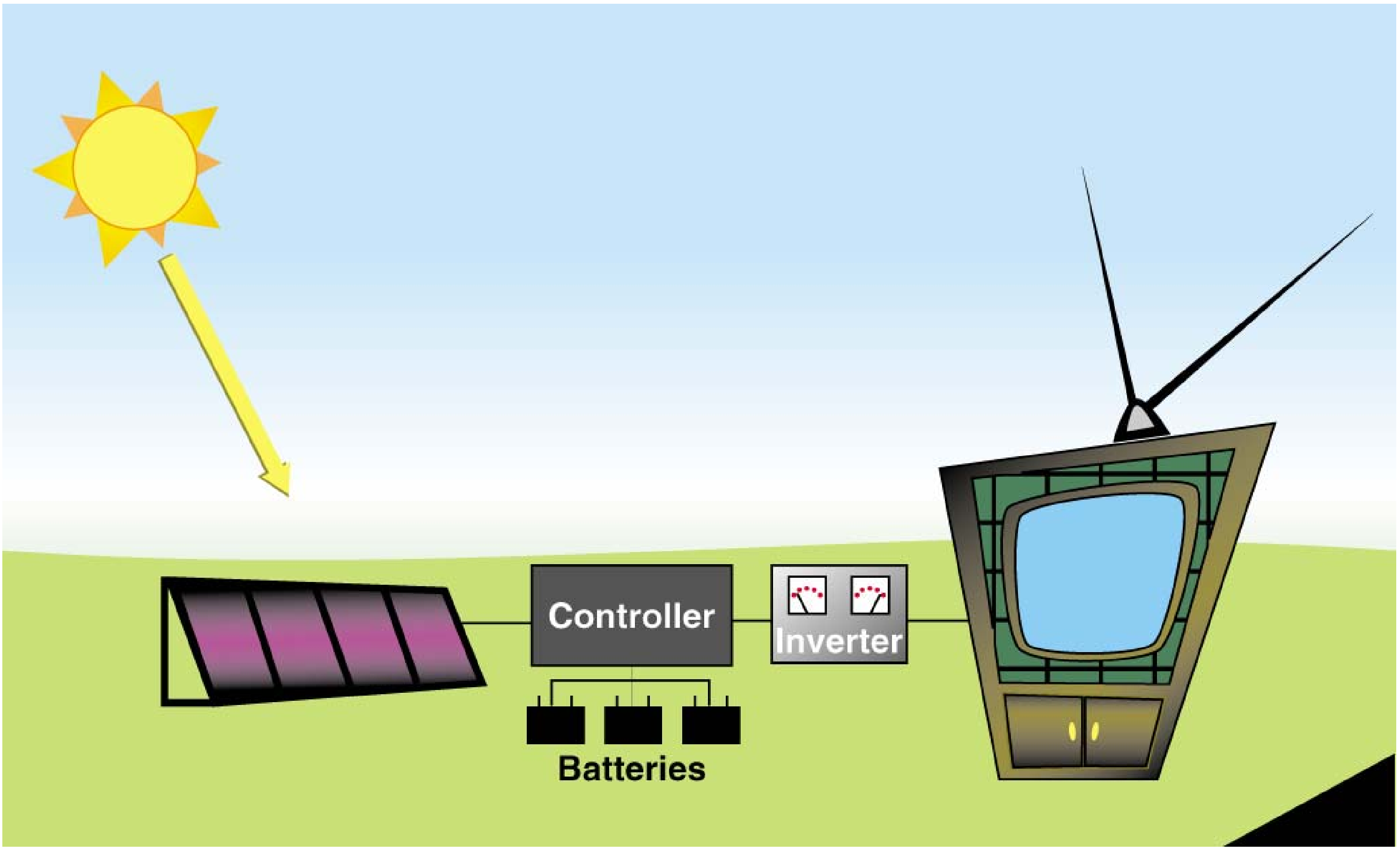
Department of Interior

National Park Service

USDA Forest Service

Military Field Applications

AC PV System with Inverter



Inverter - 5kW

50 kW Inverter

AC System Controls

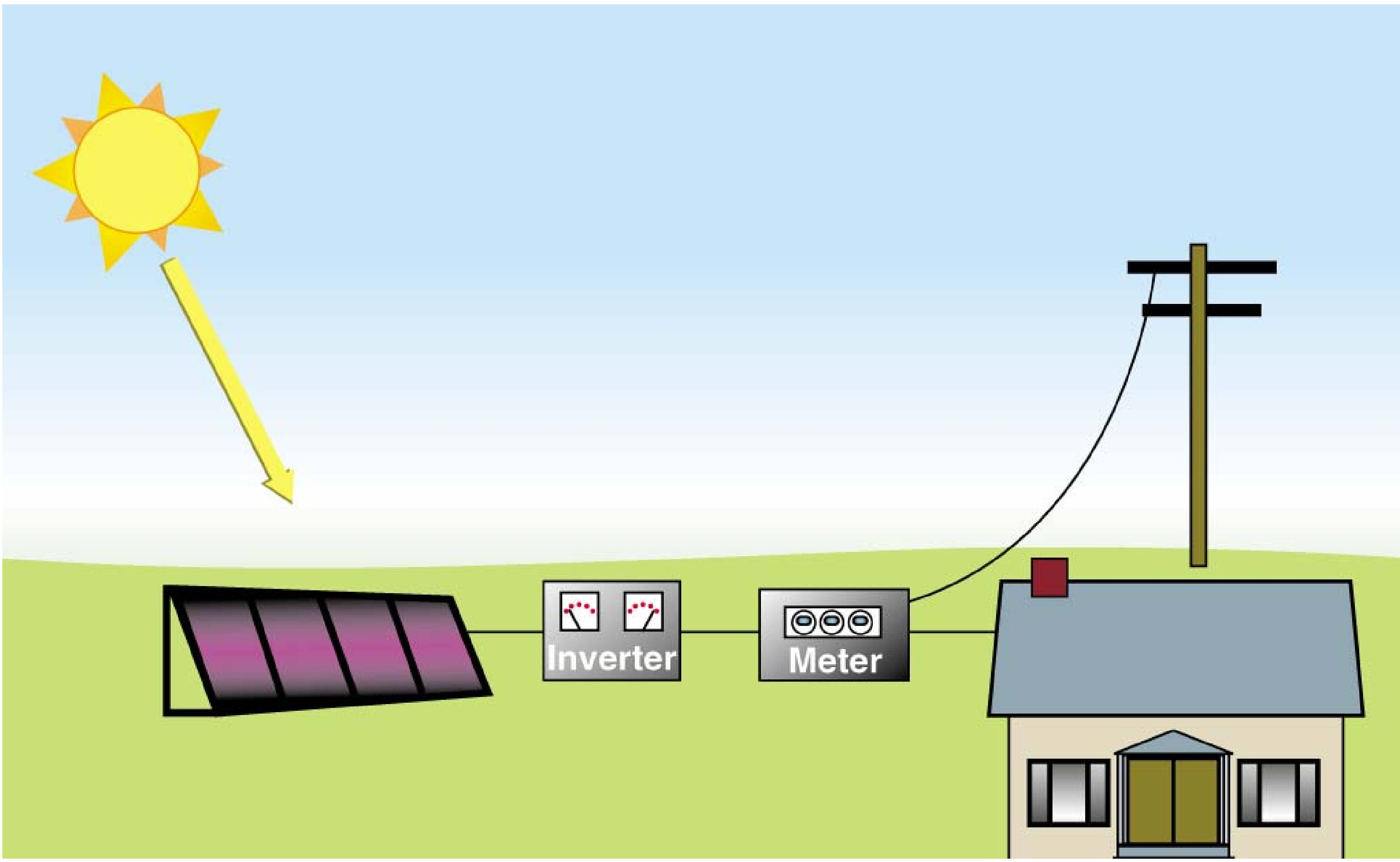
Inverters convert dc to ac

Inverters require an enclosure and may be placed with switchgear and controllers

Inverters are matched to system voltage and array power level

System controls represent the least reliable components in a PV system

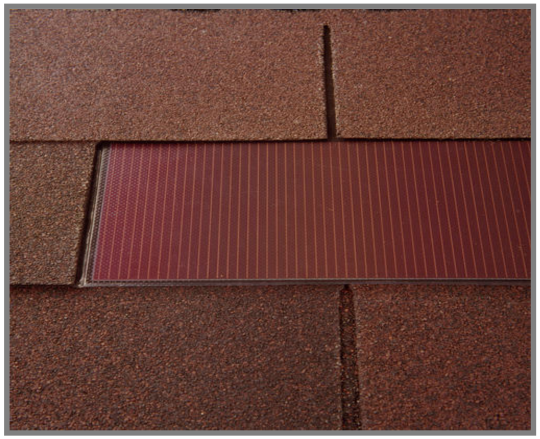
Utility-Connected (Line-Tie PV System)



