Solar Energy Technologies Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The Parker Ranch installation in Hawaii

Deep Dive

Department of Energy
Energy Efficiency & Renewable Energy
eere.energy.gov/solar

- **Goals**
- High penetration of solar energy
- Cost competitiveness with conventional electricity by 2015

- **Objectives**
- Reduce cost of technology
- Facilitate technology deployment
- Enable strong domestic manufacturing and supply base

The Program has broadened its focus in response to technology progress and the emerging industry

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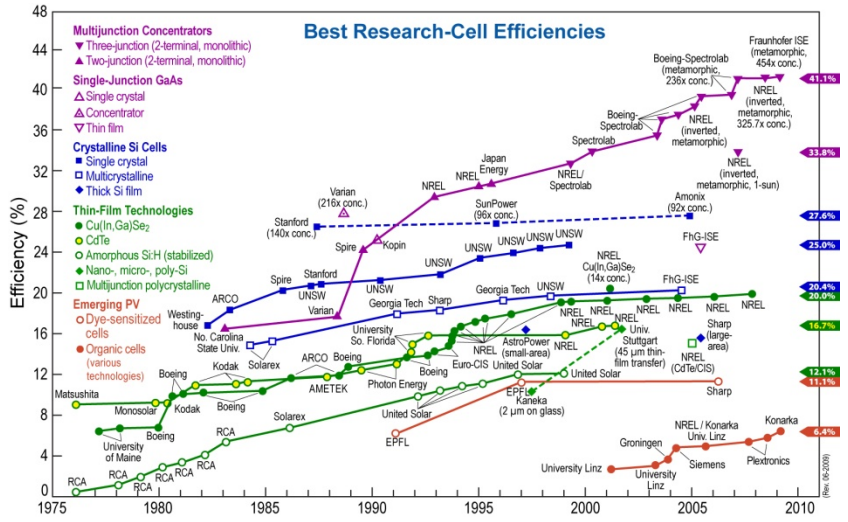
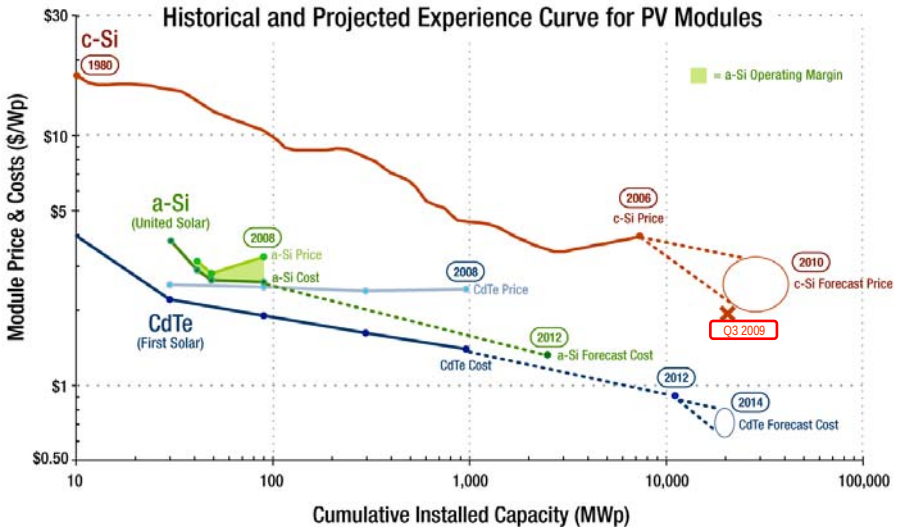
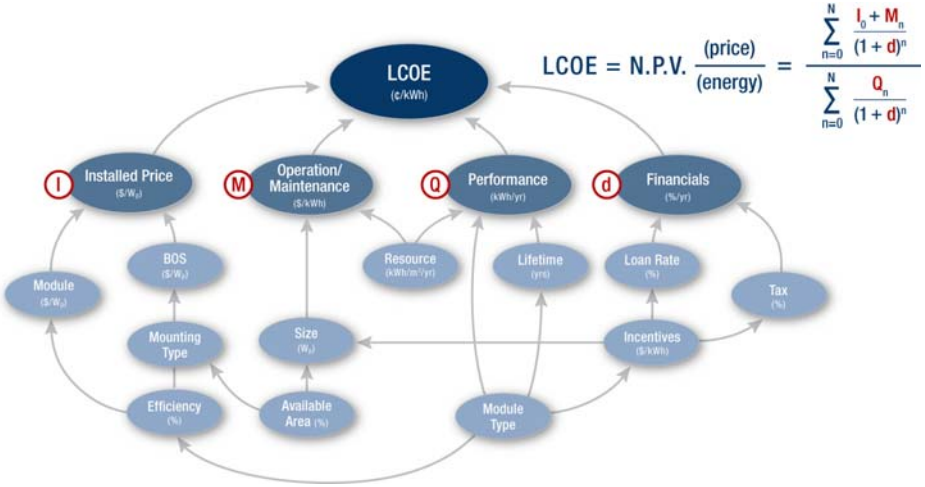
Cell efficiency was primary focus prior to 2005



