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Solar Energy Technologies, Applications, and Futures

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Presentation Outline

- Technologies and Applications: Photovoltaics and Concentrating Solar Power (CSP)
- Markets and Trends
- Research to Pave the Way for Solar
- Conclusions/Observations

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- **Technologies and Applications: Photovoltaics and Concentrating Solar Power (CSP)**
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- **Research to Pave the Way for Solar**
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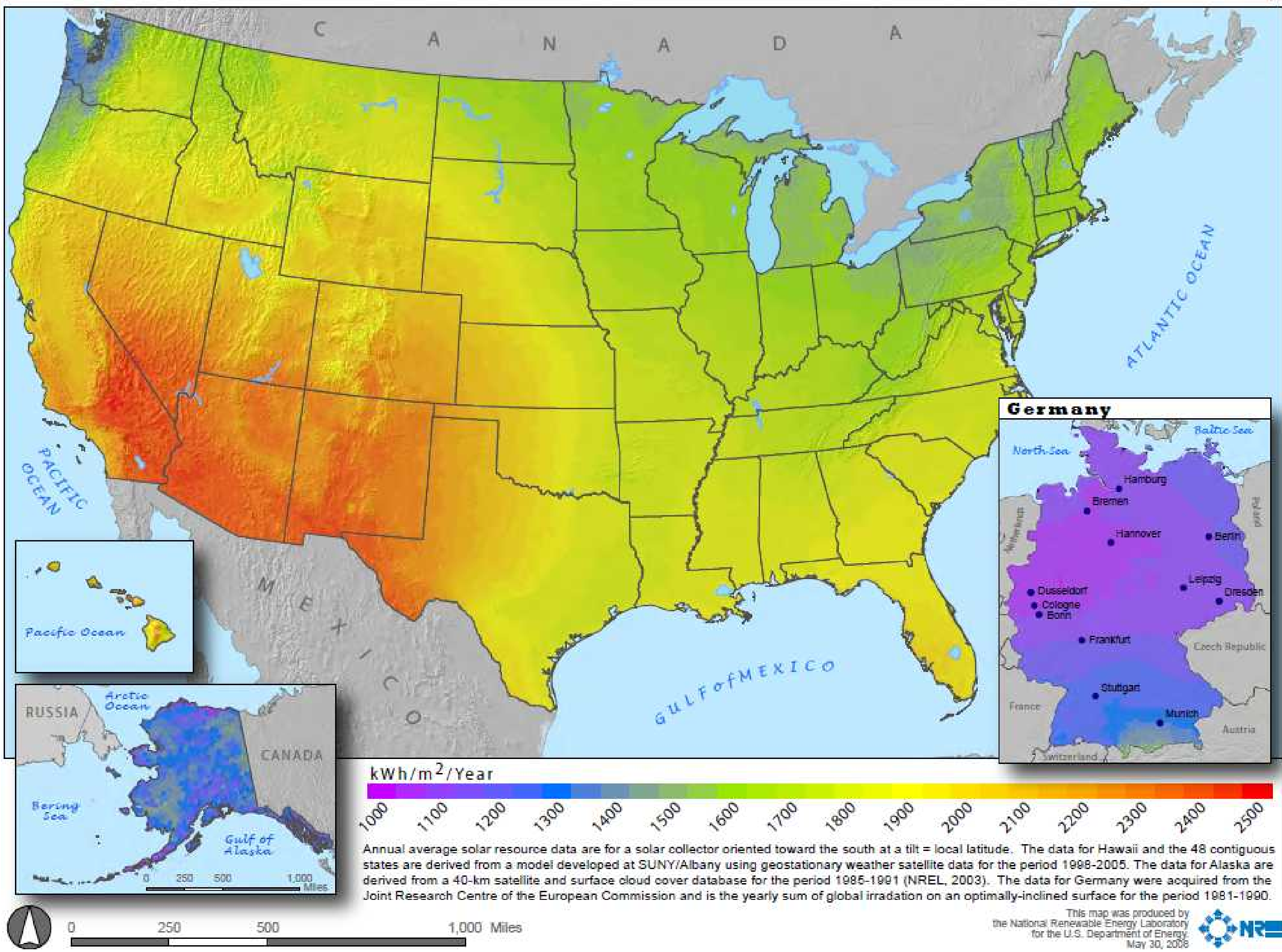
U.S. Has Great Opportunities for Increased Solar Energy Applications



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.**

2008 PV Installs
Germany: 2GW
US: 360MW

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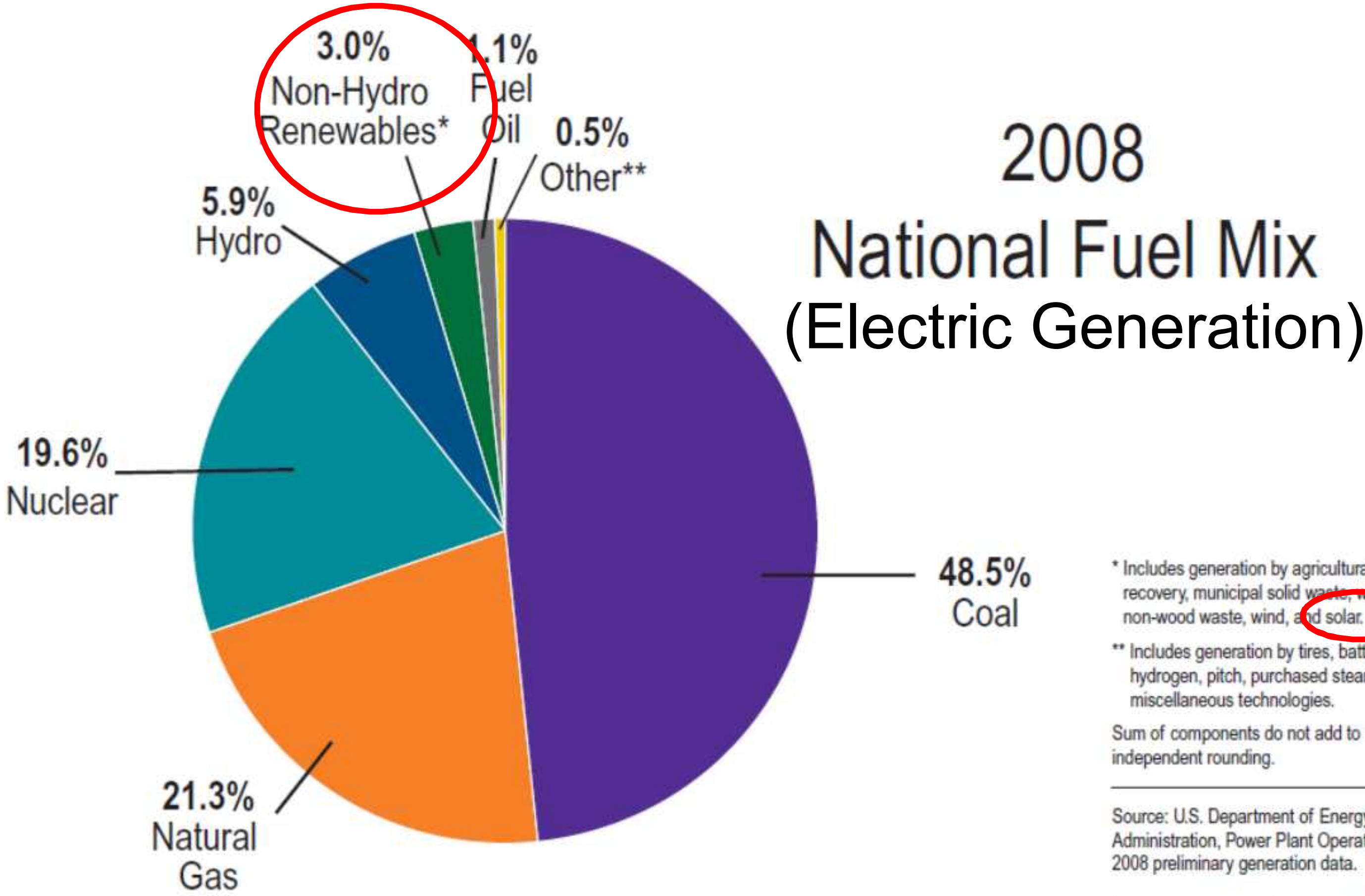
However, Solar Utilization is Still Not on the Map



* 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.

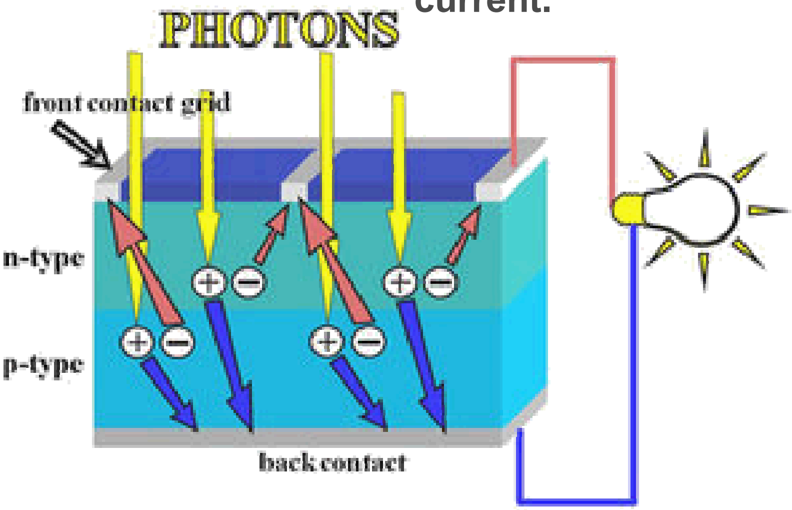
Sum of components do not add to 100.0% due to independent rounding.

Source: U.S. Department of Energy, Energy Information Administration, Power Plant Operations Report (EIA-923); 2008 preliminary generation data.

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

Photovoltaics (PV)

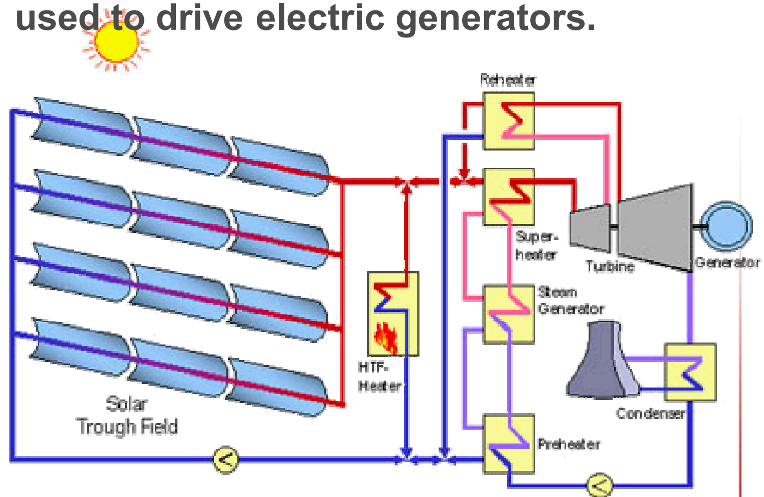
Cells of semi-conductors absorb photons and directly convert them into electrical current.



