Technology Commercialization Showcase 2008
Solar Energy Technologies Program
"Accelerating the Future of Solar"

John Lushetsky, Program Manager

http://www.eere.energy.gov/solar
Email: john.lushetsky@ee.doe.gov
Tel: 202-287-1685

Agenda

- Program Objectives
- Industry Landscape
- Investment Opportunities
- Technology Commercialization Opportunities

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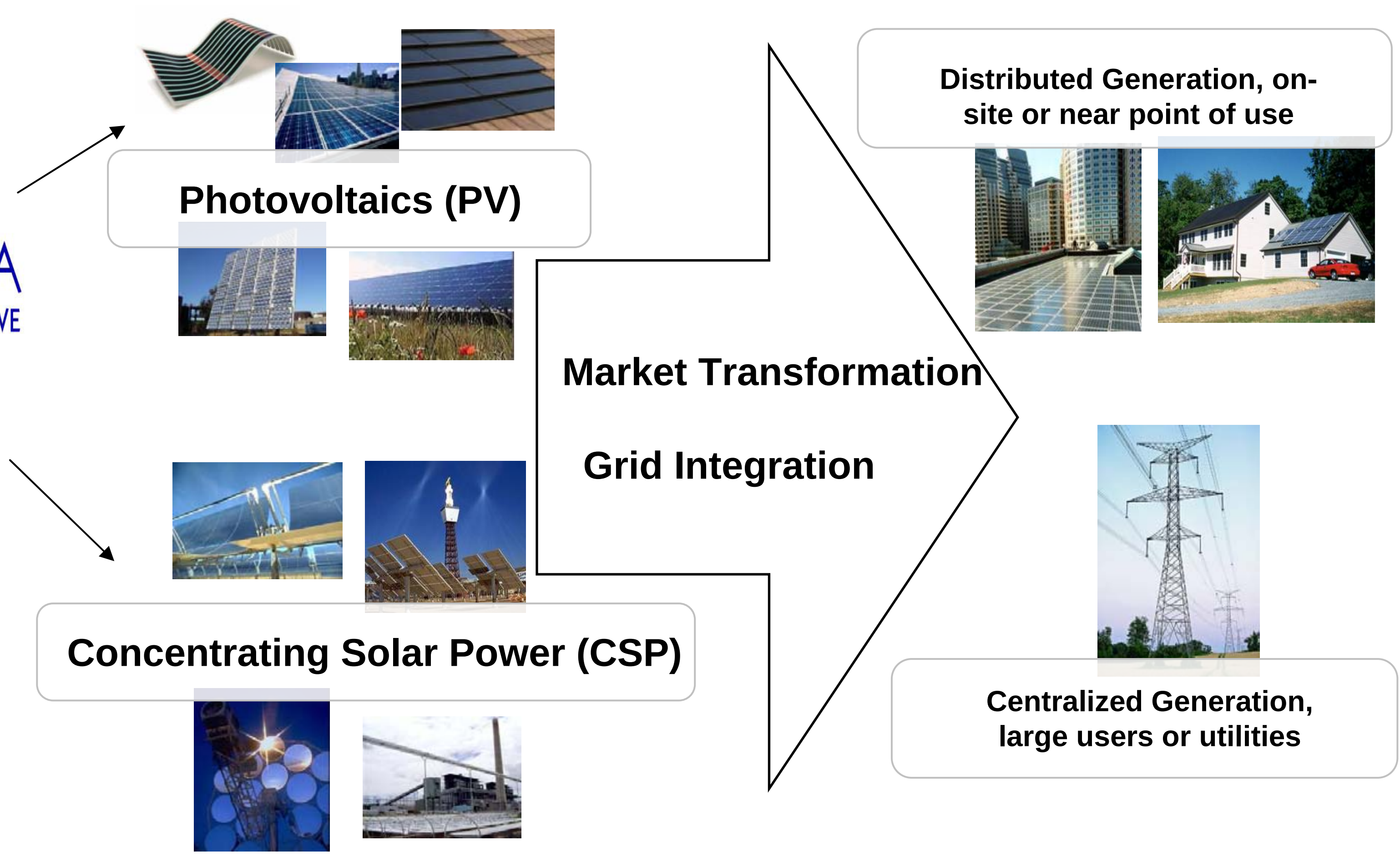
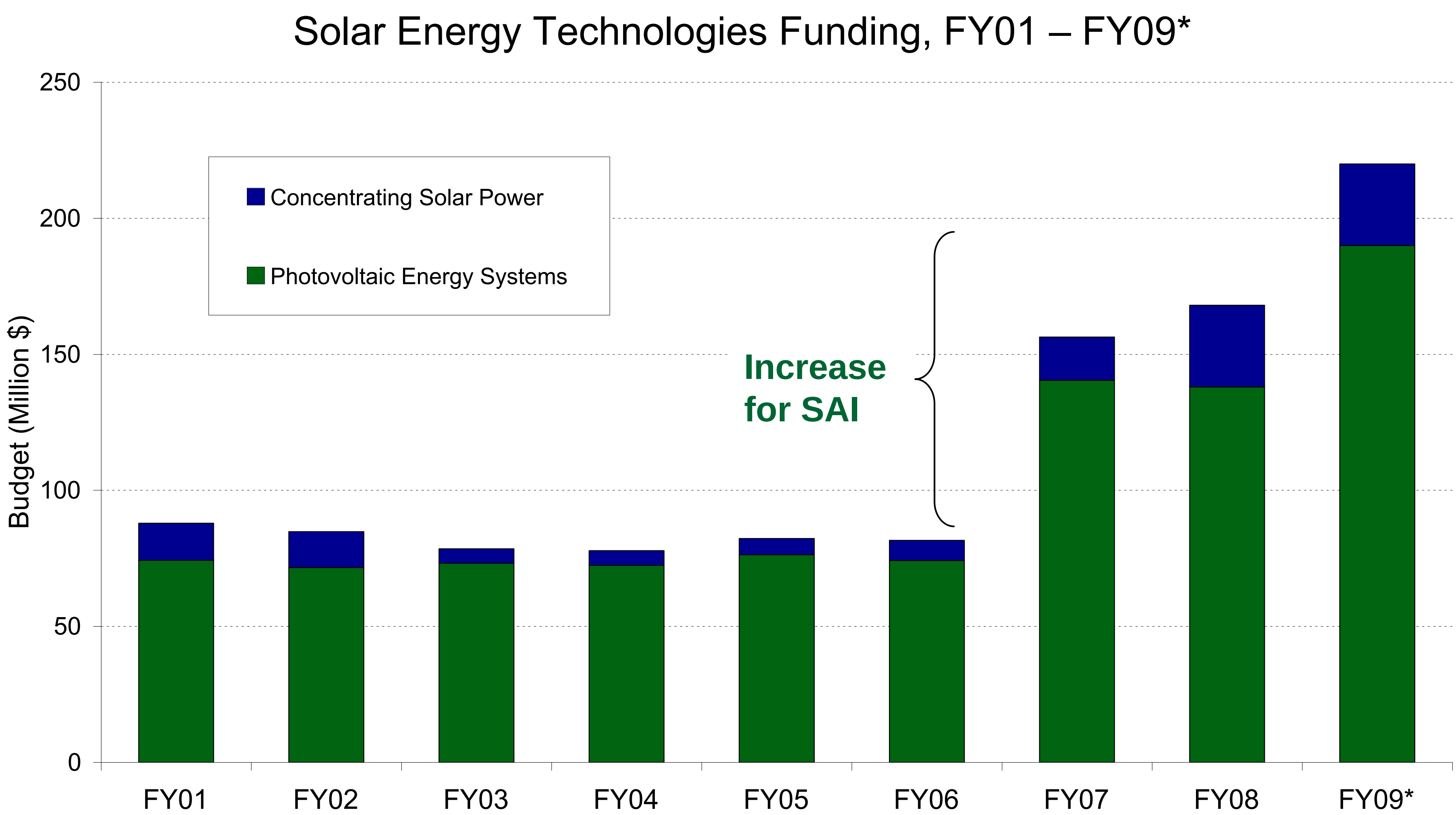
The mission of DOE's Solar Program:

To accelerate the wide-spread adoption of solar electric technologies across the United States through a program of applied research and development, demonstration, and market transformation activities.

SOLAR AMERICA INITIATIVE

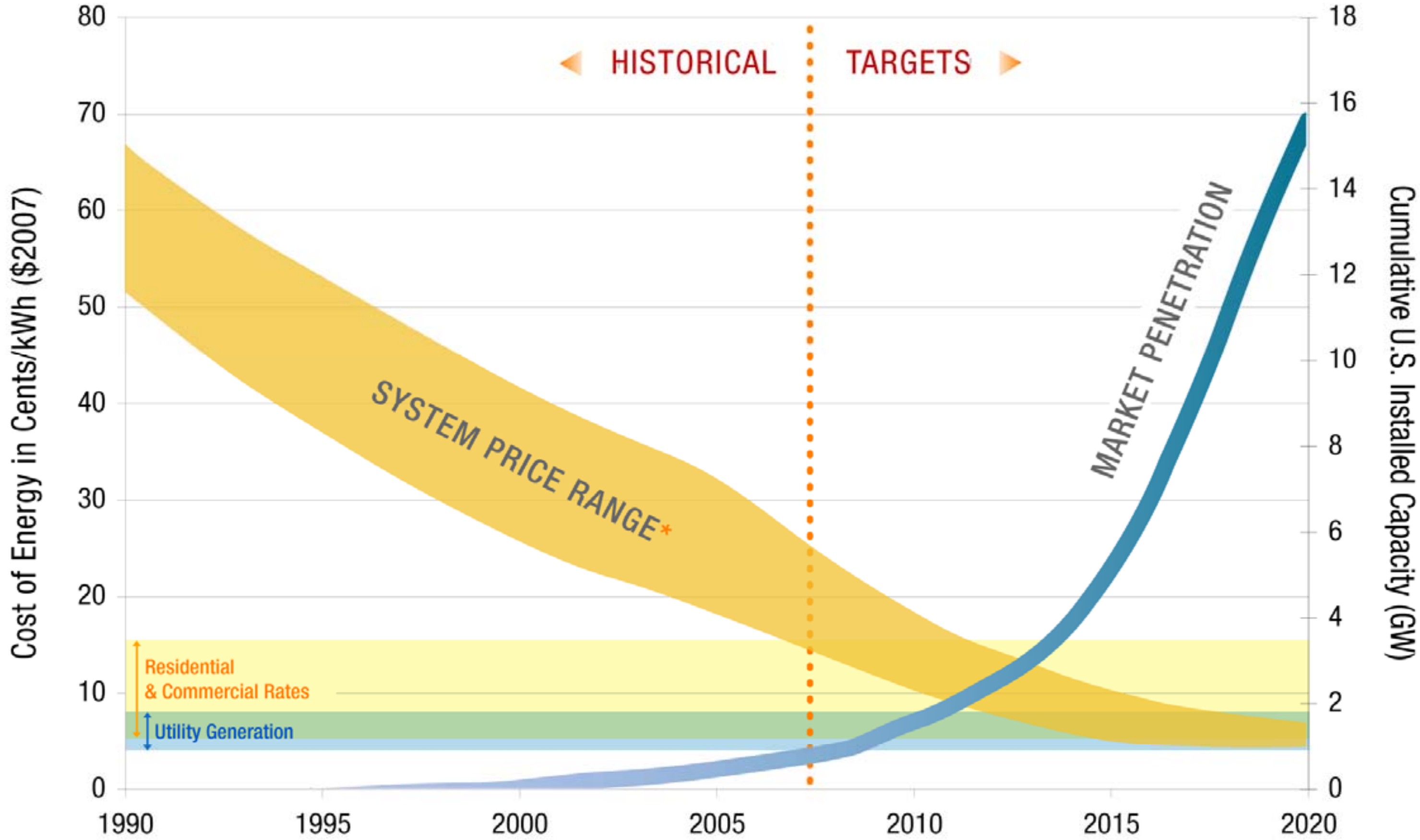


Funding for the Solar America Initiative will accelerate supply growth & adoption of PV/CSP technologies



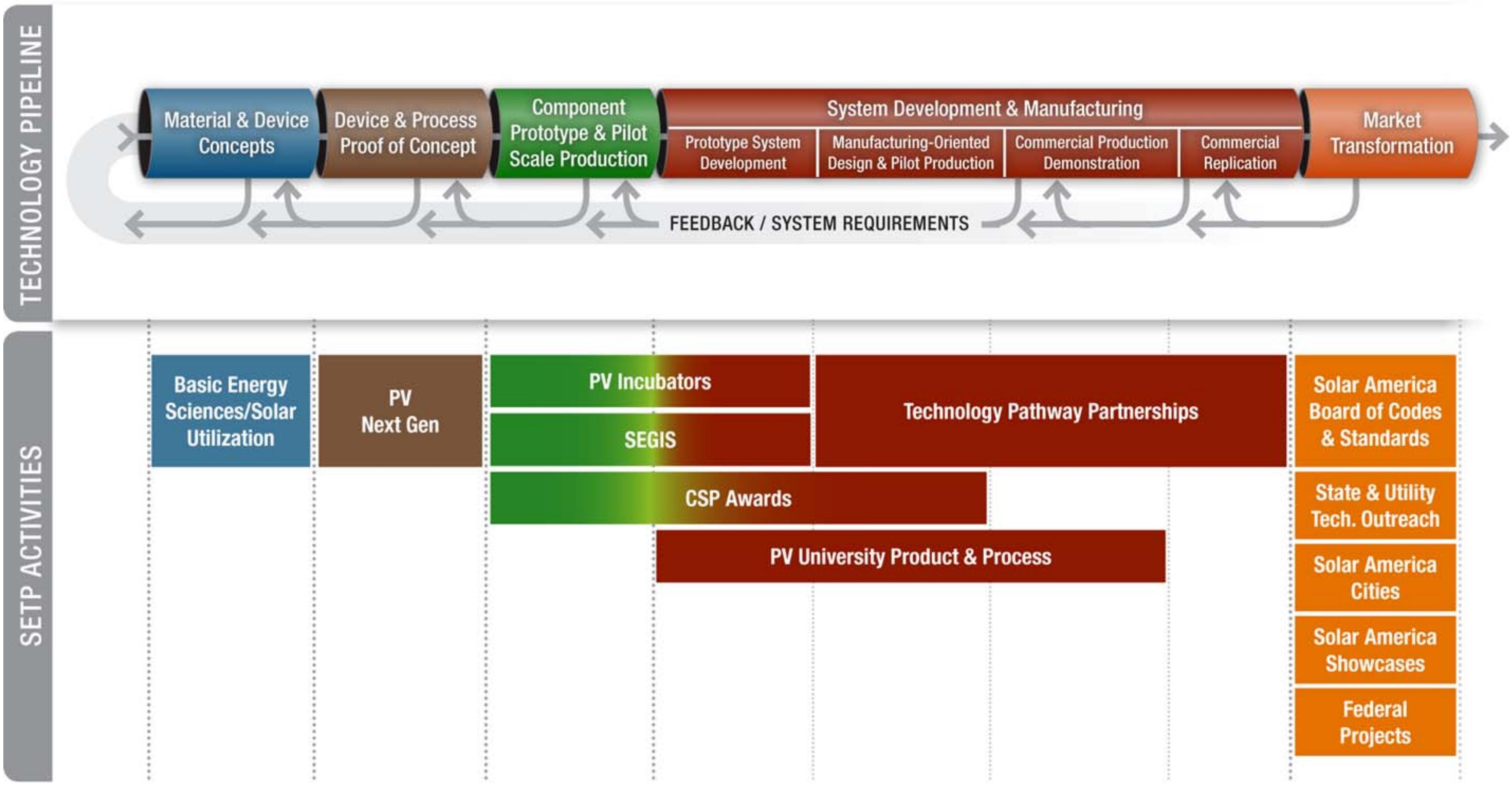
*President's request for FY09 was $150M, current House mark is $220M, current Senate mark is $229M.

