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# Charting a Course to Energy Independence

## Providence, RI
## August 9-12, 2009

# Some Facts About Solar Energy

- **More energy from sunlight strikes the Earth in one hour than all the energy consumed on the planet in one year (13 TerraWatts).**

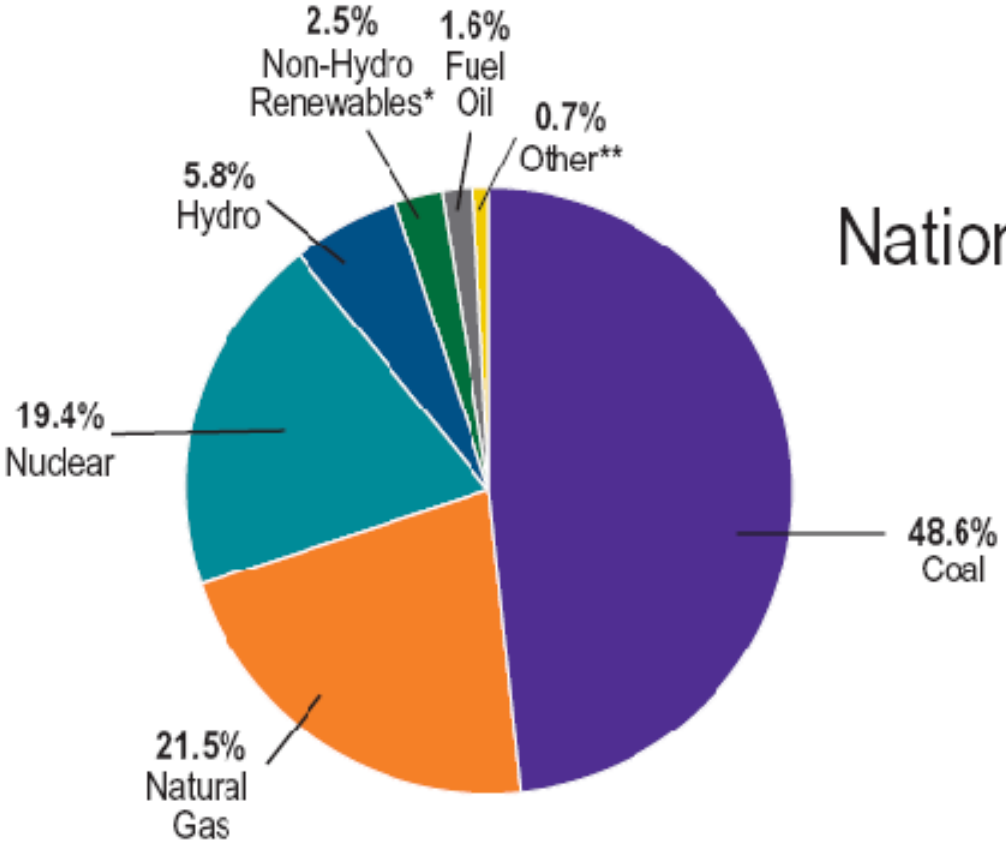
- **Completely carbon-free energy source**

- **Solar energy is the only long-term option capable of meeting the energy (electricity and transportation fuel) needs of our planet.**

- **Estimated retractable resource (DOE/Office of Basic Sciences):**

| | |
|---|---|
| **- Solar** | **7,500 TW** |
| **- Wind** | **14 TW** |
| **- Hydro** | **1 TW** |
| **- Ocean** | **0.6 TW** |
| **- Geothermal** | **2 TW** |

# Electric Companies Use a Diverse Mix of Fuels to Generate Electricity




## 2007 National Fuel Mix

* Includes generation by agricultural waste, landfill gas recovery, municipal solid waste, wood, geothermal, non-wood waste, wind, and solar.

** Includes generation by tires, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies

Sum of components do not add to 100.0% due to independent rounding.

Sources: U.S. Department of Energy, Energy Information Administration, Power Plant Report (EIA-906), and Combined Heat and Power Plant Report (EIA-920).