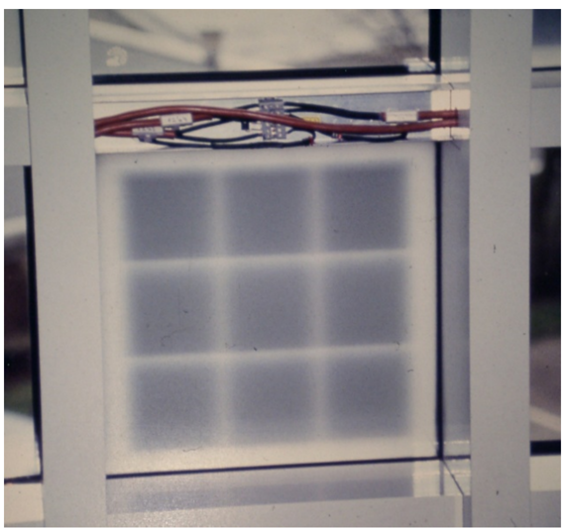

Jicarilla, Apache, NM
2.4 kW Grid Connected
Dulce High School

SunEdison 8MW, San Louis Valley, CO

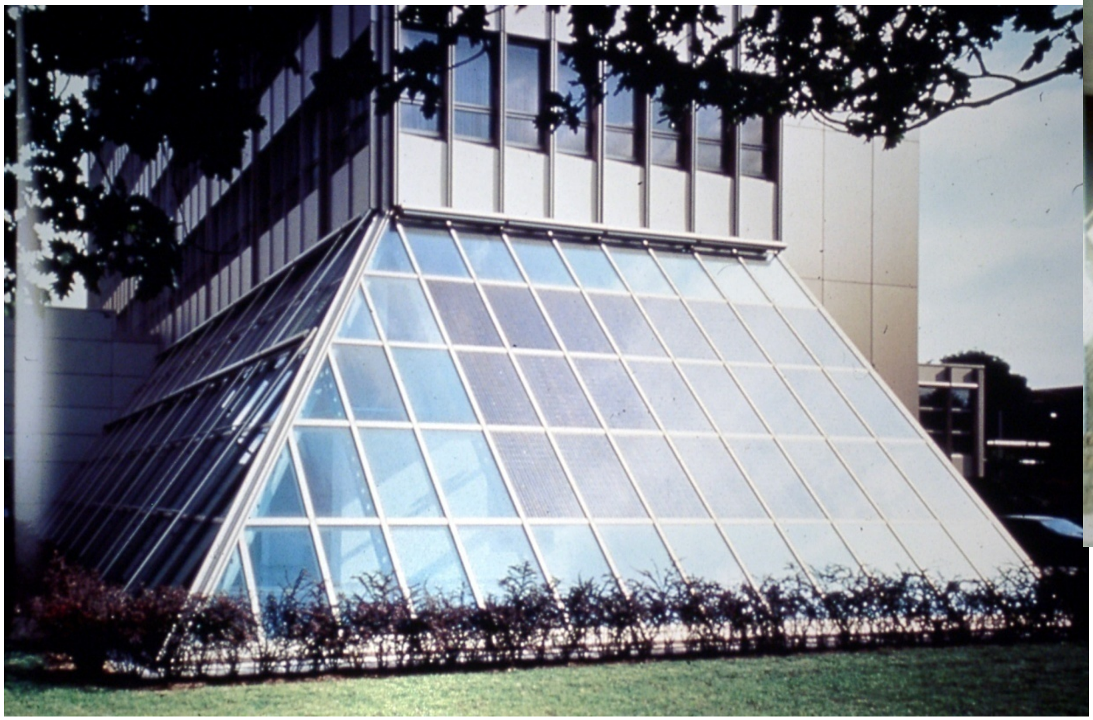
Building-Integrated PV (BIPV)