We expect system prices to continue to decline with potential grid parity as soon as 2012-2015



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8 - 16.7	23 - 32	13 - 18	8 - 10
Commercial	5.4 - 15.0	16 - 22	9 - 12	6 - 8
Utility	4.0 - 7.6	13 - 22	10 - 15	5 - 7

DOE's Solar Energy Technologies Program (SETP) works along the whole RDD&D pipeline



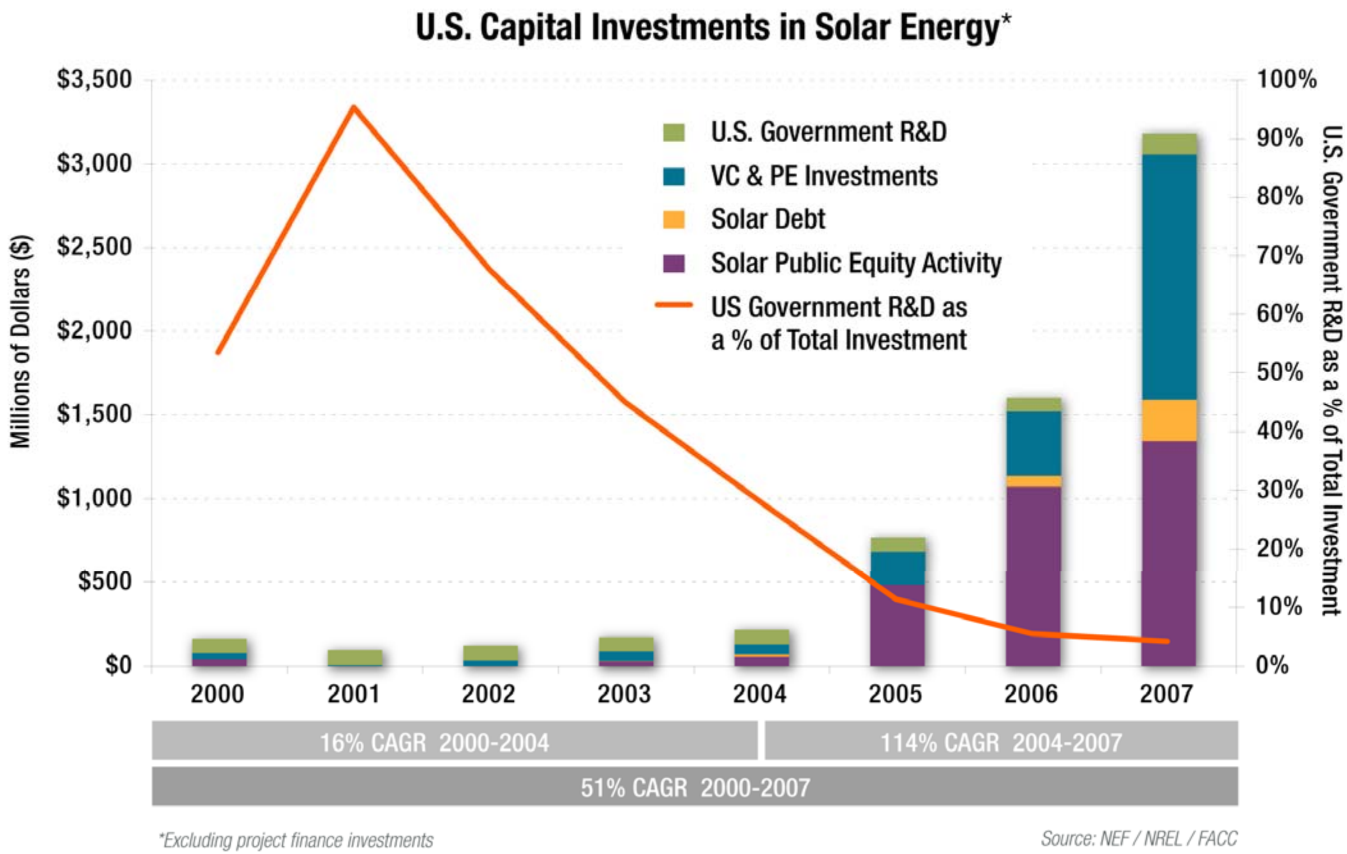
SETP project portfolios appropriately and aggressively target specific segments of the solar value chain

= Completed   = In Process

PHASES →

Material & Device Concepts	Device & Process Proof of Concept	Component Prototype & Pilot Scale Production	System Development & Manufacturing
Solar Energy Utilization (BES) First Round • Award duration: **3 years** • **25 awards** • Award amount: **$0.15-$1.5 M/yr**	**Next Generation PV Device and Process** • Award duration: **3 years** • **25 awards** • Total: **Up to $21.7 M over 3 years**	**PV Incubators First Round** • Award duration: **18 months** • **10 awards** • Total: **Up to $27 M over 18 months**	**Technology Pathway Partnerships** • Award duration: **3 years** • **11 awards** • Total: **Up to $168 M over 3 years**
Solar Energy Utilization (BES) Second Round • Award duration: **3 years** • Award amount: **$0.15-$1.5 M/yr**		**Solar Energy Grid Integration Systems (SEGIS) Program** • Award duration: **3 years** • Award amount: **Up to $6.25 M**	**University Product and Process Development Support** • Award duration: **3 years** • **11 awards** • Total: **Up to $13.7M over 3 years**
Energy Frontier Research Centers (BES) • Award duration: **5 years** • Award amount: **$2-$5 M/yr**		**PV Incubators Second Round** • Award duration: **18 months** • Award amount: **Up to $2-3 M**	**CSP FOA 2007** • Award duration: **3 years** • Award amount: Up to **$13 M**
		CSP Thermal Storage • Award duration: **3 years** • Award amount: **Up to $6.25 M**	**Supply Chain** • Award duration: **1-3 years** • Award amount: **$0.3-2 M**

Venture capital and private equity investment have become driving forces in the U.S. solar industry



DOE Funding Advantages

1. Focusing industry on full system costs (¢/kWh)
2. Structured milestones that reward performance
3. Fostering support for solar within large companies
4. Legitimizing young companies and new technology
5. Non-dilutive to company financing; minimal IP requirements

Photovoltaic Technology Incubator Projects

Explore the commercial potential of new manufacturing processes and products

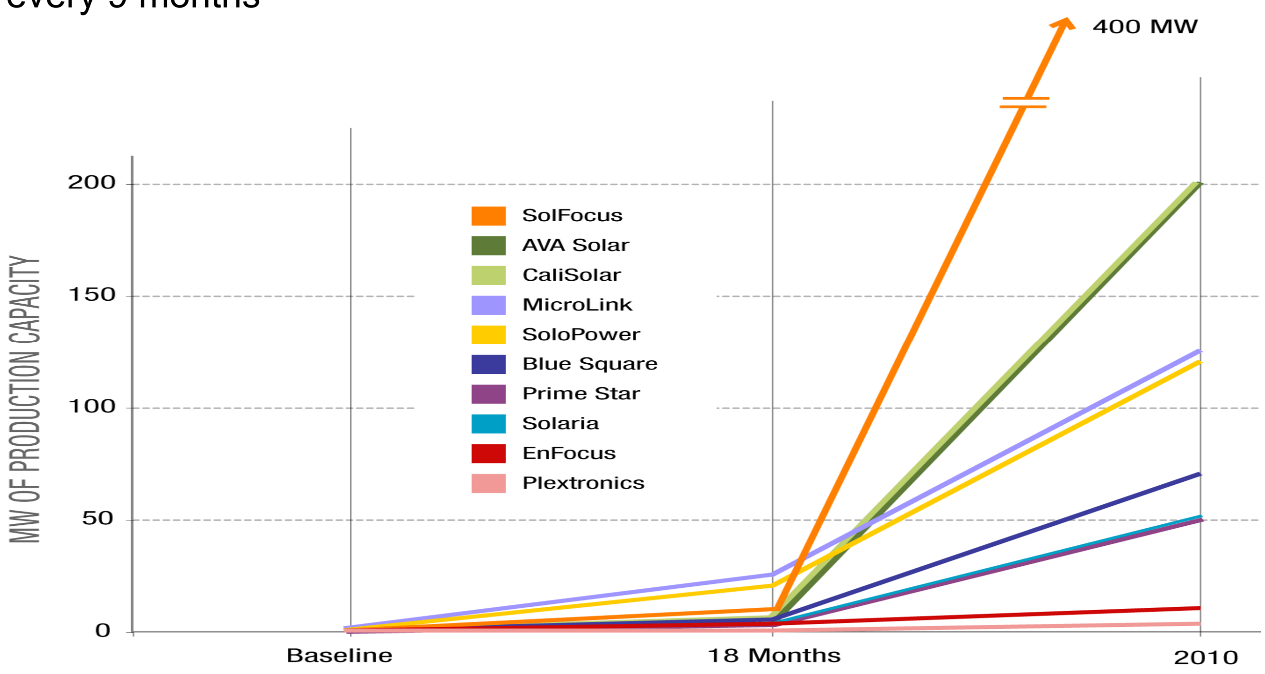
- Promote the scale-up development of a diverse set of PV technologies which have already been proven on a small scale

Foster innovation and growth in the domestic PV industry

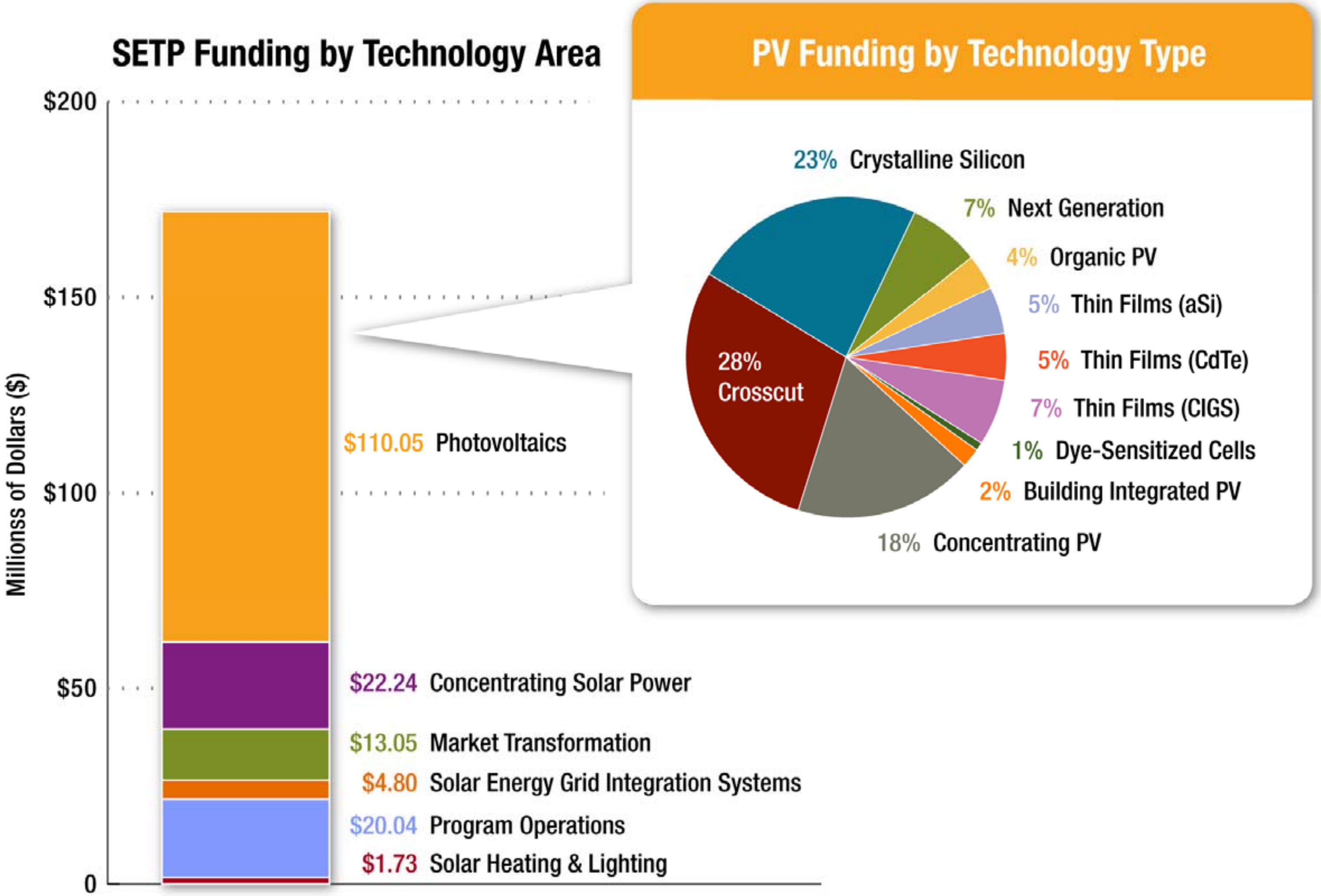
- Provide U.S. small businesses with a chance to expand quickly in a rapidly maturing industry