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)

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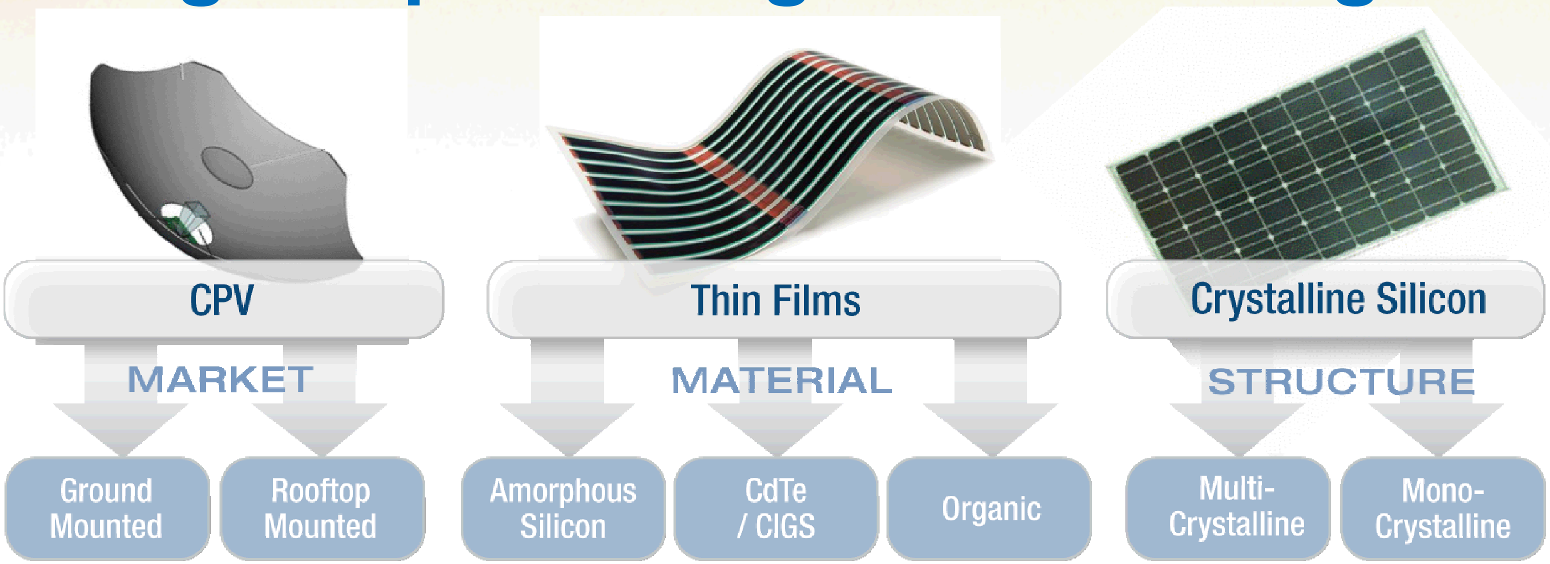
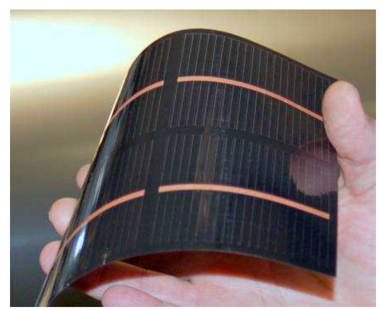
Government and industry are pursuing a range of promising PV technologies

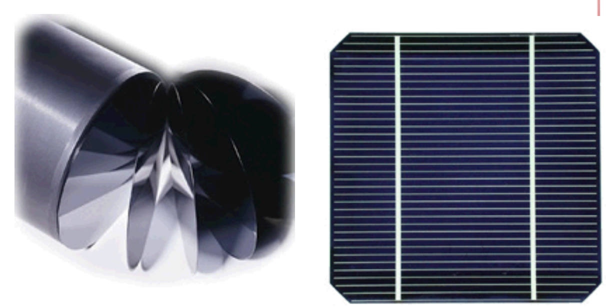


20x-100x

500x



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



c-Si ~ 180 um

Slide courtesy Robert Margolis, NREL

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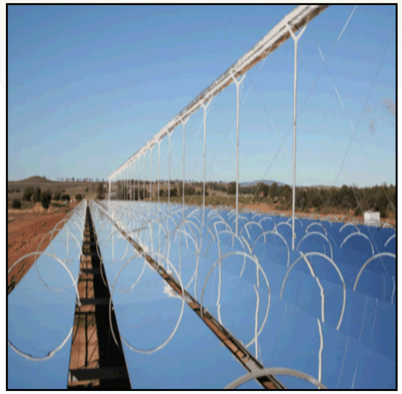
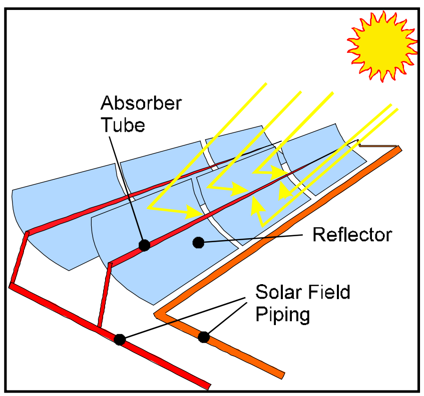
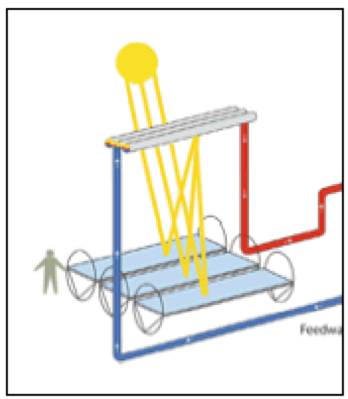
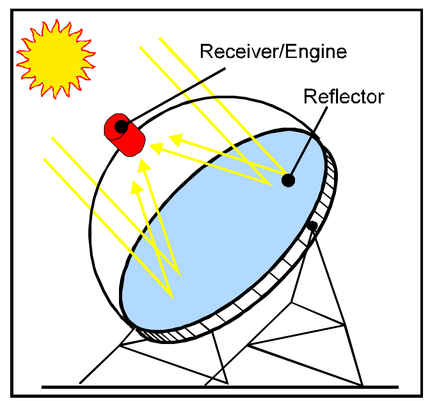
Concentrating Solar Power (CSP) technologies cover a range of promising approaches

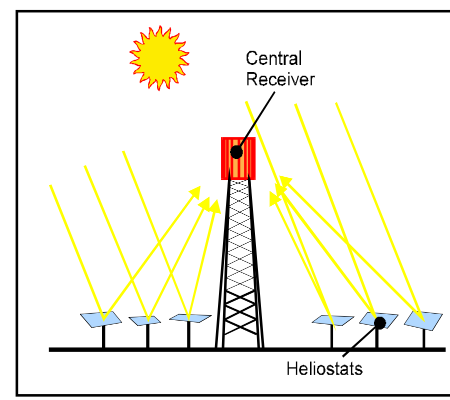


Trough | **Linear Fresnel** | **Dishes** | **Tower**









Utility scale power plants – intermediate and base load power

Slide courtesy Robert Margolis, NREL

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Photovoltaic Systems Are Used in Several Applications

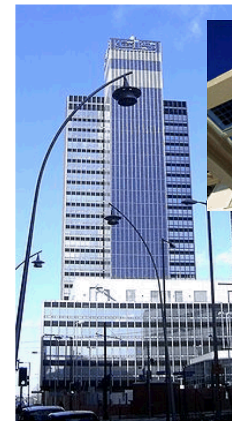
Residential

Forest City Military Communities Plans to Install PV on 2300 homes in Hawaii starting in 2010 (courtesy FCHC)

Commercial-rooftop scale

Otay Mesa Border Crossing, San Diego: 274kW PV installed by GSA (courtesy SolarCity)

Building Integrated PV



Architecturally integrated as part of building structure

Utility-scale

Nellis AFB: 14MW PV (Courtesy MMA Renewables)

…and Off-Grid (but more on this later)

Solar Tent courtesy of Iowa Thin Films

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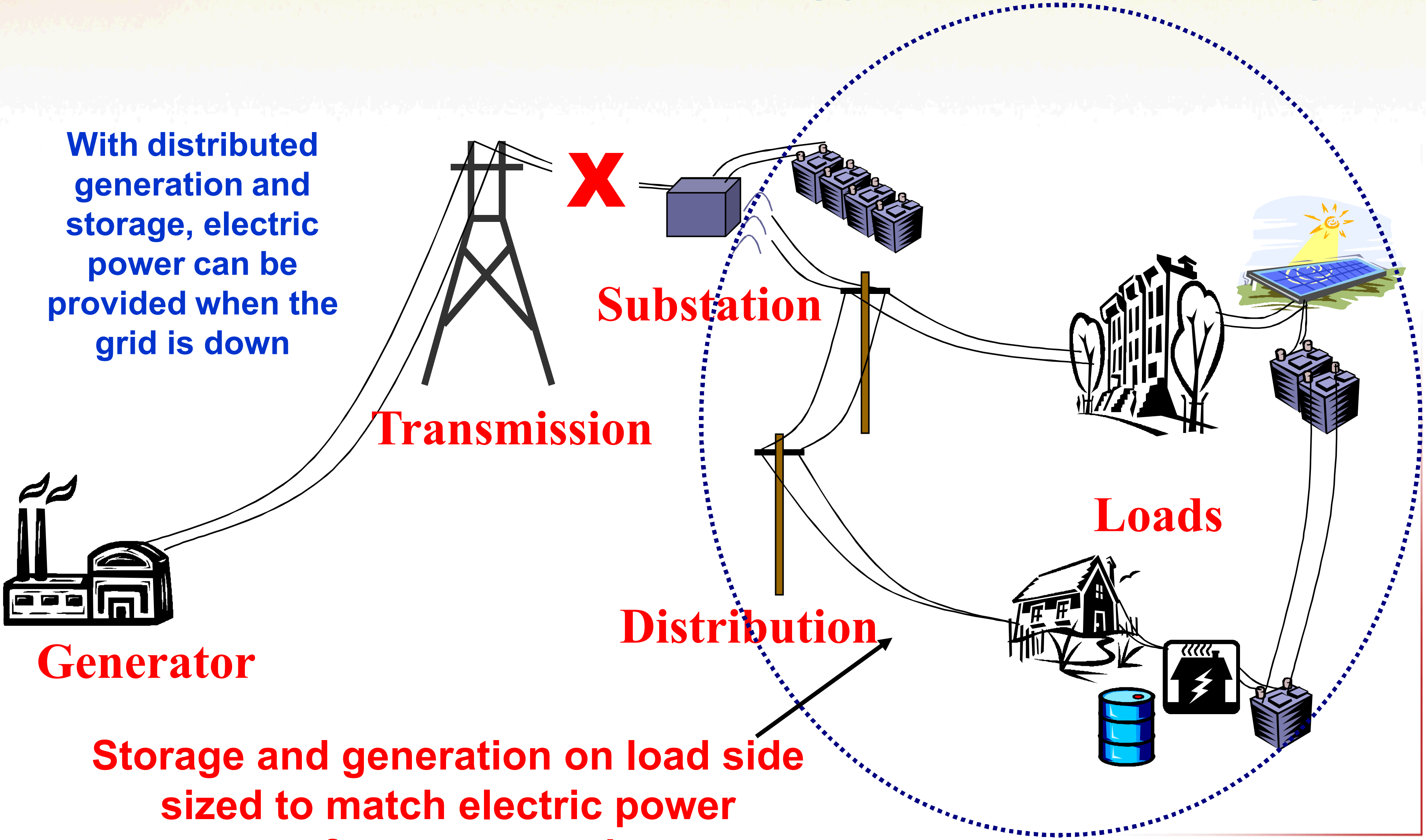
The "New" Off-Grid System: The Energy Surety Microgrid

With distributed generation and storage, electric power can be provided when the grid is down



Storage and generation on load side sized to match electric power performance needs