Building Facade



Windows



Roofing

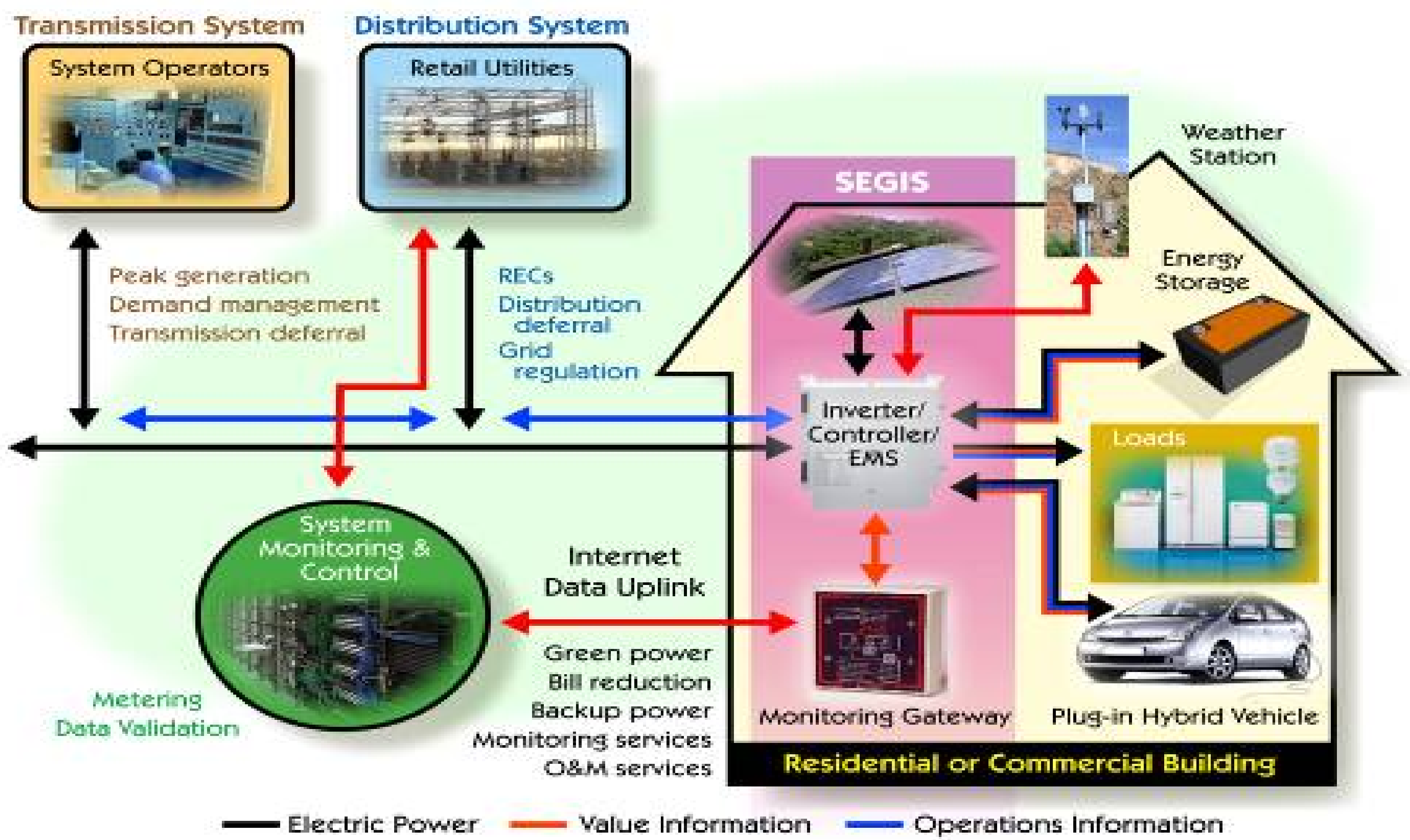
Skylights

Window Shading

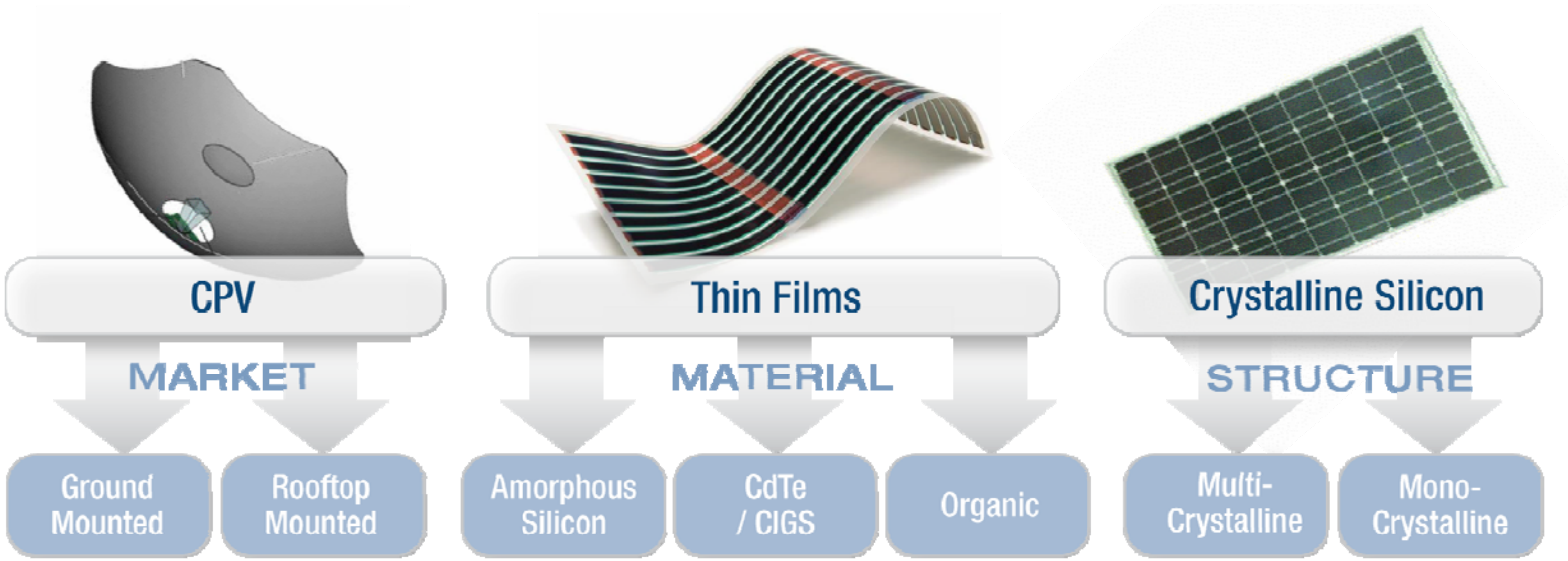
Parking Lot Covers

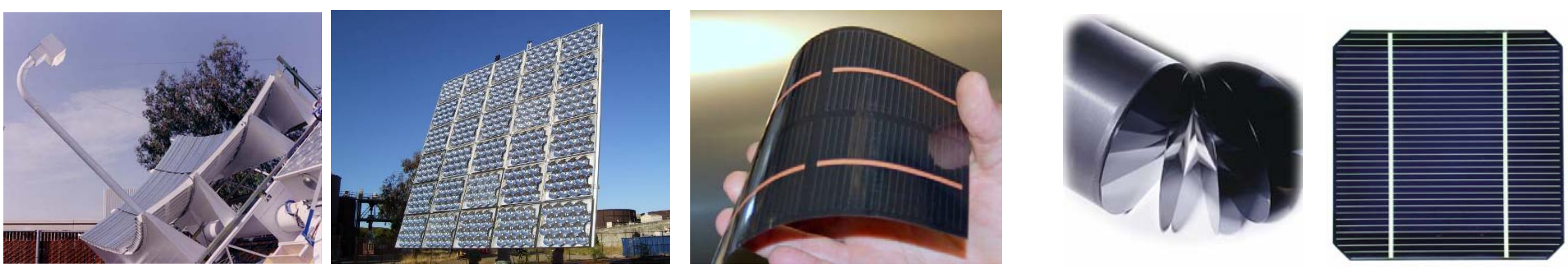
Solar Energy Grid Integration Systems (SEGIS)

- SEGIS is a "System" development program focused on new requirements for interconnecting PV to the electrical grid.
- SEGIS is the intelligent hardware that strengthens the ties of Smart Grids, Microgrids, PV, and other Distributed Generation.



Government and industry are pursuing a range of promising PV technologies

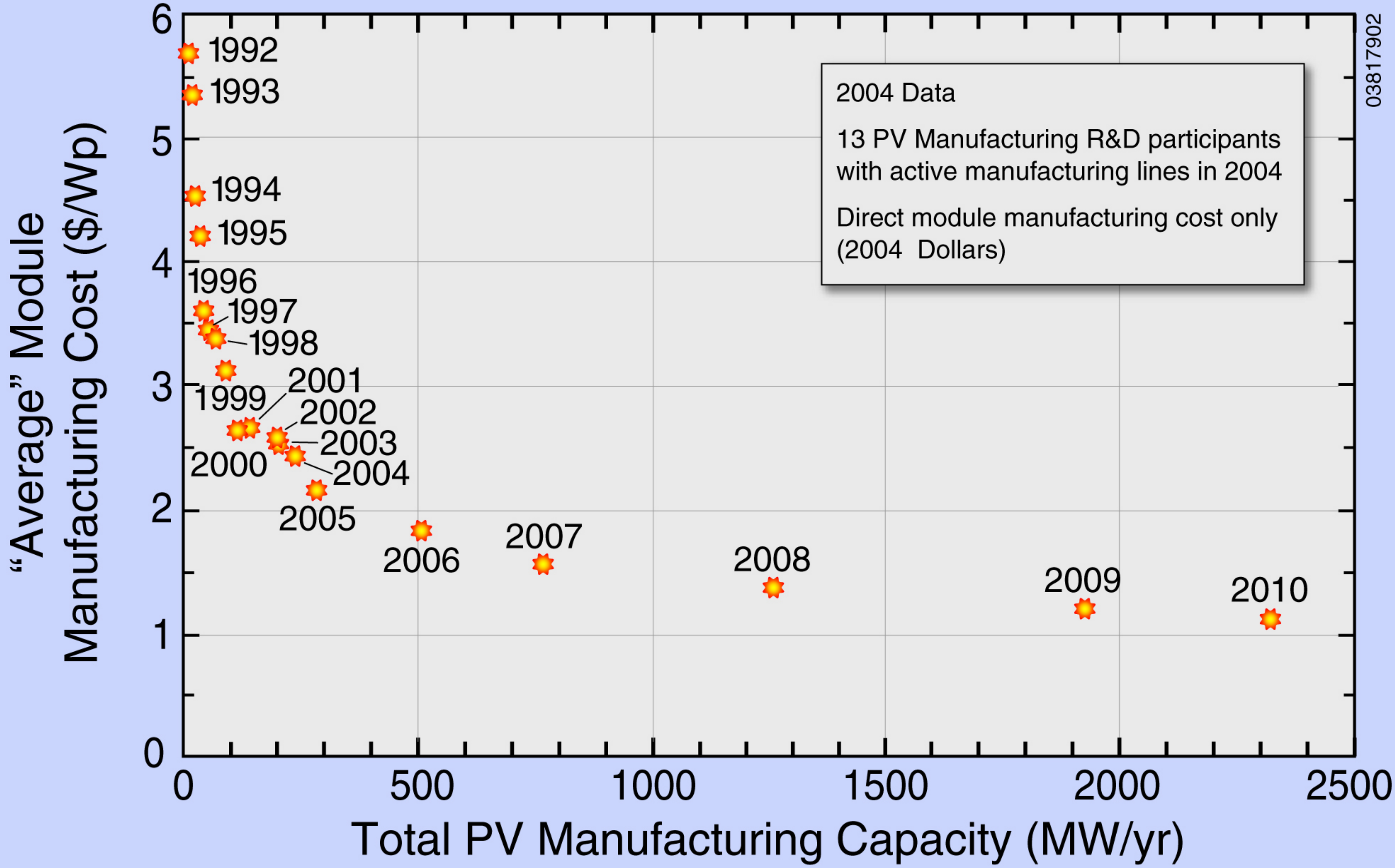




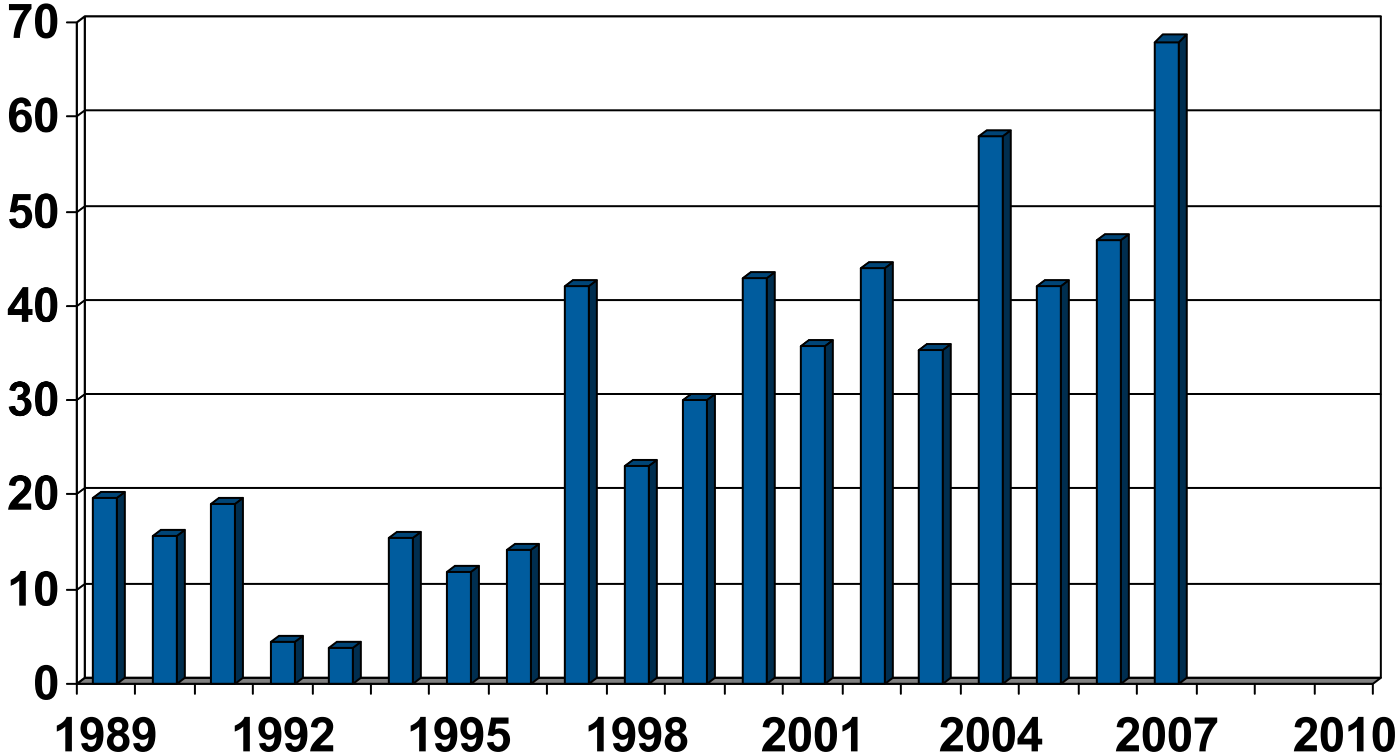
Crystalline Silicon, Thin-Films, and Concentrators