Establish an efficient and cyclic funding opportunity

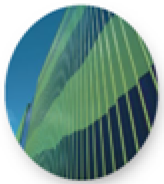
- 18 month / $3 million awards are based on timely completion of milestones
- Provide funding opportunities for new applicants and stage gate review of funded incubator projects every 9 months



2008 Technology Funding Breakdown



PV module research balances various materials through joint industry R&D and long-term research



Thin Films (aSi) 5%

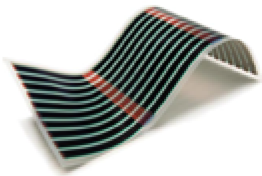
Advancing amorphous and wafer replacement crystal silicon film solar cells on low-cost substrates

5% Thin Films (CdTe)

Simplifying deposition while retaining performance and transferring record device architecture to manufacturing processes

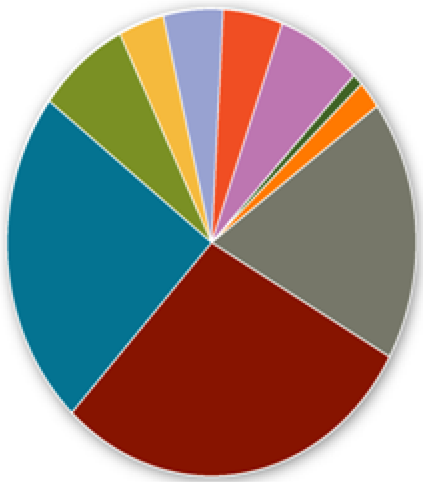
7% Thin Films (CIGS)

Supporting the manufacture of non-vacuum processes and transferring record efficiency device performance into large area commercial modules



Organic PV 4%

Customizing molecules, substrates, and deposition techniques to yield ultra low-cost modules



1% Dye-Sensitized Cells

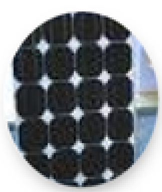
Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures

Next Generation 7%

Investigating advanced concepts aimed at delivering revolutionary performance improvements

2% Building Integrated PV

Creating module form factors aimed at dramatically reducing or eliminating solar installation costs



Crystalline Silicon 23%

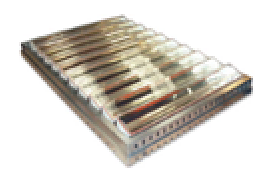
Developing higher efficiency devices and lower cost processing methods for traditional silicon cells

28% Crosscut

Synergistic technologies, evaluation approaches, and process engineering approaches applicable across multiple absorber materials and processes

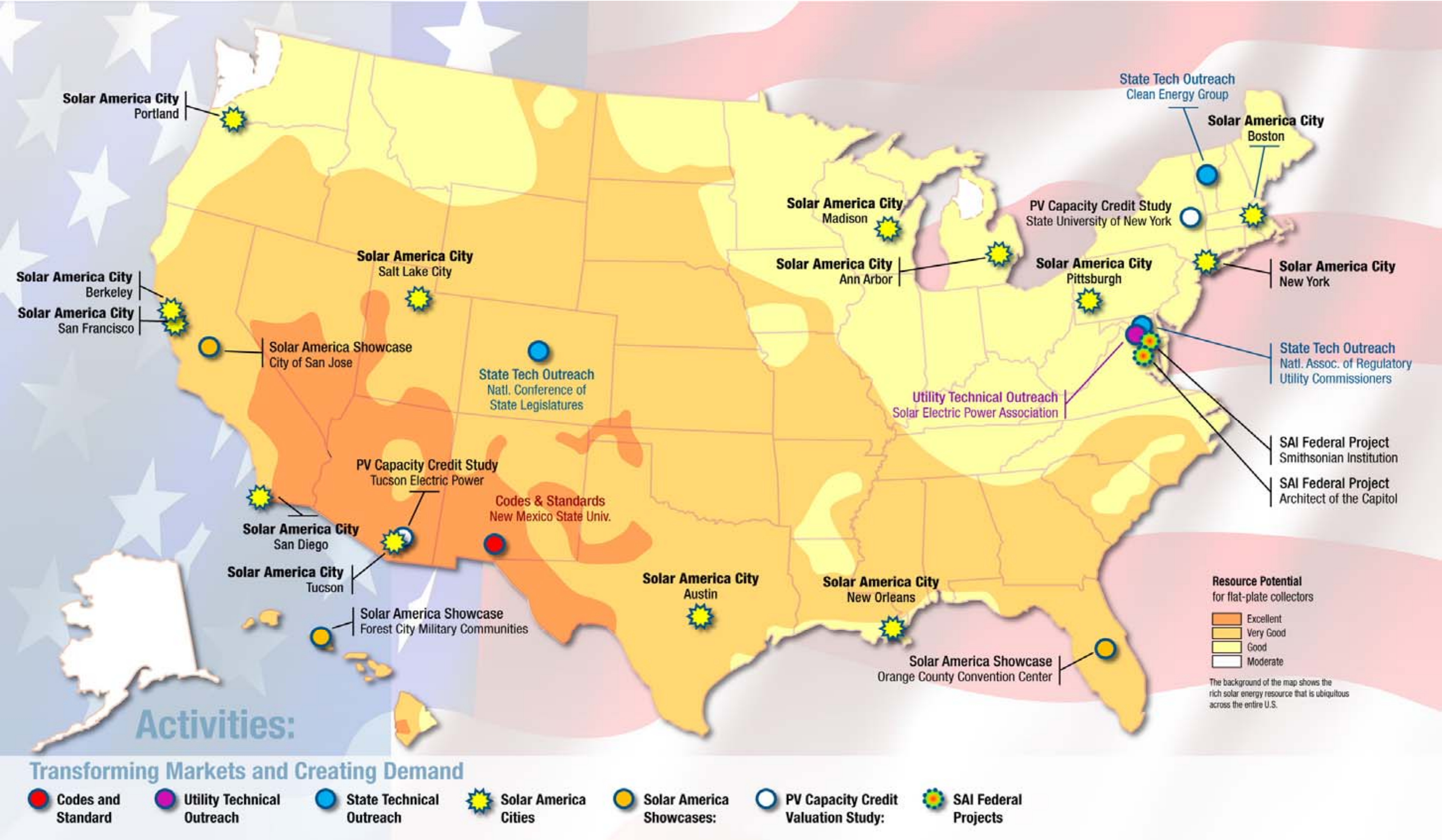
18% Concentrating PV

Combining new, lower cost multijunction cells and innovative optical packages



SAI Partnerships accelerate solar technology development across the entire R&D pipeline

SAI market transformation activities are targeted to eliminate non-technical barriers to large scale solar adoption



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By 2015, electricity rates in some parts of the country may reach as high as 27¢/kWh

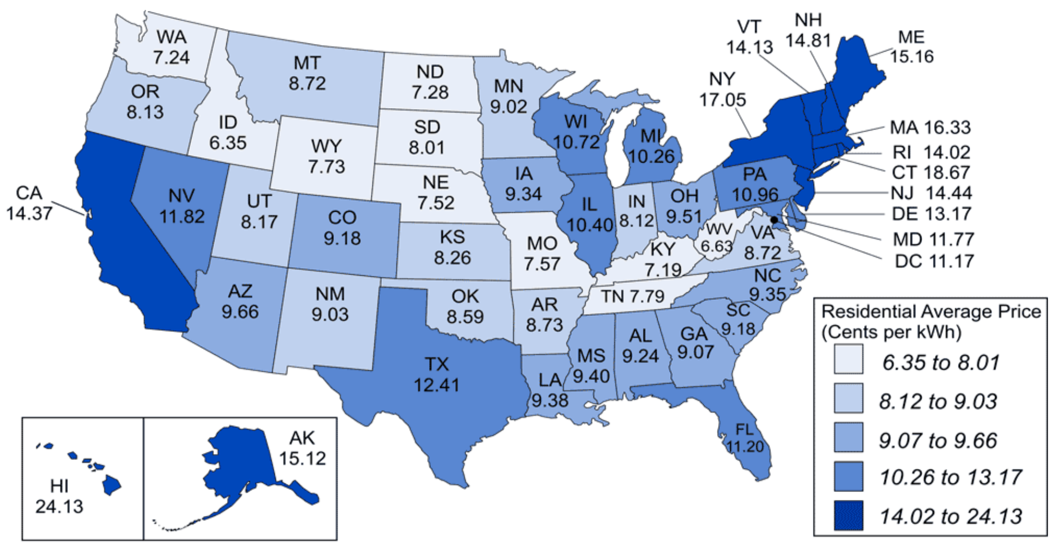
EIA National Retail Electricity (cents / kwh)	
2007	10.64
2006	10.40
2005	9.45
2004	8.95
2003	8.72
2002	8.44

4.7% historical CAGR

- EIA shows historic national average retail electricity prices outpacing inflation by ~1.2%
- Applying the same conservative 4.7% inflationary rate, average US electricity prices will reach 16 ¢/kWh by 2015

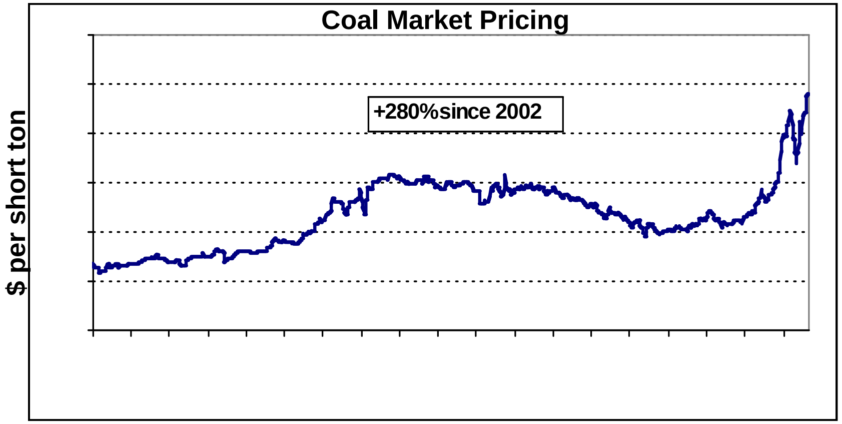
The U.S. average residential retail price of electricity was 10.64 cents per kilowatt – hour in 2007

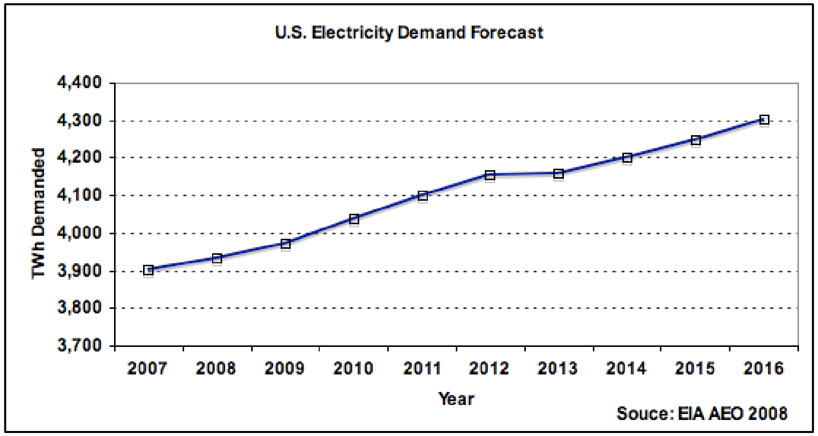
- Retail electricity rates are highly variable nationwide
- Rates in some states will be higher, with CT electricity prices forecast to reach 27 ¢/kWh in 2015



Source: Energy Information Administration, Form EIA-826, "Monthly Electric Sales and Revenue with State Distributions Report."