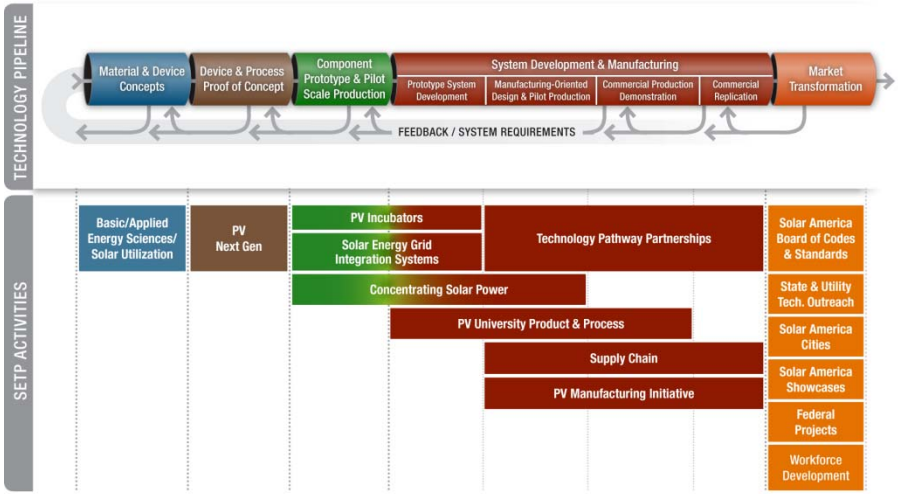
Greater focus over past 3 yrs on module/system cost



Levelized cost of electricity is the program's metric



Current program addresses entire RD&D pipeline



R&D activities address technical challenges for a diversity of PV technologies

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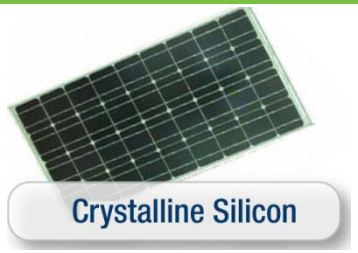
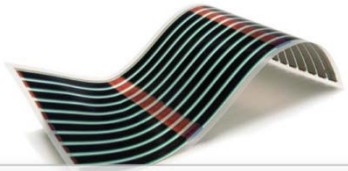


Crystalline Silicon



Thin Films

CPV

Systems Integration

STATUS

- >90% of installed market share (~20 GW_p PV installed worldwide).
- 13%-20% module efficiency (average efficiency ~ 14%).
- $2/W avg. module selling price (ASP).

- Lowest $/W Cost of Good Sold ($0.87/W First Solar).
- 6%-12% module efficiency (Averages: CdTe = 11%, a-Si=7%, CIGS=10%, Organic=2%).
- Flexible and lightweight which is enabling for Building Integrated PV.
- ASP $1.70 (First Solar), $2.40 (United Solar).

- Currently deploying prototypes
- 18%-27% module efficiency.
- Primarily targeting utility market.
- <10MW installed in 2008 (approx. 0.2% of globally installed PV).

- Inverters >95% efficient.
- Inverters + Balance of System = ~30% of system install price.
- Inverter price segmented across markets $0.20-0.70 $/W (utility scale to microinverter).