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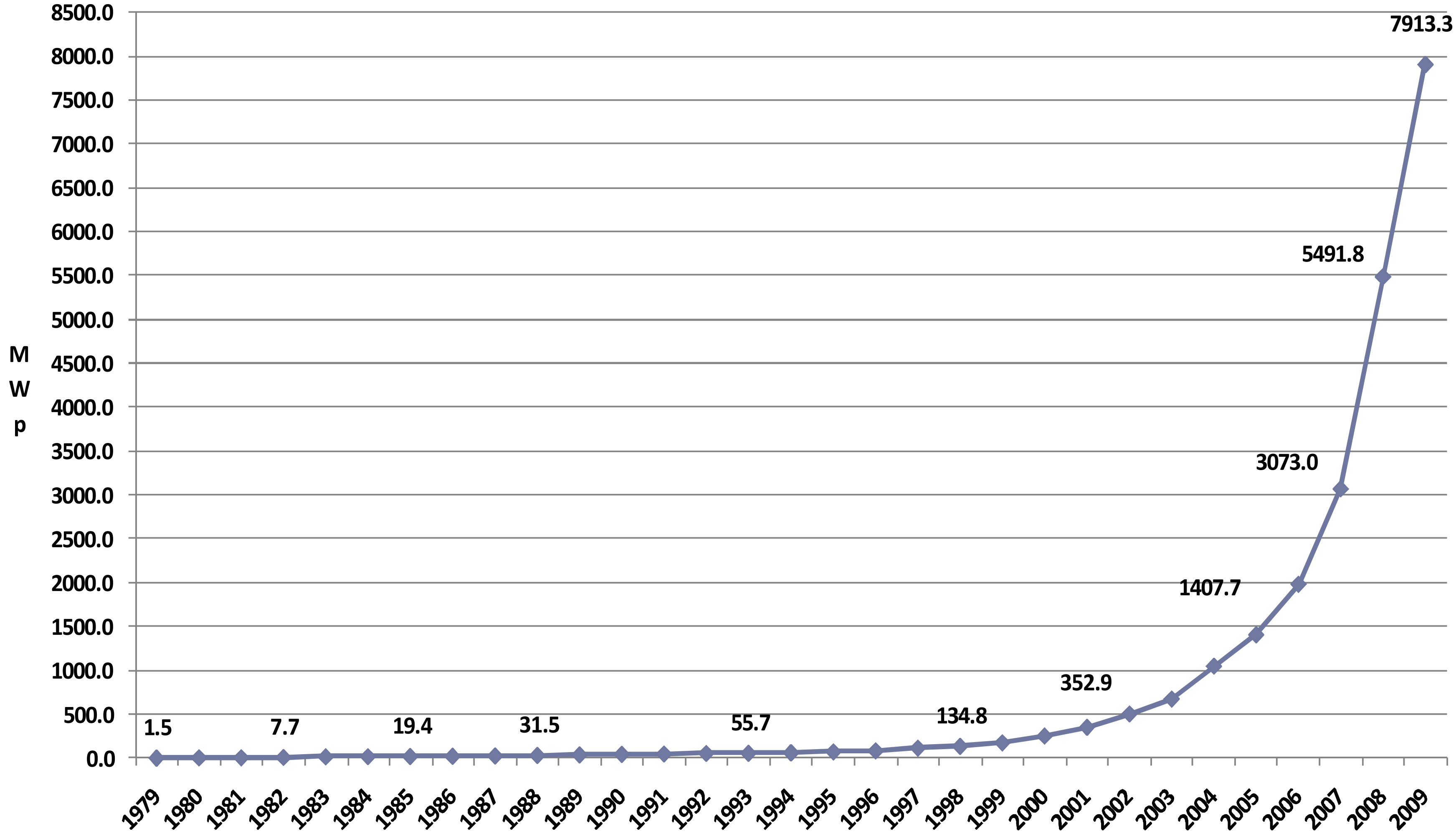
Industry Growth: 1979 to 2009: 30 year compound annual growth rate of 33%



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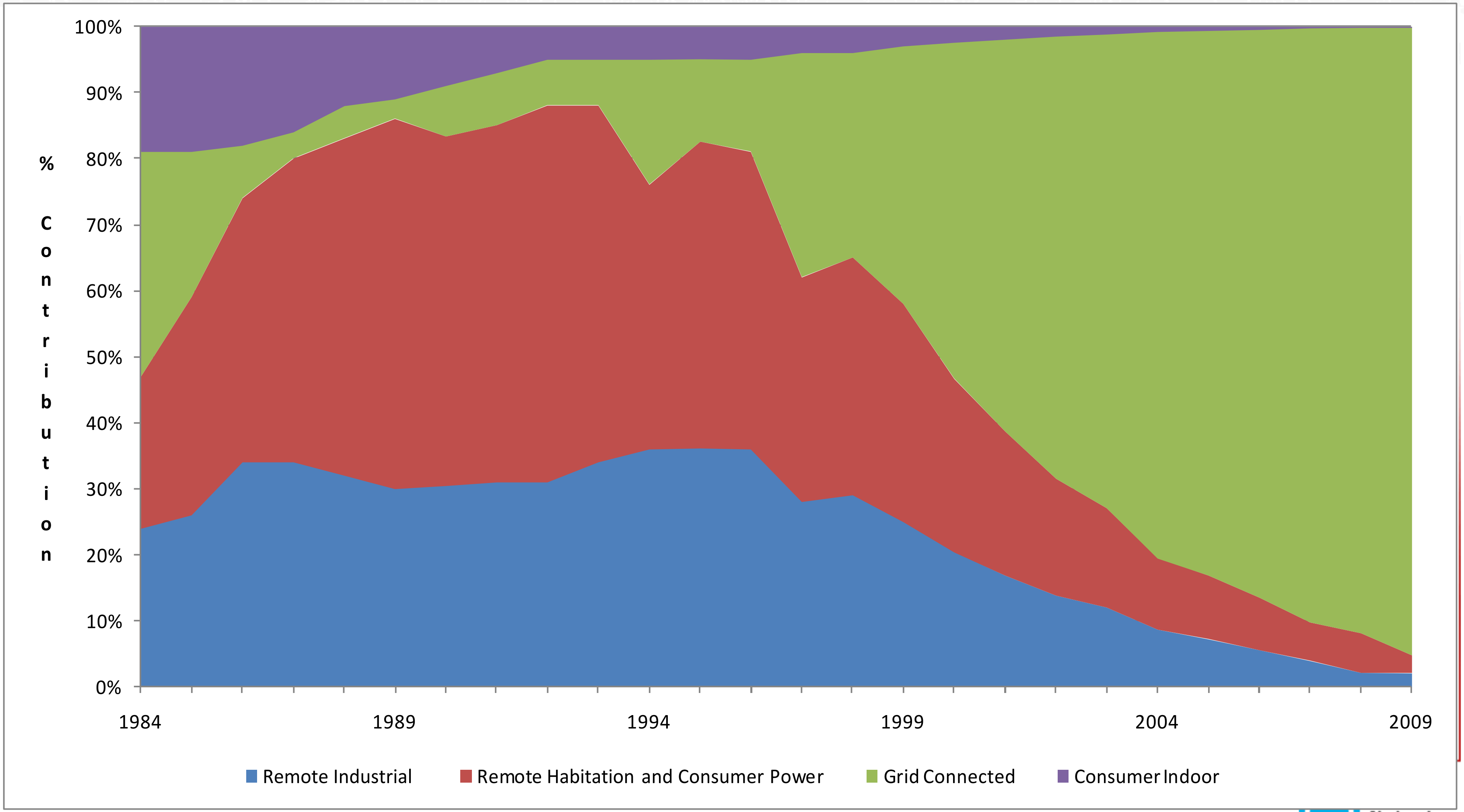
Application Contribution, 1983 to 2009

In the early days, demand was into the off grid applications, remote industrial, habitation and consumer power. Consumer indoor (watches, calculators) grew rapidly in the early 1980s, matured rapidly, with growth slowing to ~8% a year. In the late 1990s growth in the grid connected application accelerated and now dominates.



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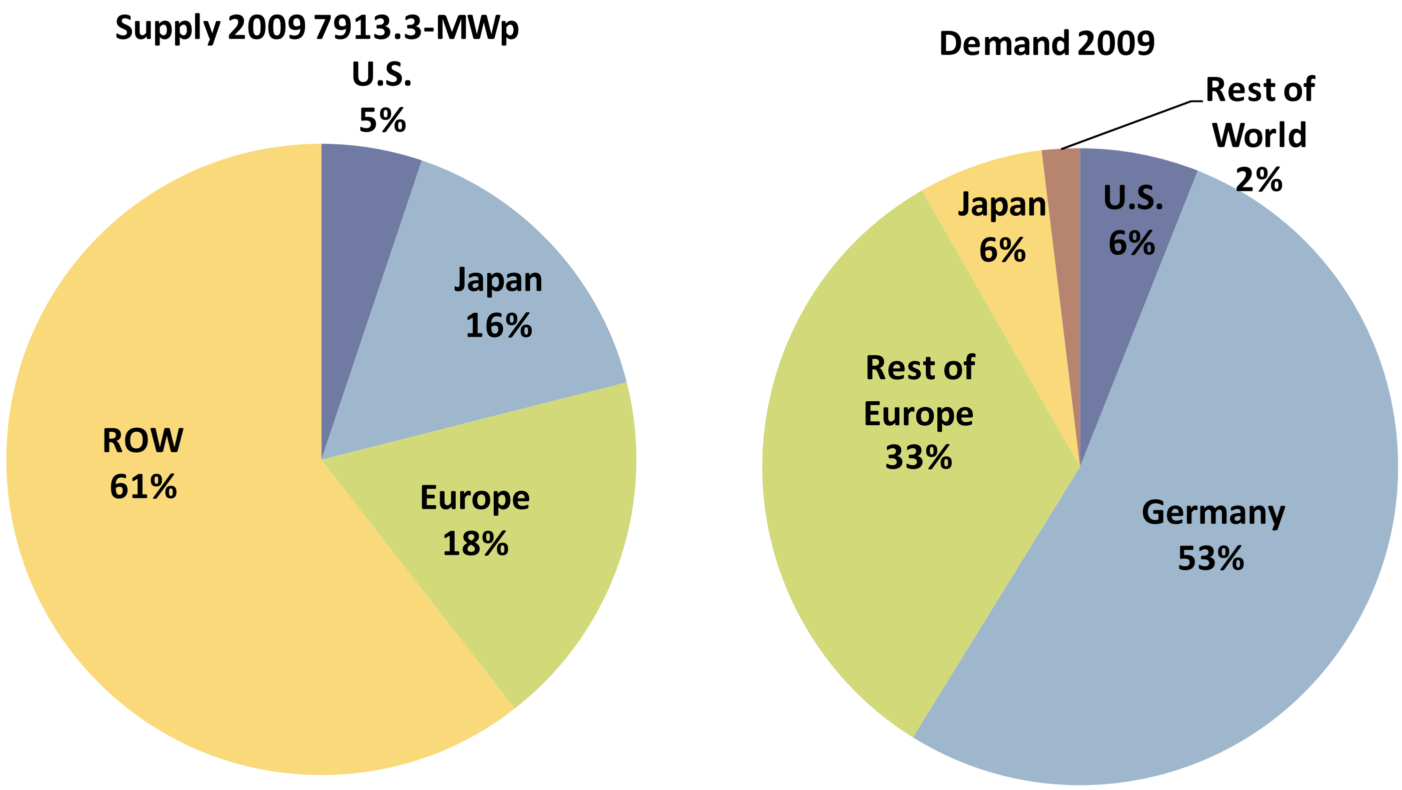
Demand and Supply are Partners

The Supply/Demand picture for the PV industry is unbalanced – one region Europe represents 86% of all demand. Germany is consumed 53% of first time sales in 2009.

46% of 2009 supply came from China/Taiwan in 2009 -- the remaining ROW countries are Malaysia, the Philippines, And India.