Increasing cost drivers from traditional generation sources could drive solar adoption faster than is currently anticipated

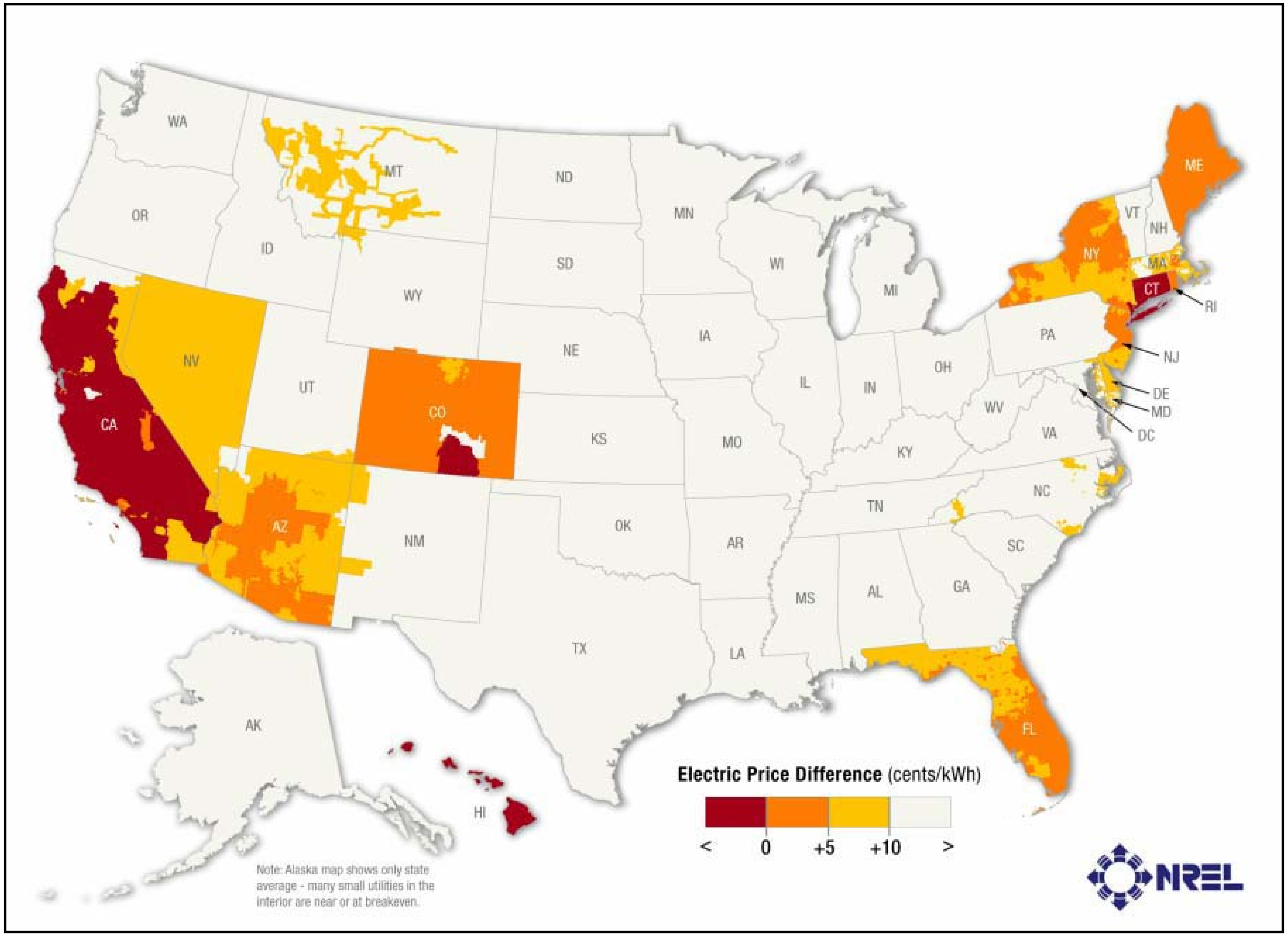




- Coal prices have nearly tripled over the past five years
- Coal power plants face increasing project uncertainty due to carbon and siting concerns
- Natural gas prices have more than doubled during the same time period
- New nuclear plants will not be ready until post 2015
- Electricity demand is forecast to increase by 10% or **386 TWh** through 2015, requiring substantial capacity additions

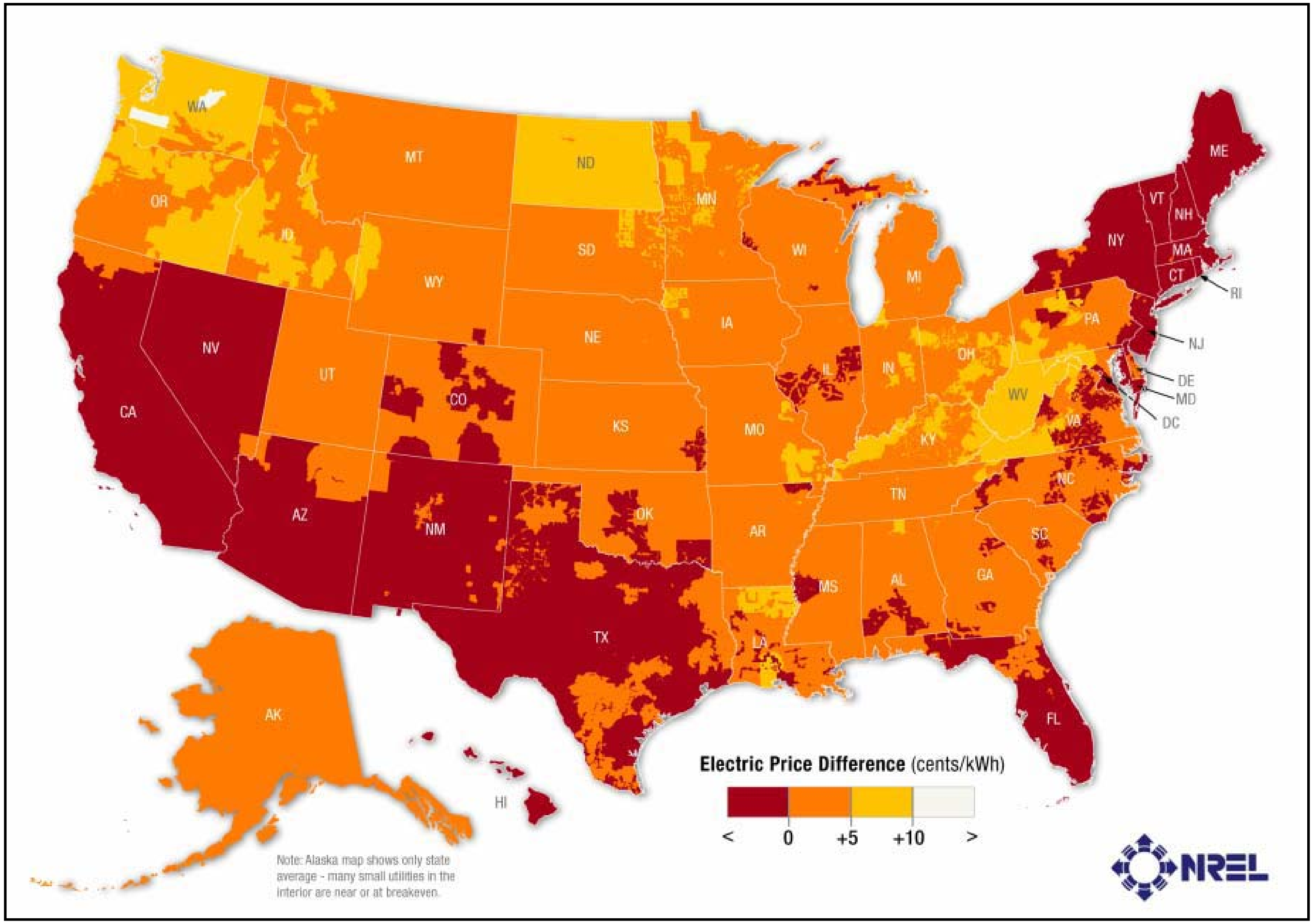
Market penetration begins - 2007 residential PV and electricity price differences with existing incentives

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



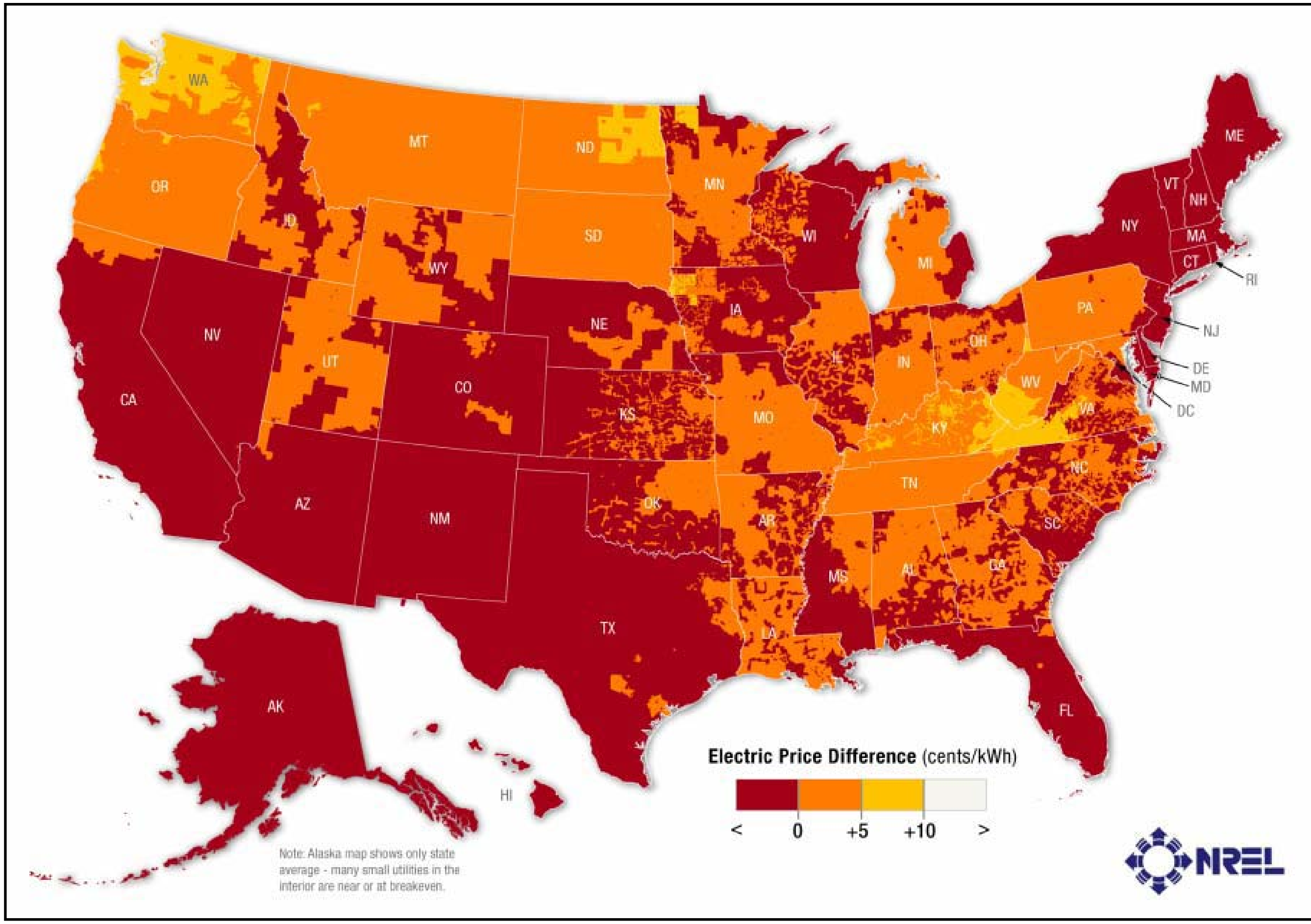
The conservative forecast - 2015 residential without incentives and moderate (1.5%PA) increase in electricity prices

- 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

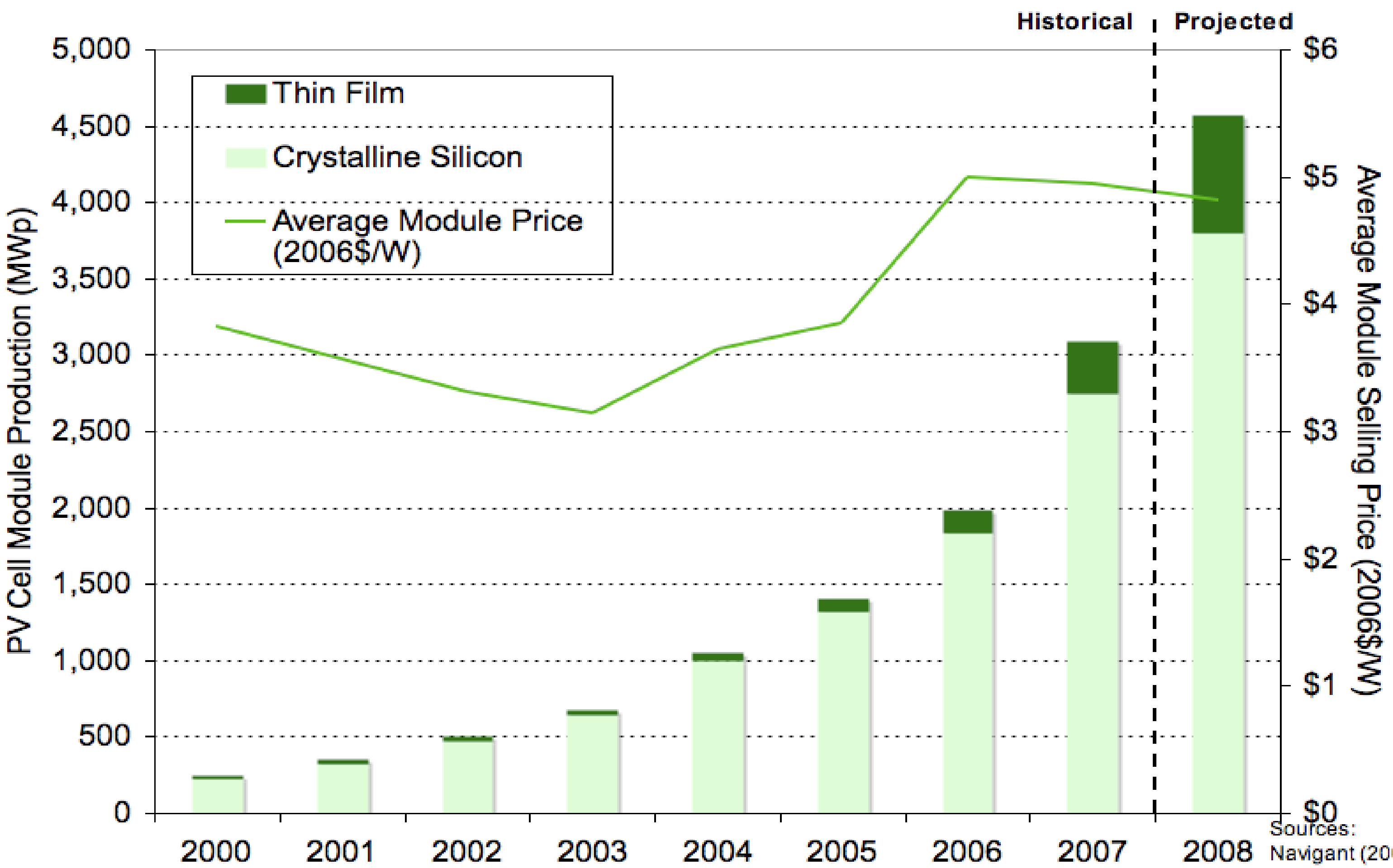


The realistic forecast - 2015 residential installations without incentives and aggressive (2.5% PA) increases in electricity prices