TECHNICAL BARRIERS

- Polysilicon price ($65/kg = $.5/W = ¼ of module costs).
- Segmented mfg processes → high capital expenditure ($2-3/W per yr. Cost per annual production capacity.).
- Manufacturing largely based upon semiconductor industry processes.

- CIGS and OPV reliability concerns; CIGS sensitive to moisture, Organic sensitive to heat.
- Up to 50% gap between the efficiency of small cells and modules.
- Lack of fundamental device understanding – minority carrier diffusion length, recombination, separation.

- Moisture ingress into cell packaging and operation and maintenance (soiling, tracking) costs.
- Cost reductions dependent upon mfg scale (>50MW/yr).
- Lack of system design to interface cell packaging with optics.

- 5-10 year inverter lifetime.
- Design focus is on kWpeak not kWh
- Inverters are the largest driver of O&M costs for residential and commercial systems.

GAME CHANGING BREAKTHROUGHS

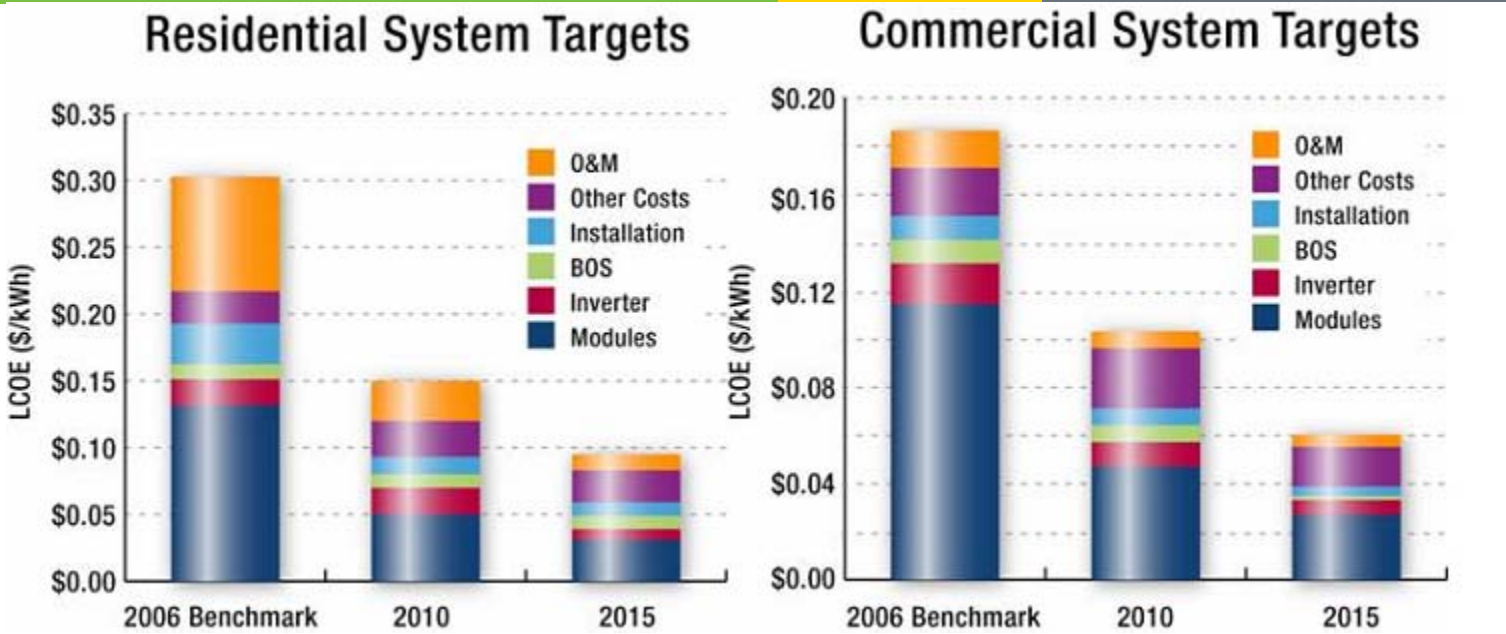
- Crystalline silicon wafers with low silicon intensity (avoid wafer sawing step) <2 grams/W via epi growth, direct solidification, or liftoff process.
- Low cost (<$1/W), high efficiency (>20%) back-contacted cell architectures.