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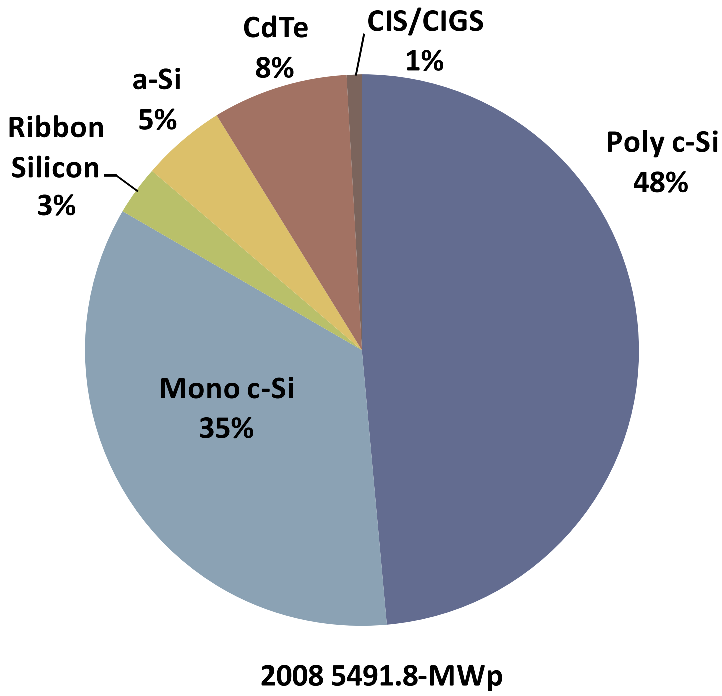
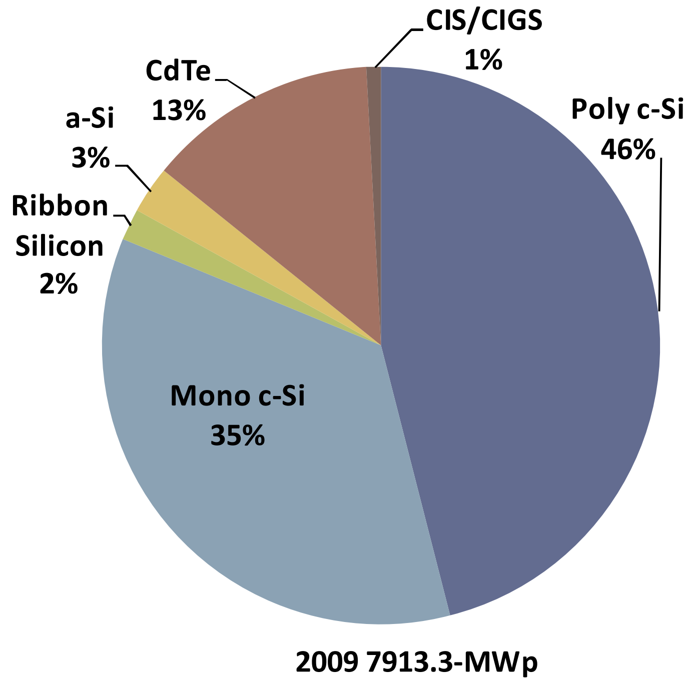
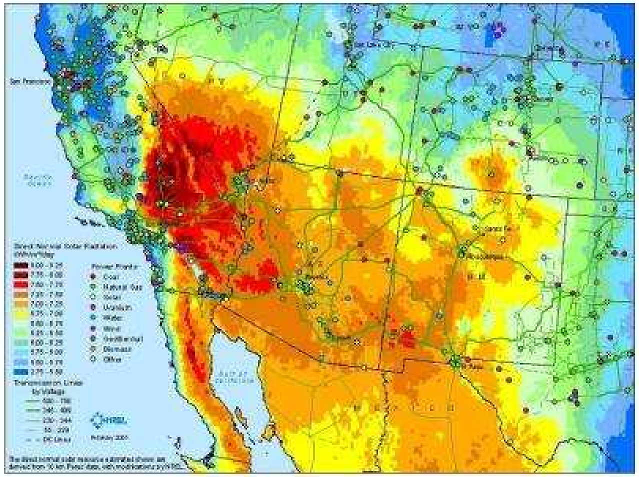
Technology shipments: Thin film's made gains in 2008 and 2009, gaining three percentage points in 2009 for a 17% share.



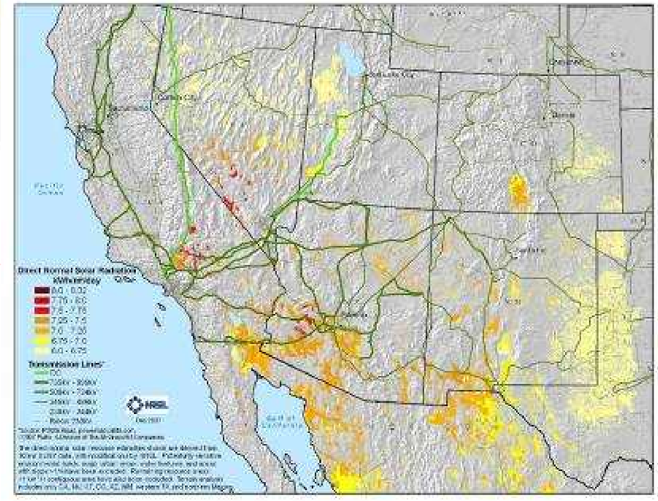


CSP Resource Potential



Filters applied:

- Direct-normal solar resource.
- Sites > 6.75 kwh/m²/day.
- Exclude environmentally sensitive lands, major urban areas, etc.
- Remove land with slope > 1%.
- Only contiguous areas > 10 km²



State	Land Area (mi²)	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

U.S. Electrical Capacity is 1,000 GW

Annual power generation of 4,000,000 GWh

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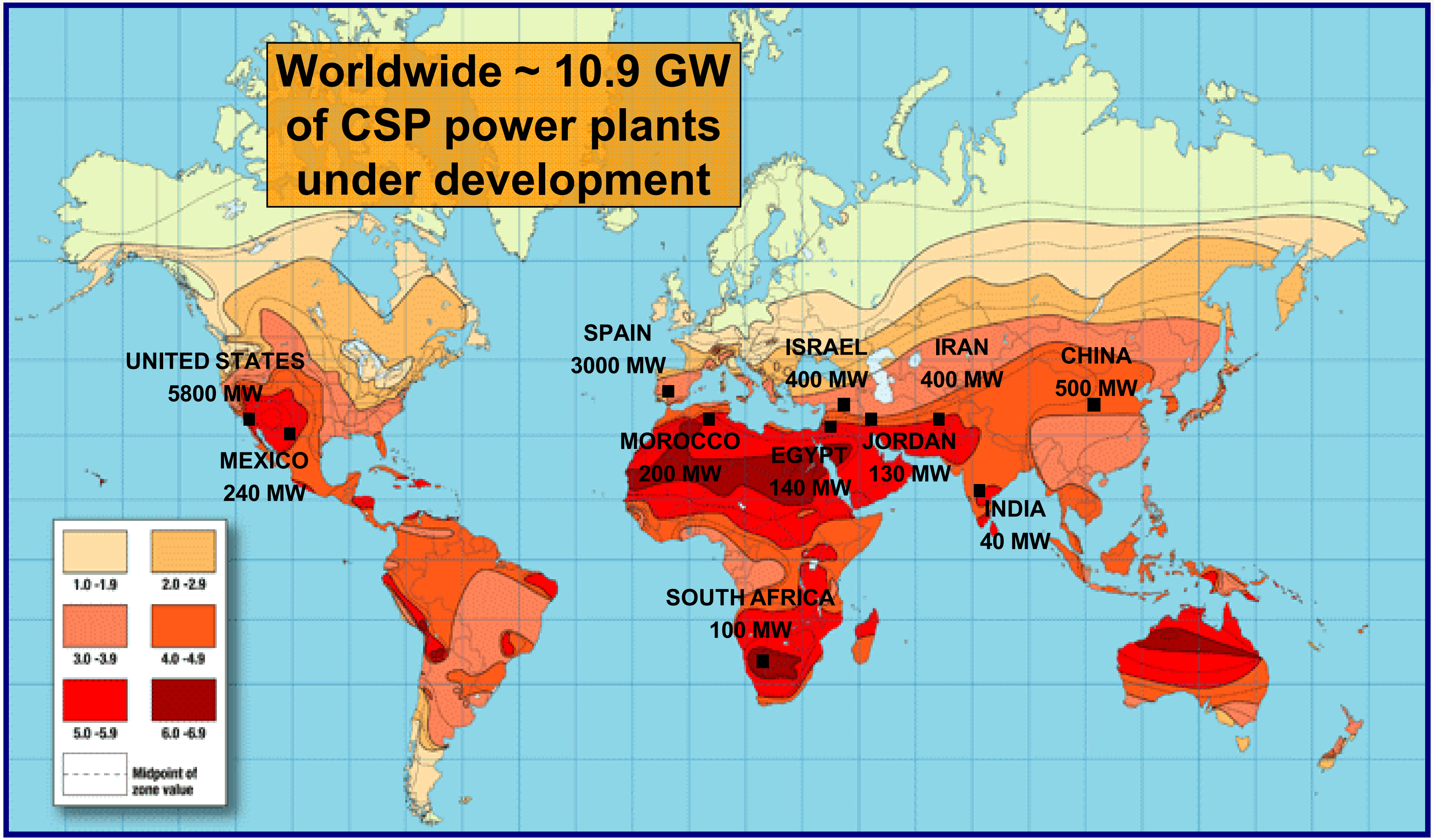
CSP Worldwide Deployment Plans



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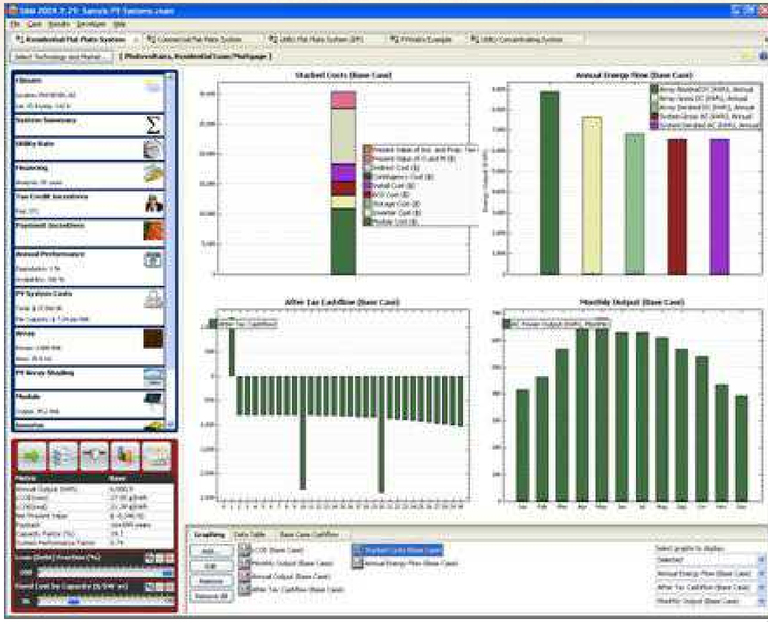
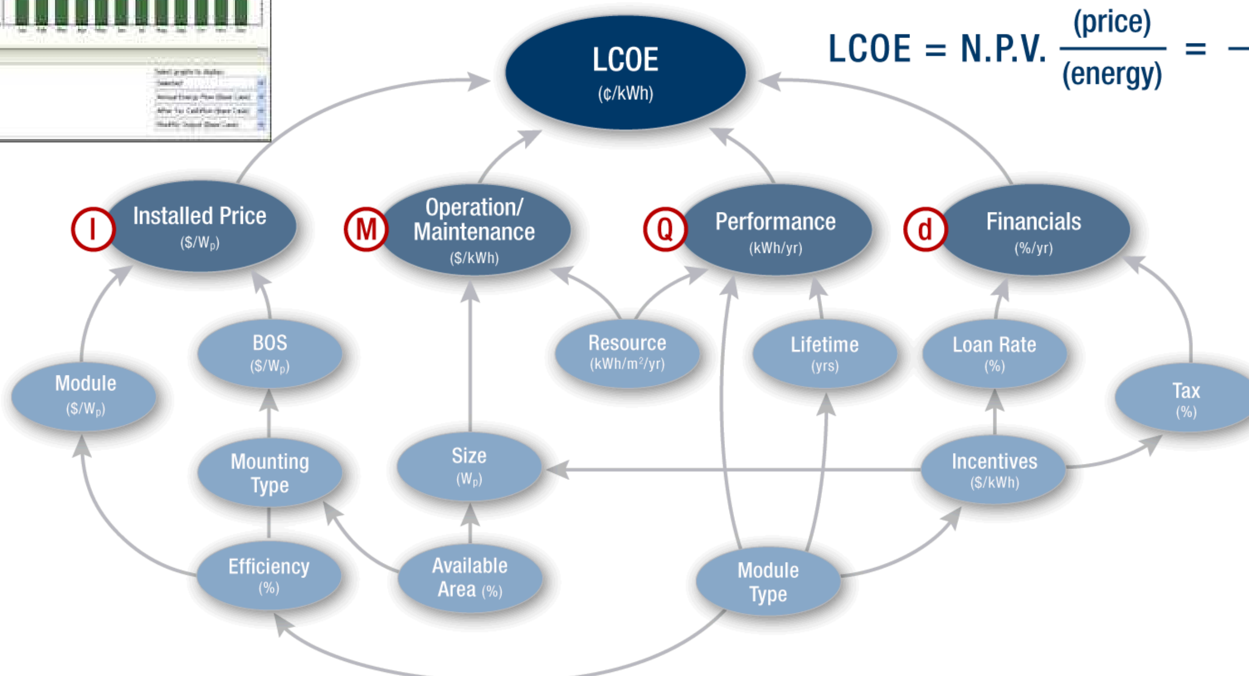
Technology roadmaps are based on a detailed assessment of LCOE using SAM



Solar Advisor Model (SAM) includes

- All solar electric technologies (PV, CPV, CSP)
- State of the art component performance models
- Validated financial and incentive models
- Weather and solar resource data libraries
- Graphical user interface to support parametric analysis

$$LCOE = N.P.V.\frac{(price)}{(energy)} = \frac{\sum_{n=0}^{N} \frac{I_0 + M_n}{(1+d)^n}}{\sum_{n=0}^{N} \frac{Q_n}{(1+d)^n}}$$



PV: LCOE Targets

Residential PV

	2009	2015 (est.)	2030 (est.)
PV LCOE without ITC *	21 - 34	10 - 16	6 - 10
PV LCOE with 30% ITC *	16 - 25	7 - 12	N/A
Residential Electricity Rates ‡	8 - 14	8 - 15	9 - 19

Commercial PV

	2009	2015 (est.)	2030 (est.)
PV LCOE with 10% ITC *	29 - 50	11 - 20	9 - 15
PV LCOE with 30% ITC *	18 - 34	7 - 13	N/A
Commercial Electricity Rates ‡	6 - 13	6 - 13	7 - 16

Utility PV

	2009	2015 (est.)	2030 (est.)
PV LCOE with 10% ITC *	17 - 29	7 - 13	6 - 10
PV LCOE with 30% ITC *	11 - 20	5 - 9	N/A
Wholesale Electricity Rates ‡	4 - 7	4 - 8	5 - 11
CA Market Price Referent §	12 - 14	12 - 15	13 - 16

The goal of the PV sub-program is to reduce:

- Residential LCOE by 18¢/kwh – a 53% reduction – by 2015 and 24¢/kwh – a 70% reduction – by 2030.
- Commercial LCOE by 30¢/kwh – a 60% reduction – by 2015 and 35¢/kwh – a 70% reduction – by 2030.
- Utility COE by 16¢/kwh – a 55% reduction – by 2015 and 26¢/kwh – a 65% reduction – by 2030.