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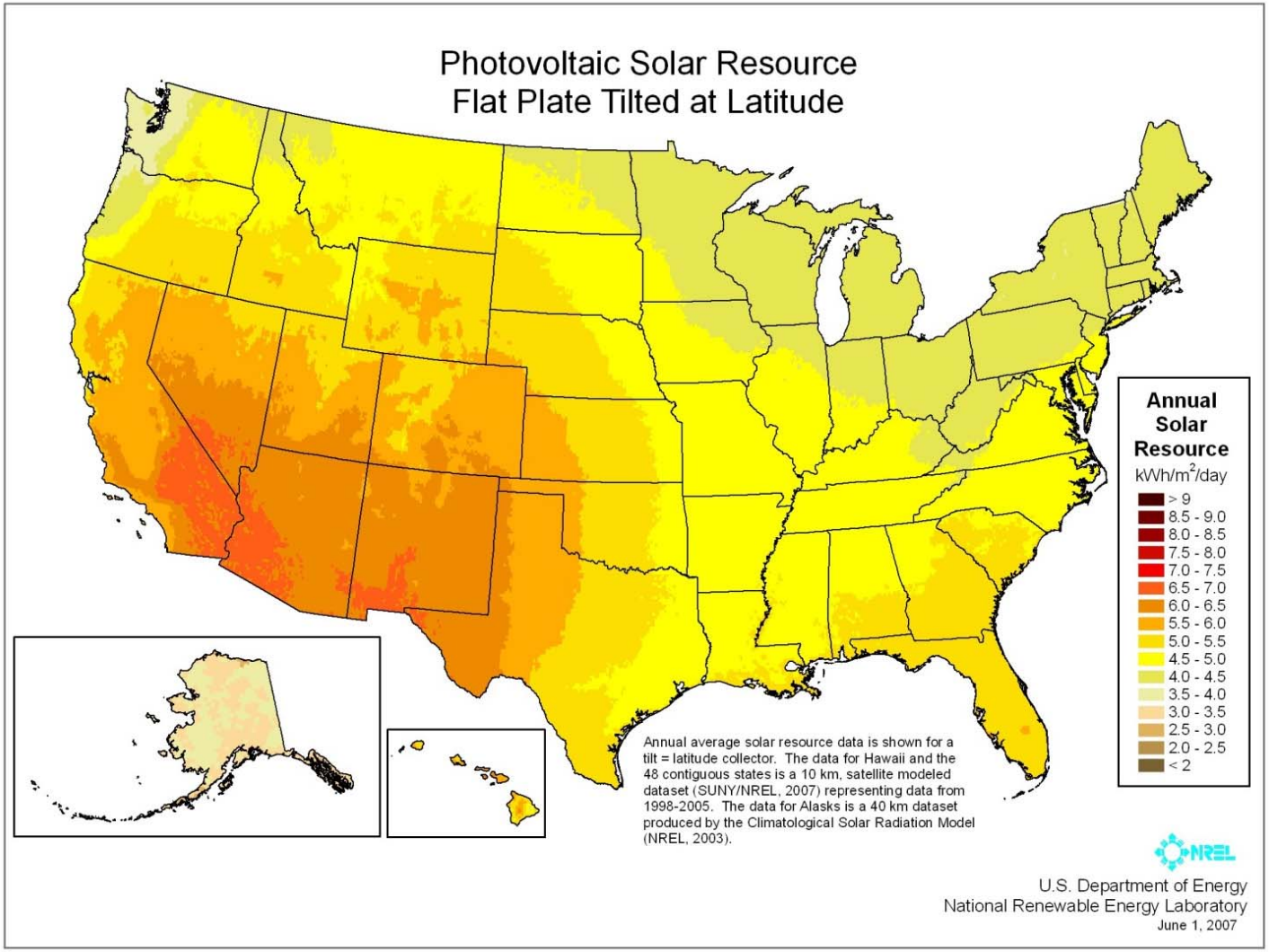
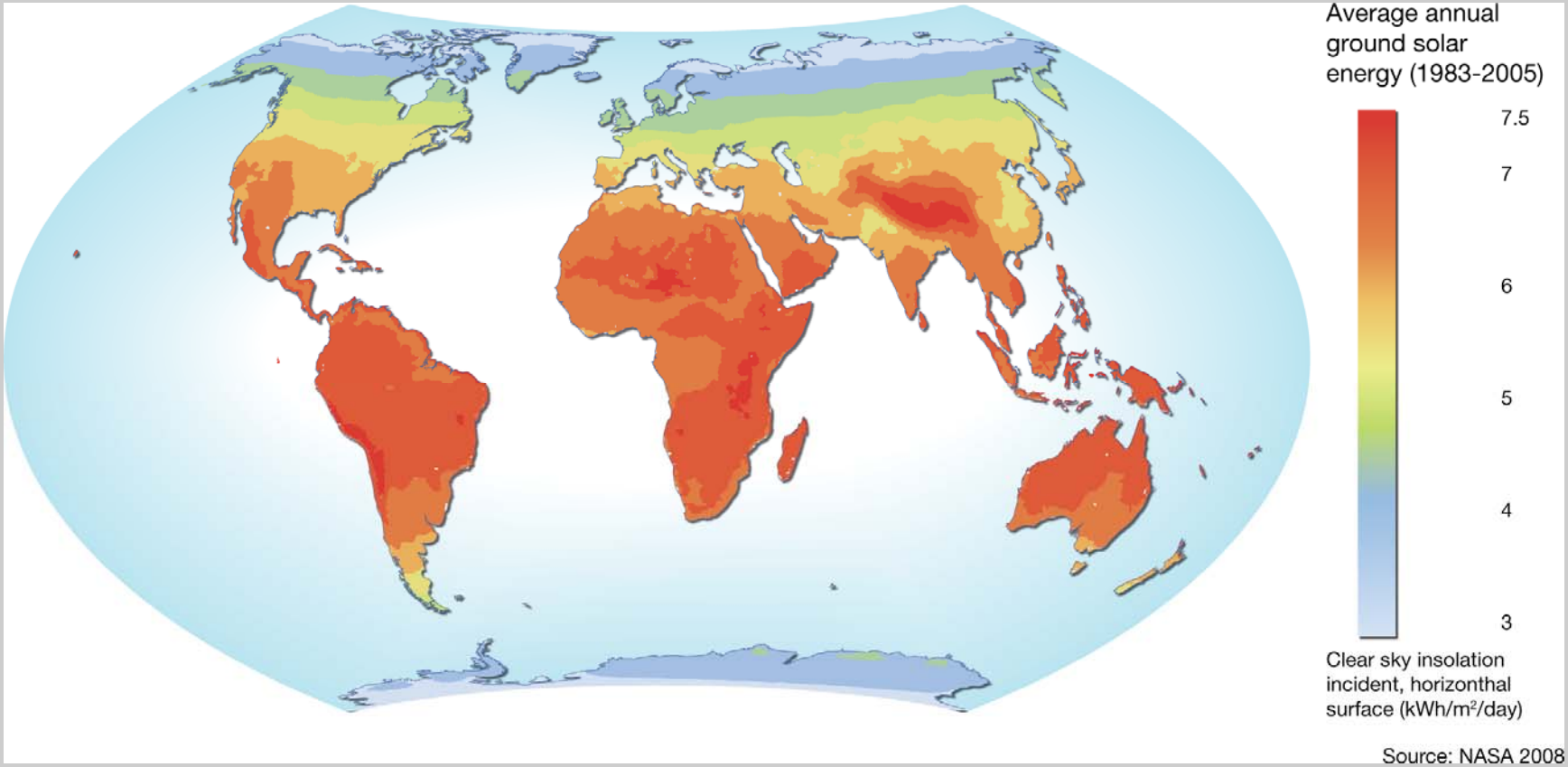
# In the U.S. solar resources significantly outweigh energy use

- Currently, solar provides less than 0.1% of the electricity used in the U.S.
- All of the electricity in the U.S. could be provided using:
  - Less than 2% of the land dedicated to cropland and grazing.
  - Less than the current amount of land used for corn ethanol production.



# Also globally solar resources significantly outweigh energy use

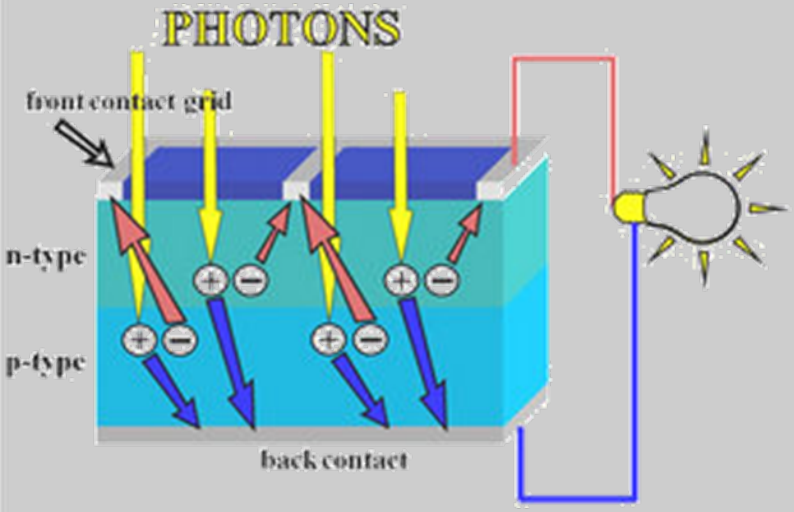



- Covering less than 0.2% of the land on the earth with 10%-efficient solar cells would provide twice the power used by the world.