- Robust, flexible PV encapsulants 10^{-5} $g/cm^2/day$ @ $20/$m^2$ or approximately 20¢/W at 10% module efficiency.
- Transformational materials including organics, nanomaterials and nanostructures >25% cell efficiency at <$0.50¢/W.

- Microconcentrator arrays (<1mm^2 cells) reduce materials cost, heat-sink requirements, and manufacturing scale.
- III-V cell technology achieves >45% efficiency for commercial cells.

- Robust component design yielding >20 year lifetime.
- Module level power conversion through microinverters or DC/DC boosts to dramatically simply installation and increase energy yield: “plug and play” solar.

Cost analysis provides guidance for R&D portfolio (PV)



- Modules: SETP is funding over 10 non-commercialized technologies with <$1/W (<5¢/kWh) cost targets. Approaches include technologies that avoid wafer sawing step, using upgraded metallurgical polysilicon feedstock, atmospheric thin film deposition, and a wide range of concentrating designs.
- Inverter: Emphasis on reliability and accelerated lifetime tests to achieve 10 – 15 year lifetimes while reducing $/W costs. Examples – eliminating electrolytic capacitors, improved potting for heat removal.
- Installation and Operation & Maintenance (O&M): Micro inverters and advanced power controls reduce system design and install time. Advanced module design (e.g. Sunpower T5) simplify installation. Building integrated form factors may expand installer (untrained labor) base and emerging markets.
- Balance of System (BOS): Systems driven approach has yielded modules designs optimized for reduced part count, system performance, and software for rooftop-specific system design.

	2015 PV Targets (2008 $)*	2015 Grid Forecasts (2008 $)	Notes
Residential Retail (¢/kWh)	9-11	9	Source: EIA Rates range from 5-21
Commercial Retail (¢/kWh)	7-9	7	
New Utility Wholesale (¢/kWh)	5.5-8	5-9.5^	Avg of EIA, EPRI, CEC, NETL ^w/carbon sequestration

*Assumptions: Targets calculated using 6% Nominal Discount Rate, 30 year system life, solar insolation from Phoenix AZ Climate (~20% capacity factor; 15-20% range: dependent on insolation, orientation, and absorber material), Federal 28% tax rate,, applying 3 tax benefits 1.) 10% Investment Tax Credit, 2.) Modified Accelerated Cost-Recovery System (i.e. accelerated depreciation of PV hardware asset), 3.) tax benefits from building system into mortgage. Installed system $/W for 2015 for these LCOE targets correspond to Residential = $3.50, Commercial = $2.50.

The Program is developing three promising CSP technologies

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STATUS

Operating temp: 400C, annual efficiency: 14%, storage, commercially proven, capacity factor 24-40%

Operating temp: 560C, annual efficiency: 18%, storage, no commercial plants in U.S. (240C steam plants in Spain, no storage)

Operating temp: 800C, annual efficiency: 23%, no storage, no commercial plants

TECHNICAL BARRIERS

- Thermal storage (price of salt has more than doubled in last 2 yrs)
- Heat transfer fluid capable of operating at up to 450C (present limit is 390C)

- Efficiency limited by temp capability of molten salt. Would like to use high efficient gas turbine (1200C) vs. the present steam turbine power cycle.
- No high temp storage

- Reliability (Stirling engine has problems with seals, valves, control system): improve mean time btw failure from 100 hrs to 1000 hrs
- No storage capability