PV Industry Cost/Capacity

(DOE/US Industry Partnership)

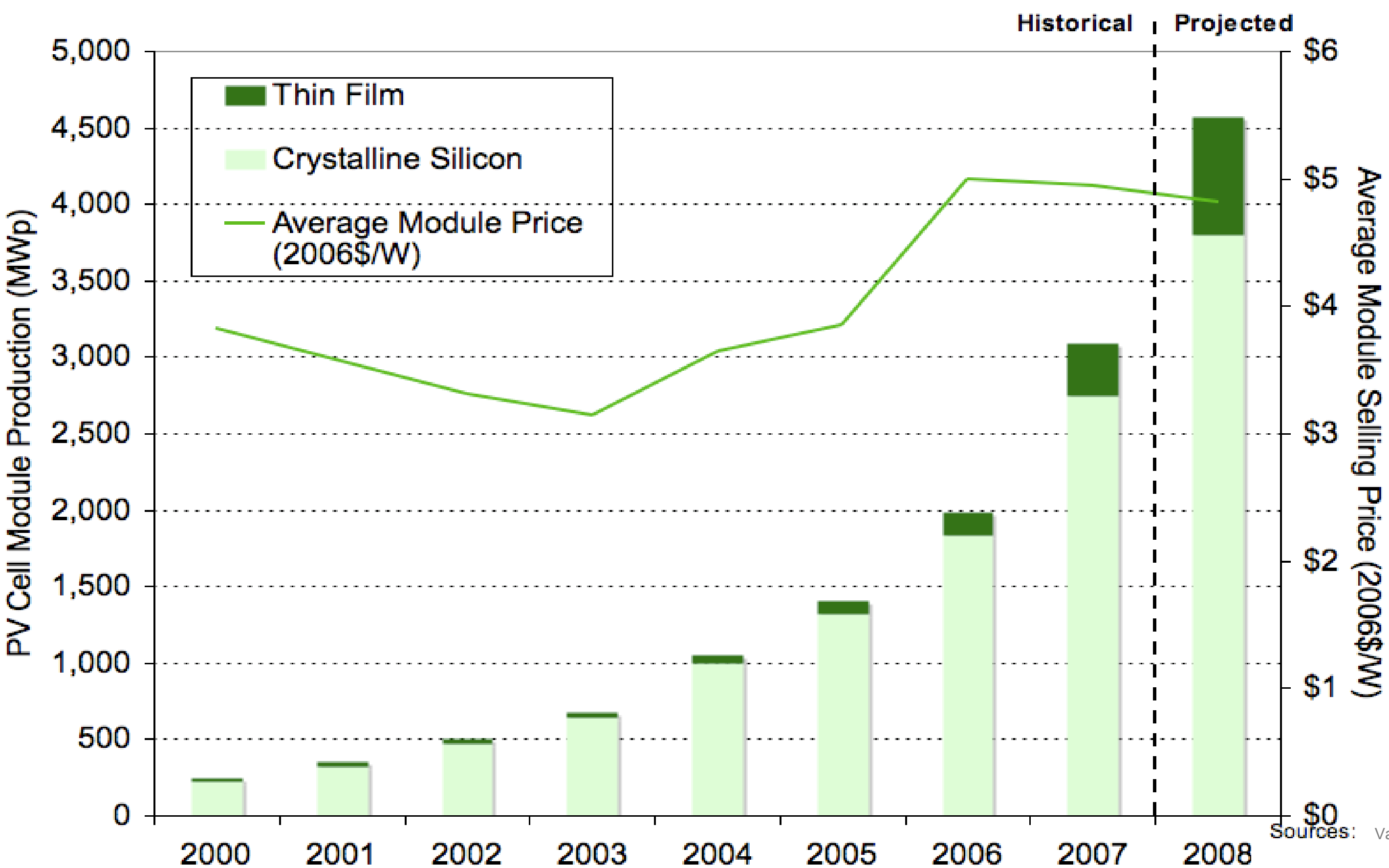


Percent Annual Growth in World Total PV Production



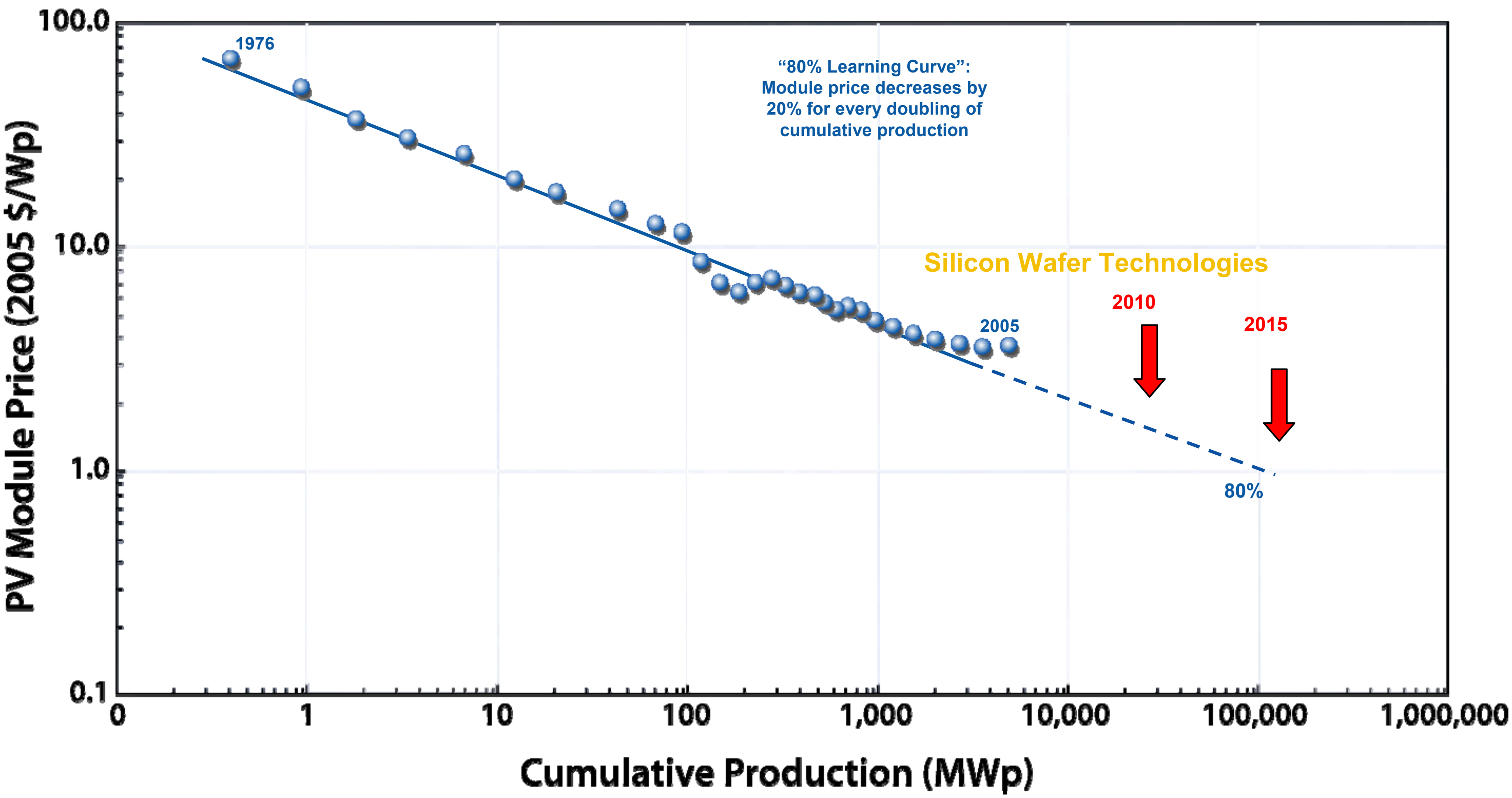
The PV market has enjoyed strong growth over the last 5 years

PV module production has grown significantly, but the rise in silicon feedstock prices has temporarily reversed the historical trend of declining average module selling prices