# Converting the sun's radiation into electricity – two main pathways

## Photovoltaics (PV)

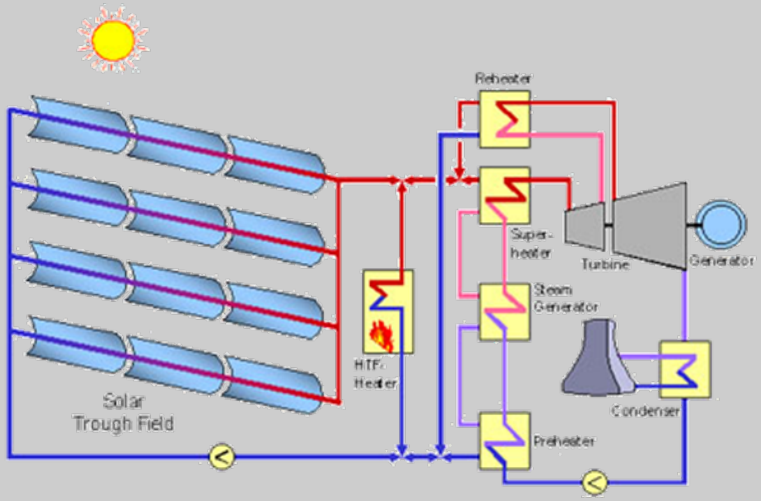
Cells of semi-conductors absorb photons and directly convert them into electrical current.




Can be used anywhere in the U.S.

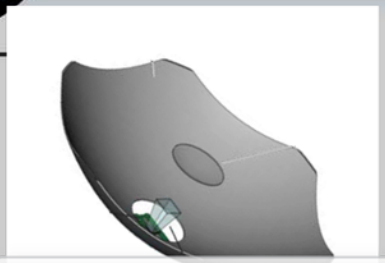
## Concentrating Solar Power (CSP)

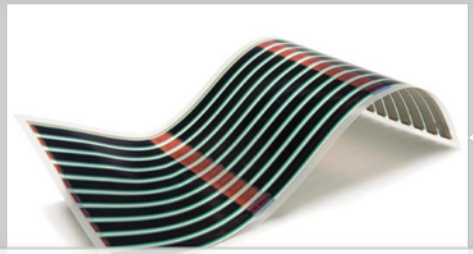
Mirrors focus solar radiation to heat fluids that are used to drive electric generators.

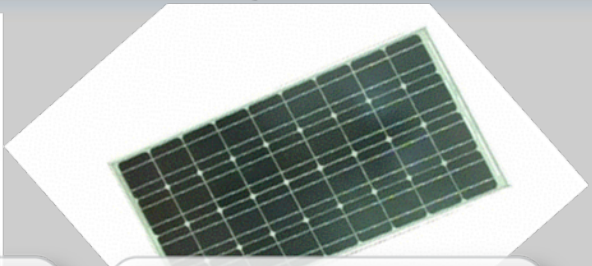



Predominantly in the Southwest U.S. (requires direct sunlight)

# Government and industry are pursuing a range of promising PV technologies…







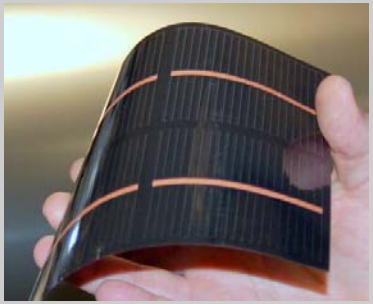
**CPV** — MARKET: Ground Mounted; Rooftop Mounted

**Thin Films** — MATERIAL: Amorphous Silicon; CdTe / CIGS; Organic

**Crystalline Silicon** — STRUCTURE: Multi-Crystalline; Mono-Crystalline

20x-100x

500x



$Cu(In,Ga)Se_2$ ~ 1-2 um

c-Si ~ 180 um

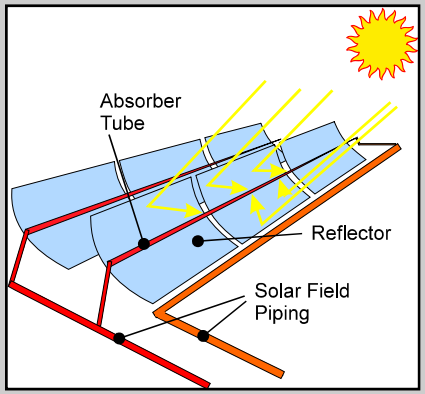
# … and a range of promising Concentrating Solar Power (CSP) technologies