GAME CHANGING BREAKTHROUGHS

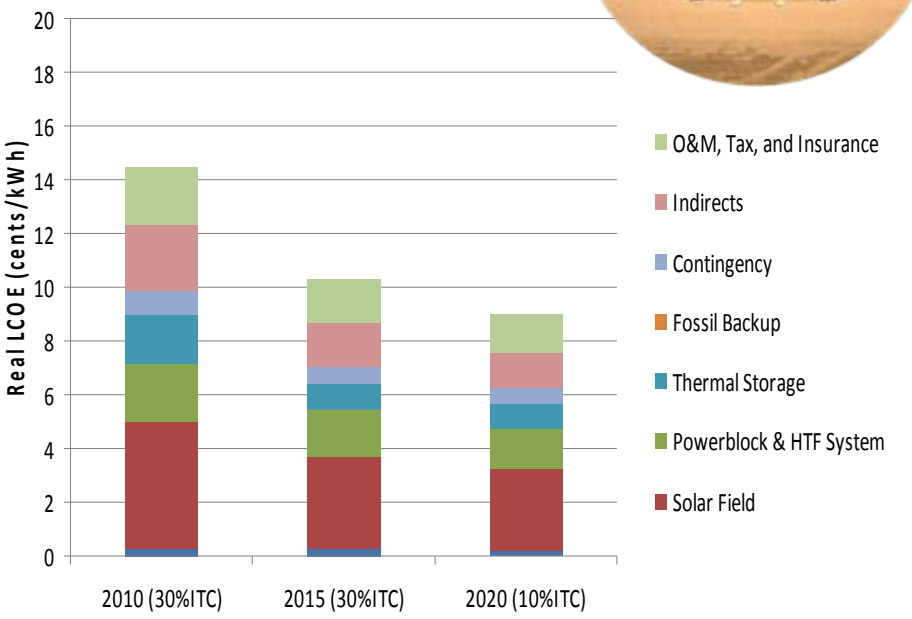
- High heat capacity salt storage through addition of nano-particles or storage of phase change materials
- Low melting temp molten salt in field enabling higher system efficiency (17-18%) and removing heat exchanger

- High temperature receiver (1200C) with supercritical CO_2 ,as heat transfer fluid with gas turbine power cycle,
- Storage of ceramic coated phase change material

- Accomplished breakthrough: record system efficiency of 31.25%, redesign of collector removed 25% of weight (redesign of engine reduced moving parts by 60% (engine now undergoing reliability tests
- Possible breakthrough: adding phase change storage

CSP Goal: Trough with 6 hrs storage (capacity factor of 40%)

Component	Base Case	Barrier/Approach	Impact on LCOE
O&M	1.5 ¢/kWh	Develop a more efficient collector drive - NREL	-5%
Storage	1.8 ¢/kWh	Increase heat capacity of molten salt (+50%) by addition of nano-particles – NREL, Texas A&M	-5%
Solar Field	4.8 ¢/kWh	Increase operating temp thru salt or steam in field enabling higher system efficiency (to 17.4%) and eliminating a heat exchanger – Abengoa, Solar Millennium	-4%
Solar Field	4.8 ¢/kWh	Replace glass reflector with polymer (-50%), lighter structure (-25%) – 3M, SkyFuel, NREL	-6%
Solar Field	4.8 ¢/kWh	Eliminate hydrogen diffusion into receiver annulus – NREL and Schott tasks	-5%