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Commercial PV: LCOE Targets

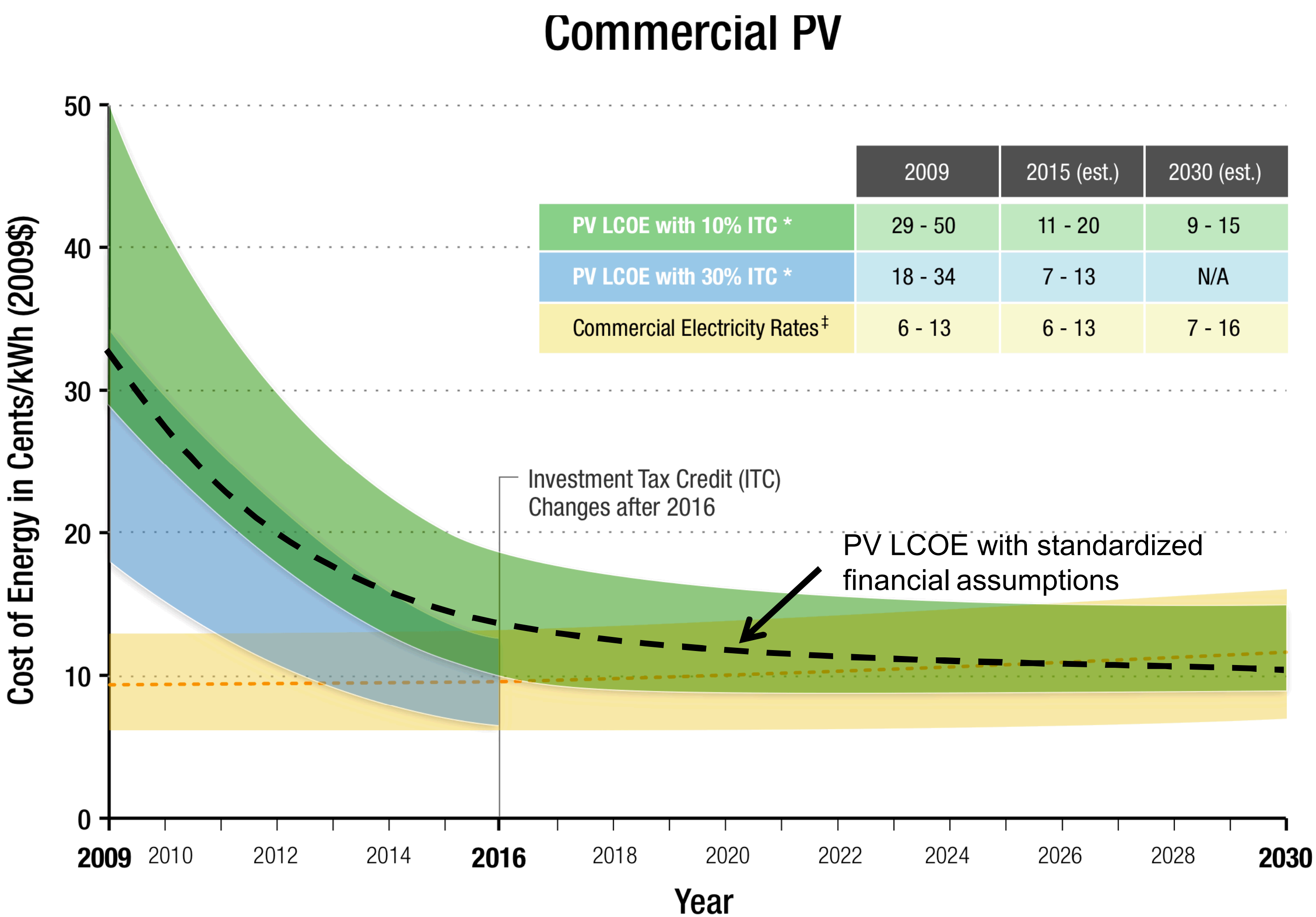
2015

- With the 30% ITC, PV is broadly competitive with commercial electricity rates.
- With the 10% ITC, PV is competitive with high electricity rates under the best insolation and financing conditions

2030

- With the 10% ITC, PV is broadly competitive under all financing, insolation and orientation conditions.

- **Standard financial assumptions yield LCOE estimates that are within the program's range of estimates due to similar cost of capital and mix of tax and financing period effects.**



	2009	2015 (est.)	2030 (est.)
PV LCOE with 10% ITC *	29 - 50	11 - 20	9 - 15
PV LCOE with 30% ITC *	18 - 34	7 - 13	N/A
Commercial Electricity Rates ‡	6 - 13	6 - 13	7 - 16

* Assumes third-party ownership of PV, and thus the LCOE includes the taxes paid on electricity generated. Includes 5-year MACRS but not state, local or utility incentives. The range in commercial PV LCOE is due to different insolation, financing and orientation conditions. For a complete list of assumptions, see DOE Solar Cost Targets (2009 – 2030), in process.

‡ The electricity rate range represents one standard deviation below and above the mean U.S. commercial electricity prices.

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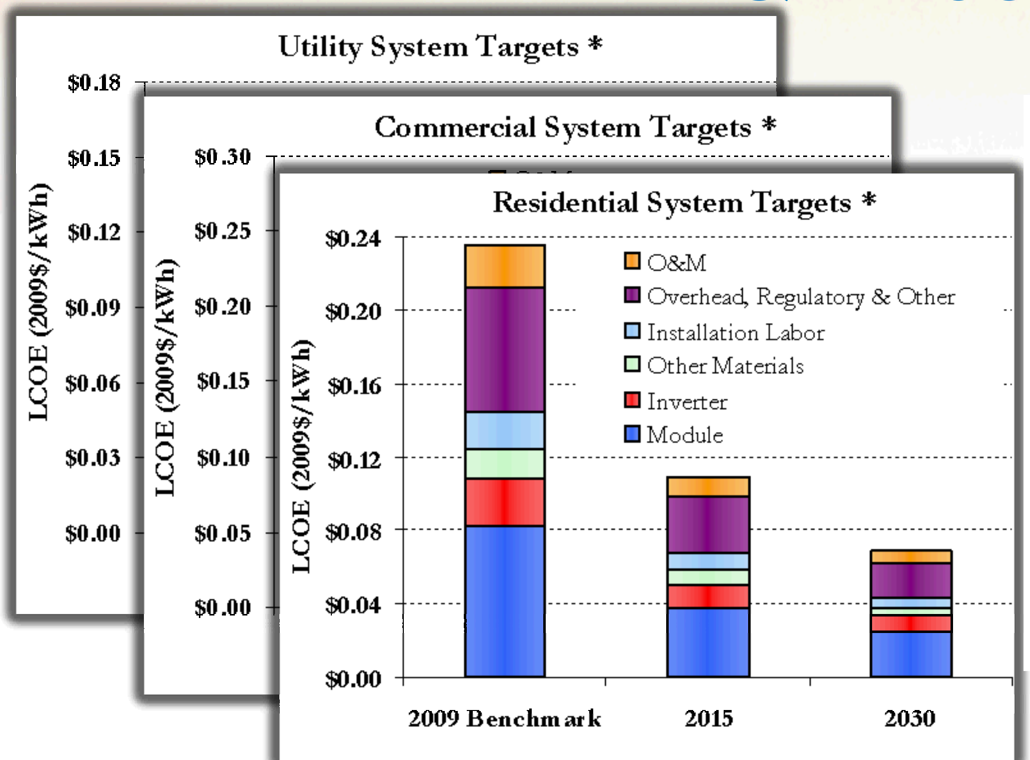
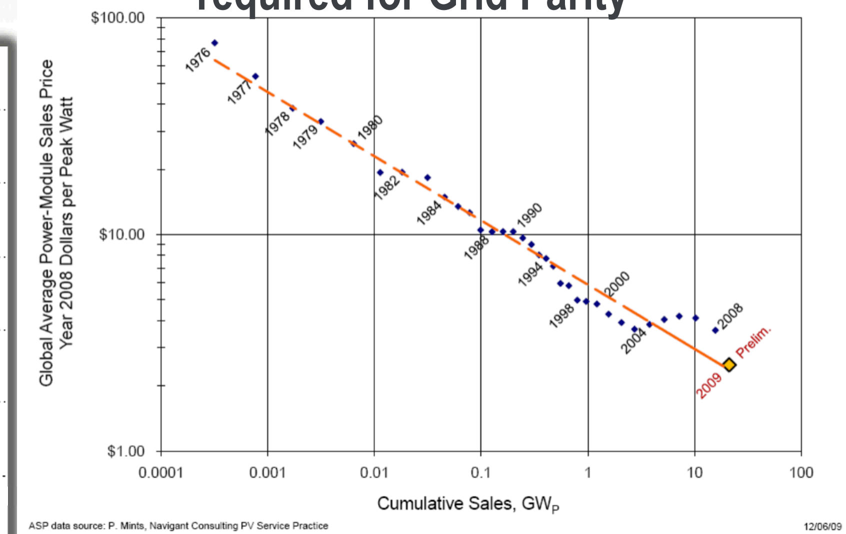
Price/Cost Analysis provides guidance for R&D Focus



2-3X Cost reduction required for Grid Parity



- **PV module prices are 30-50% of installed system cost**
- **PV module efficiency is a <u>significant lever</u> into the rest of the system**

Slide courtesy DOE

*Assumptions: Targets calculated using 30 year system life and solar insolation of Phoenix, AZ.
For Residential PV, system is 80% financed with a 30-year fixed mortgage at 6.0% (nominal). Does not include the 30% ITC or state, local or utility incentives.
For Commercial and Utility PV, system is 60% financed with a 15-year loan at 6.0% (nominal) and 40% with equity at 15%. Includes the 10% ITC as well as 5-year MACRS depreciation, but does not include state, local or utility incentives. Assumes the system is developer-owned, and so the levelized costs include the taxes that must be paid on the electricity generated.