Sources: Various

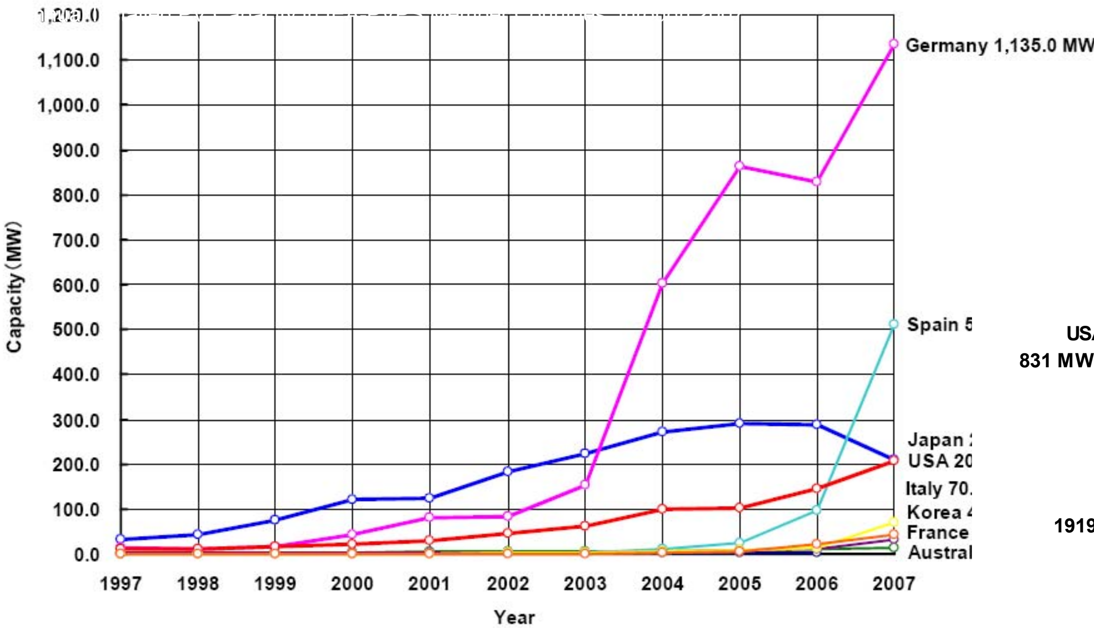
Silicon shortage has held up cost reductions

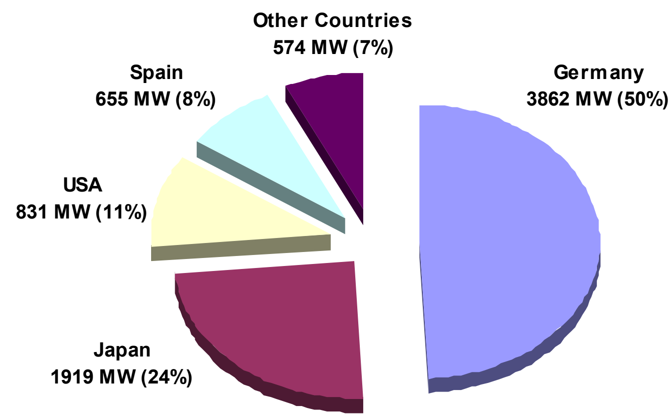


The PV industry is being driven by markets outside the US

At the end of 2007, cumulative installed PV capacity was estimated to be 7,800 MW world-wide, 93% of which is located in Germany, Japan, the US and Spain

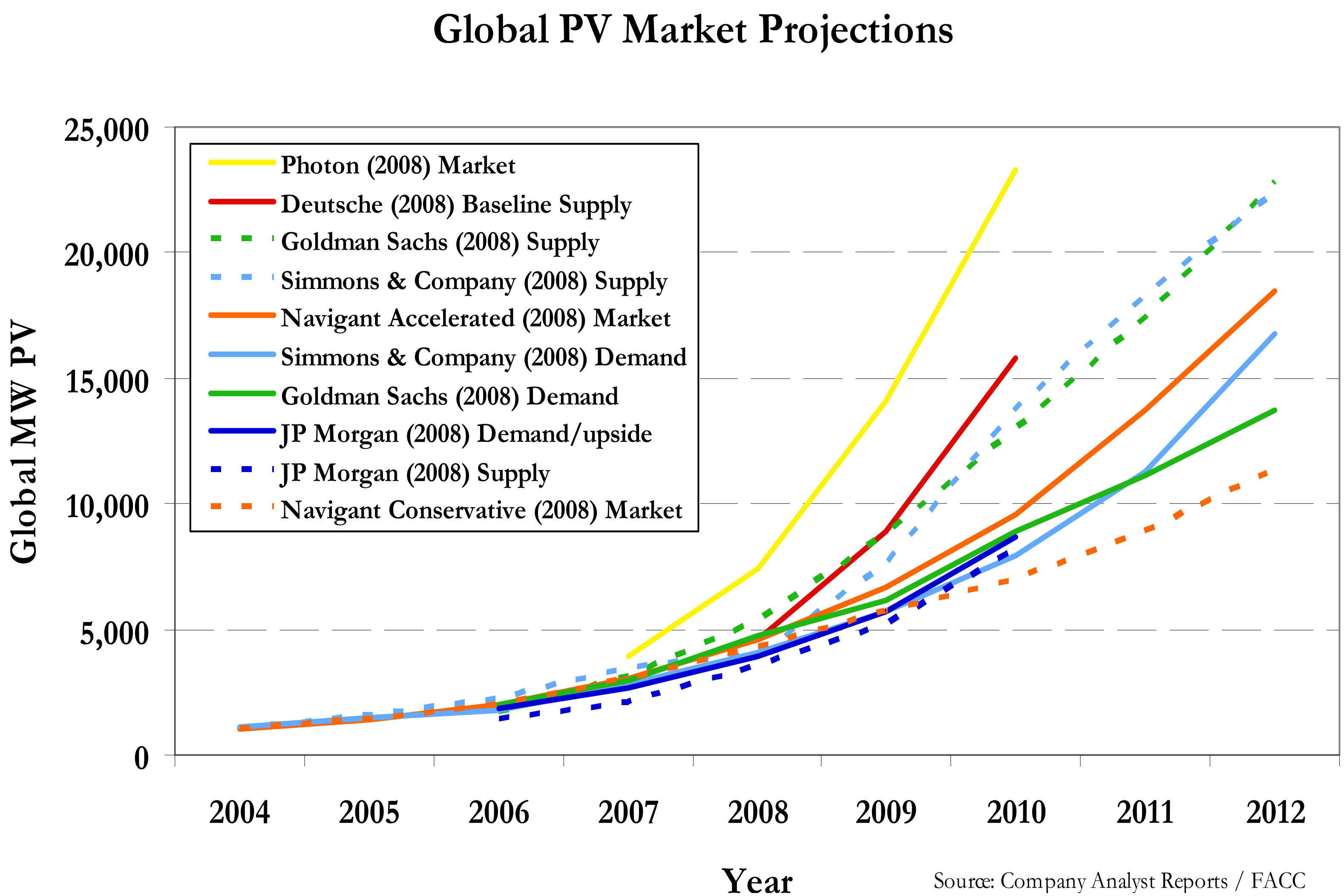
- 7,200 MW is grid-connected
- In addition, there is 430 MW of installed concentrating solar power (CSP), including 419 MW in the US and 11 MW in Spain





There has been considerable uncertainty on PV market size growth projections due to a number of industry factors

This uncertainly has been compounded by the recent global economic slowdown and financial crisis



Source: Company Analyst Reports / FACC

Barrier:

Demand greater than Supply, holding up price

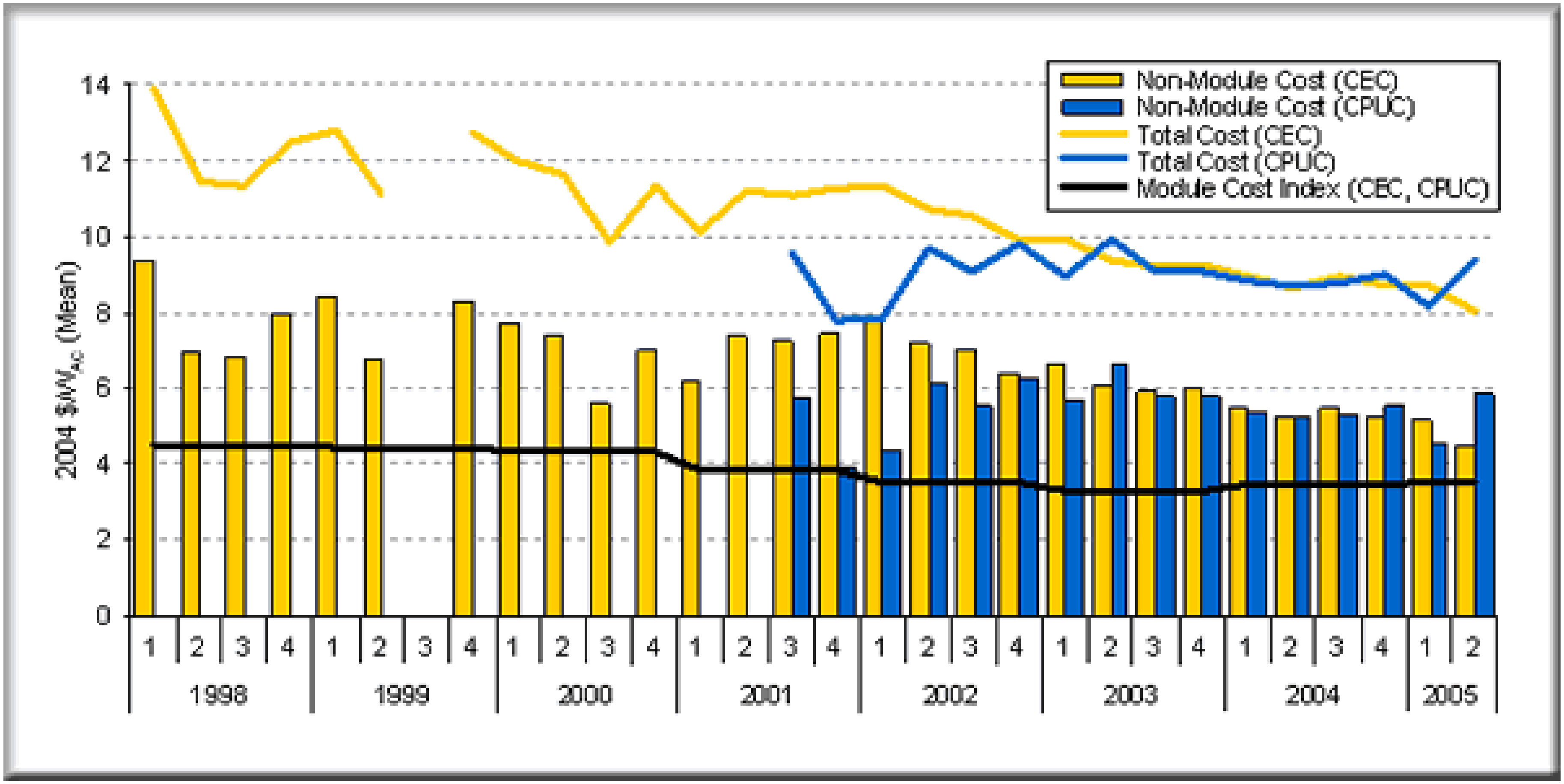
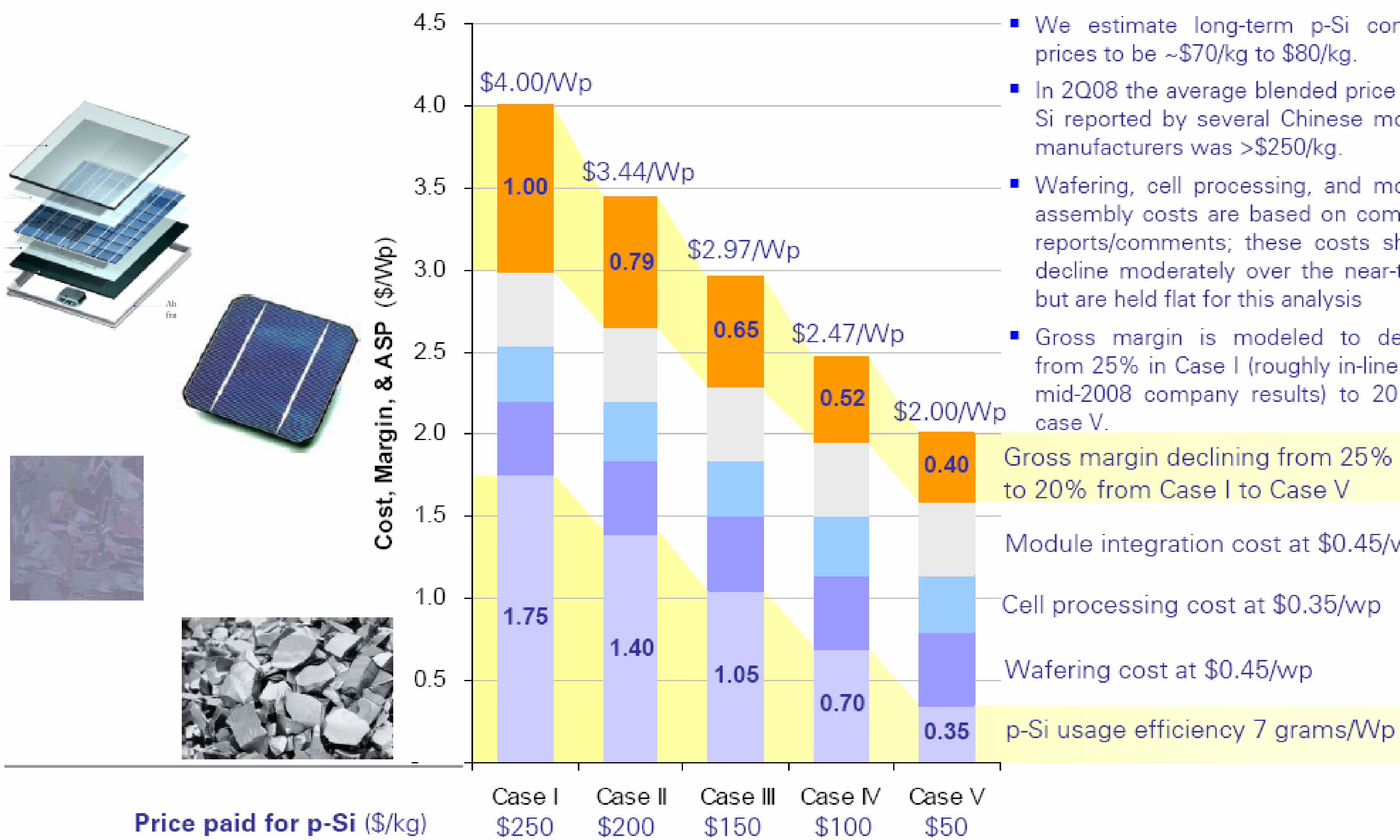


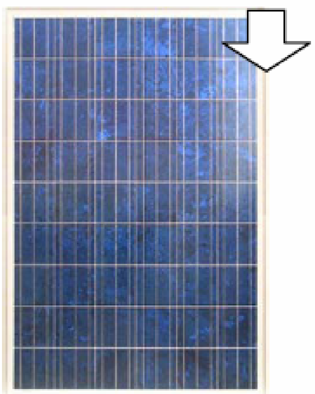
Figure 17: Crystal silicon solar PV module cost breakdown, margins, and ASP

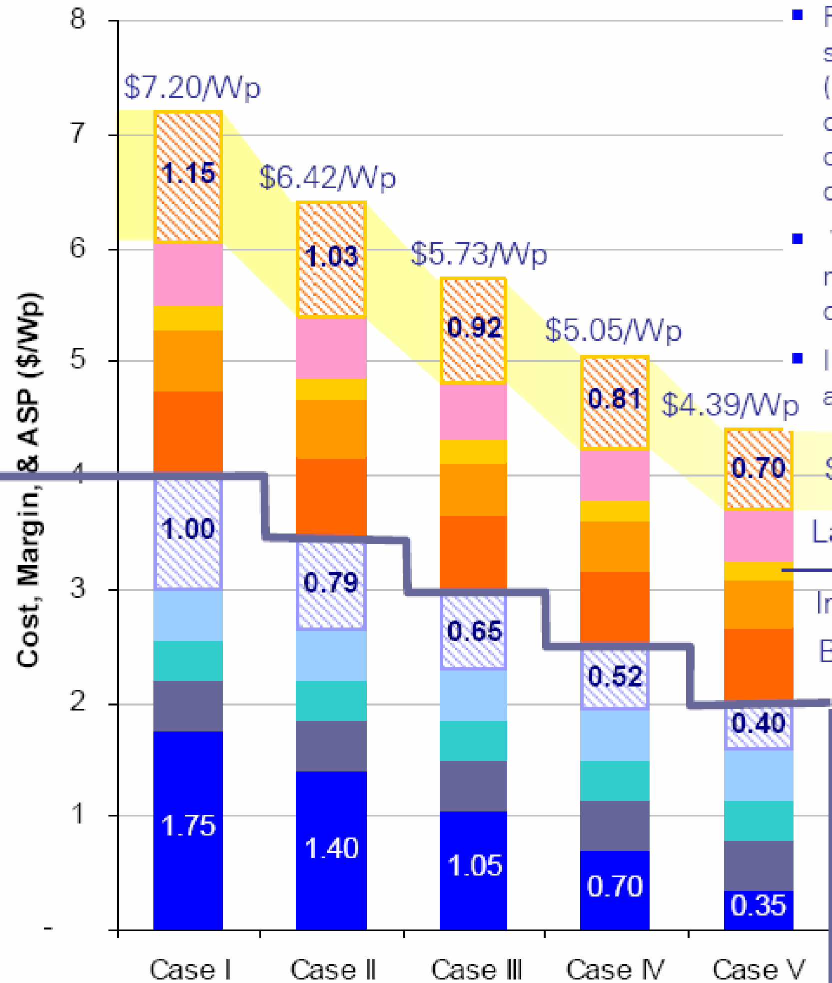


- We estimate long-term p-Si contract prices to be ~$70/kg to $80/kg.
- In 2Q08 the average blended price of p-Si reported by several Chinese module manufacturers was >$250/kg.
- Wafering, cell processing, and module assembly costs are based on company reports/comments; these costs should decline moderately over the near-term, but are held flat for this analysis
- Gross margin is modeled to decline from 25% in Case I (roughly in-line with mid-2008 company results) to 20% in case V.