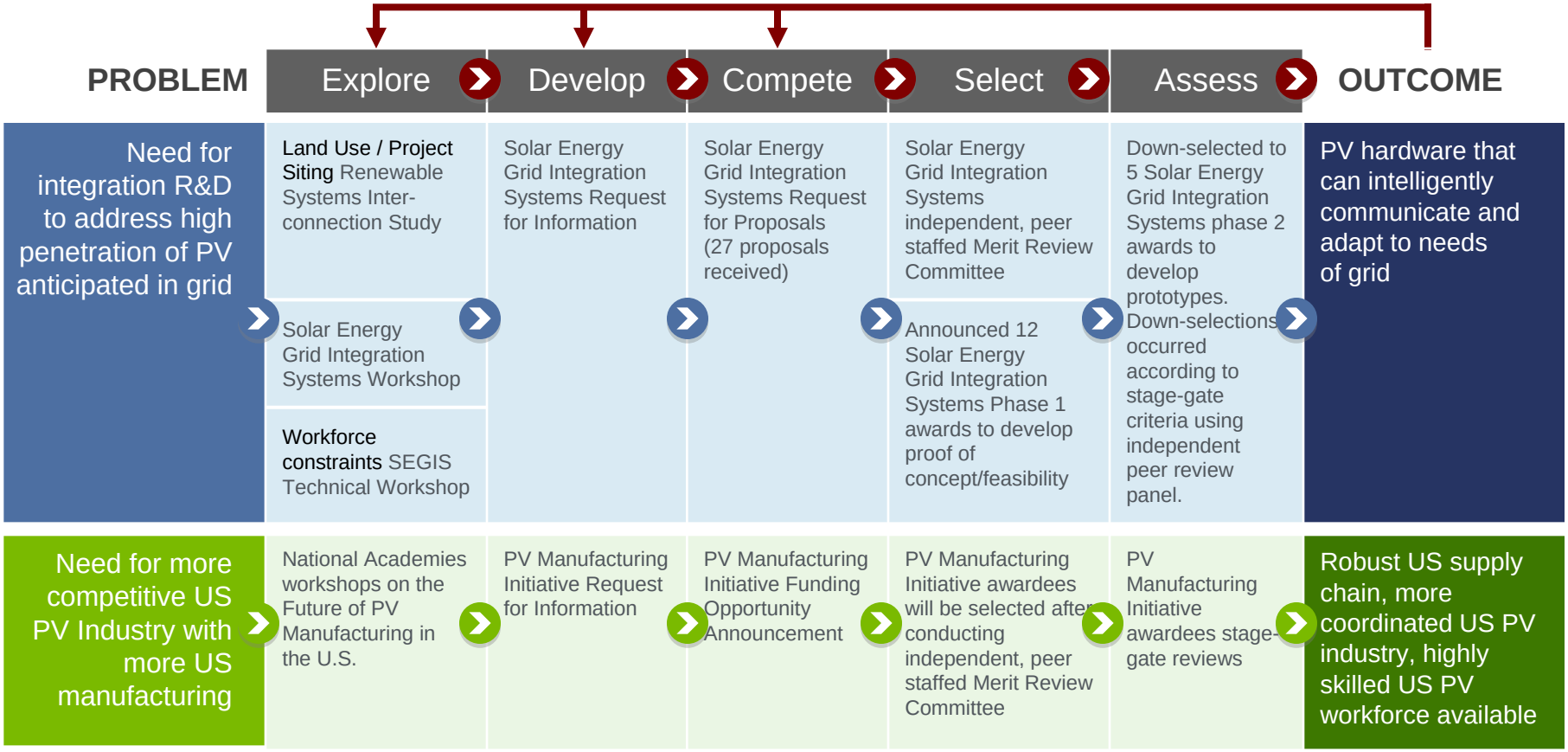
Estimated Cost of New Electric Generation, LCOE (¢/kWh)* Primary early market is California

	Pulverized Coal	Gas Turbine Combined Cycle	Nuclear
2015	5 – 6.5	5.5 – 8	5.5 – 8
2020	8 – 9.5^	5.5 – 8	5.5 – 8

* Avg of EIA, EPRI, CEC, NETL

^w/carbon sequestration

Solar Energy Technologies Program - Methodology



Market Transformation activities seek to overcome the barriers to Speed and Scale

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	BARRIER	PROGRAM APPROACH AND OUTCOMES
Enabling Scale	Land Use / Project Siting	• Partnering with BLM to permit 1000 sq. miles for solar projects and develop a pilot solar zone. Pilot solar zone would initially hold 1-2 GW of projects, with rest of lands able to hold up to 50 GW.
	Transmission/Interconnection	• Centralized Generation: Collaborating with FERC, WAPA, and DOE OE to facilitate 1 GW of transmission to pilot solar zone • Distributed Generation: Analyzing impacts of interconnecting PV onto network/area grids in NYC and other downtown areas to facilitate solar integration into large cities.
	Workforce constraints	• Funding 8 Regional Training Providers to enable rapid "Train the Trainer" scale- up of nationwide installer instructor training. • Supporting solar training curriculum development to enable rapid training program scale-up • Supporting installer certification efforts to encourage high-quality workforce
	Fragmented state/local policy	• Supporting best practices on distributed PV interconnection procedures (2 MW system size limits, technical screens, process transparency) to enable lower-cost, streamlined installs. • Partnering with 25 cities to streamline local permit processes from weeks to hours, develop innovative property assessed financing models, integrate solar into energy infrastructure planning • Working with state clean energy funds and regulators to improve solar incentive programs, optimize use of solar within renewable portfolio standards, and explore feed-in tariff design
	High PV penetration grid issues	• Developing advanced inverters and software to manage energy dispatch and loads, and enable solar integration into smart grid
Standardizing Approaches	Inadequate codes and standards	• Streamlining industry input into 2010 National Electrical Code Article 690 and IEEE 1547 Interconnection Standard to ensure safe, high-quality installations • Developing a PV cell pre-qualification standard for module manufacturers to reduce time to market • Integrating national solar product safety standards (UL 1703) into international protocols (IEC 61730) to reduce industry compliance costs and enable global growth. • Working with California fire marshals to create fire fighting codes and protocols for buildings with PV; spreading results nationwide
	Uncertain expected system performance	• Supporting resource assessment and advanced modeling approaches to improve system performance estimates for project developers and the finance community
Educating Consumers	Lack of utility acceptance	• Improving utility uptake through executive education, new business model development, and peer sharing
	Low awareness and experience with solar	• Leveraging experience of 25 direct city partnerships through nationwide local government outreach, enabling more cities to reach out to local businesses and residents • Providing technical support on 20+ large solar installation efforts across multiple applications: federal, residential, historic preservation, low-income, convention centers