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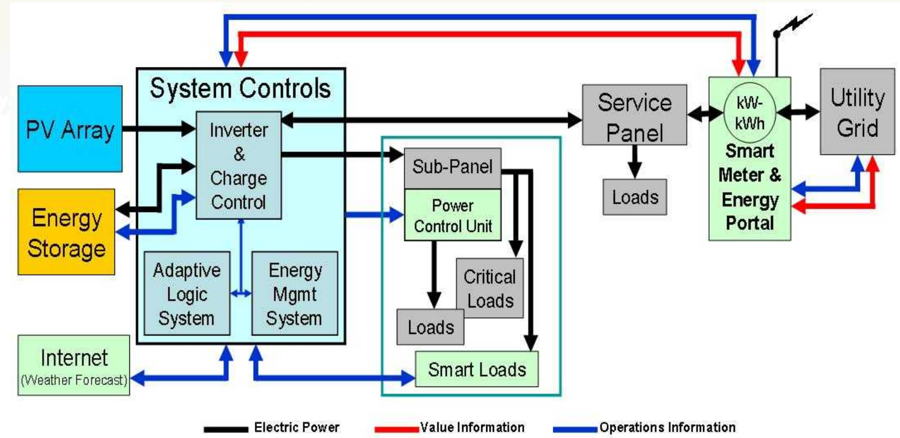
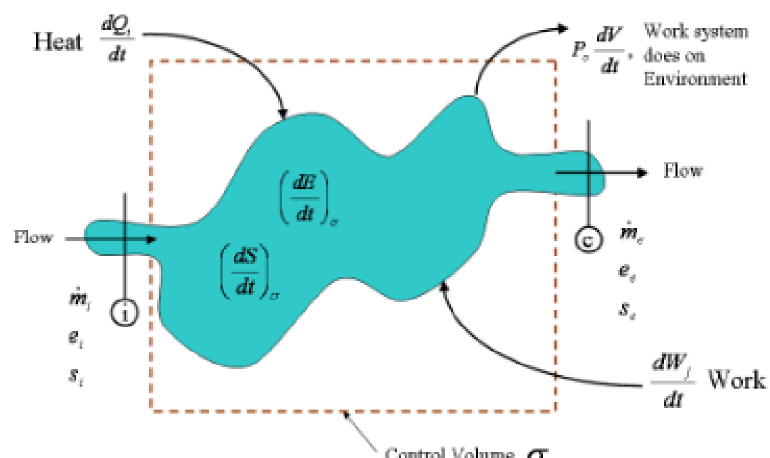
Addressing High Penetration of Renewable Technologies on the Electric Grid

Step 1: Define the problem - Collect data and build predictive models



Step 2: Develop near-term solutions - SEGIS



Step 3: Conduct the longer-term R&D – unifying, scalable, nonlinear control theory; advanced communications engineering

Step 4: Close the loop – implement new technologies in the lab and field

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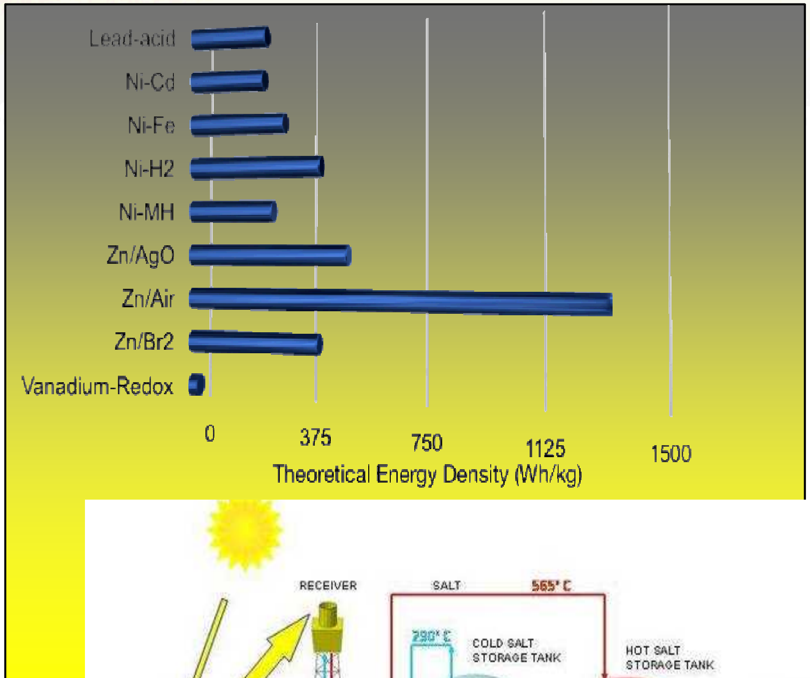
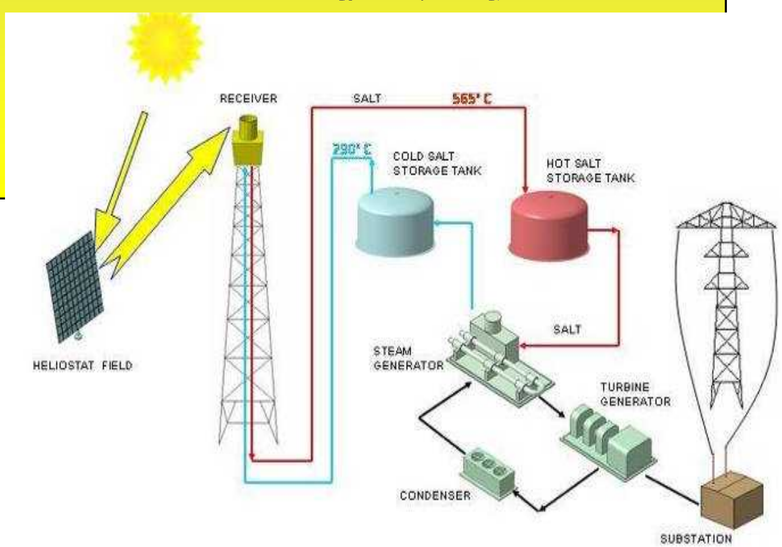
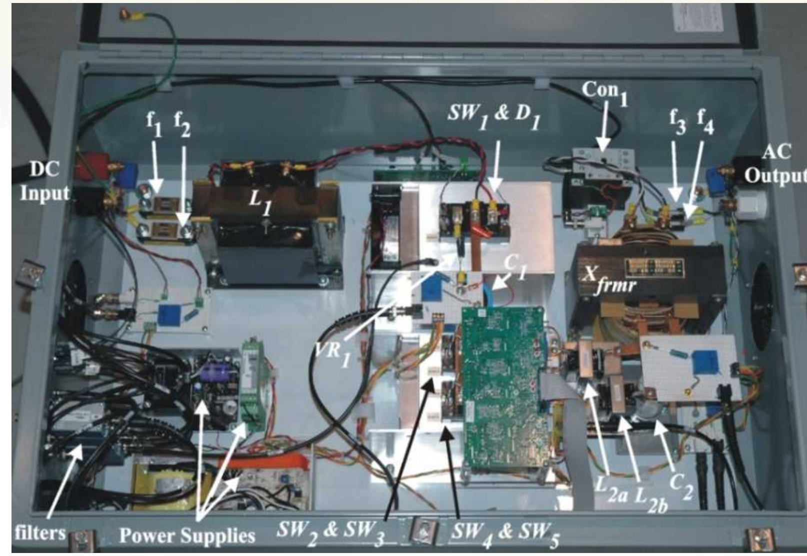
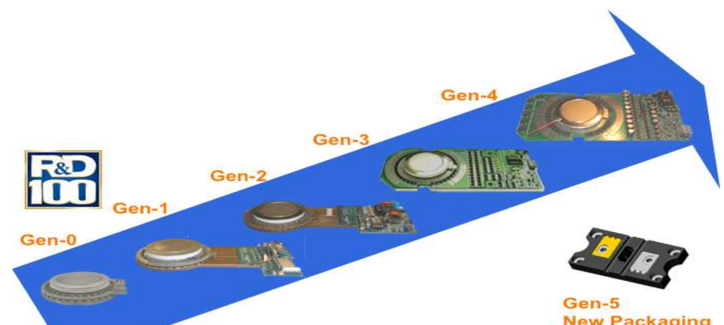
Storage and power electronics are critical for unleashing renewables







Modular Macro Inverter



ETO Research and development for power electronics

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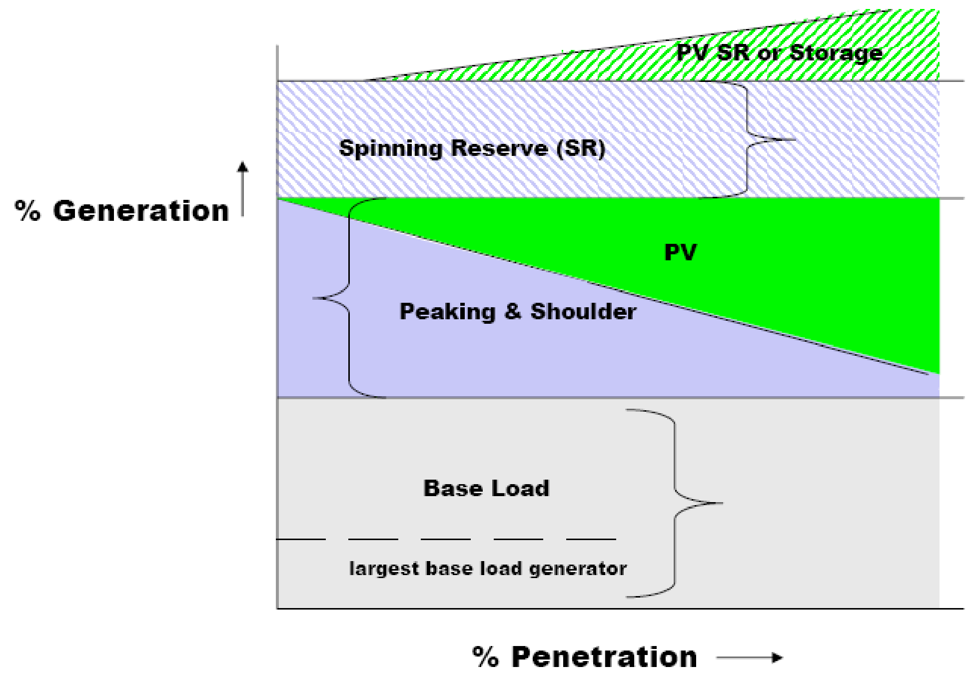
Storage for PV: The Technology Solution to Intermittency



The need for additional spinning reserve or storage to back up intermittent PV generation at increasing levels of penetration.

- Range of Technologies
  - Batteries
  - Capacitors
  - Flywheels
  - Compressed air
- Batteries most prevalent and near-term promising
- Increases complexity of system:
  - Initial cost
  - Operation and maintenance
- Current limitations:
  - Added cost
  - Physical capacity and cycle life

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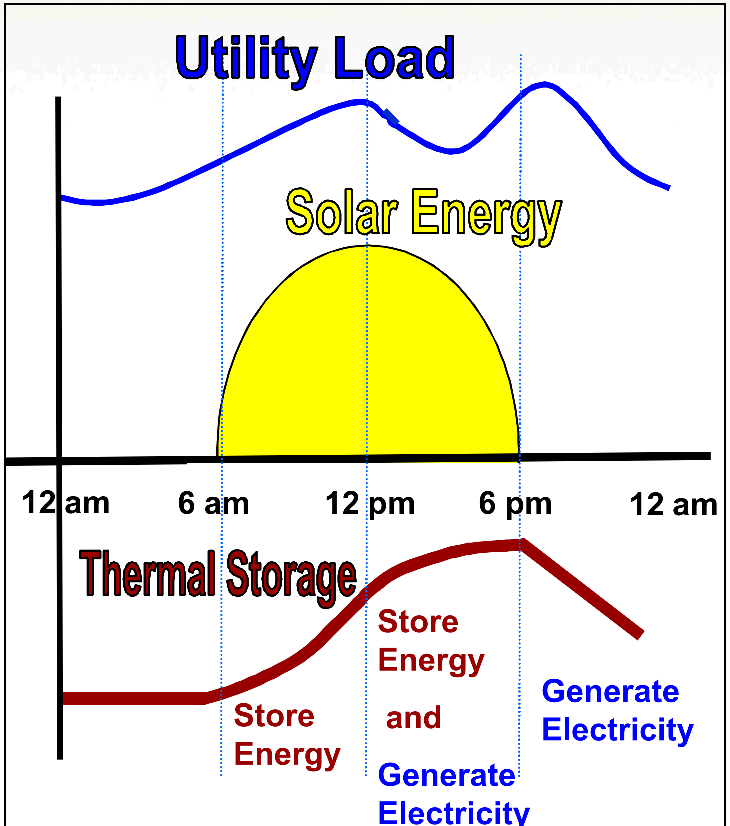
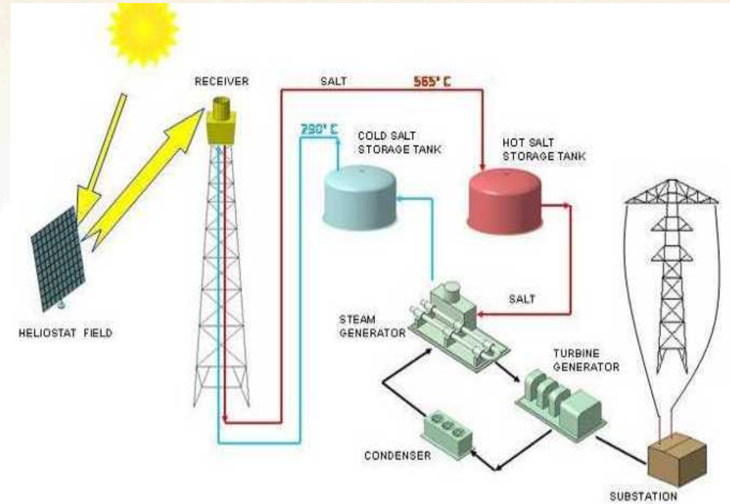
The Value of Thermal Storage for CSP Plants