Source: Company reports and Deutsche Bank estimates

Figure 21: c-Si installed system cost/Wp – costs by segment and gross margin



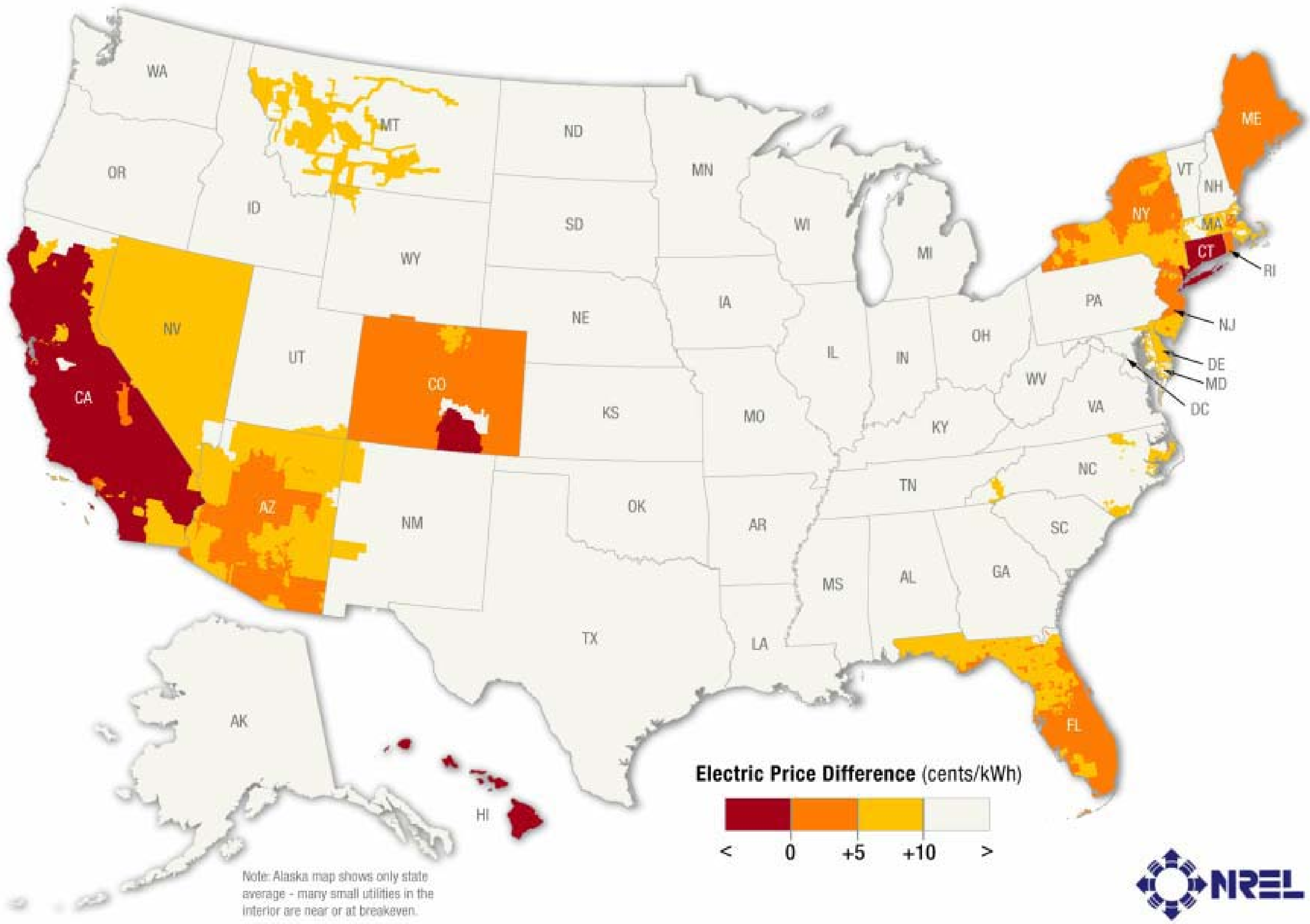


- For a fully integrated installer (e.g. ingot through system), margin stacking with our base case (e.g. module at 20% to 25%, system at 16%) can offer a GM in a mid- to upper-20% range, consistent with industry leaders. This could decline through 2009 as system prices declines.
- We believe gross margin dollars can shift from module to installation, helping fully integrated companies (i.e. all the way to the system).
- Integration/installation costs drop between 3% and 6% per yr in each of the five cases shown.

- Aggregate installed cost declines 39%, from $7.20/Wp to $4.39/Wp through 5 scenarios.
- Installation cost declines 25%, from $3.20/Wp to $2.39/Wp through 5 scenarios.
- Module ASP declines 50%, from ~$4.00/Wp to $2.00/Wp, through 5 scenarios, modestly below our c-Si ASP forecast looking to 2011.

Source: Deutsche Bank estimates

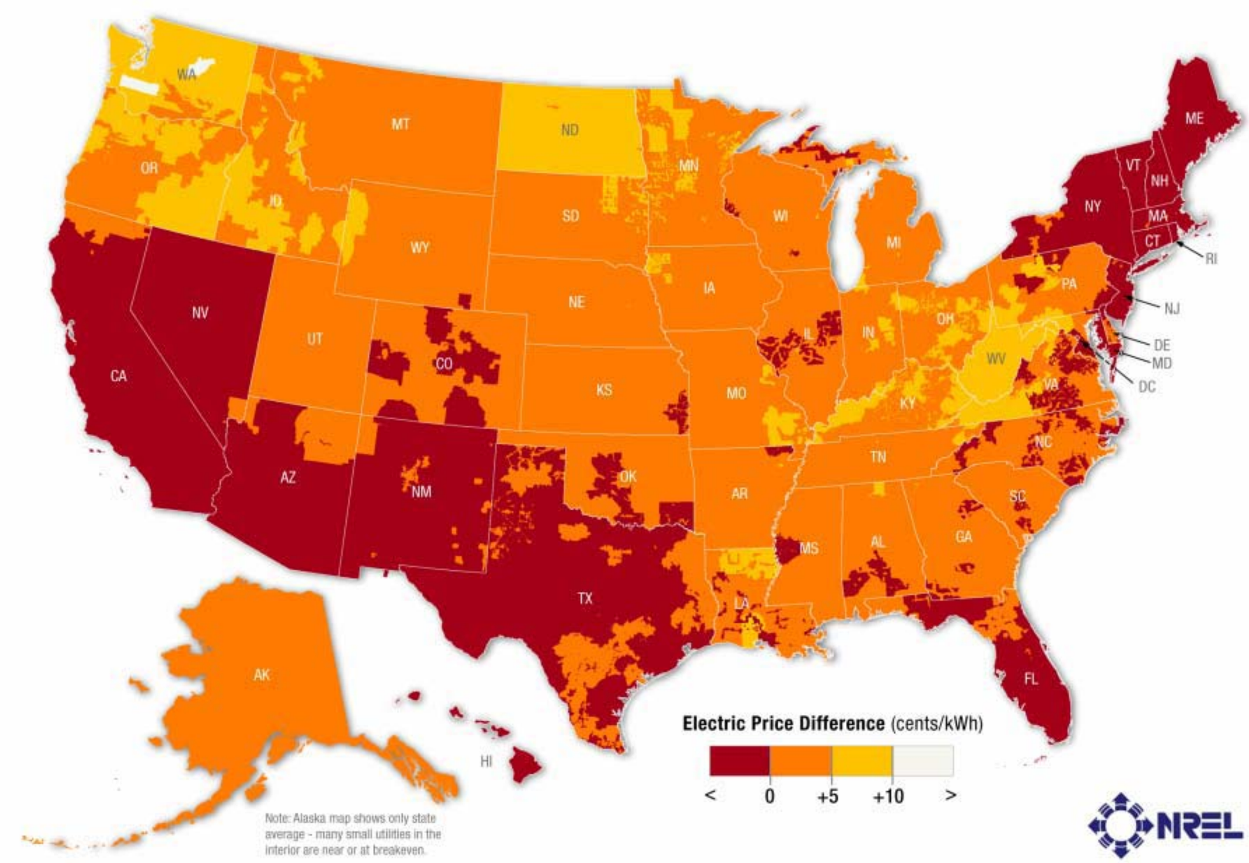
Currently PV is *financially competitive* where there is some combination of high electricity prices, excellent irradiance and/or state/local incentives.



Assumptions: For the price of electricity, the average electricity price for the 1000 largest utilities in the U.S. based on EIA data for 2006 (except CA, where existing tiered rates structures were used). **The installed system price is set at $8.5/Wp** in the current case and is assumed to be financed with a home equity loan (i.e., interest is tax deductible), with a 10% down payment, 6% interest rate, with the owner in the 28% tax bracket, and a 30 year loan/30 year evaluation period. Incentives included are the Federal ITC worth $500/kW due to $2000 cap and individual state incentives as of December 2007.