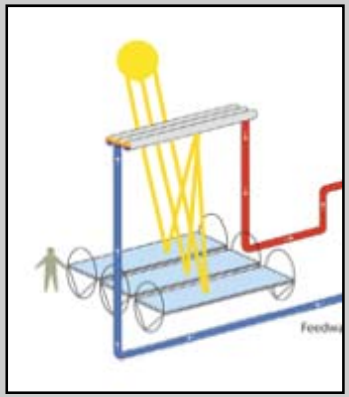
**Trough**

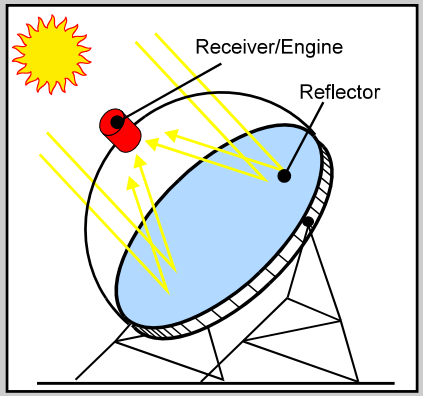
**Linear Fresnel**

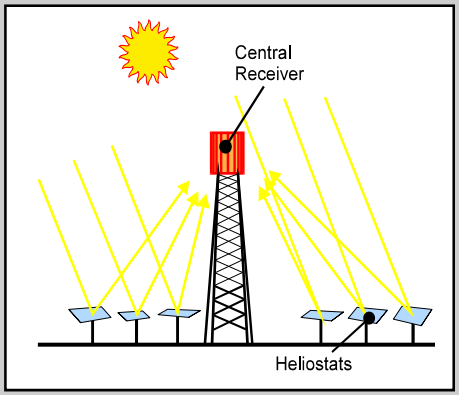
**Dishes**

**Tower**






Utility scale power plants – intermediate and base load power

# Both PV and CSP applications and markets are evolving very rapidly

Residential

Commercial

Utility-scale

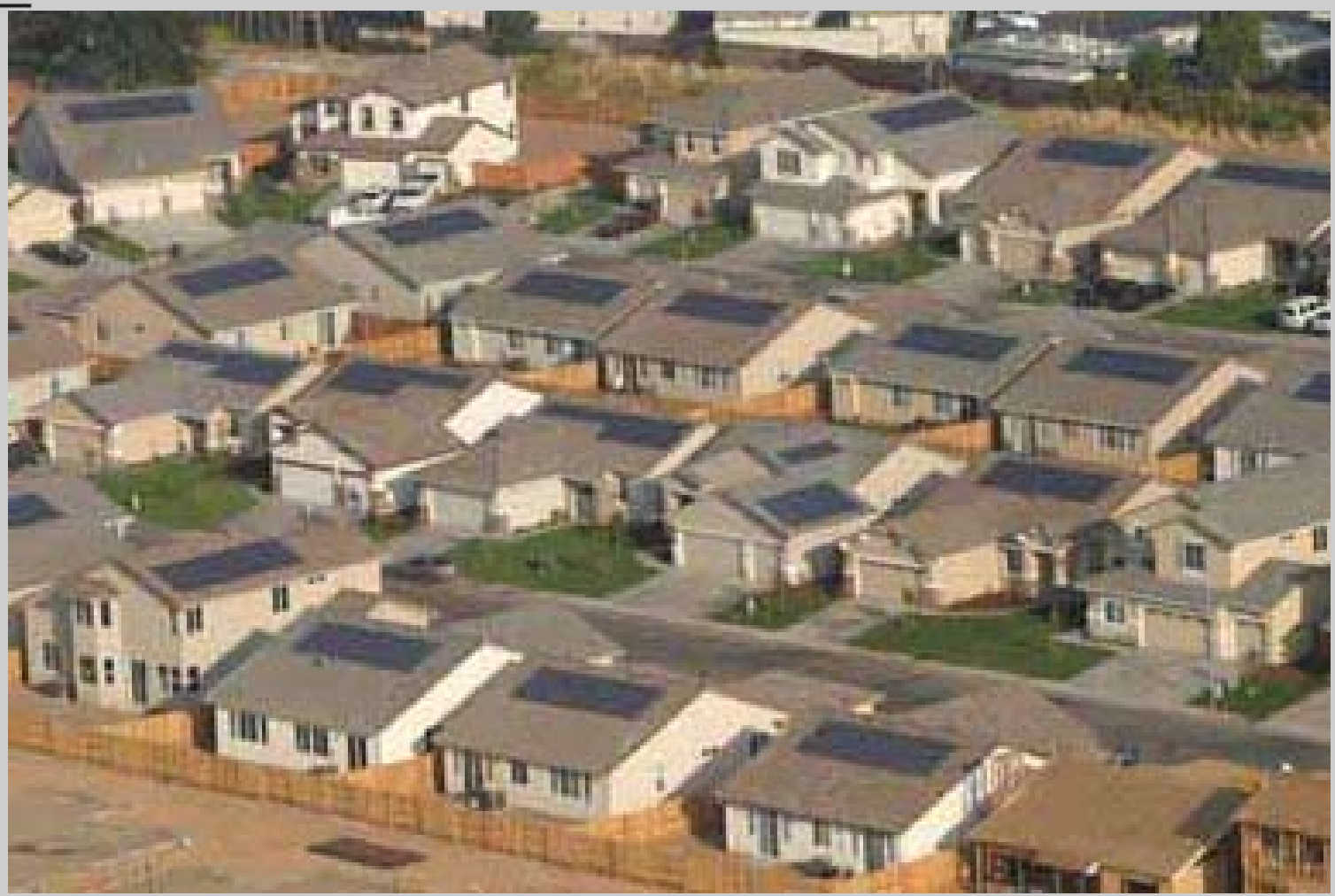
- Solar is a growing source for distributed & centralized electricity generation

## Millennium SportsClub Vacaville

## 152 kW DC

SolarIntegrated

# The landscape for residential PV could change via aggregation: power purchase agreements



# Power Towers

Solar Two  Experiment (1995 – 1997)

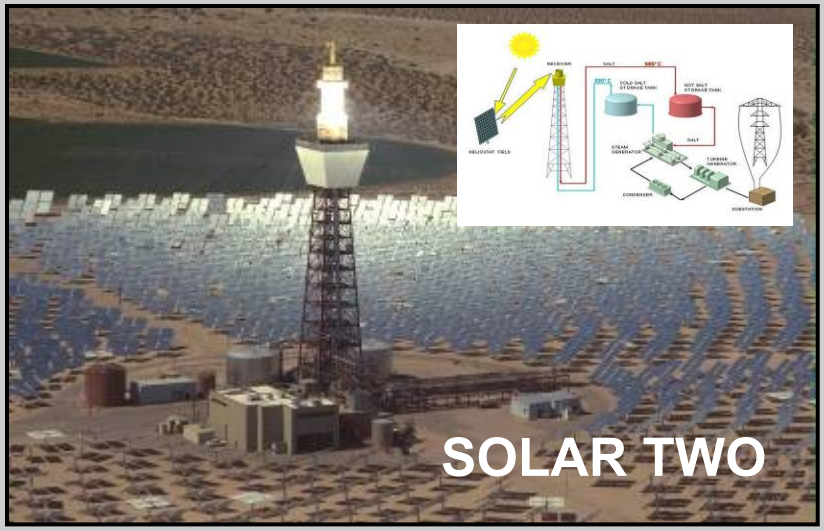
10 MW Capacity

Molten Salt working fluid/thermal st.

Receiver η = 88%

η of Storage > 98%

Dispatchability demonstrated



PS 10 (2006) PS 20 (2009)

11 MW & 20 mw Capacity

Once-through steam boiler

1 Hour thermal storage (steam)

1878 heliostats (120 m² each)

Towers height 100 m and 160 m

73 GWhr/annually

# Parabolic Troughs

Solar Electric Generating Stations (SEGS): 354 MW (1985 – 1990)

"hybridized" with Natural Gas

Total reflective area > 2.3 Mill. $m^2$

More than 117,000 HCEs

30 MW regulated power block

Nevada Solar One (2007)