Collaborations are critical achieving objectives – e.g.,

DOE/BLM partnership for solar to installations on Federal lands

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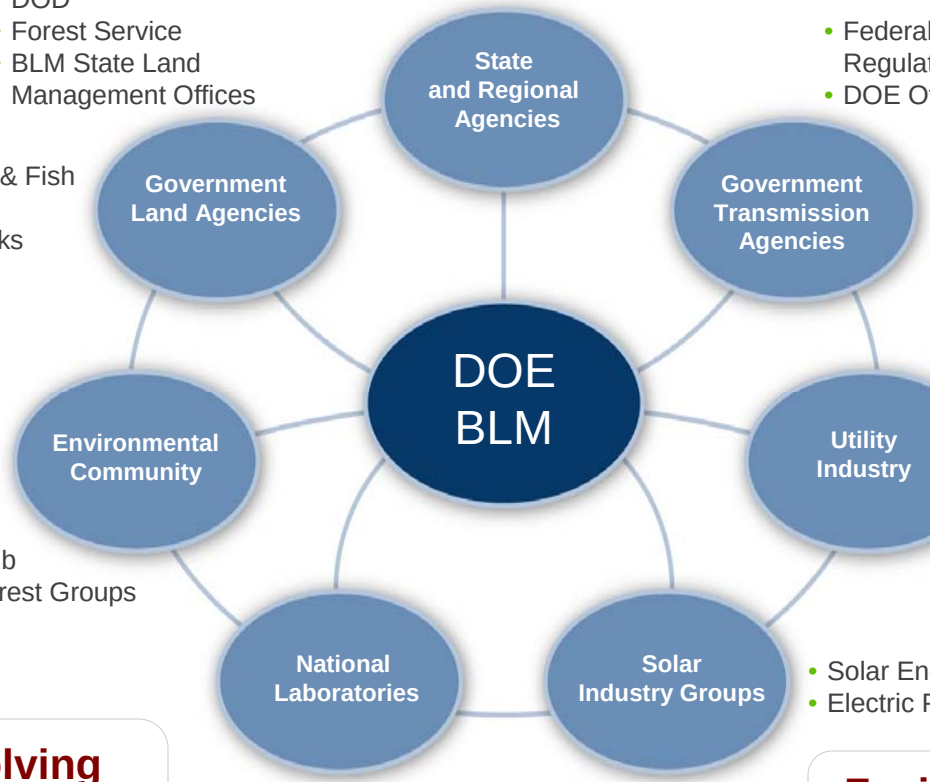
Creating Solar Zones

Assuring Transmission Access

- Western Governors Association
- California Public Utility Commission

- DOD
- Forest Service
- BLM State Land Management Offices

- Federal Energy Regulatory Commission
- DOE Office of Electricity



- State Game & Fish
- Tribal
- National Parks

- Pacific Gas & Electric
- San Diego Gas & Electric
- Excel Energy

- Sierra Club
- Local Interest Groups

Outcome:

1-2 GW sited in pilot zone

Lands designated for 50GW

Resolving Environmental Issues

- Sandia
- Nat'l Renewable Energy Lab
- Argonne

Industry Funding Recipients:
- Trough, Tower, Dish, Fresnel

- Solar Energy Industry Association
- Electric Power Research Institute

Facilitating Pilot Demonstrations

The Program is having a positive impact – successful new companies, deployment in U.S. cities, and solar workforce