The ***conservative forecast*** - 2015 residential <u>without</u> incentives and <u>moderate</u> (1.5% annual) increase in real electricity prices

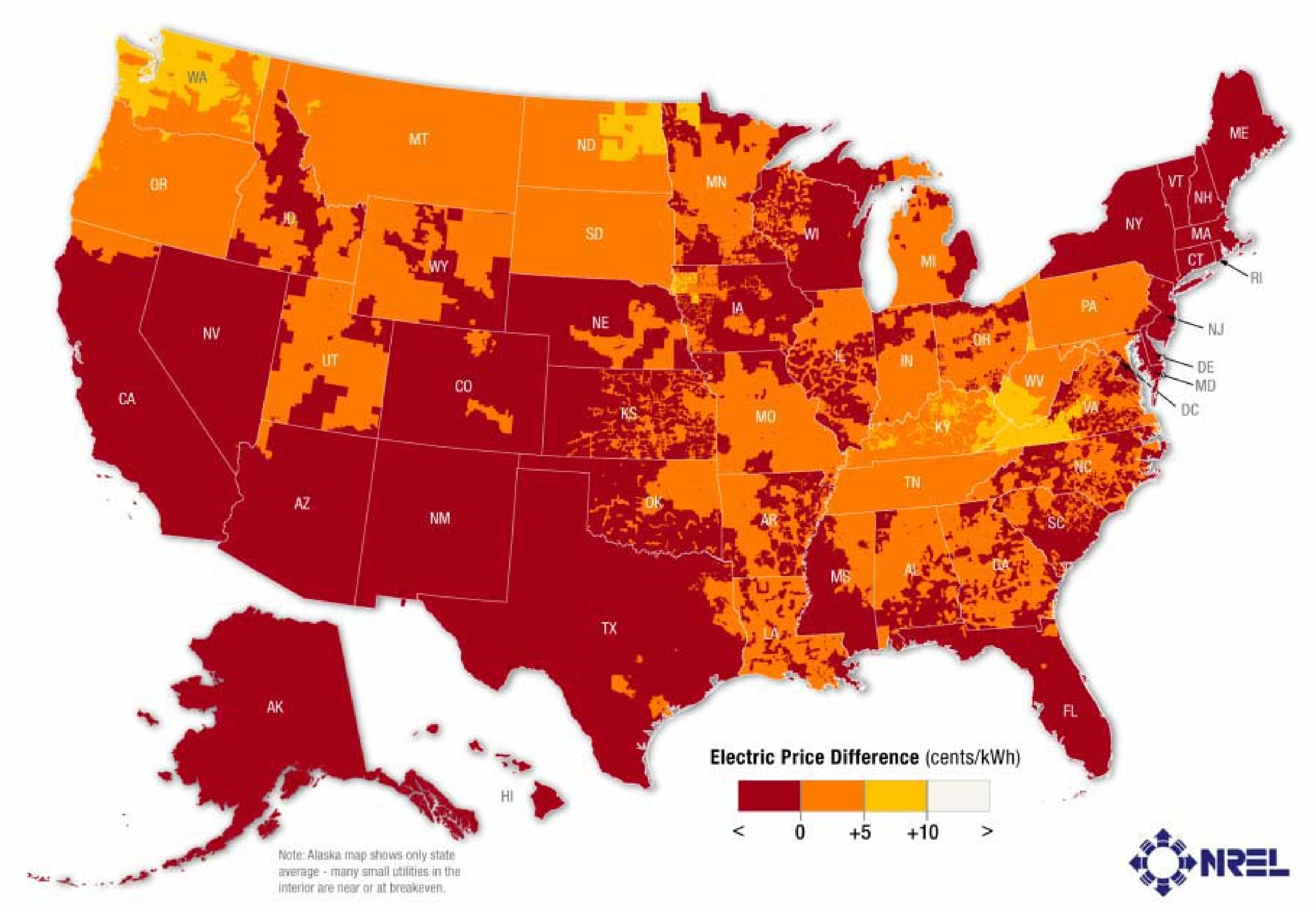
- PV is less expensive in 250 of 1,000 largest utilities, which provide ~37% of U.S. residential electricity sales
- 85% of sales (in nearly 870 utilities) are projected to have a price difference of less than 5¢/kWh between PV and grid electricity



Notes: The installed system price is set at **$3.3/Wp.**

The *realistic forecast* - 2015 residential installations without incentives and aggressive (2.5% annual) increases in real electricity prices

Price of carbon: Not included

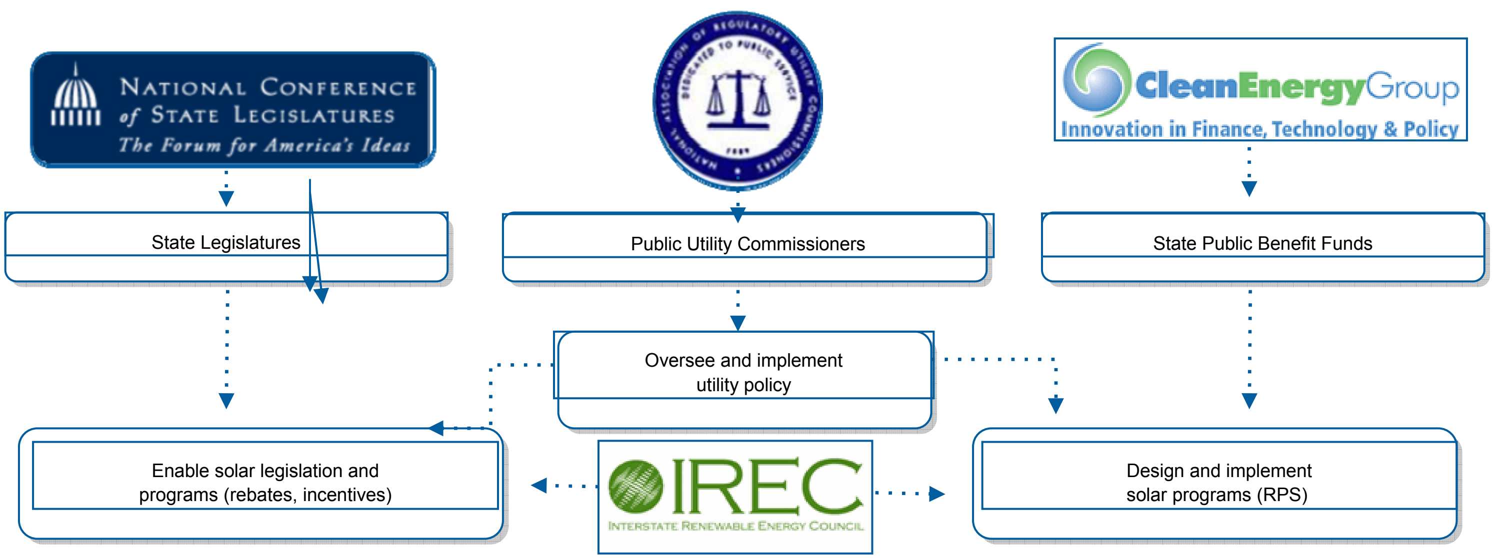


Notes: The installed system price is set at **$3.3/Wp.**

State Technical Outreach

Activity Objectives:

- Build relationships with State decision-makers responsible for enacting policies, programs, and plans that are key drivers for solar technology market transformation.
- Provide state policymakers with best practice and current data about solar technology, so they can make informed solar policy decisions.



Utility Technical Outreach

Activity Objective:

- Deliver key technical and informational assistance to utilities to promote their acceptance and use of solar.

SEPA will assist their 175 member organizations and non-member utilities in the following ways:

- Develop new business cases for solar
- Provide current information on solar technologies
- Disseminate innovative solar program design information to utilities

Boston, MA – February 18, 2009

– Few doubts remain that the solar market is at the leading edge of a massive correction. The latest report from Lux Research, entitled "Finding the Solar Market's Nadir," projects that the available capacity of solar cells and modules will measure twice the demand in 2009, while the overall market could shrink from last year's $36 billion over 5.5 GW to $29 billion over 5.3 GW this year. The report also addresses the question that suppliers, manufacturers and investors are asking now: Where and how soon can they expect the market to bottom out.

"While oversupply in the solar market has been looming for some time, the correction has been more aggressive due to the economic crisis," said Ted Sullivan, Senior Analyst at Lux Research, and the report's lead author. "In order to reduce inventories, suppliers will have slashed their cell and module prices by 25% or more. While this spells a shakeout in the near term, the price reductions will push solar closer to grid parity and prime the market for recovery and growth."

In preparing its report, Lux Research updated the market size and demand forecast made in the September 2008 report "Solar State of the Market Q3 2008," and matched this revised demand forecast with updated capacity projections from 184 polysilicon producers, 162 crystalline silicon cell and module makers, 29 high-concentrating PV (HCPV) developers, 91 thin-film silicon producers, 10 cadmium telluride (CdTe) thin-film module manufacturers, 33 copper indium (gallium) diselenide (CIGS/CIS) developers, and 12 solar thermal providers. The report finds that:

- **Cell and module capacity will overshoot demand by twofold in 2009 to reach 10.4 GW, precipitating a shakeout that will eliminate all but the top players.**

- **Silicon availability will become increasingly irrelevant as module players seek to cut inventory. But the resulting price reductions will flatten out by 2011, bringing solar closer to grid parity and enabling the market to grow to $70 billion across 18.5 GW in 2013.**

- **As the most readily financeable technology, crystalline silicon will continue to dominate the market this year. But competing thin-film technologies, including amorphous silicon and CdTe, will continue to grow aggressively, and CIGS also stands to gain overall despite expectations of widespread company failure.**

- **As the Spanish market dwindles, Germany will again become Europe's buyer of last resort. The U.S. market growth, meanwhile, will depend heavily on the government stimulus package just signed.**

"Last year, we successfully predicted that an oversupply of solar modules and dwindling project financing would lead to a shakeout," said Sullivan. "Now we're projecting that in coming years the decrease in solar module prices will begin to taper off and that demand will pick back up, setting the stage for even broader adoption."

Wide Range of PV Applications