An operational scenario



- Can be oil, steam, or molten salt
- Buffer during periods of solar transients
- Increased plant capacity factor
- Greater utilization of power generation equipment
- 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

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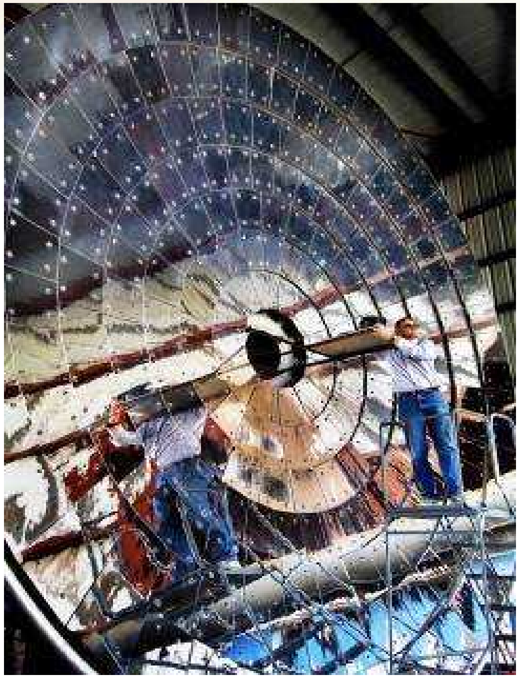
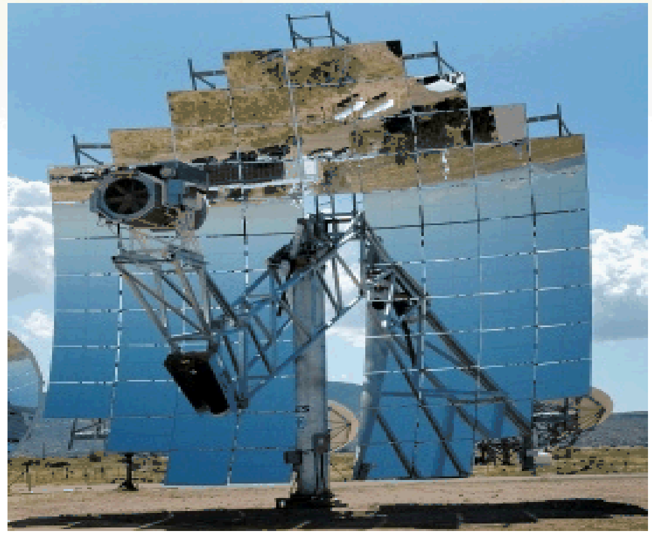
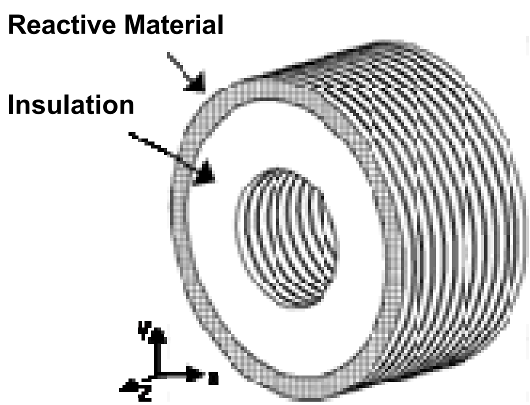
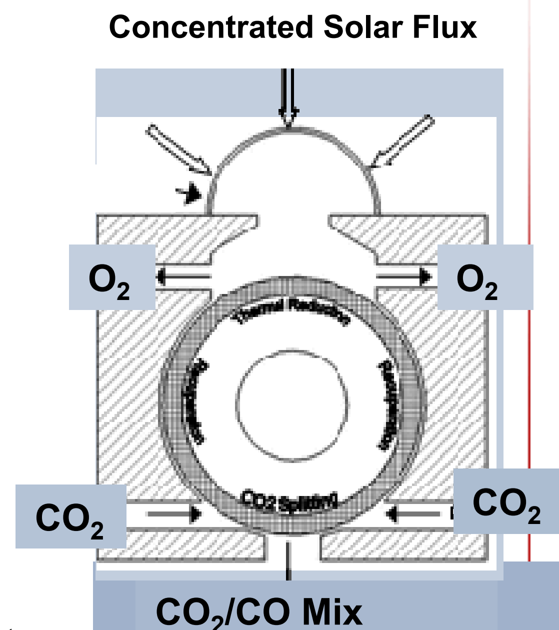
"Sunshine to Petrol" uses the sun to break apart CO_2 and store energy in hydrocarbons









Counter-Rotating-Ring Receiver/Reactor/Recuperator

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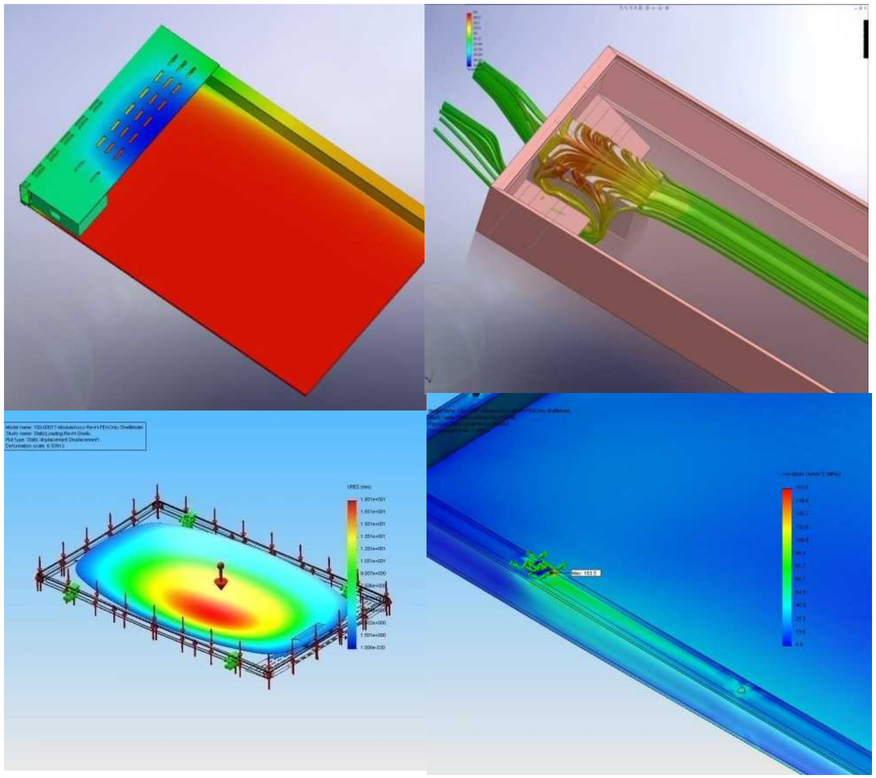
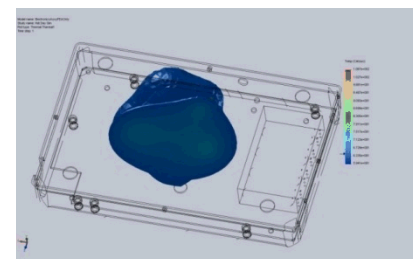
PV Systems Modeling
Coupled Thermal, Structural, and Fluid



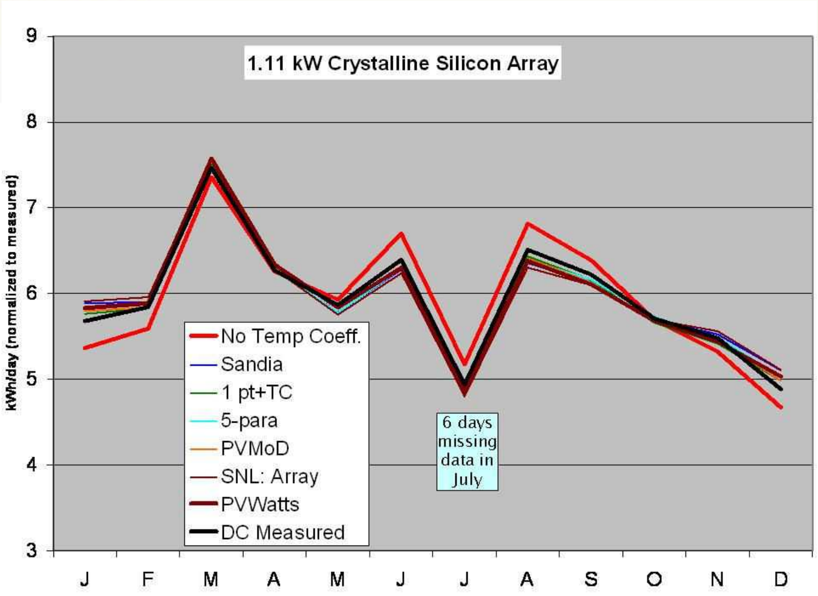
BOS Component

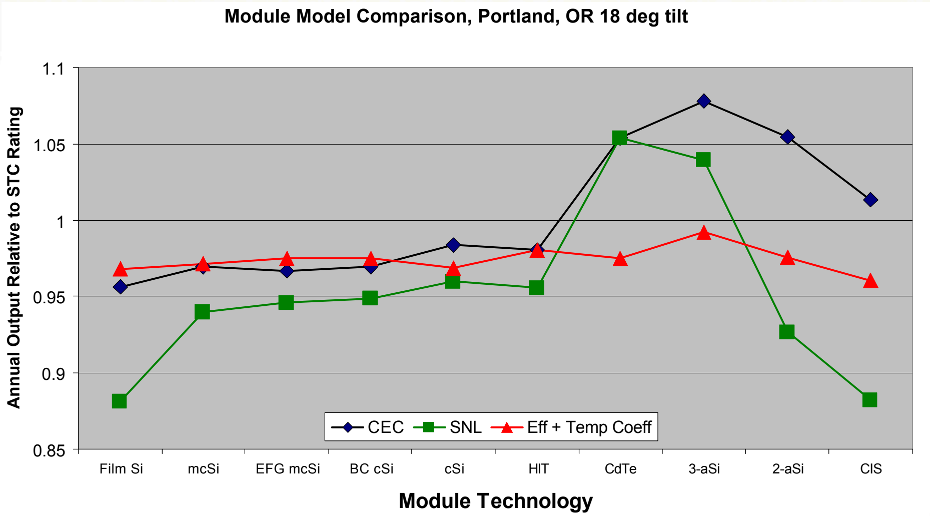
→

Environments



Sandia is well-known for its PV component and system performance models





- Validation depends on quality measured data for reference
- General agreement with c-Si, but wide variances with thin film technologies
- Papers presented at 2008/2009/2010 IEEE PVSC, ASES conferences
- New models under development to address
  - **uncertainty, geo-spacial effects on large system performance**
  - **Interactions of PV systems and the electric grid**
  - **Emerging technologies, such as Concentrating PV, etc.**