70 MW Capacity

357,200$m^2$ Solar Field

30 Minutes Thermal Storage

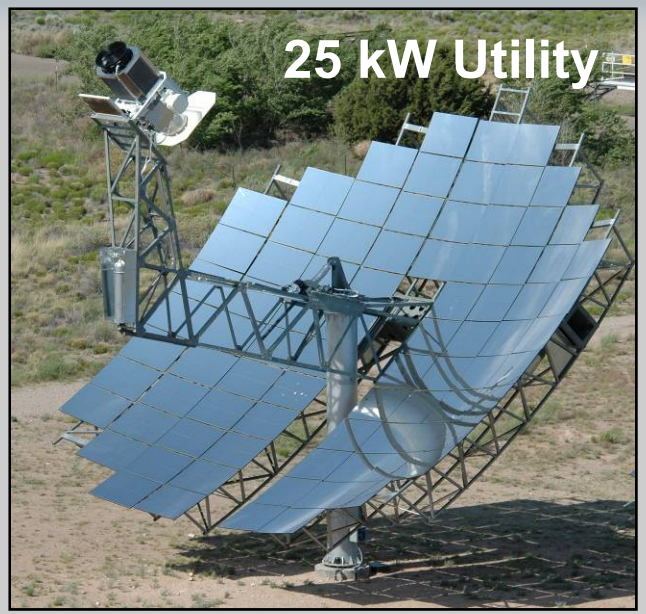
Startup April 2007

# CLFR Designs

- **Continuous Linear Fresnel Reflector**
- **Approximates a line-focus trough collector**
- **May be lower cost because it doesn't use curved mirrors and places the reflectors near ground level -- reducing wind loads**

# CSP Dish Stirling Systems

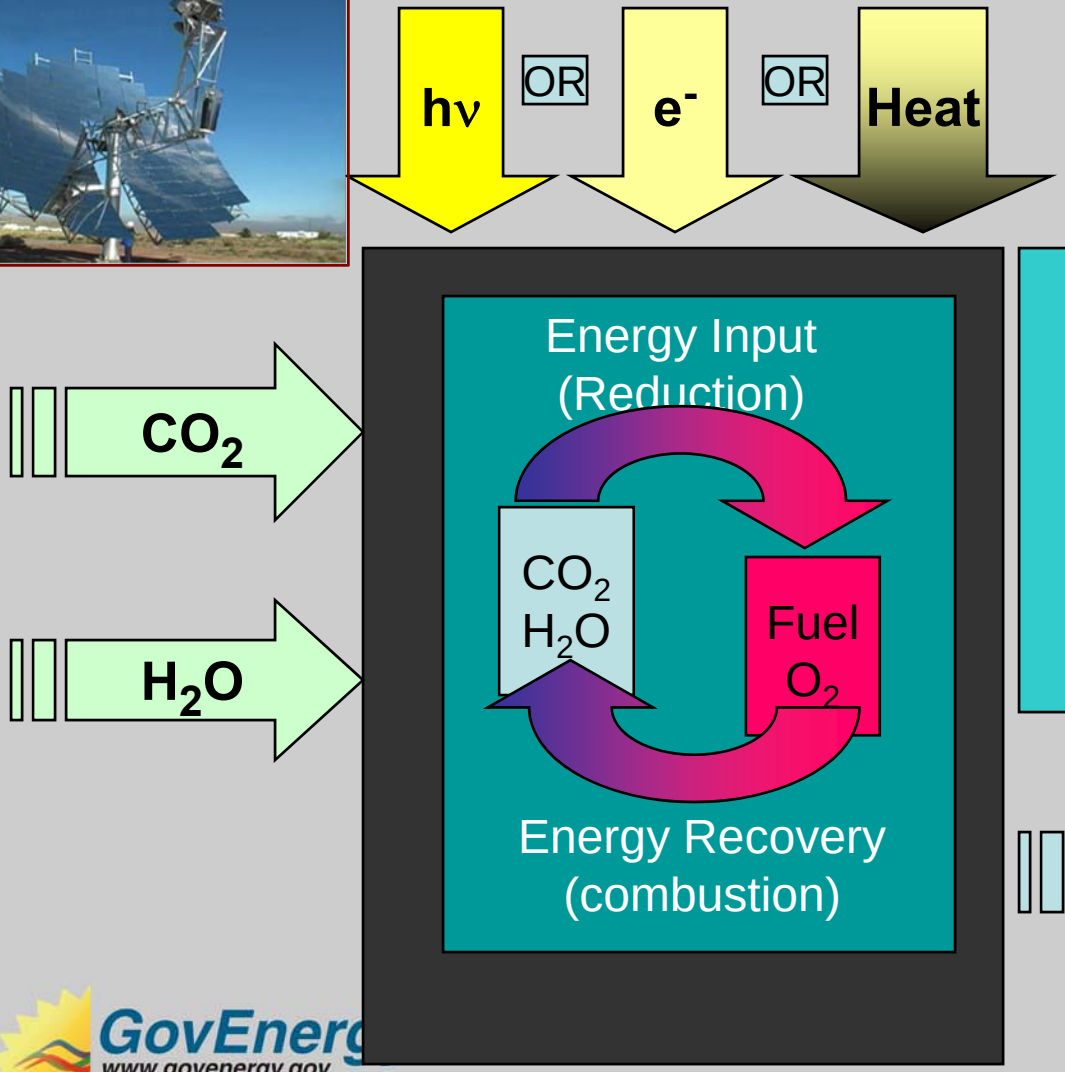
Utility-Scale System:
25 kW system
Peak (net solar-to-electric) efficiency 31.25%
Autonomous operation