- PV is less expensive in 450 of the 1,000 largest utilities, which provide ~50% of U.S. residential electricity sales
- 91% of sales (in nearly 950 utilities) have a price difference of less than 5 ¢/kWh between PV and grid electricity

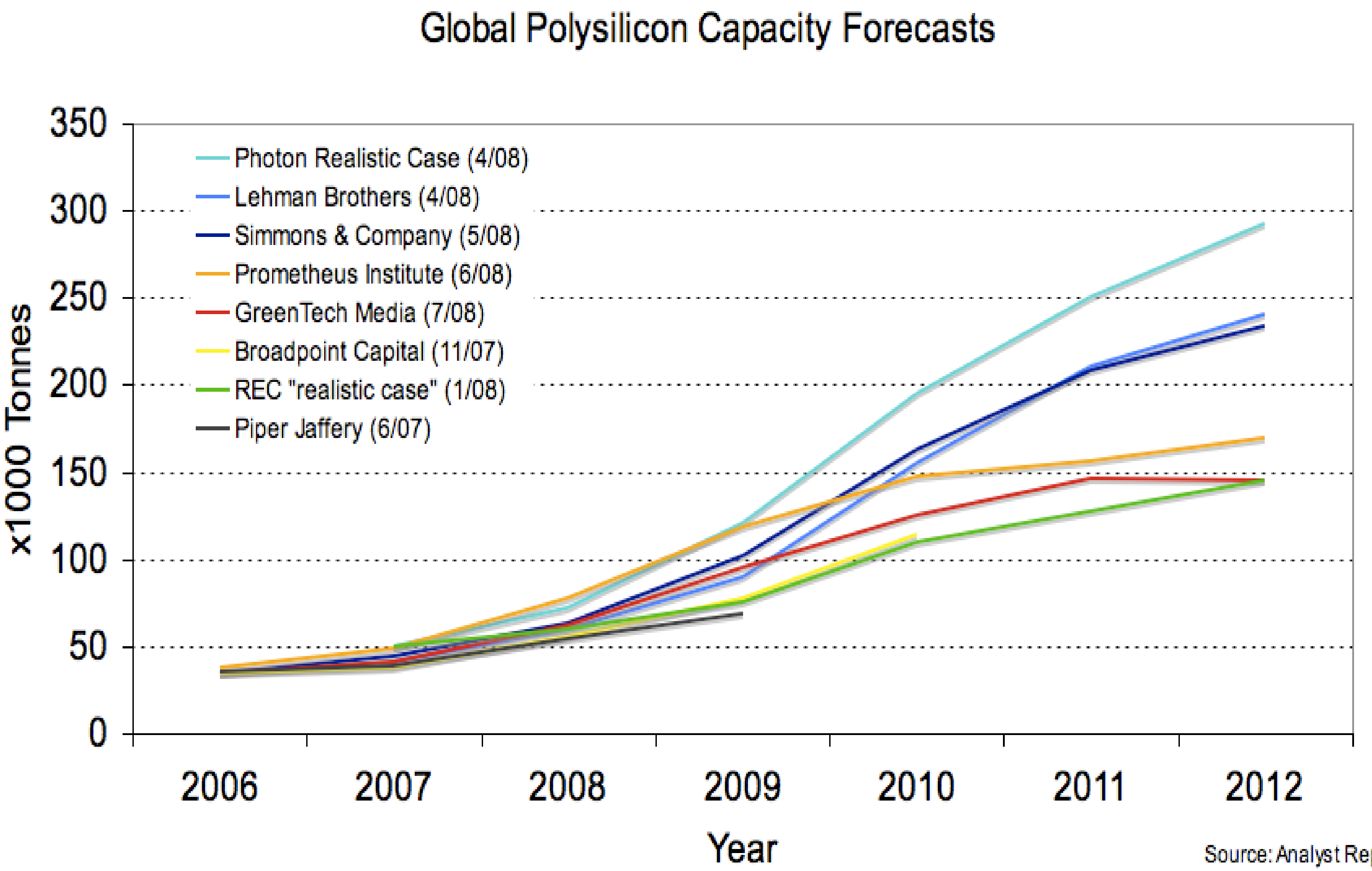


PV module production has experienced increasing growth, but rising silicon feedstock prices have reversed the historic trend of declining module average selling prices (ASP)



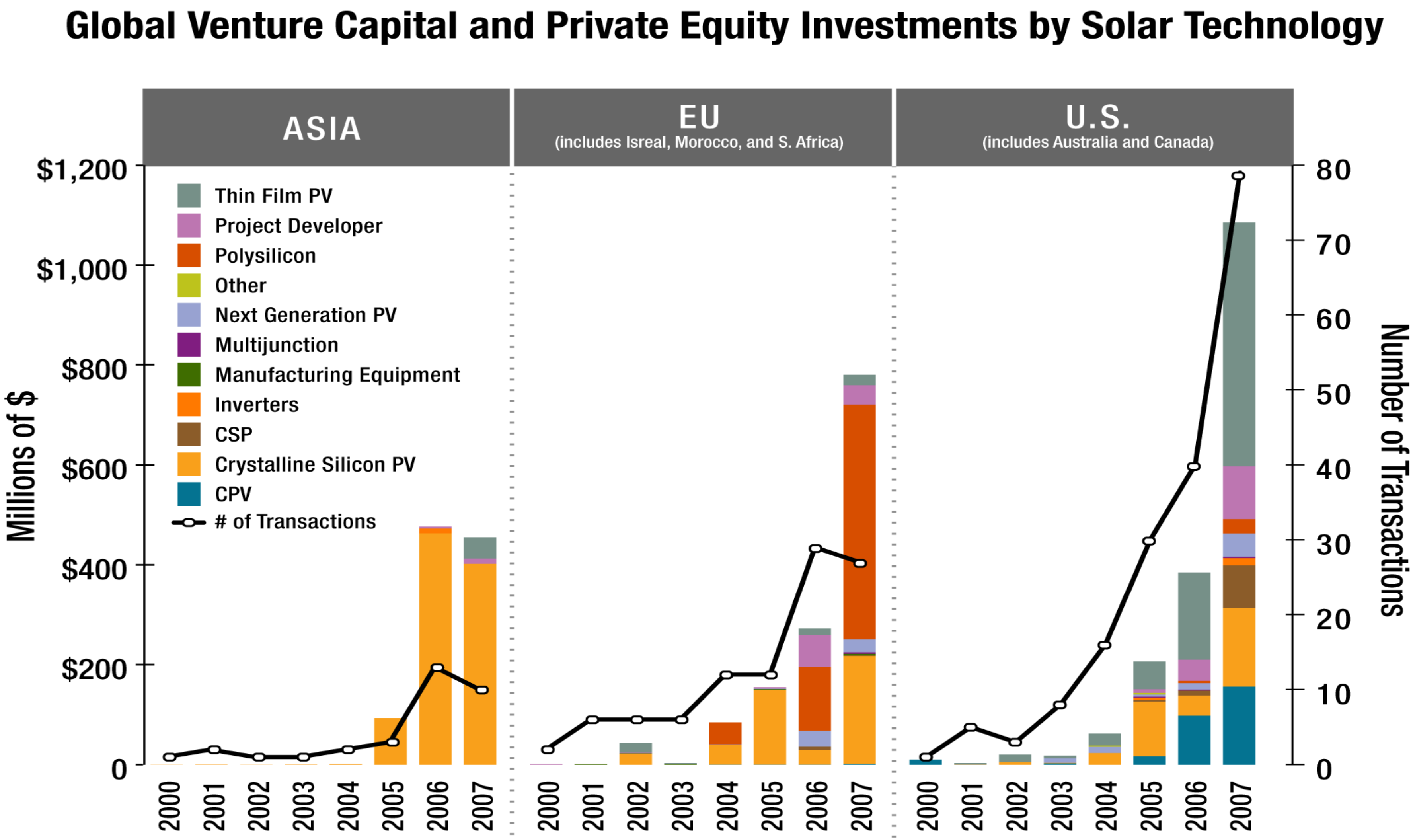
Sources:
Navigant (2007/8)
Deutshe Bank & Solarbuzz (2008)

Forecasts of significant new supplies of polysilicon will cause market price to decline



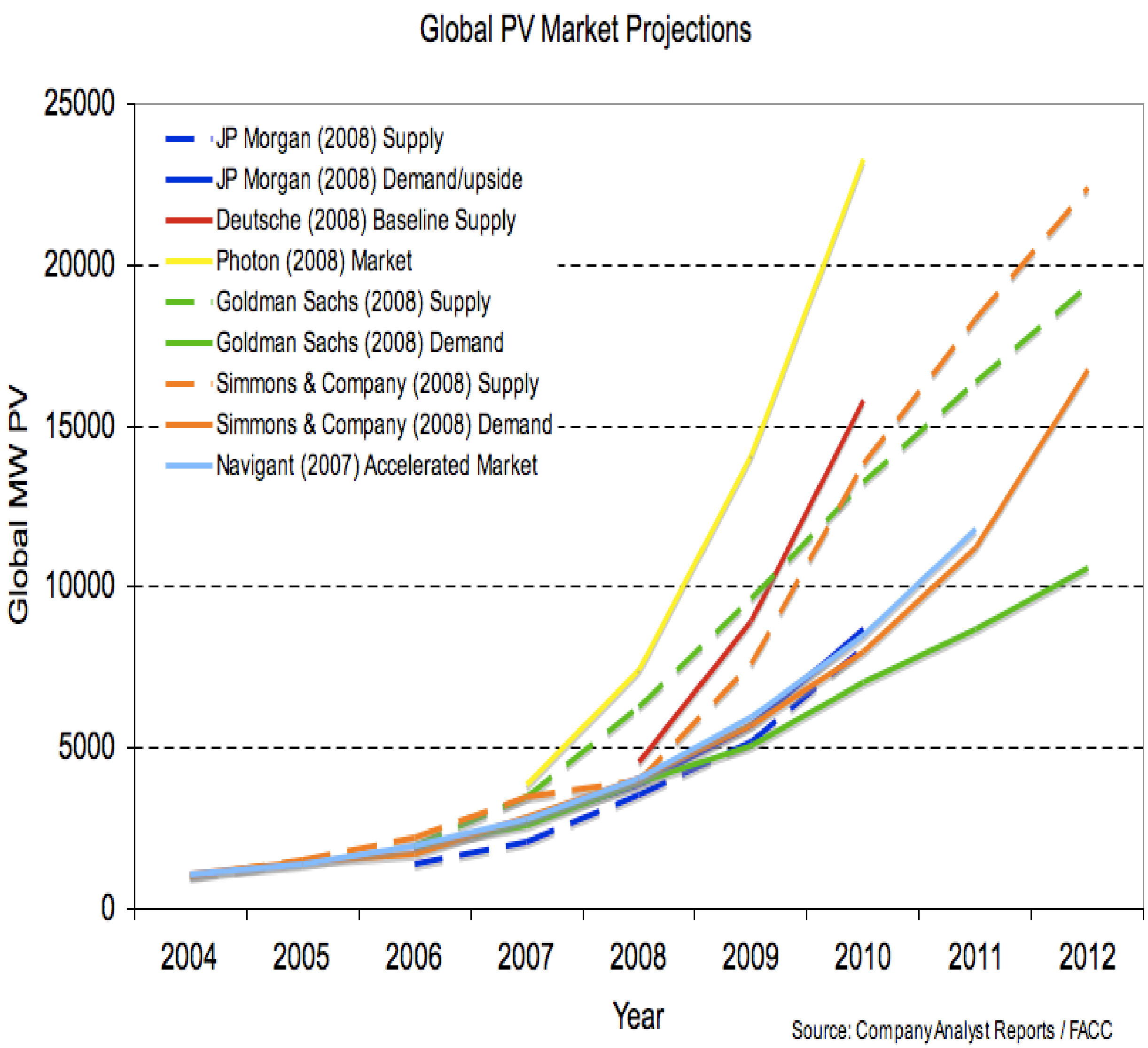
Source: Analyst Reports / DOE

U.S. private equity solar technology selections show a technology rich, innovative industry



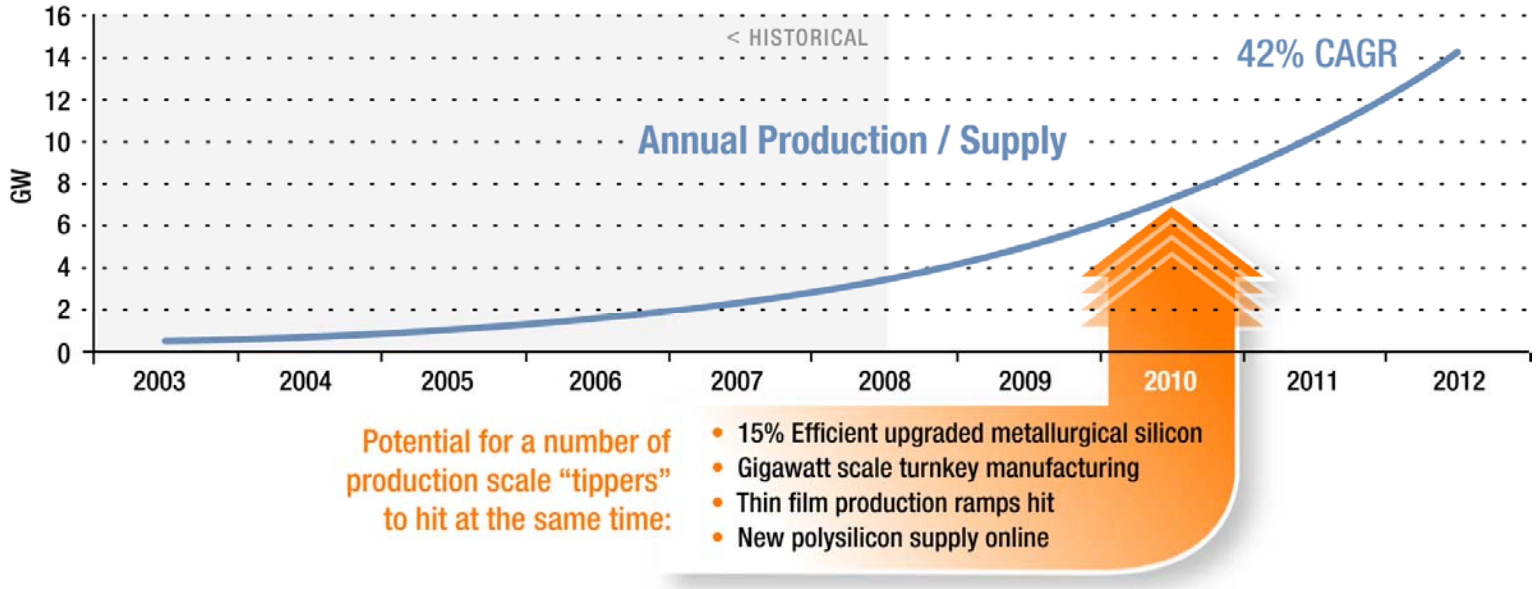
Source: NEF / NREL / FACC

Analyst market projections show significant variations



- Supply differences are driven by expectations for polysilicon and thin film manufacturing ramps
- Demand differences are driven by incentive and demand elasticity assumptions