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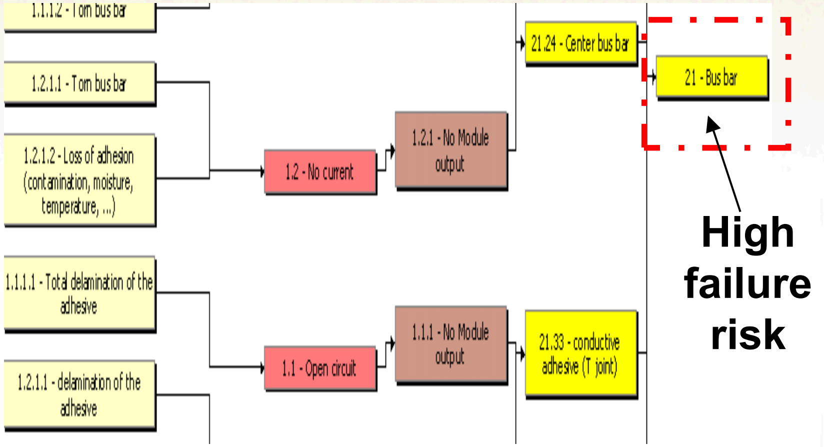
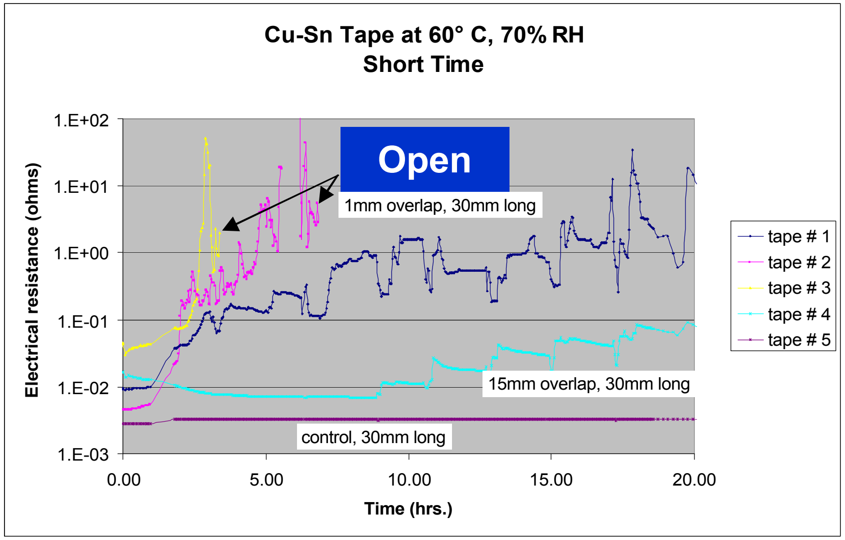
PV Reliability and Availability Model

Component	Actual Number of Failures 5 yr Cum	Expected Number of Failures 5 yr Cum	Expected Number of Failures 10 yr Cum	Expected Number of Failures 20 yr Cum
PV 150 Inverter (26 cSi arrays)	125	132	231*	429*
PV Module	29	26	31	38
AC Disconnect	22	17	23	31
Lightning	16	10	20	41
208/480 Transformer	5	3	3	3
Row Box	34	25	35	50
Marshalling Box	2	4	7	11
480VAC/34.5KV Xformer	5	4	5	9

FMEA: Identify reliability issues



ALT's quantify risk & suggest mitigation

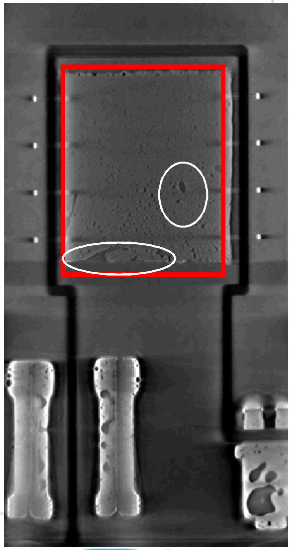


Foil conductor w/PSA in damp heat

Diagnostics

Example

- **CT Scan used to evaluate interface between CPV cell and substrate**



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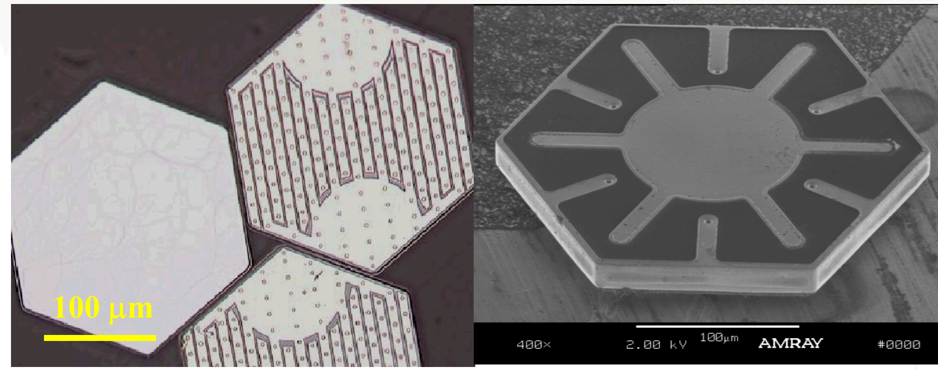
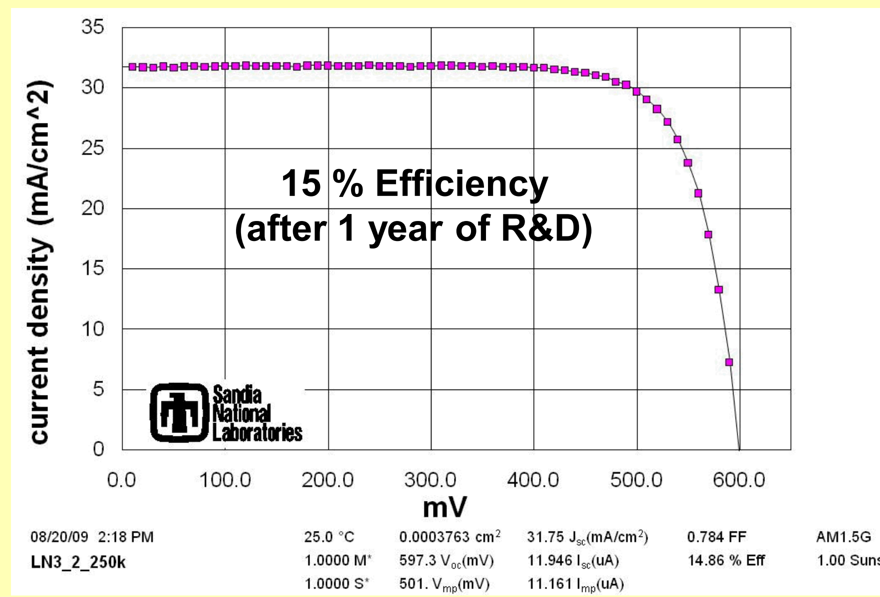
New Concepts in Thin-Film PV and CPV Microfabrication:

Design of High Watt/Gram, Ultra-Thin c-Si Photovoltaic Cells

- Using IC and MEMS techniques, we have developed thin, small c-Si PV cells. These cells have backside contacts and are 10-20 μm thick.
- These advances will enable new Thin-Film PV and CPV system concepts.





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Sandia's Photovoltaic Facilities

PV Systems Evaluation and Optimization Lab

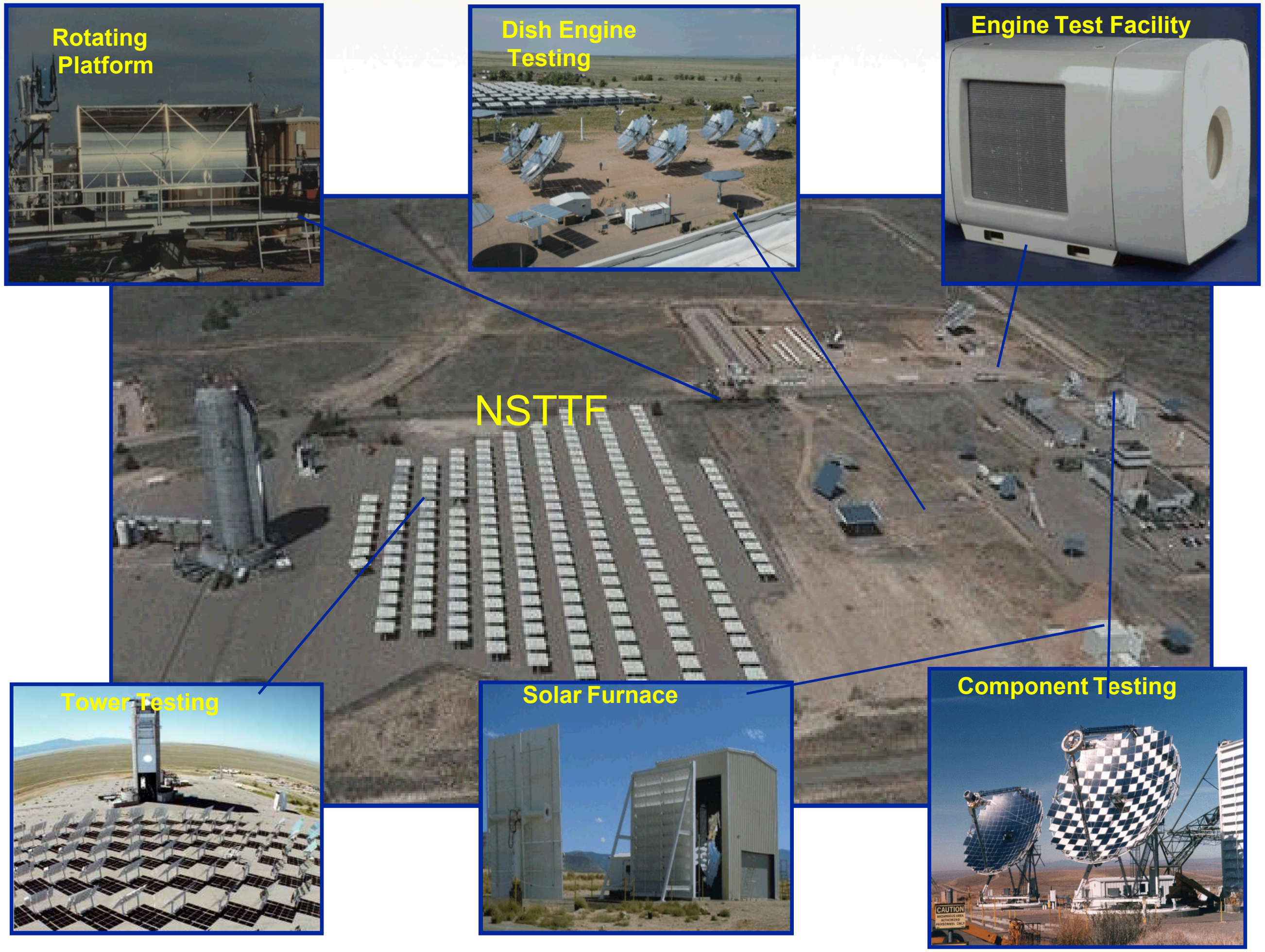
- Controlled Side-by-Side Component, Array and System Characterization
- Full-scale cell and module characterization laboratory
- Comprehensive Data Acquisition Systems
- Grid Integration, Inverters, Combiners, Disconnects- All Reconfigurable

Distributed Energy Technology Lab

- Simulate micro-grid or community (25 homes and businesses), including
  - PV
  - Storage
  - Fuel Cells
  - Microturbines
  - Diesel gensets
- Testbed for advanced power conversion and energy management systems

National Laboratories

Sandia National Laboratories
National Solar Thermal Test Facility



Sandia National Laboratories

Sandia State-of-the-Art Facilities
Microelectronic, Materials, and Nanotechnology

Sandia National Laboratories

Microelectronics and Semiconductor Materials Processing

Microelectronics Development Lab (MDL)

Microelectronics Development Lab (MDL)

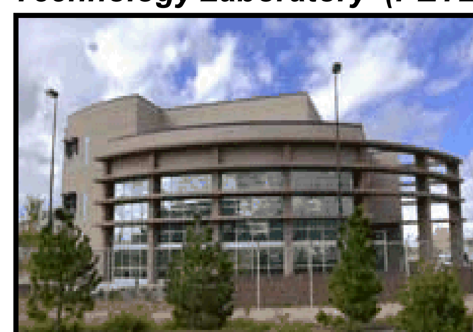
Microsystems & Engineering Science Applications (MESA)

Materials Sciences and Nanotechnology Technology

Center for Integrated Nanotechnology (CINT)

Integrated Materials Research Lab (IMRL)

Process & Environmental Technology Laboratory (PETL)



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Presentation Outline

- Technologies and Applications: Photovoltaics and Concentrating Solar Power (CSP)
- Markets and Trends
- Research to Pave the Way for Solar
- **Conclusions/Observations**

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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) are changing the PV market
  - Utilities need (and are developing) 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

Solar Power: The Path Forward

- **Some things to watch for:**
  - **Utility access to federal Investment Tax Credit (ITC)**
  - **Increasing focus on water-related issues and constraints on development**
    - PV – no water to operate; CSP – need to reduce water consumption (dry cooling)
  - **New building and community-scale energy management systems**
  - **Significant CSP production in Southwest U.S. – troughs**
  - **California continues to lead the way in the U.S.**