Distributed Generation System:
3 kW system
120/240 Volts AC
Autonomous operation

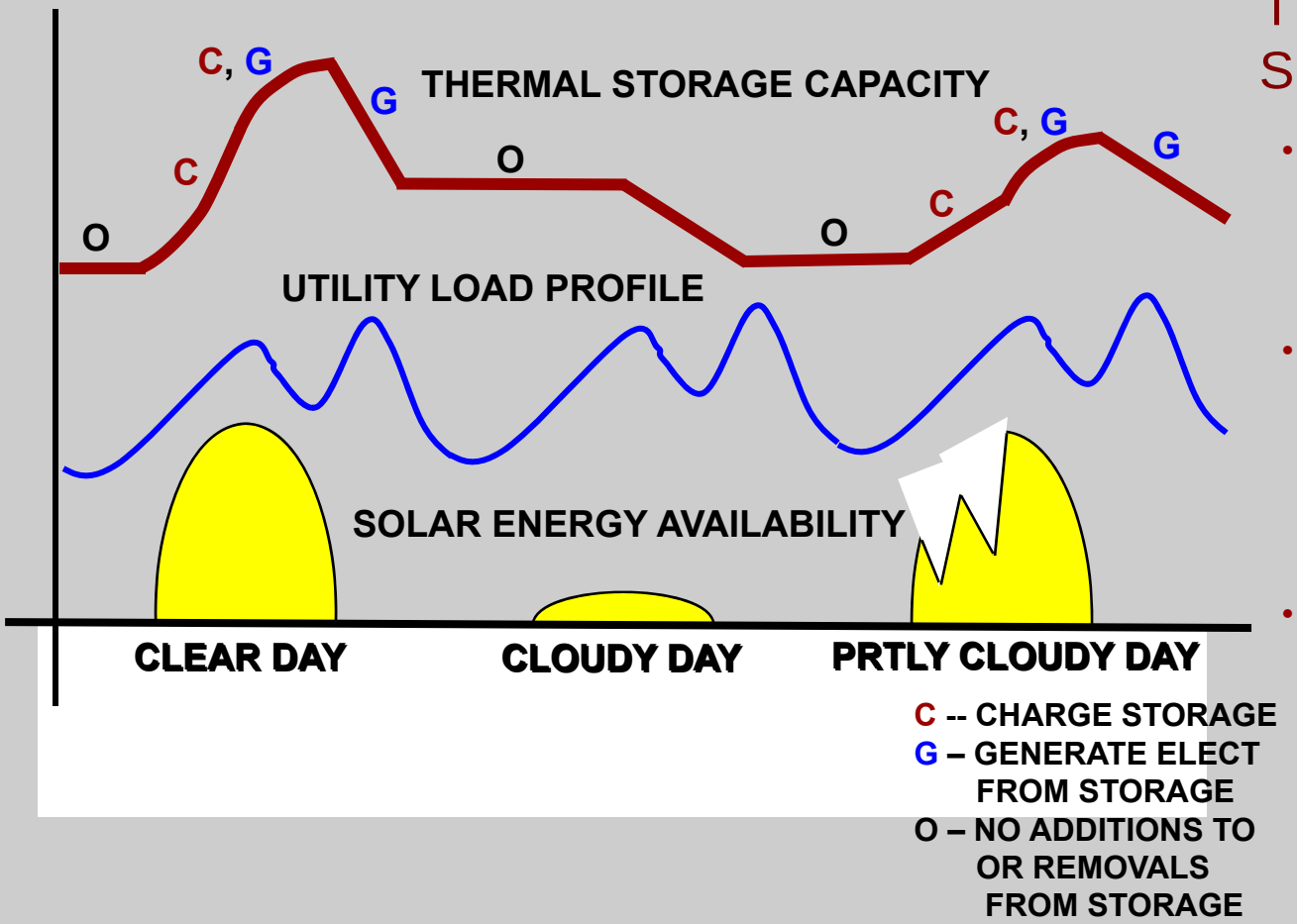
# Solar Driven $CO_2$ to Fuel

## *Biofuels Without the Biology*



# The Value of Thermal Storage

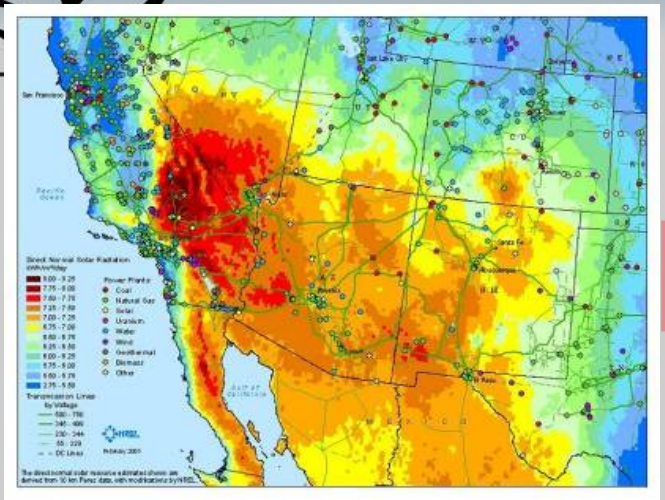
## 3 Days of Operation with Thermal Storage




## THERMAL STORAGE

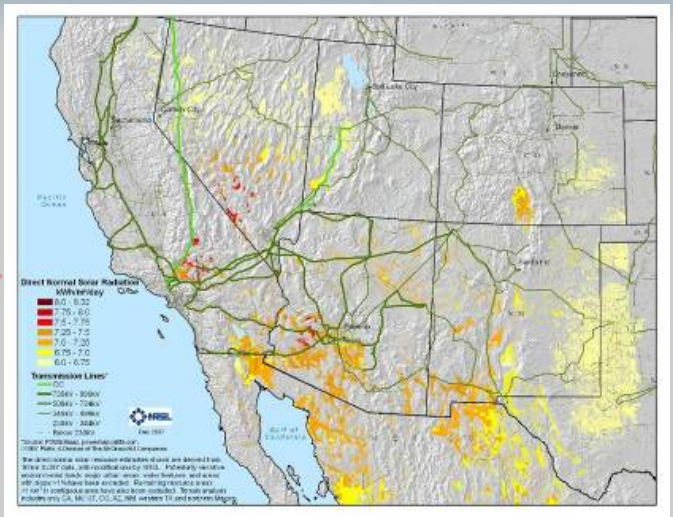
- Decouples solar energy collection and generation
- Has high value because power production can match utility needs
- Is lower cost because storage is cheaper than incremental turbine cost

# CSP Resource Potential



**Filters applied:**

- Direct-normal solar resource.
- Sites > 6.75 kwh/m$^2$/day.
- Exclude environmentally sensitive lands, major urban areas, etc.
- Remove land with slope > 1%.
- Only contiguous areas > 10 km$^2$