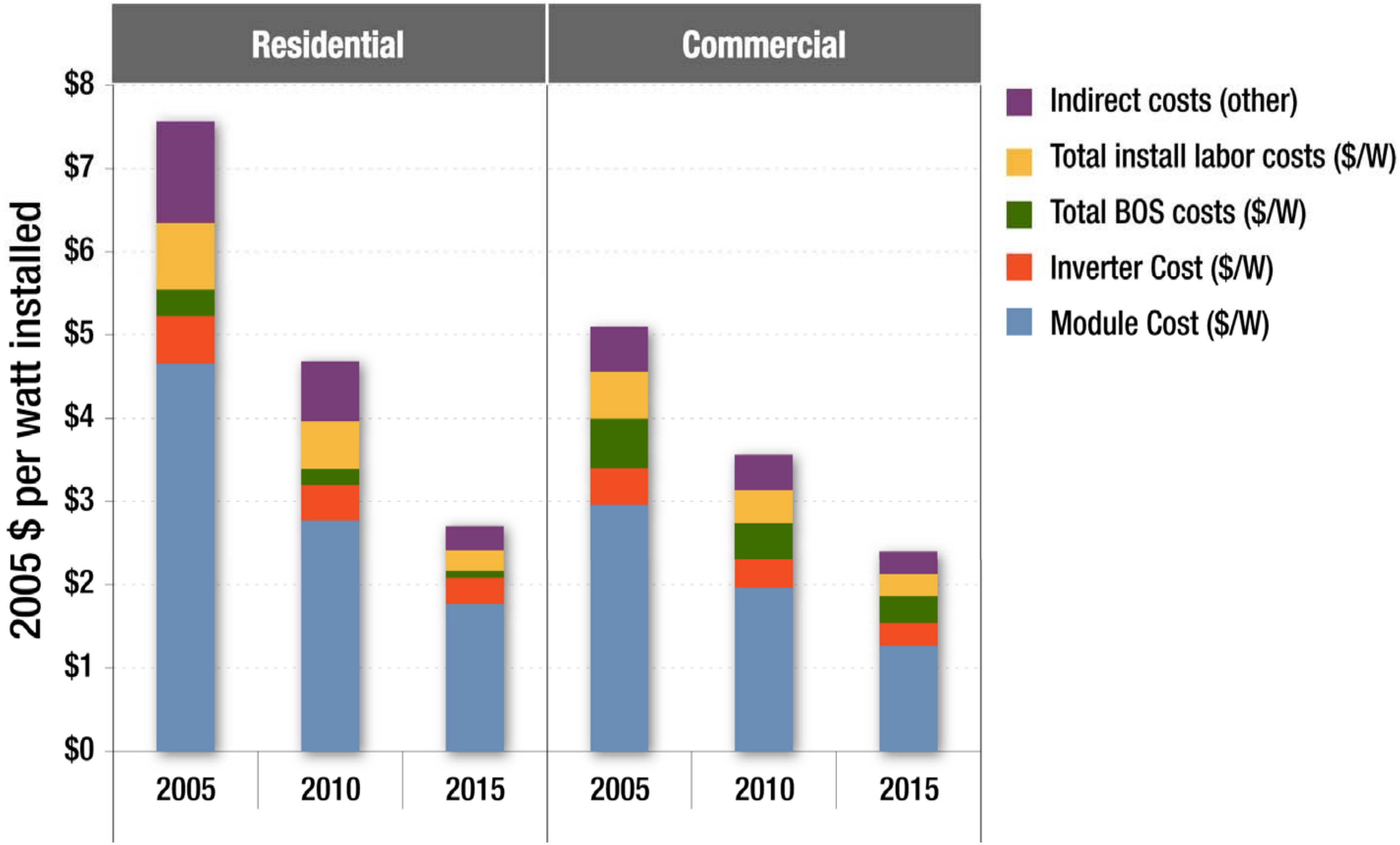
In a rapidly growing market with demand reliant on government incentive programs, oversupply is a risk…



Policy and market risks in an oversupply situation

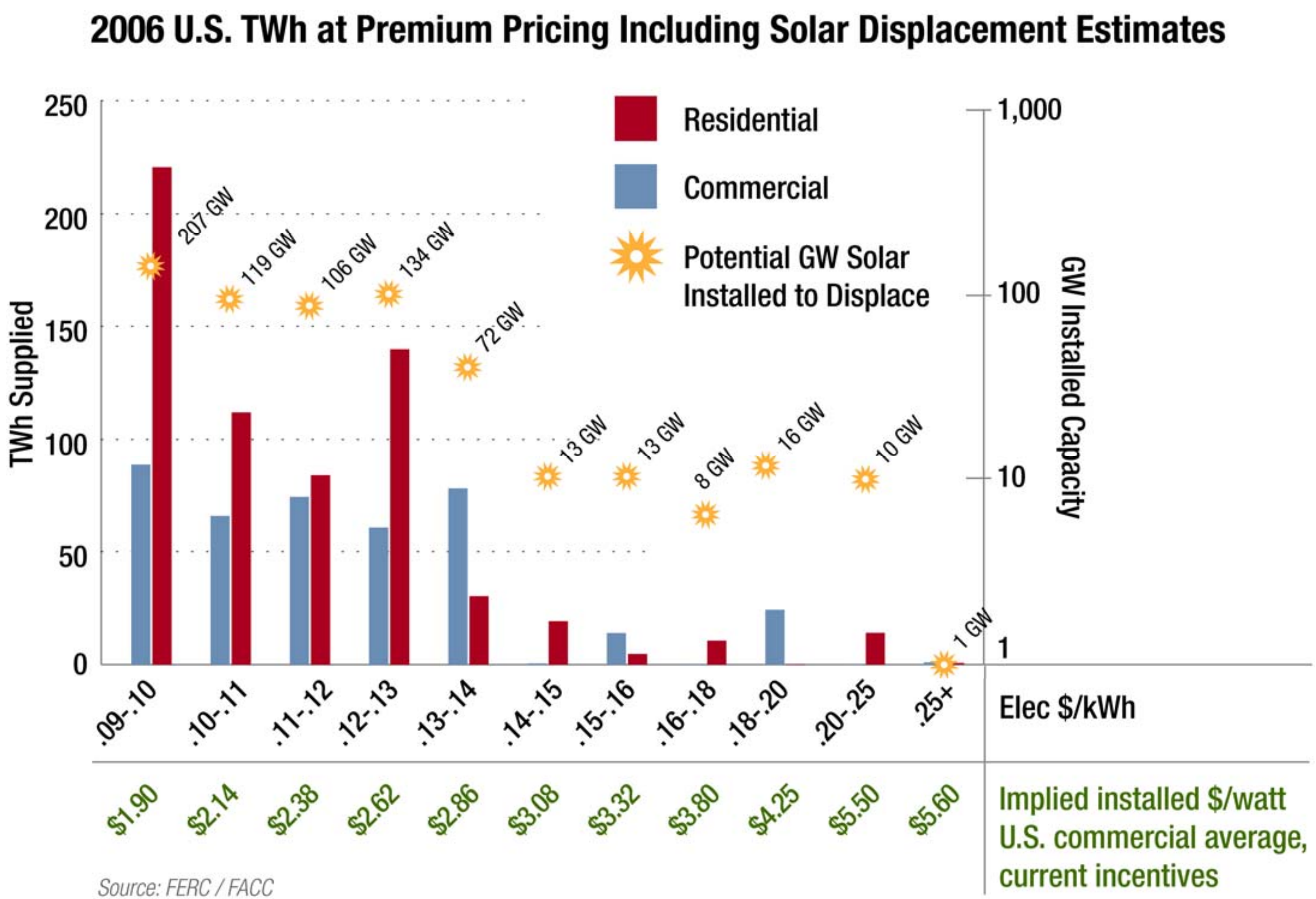
- Policy risks
  - Germany may revisit accelerated EEG cuts in 2009 - currently uncapped
  - U.S. ITC extension?
  - Spain may stick to lower caps - recently a 300MW/yr cap has been proposed
  - Korea could slash post 2009 subsidy program
- Market risks
  - Politicians may not support subsidizing 10GW of Chinese PV
  - Excessive profits at >35% margins could erode public support
  - Global recession / inflation could halt expensive programs
  - German utilities may have difficulty integrating >15GW of PV on grid

However, installed system costs are expected to achieve significant reductions across the supply chain



And, in the U.S., demand is highly elastic and could take up any drop in system prices

- 40% of U.S. electricity or 1,000 TWh sold for > $0.10/kWh in 2006



Assumptions:
1kw installed produces 1500 kWh/year
Federal incentives (30% ITC & MACRS)
5% interest rate
25 year term
35% tax rate
15.5% capacity factor (US average)
92% AC/DC conversion
80% BOS derate factor

- Current PV margins of 30-50% allow manufacturers significant headroom
- Decreased margins at inventory clearing price levels and raised demand will drive a virtuous cycle with cost reduction from increased manufacturing capacity

Solar energy technologies serve many, varied addressable market segments

Photovoltaics

- ‘Behind the Meter’ - customer sited on rooftops, field installations, or in building integrated applications
- ‘Utility scale’ - large ground mounted installations where electricity is transmitted to load centers

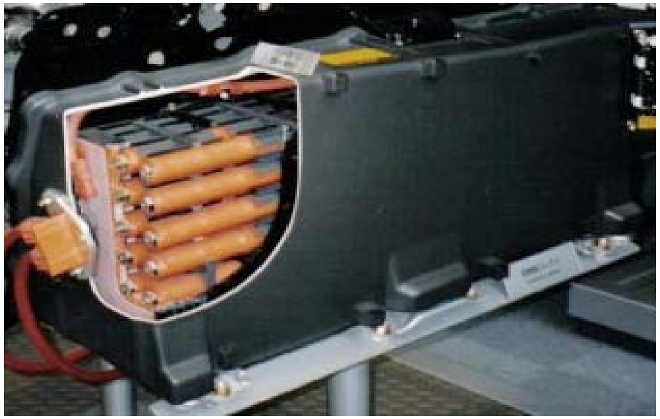
Concentrating Solar Power

- ‘Nodal’ - smaller scale systems, such as dish Stirling engines, with no energy storage capabilities
- ‘Utility scale’ - large scale installations with energy storage capabilities that will enable high capacity factors

In the long term, the solar market will be segmented based on technology attributes and user needs

Alkaline – Low Cost, Disposable

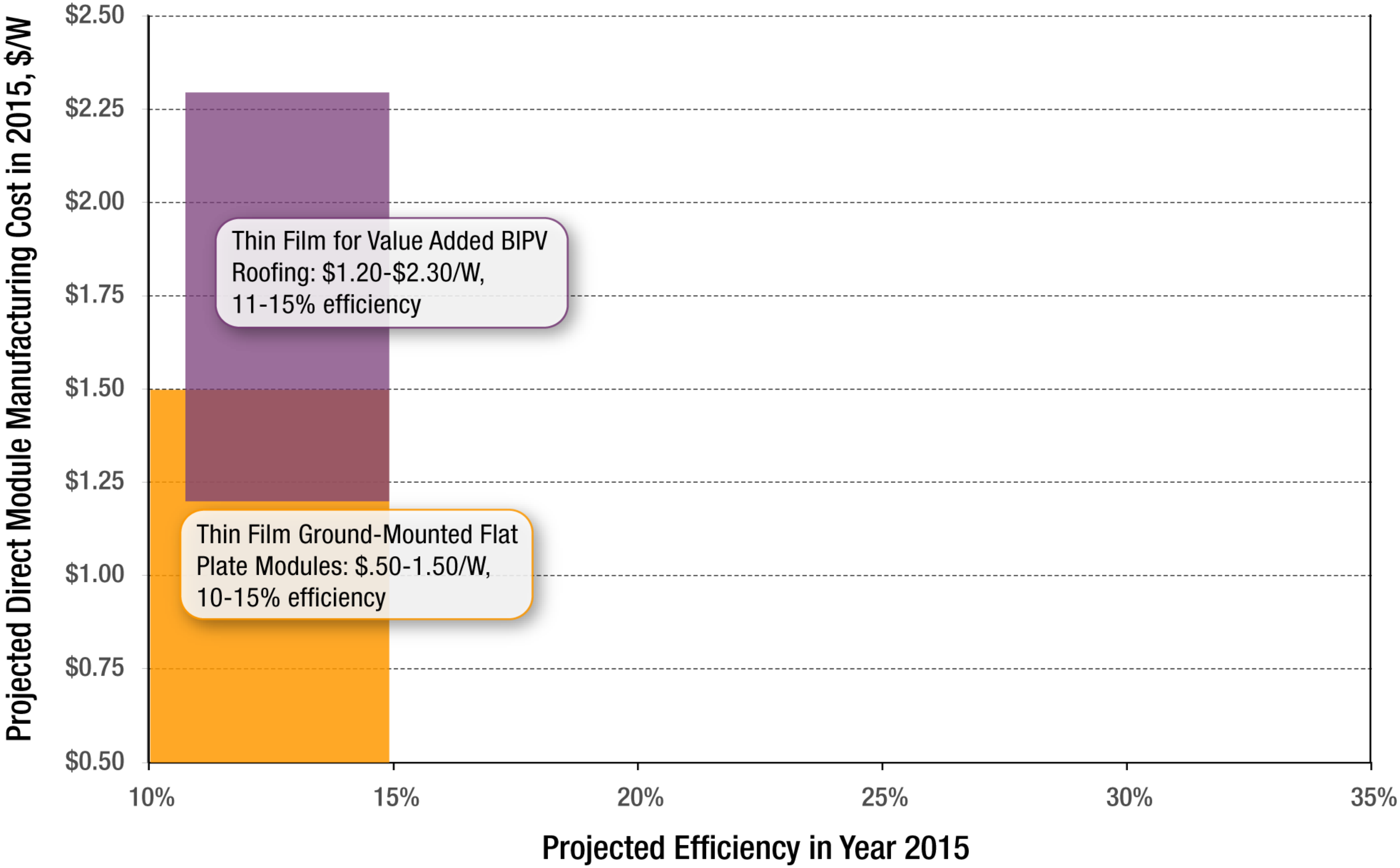
Lithium Ion – High Performance / Light



Nickel Metal Hydride – Performance / Durability

Lead Acid – Inexpensive / Rechargeable

The result is that downstream customers *(and investors)* will see diversified product offerings, and suppliers will compete on application-specific advantages