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- ***Solar Companies with Diverse Photovoltaic Approaches Achieve Success Through DOE R&D Funding***: First Solar, Sunpower, Abound Solar, and SolFocus, four companies sponsored by DOE to conduct photovoltaic R&D, showcase the acceleration achieved by the DOE Solar Energy Technologies Program in commercializing cutting edge solar technologies.
  - Over nearly two decades, the DOE supported First Solar and its predecessor, Solar Cells Inc. with over $25M of project funding to develop a monolithically integrated CdTe all-glass module. Industry focused programs, funded by DOE and coordinated through technology experts at NREL, provided First Solar with direct funding, transferred critical IP, and guided their development with device characterization and module evaluation. Today, First Solar has advanced the manufacture of this technology to achieve the lowest per watt cost and will be the world's largest PV manufacturer (in terms of both power and revenue) in 2009.
  - Sunpower was funded through DOE's Technology Pathway Partnerships activity to pair its highly innovative silicon wafer-based technology with streamlined installation. As a result of this partnership, Sunpower has recently received UL certification on its "T-5" integrated plastic-framed rooftop commercial module system, which exhibits significantly reduced costs in logistics, installation, and labor.
  - Abound Solar is a thin film photovoltaic company producing cadmium telluride-based solar modules that was funded through DOE's PV Incubator activity. Under this project, Abound accelerated the development of their new technology, moving into pilot-scale testing and full-scale manufacturing within an aggressive 18-month time frame, specifically by demonstrating their 60-cm x 120-cm CdTe module with competitive efficiency in a 65 MW production line.
  - SolFocus, a concentrating photovoltaics company, has also recently completed their PV Incubator project to develop reflective optics that concentrate sunlight by a factor of 650. These optics have been incorporated into the SolFocus 1100S CPV system, which has recently transitioned into full scale commercialization, with 11MW of product being shipped this year and an estimated 100MW of manufacturing capacity in place by the end of 2011.

- ***DOE Helps Local Governments Integrate Solar Energy Into Their Communities****:* In Portland, Oregon, it used to take months to get a permit to install a solar system; now it takes 24 hours, and you can do it online. In New York City, electric utility ConEdison used to prevent solar PV installations, worried about impacts to the city's complex electric grid; now ConEd's Vice President of Engineering is encouraging distributed solar. And in New Orleans, Louisiana, Katrina-affected workers were wondering how to regain steady employment in a crippled economy; now over 180 of them have graduated from Louisiana Clean Tech's solar installer training course and have the skills to build a stable green career.
  - All of these achievements were made possible by DOE's Solar America Cities activity, through which the Department has partnered with 25 large U.S. cities to overcome barriers to urban solar energy adoption. From installing solar on city facilities to updating zoning codes and permitting processes to providing financial incentives, Solar America Cities demonstrate comprehensive, city-wide approaches that encourage and facilitate solar as a viable energy solution for residents and businesses. In September 2009, DOE announced $10M for 40 Solar America Cities Special Projects that will enable cities to scale up innovative programs and concepts for replication across the U.S. In July 2009, DOE published *Solar Powering Your Community: A Guide for Local Governments,* a 150 page resource that contains best practices for local solar policies and programs. DOE will expand its outreach efforts to hundreds of local governments through the $10.5M Solar America Cities Technical Outreach funding opportunity, which closes October 15.

- ***DOE Supports High Quality Green Workforce through Solar Installer Instructor Training:*** The Department of Energy's Solar Program held a training session in July 2009 at the Florida Solar Energy Center for 18 representatives from 8 major markets. By the end of their 5 days at the Florida Solar Energy Center these individuals were prepared to go back into their communities and effectively roll out solar installer training programs, including effective curriculum, hands-on training and classroom materials.
  - Training programs like these have a multiplier effect; DOE provides high quality training to a small set of solar instructors, who then train new installers and trainers, and so on. Recognizing the power of this approach, DOE has awarded $27M to eight new solar installer instructor training institutions. These institutions will offer high quality training across the nation in both solar photovoltaic (PV) and solar heating and cooling installation, helping to usher in the new green workforce.