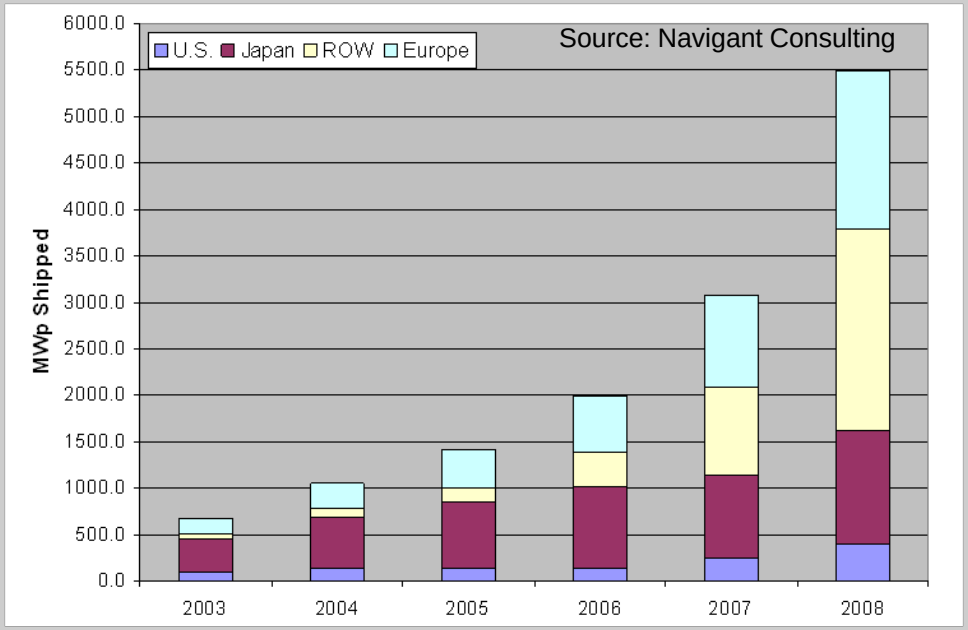


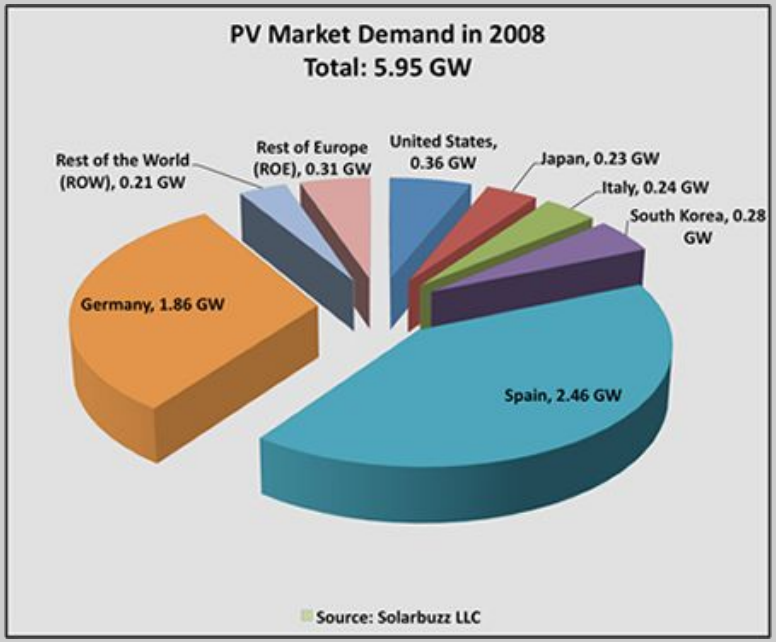
## U.S. Electrical Capacity is 1,000 GW

## Annual power generation of 4,000,000 GWh

| State | Land Area (mi$^2$) | Solar Capacity (MW) | Solar Generation Capacity GWh |
|---|---|---|---|
| AZ | 19,279 | 2,467,663 | 5,836,517 |
| CA | 6,853 | 877,204 | 2,074,763 |
| CO | 2,124 | 271,903 | 643,105 |
| NV | 5,589 | 715,438 | 1,692,154 |
| NM | 15,156 | 1,939,970 | 4,588,417 |
| TX | 1,162 | 148,729 | 351,774 |
| UT | 3,564 | 456,147 | 1,078,879 |
| Total | 53,727 | 6,877,055 | 16,265,611 |

# PV Market Still Taking Off



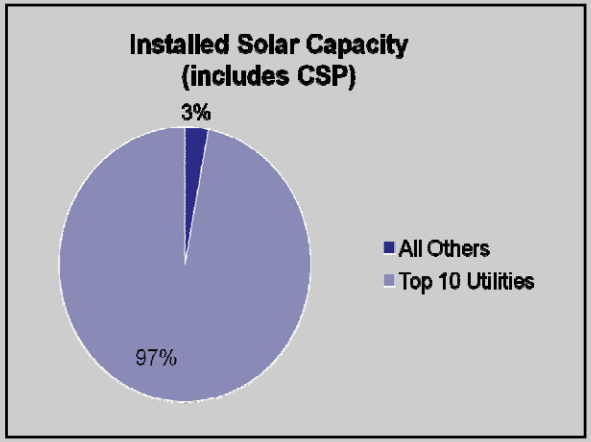



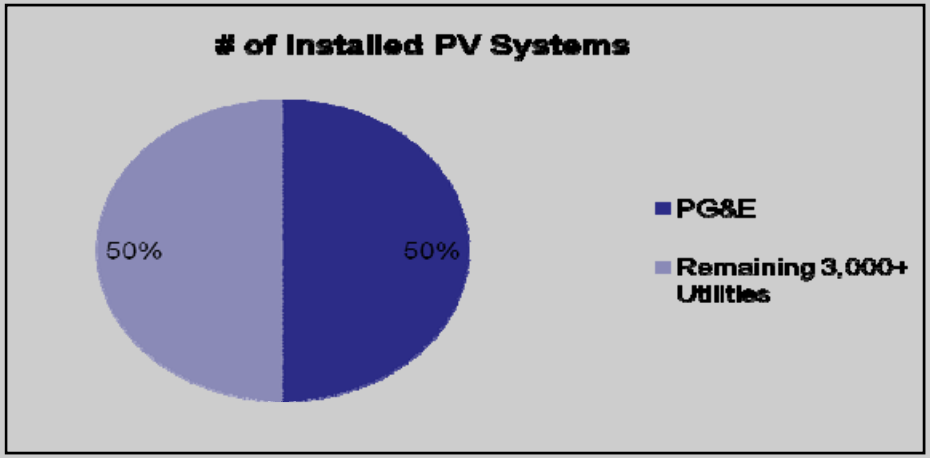

- In 2008, Spain overtook Germany as the market leader (U.S. 3rd place)
- In 2008, thin film modules (led by First Solar) were 14% of shipments

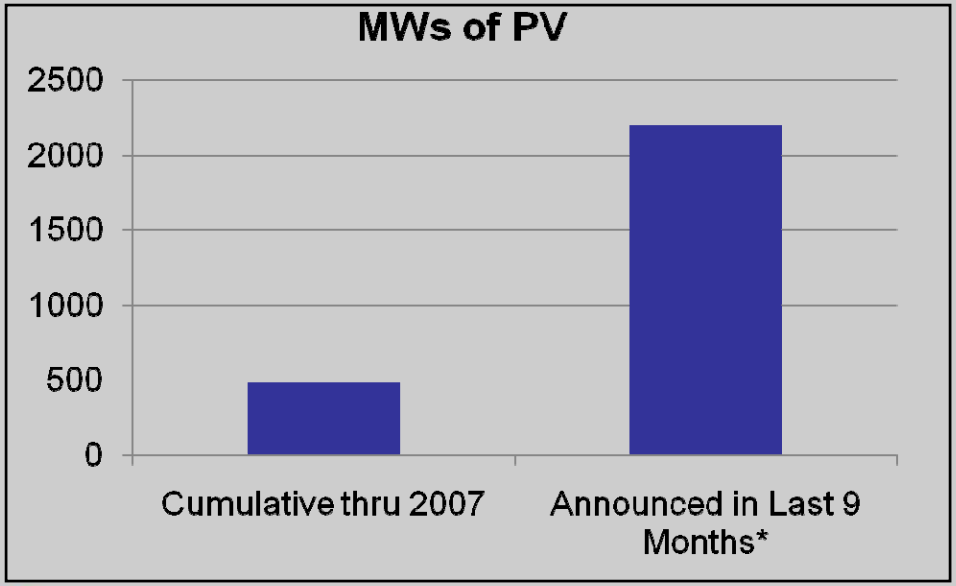
- *(Discrepancy in totals on charts may be due to survey methodology differences between supply and demand)*