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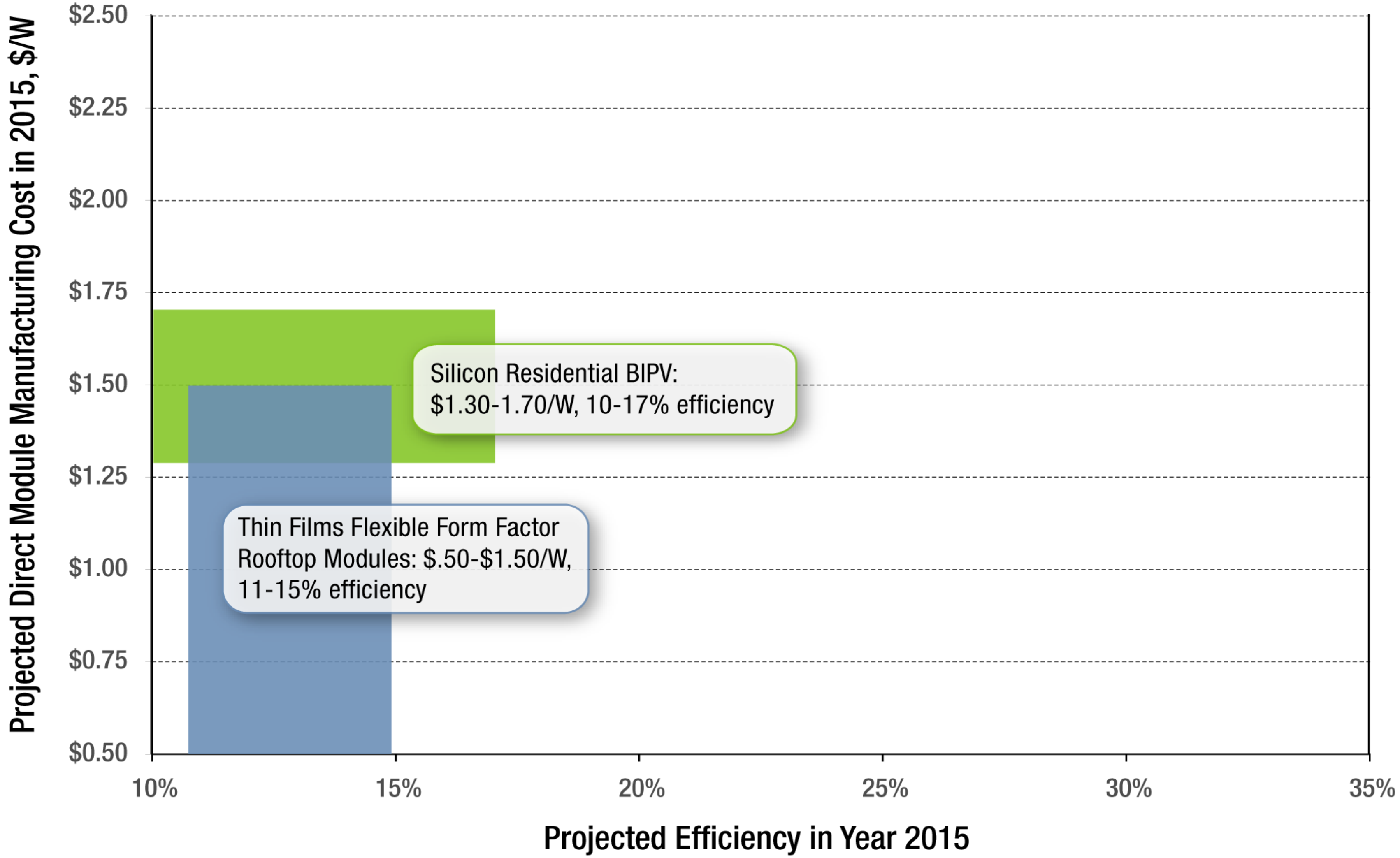

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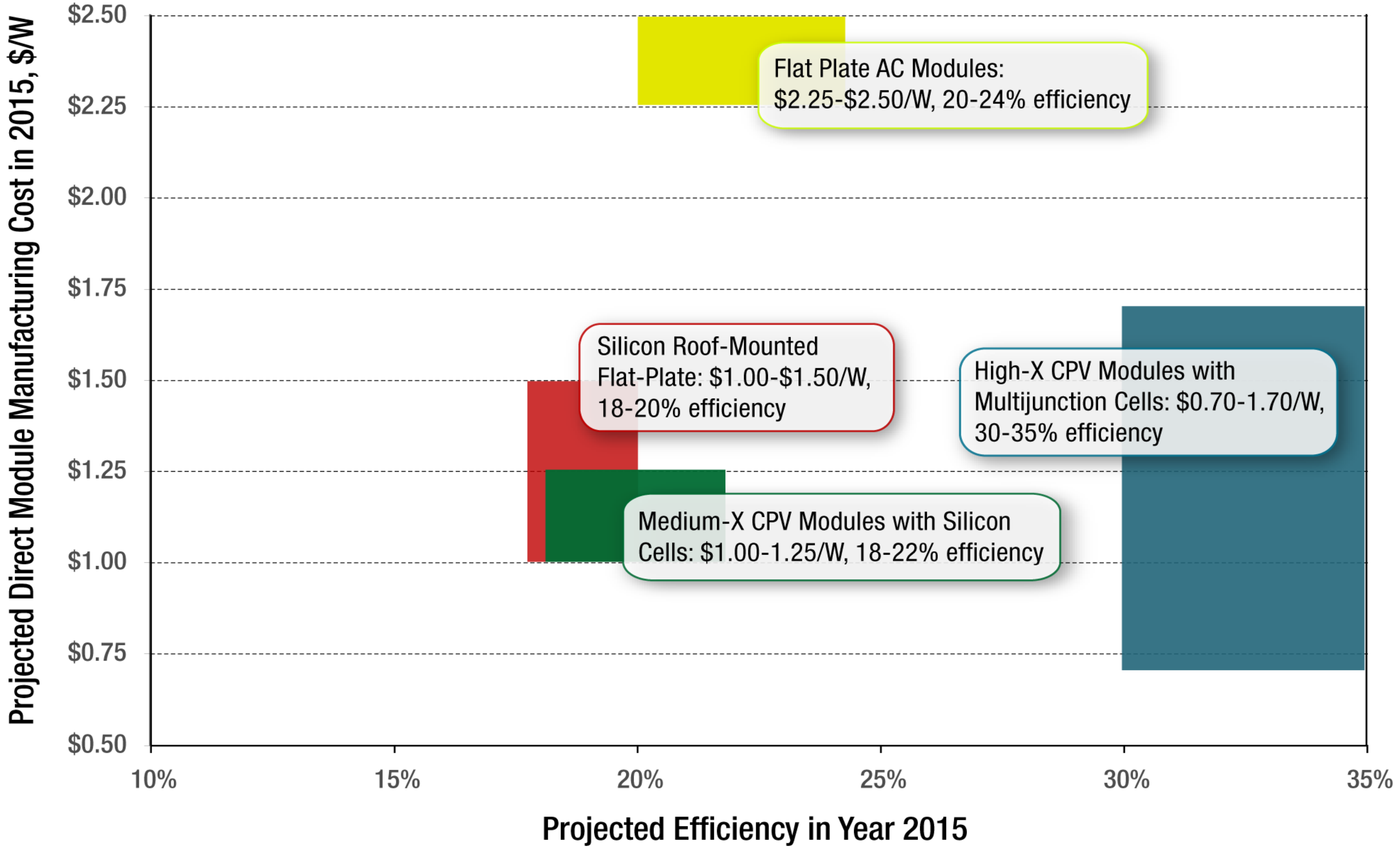

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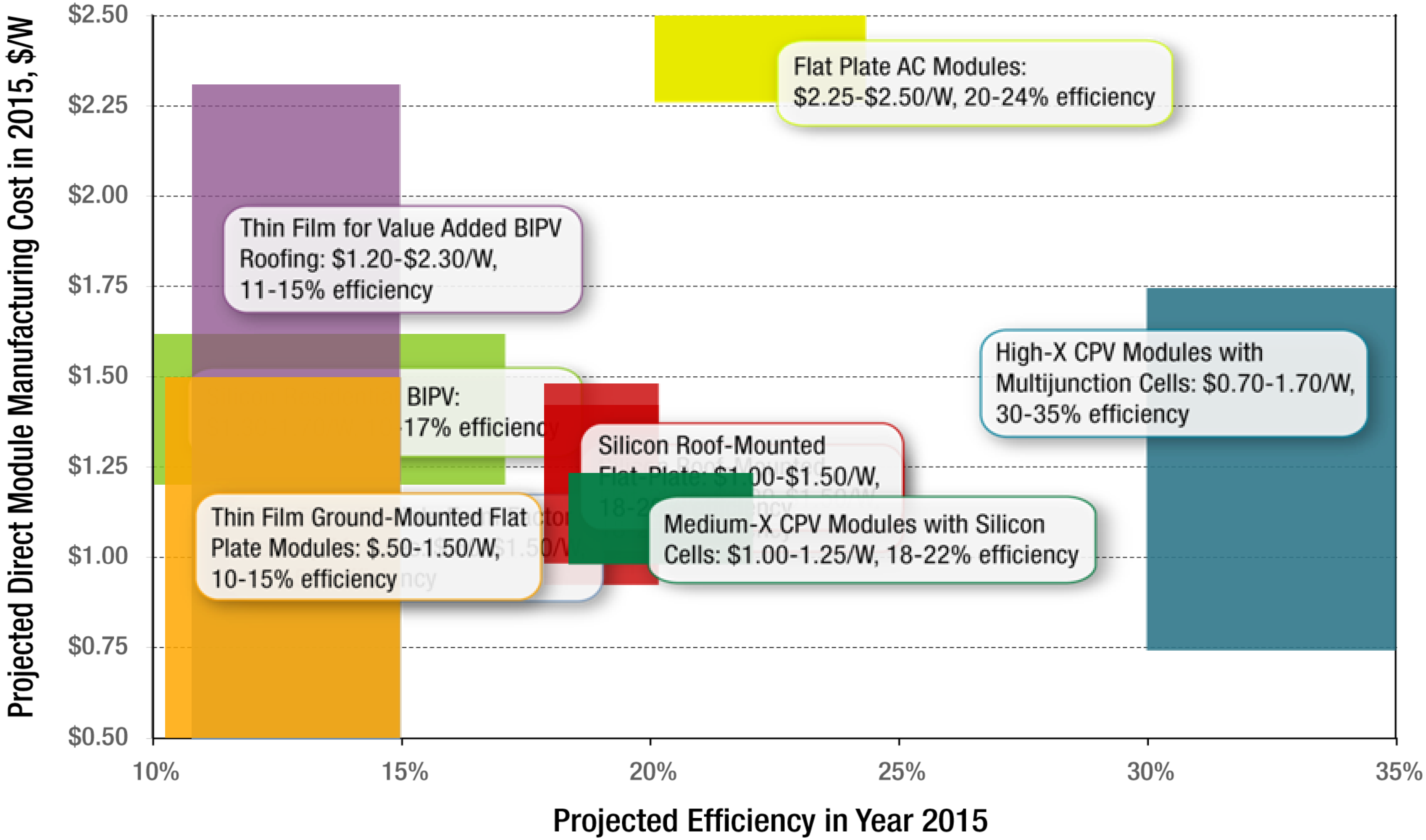


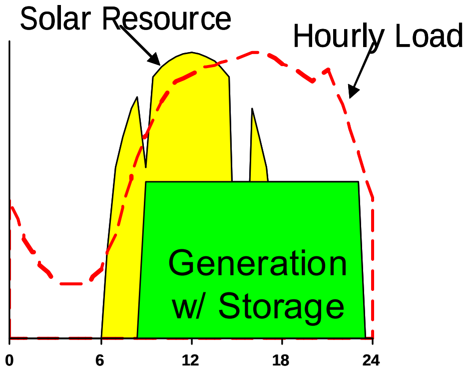
Concentrating solar power (CSP) enables solar power at scale and in a manner familiar to the electric utilities

Generation is predictable

- Solar resource analysis allows for consistent understanding of power production

Generation is predominantly on-peak

- Resource profile provides high value power

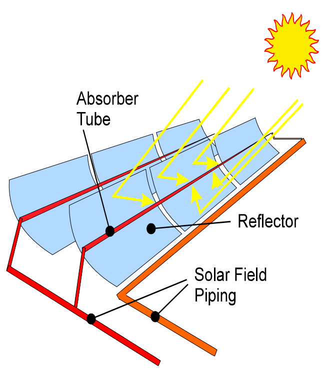


- **High capital expenditure, coupled with low operating expenditure provides opportunity for cost improvements through financial structuring**
  - Opportunity to “pre-pay” for 20+ years of fuel

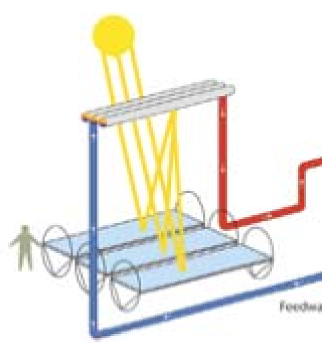
The addition of storage is expected to lower the cost of power and make CSP a generation resource that can be managed by utilities with conventional practices.