# U.S. Utility Involvement Lagging, but Rounding the Bend…

As of the end of 2007…



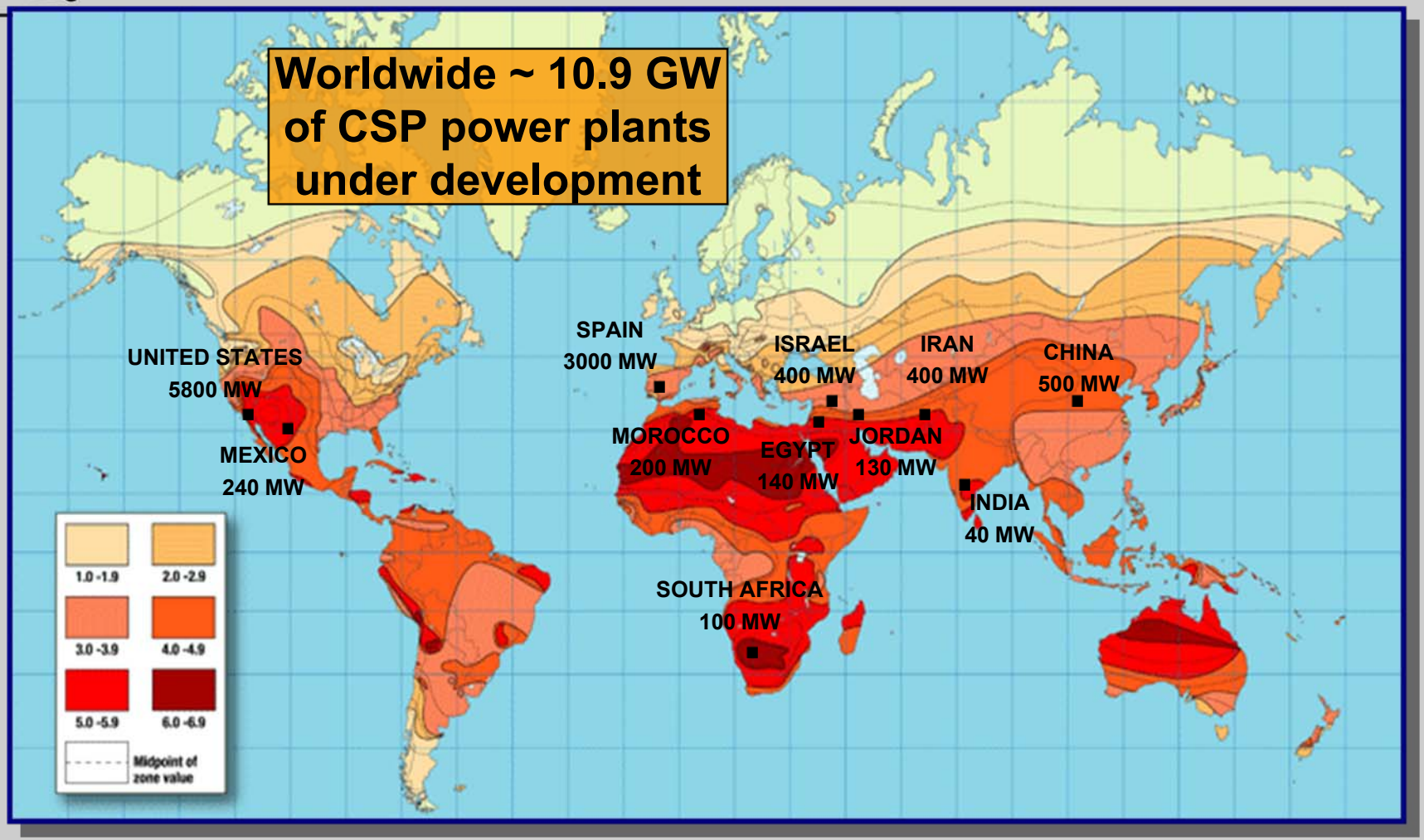




*Utility-driven installations planned for 2009 – 2013 (March 2009)

*Source: Solar Electric Power Association*

# CSP Worldwide Deployment Plans



# CSP Projects in SW U. S.

- 1 MW trough/ORC in Arizona (APS, Acciona) operating
- 64 MW trough electric project in Nevada (Nevada Power, Acciona) commissioned June 2007
- 500 (option to 850 MW) Dish Stirling plant in Southern California (SCE, SES, Aug 2005)
- 300 (option to 900 MW) of Dish Stirling plants in Southern CA (SDG&E, SES, Sep 2005)
- 553MW Trough plant (PG&E, Solel, July 2007)
- 177 MW Linear Fresnel Reflector (AUSRA, PG&E, Nov 2007)
- 280 MW Parabolic Trough with storage (Abengoa, APS, Feb. 2008)
- 250 MW Arizona PS Consortium RFP issued Dec 2007
- 250 MW Parabolic Trough (FPL Energy, AFC filed)
- 900 MW Power Tower (BrightSource, PG&E, April 2008)
- 245 MW Power Tower (EP Elect., eSolar, June 2008)
- 1,300 MW Power Tower (SCE, Brightsource, Feb 2009)
- 290 MW Trough (APS, Starwood Energy, May 2009)
- Other RFPs issued but not announced (120 MW PNM, trough)

# Solar Power: The Path Forward

- **Technology**
  - **PV: Factory-developed "systems" – low cost, easy install, high reliability**
  - **New approaches to high-penetration scenarios: distributed microgrids, "smart" energy management systems**
  - **STORAGE IS KEY! - both for PV and for CSP**
    - **Batteries, molten salts, chemical fuels**
- **Markets**
  - **Power Purchase Agreements (and other innovative financing) will change PV market**
  - **Utilities will need new business models**
- **Policy**
  - **Federal stimulus creating multiple deployment, R&D opportunities**
  - **Local/state: Berkeley folding costs into property taxes**
  - **Need for solar set-asides as part of state Renewable Portfolio Standards**
- **Some things to watch for:**
  - **Thin Film PV: First Solar leading way, many startups coming along**
  - **New, home, building, and neighborhood-level energy management systems**
  - **Significant CSP production in Southwest U.S. – troughs**
  - **California continues to lead the way in the U.S.**