The CSP industry is pursuing multiple pathways to intermediate power parity

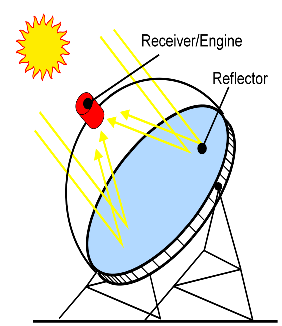
Trough



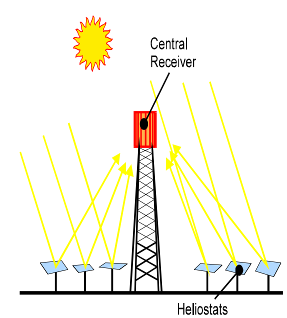
Linear Fresnel



Dishes



Tower



The large scale nature of CSP generation capacity investments requires a long term extension of the ITC

Projects in various stages of development on 5 continents

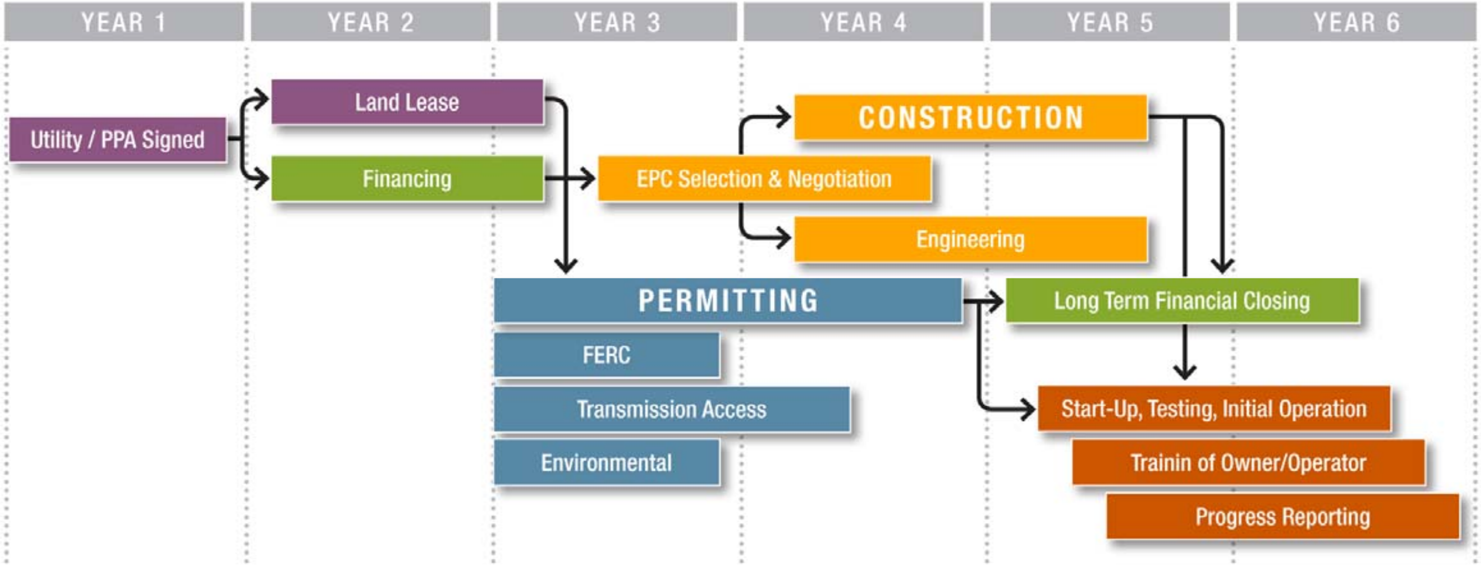
- U.S. and Spain leading the market
- With 419MW operating, the U.S. is currently the leading CSP market
- Projects are in development in Africa, the Middle East, Asia, and Australia

4.5GW operating and under PPAs in the U.S.

- >4GW in 13+ projects anticipated to be built over the next five years - will not happen without **long term ITC** extension

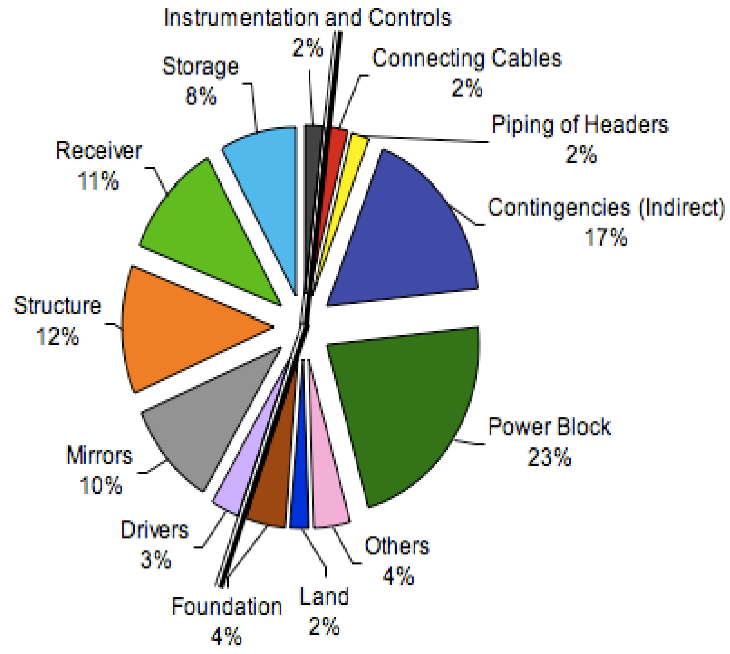
700MW under development in Spain

- Spanish plants are limited to 50MW by feed in tariff law and are testing innovative CSP technologies

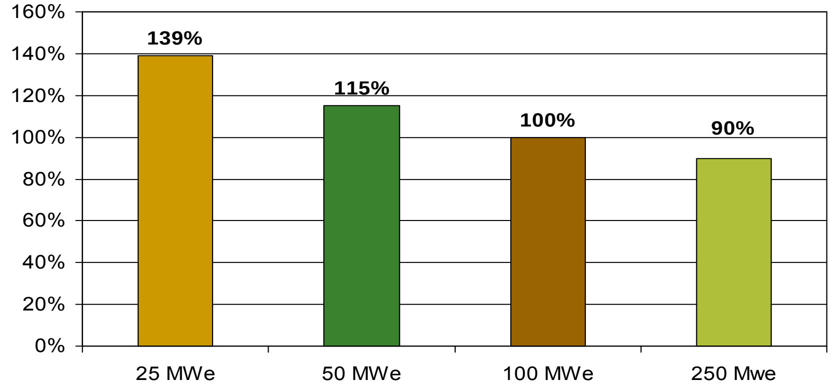


Scale, storage, and component cost reductions will allow CSP to compete with traditional generation

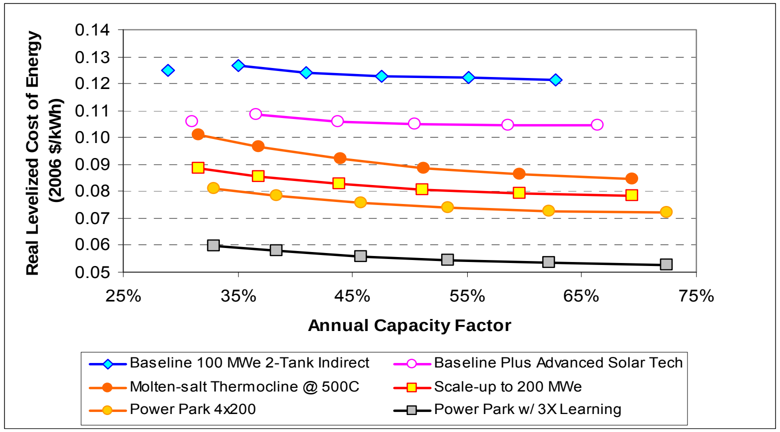
Plant BOM Cost Reduction: Reduce cost of receivers & collectors through scale; reduce cost of structures through design



Scaling-Driven Economies: >250MWe allows utilization of standard power block & component volume savings



Value of Storage: Storage opens larger market via dispatch-ability and amortizes field costs over more kWh's



The Industry Landscape:

Hurdles / Barriers

Market

- Speed of capital intensive installations will be impacted by the depth and duration of the credit crunch and financial innovation (Berkeley model)
- Installation and technical workforce will have to significantly increase ramp
- New utility pricing models that take into account different values of PV generated electricity

Technical

- Maturation of the solar supply chain
- Industry testing & validation
- Long term industry R&D
- Grid integration and related enabling technologies

Policy

- Net metering & interconnection
- Federal programs, Loan Guarantee, RPS, FIT
- New transmission construction
- Investment Tax Credit
- State / local policy incentives

Agenda

- Program Objectives
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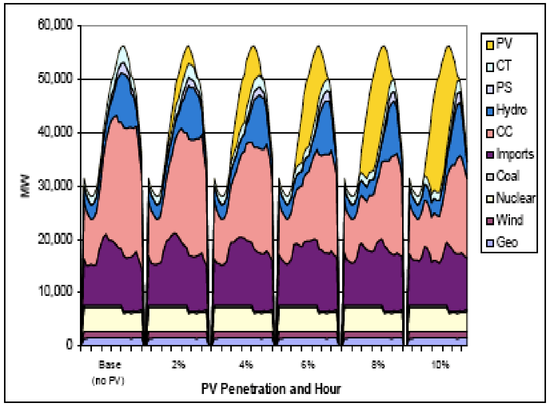
- Technology Commercialization Opportunities

Investment Opportunities:

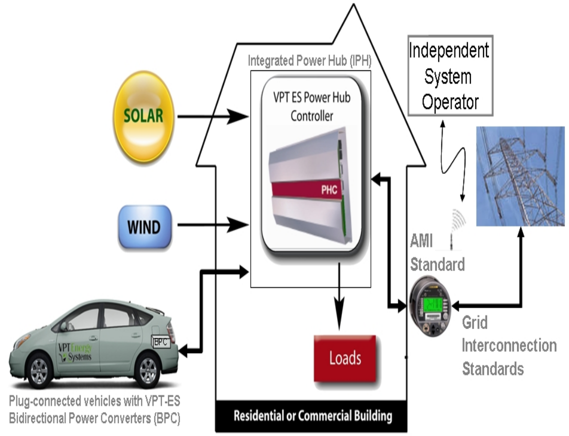
Opportunities are available - but outside of traditional solar innovation plays

- High penetrations of solar technology will have to be enabled by grid integration technologies - power electronics, storage, power management
- Concentrating PV has yet to find its niche, but could evolve into several segments based on power density, cell type and footprint
- Balance of systems costs still require innovation and scale with the number of installations rather than the number of watts
- Improved materials utilization will play an important part in future cost structures
- Flexible encapsulants and other innovations will be required for BIPV
- The CSP value chain has important components with limited competition

"Opportunity 1" : Grid Integration / Energy Storage



High Penetration PV

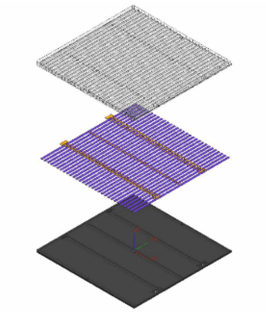


Interface Module

- Inverter/controller markets are segmented in automotive, telecom, mobile, & retail end-uses
- Solar energy market quickly becoming the biggest contributor to inverter markets; 2007 ~$2Bn sales, 2010 ~$10Bn sales

- **Investment opportunities may exist for integration of power management and energy storage technologies**
  - Grid-tied products with incentives for individual end-users to feed the power to the grid
  - Off-grid products to provide quality power through distributed generation
  - Example: SolarCity (Residential PPAs) + Fat Spaniel (Monitoring) + GridPoint (DR)
- **Major drivers that will propel accelerated growth**
  - Increasing time-of-use pricing offerings – pressure to expand net metering caps
  - Growing demand response program practices
  - Increasing use of intermittent renewable generation and continued power quality / grid reliability requirements
  - Integration with smart grid, microgrid, and PHEV

"Opportunity 2" : Novel Concentration Approches



2x-8x

20x-100x

250x-1000x

- A wide solution space currently exists because of the infancy of CPV industry
- Intelligent plays in the CPV industry will require anticipating cell pricing trends and implementing tight supply chain management

- **Investment opportunities may still exist across the CPV space**
  - Dependent upon the tolerances and costs of components
  - Dependent upon current III-V R&D progress
  - Next gen approaches such as µCPV or tracker-less designs (i.e. TIR)

- **With lower concentrations:**
  - Higher tracker tolerances (single axis perhaps up past 50x)
  - Passive heat sinks (500x = 50W/cm2 ~ hot desktop CPU)
  - Lower cost optics (higher f-ratios, fewer elements, higher eff., etc)
  - Reduced Mfg. Costs (automation, fewer steps, greater tolerances)
  - Reduced installation precision (perhaps allowing higher modularity)

"Opportunity 3": Non-Module cost reduction plays

- Current PV cost reduction roadmaps focus on reducing manufactured module cost per watt
- Non-Module costs are expected to rise from 55% of LCOE costs as module manufacturing scales and reduces costs more quickly

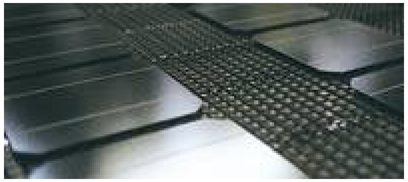
Investment Opportunities will exist in reducing installed system costs beyond module cost reductions

- Inverter durability increases and cost reductions could impact BOS costs
- Microinverter technologies could enable lower cost AC/DC conversion as well as reduced installation costs
- BIPV or system standardization

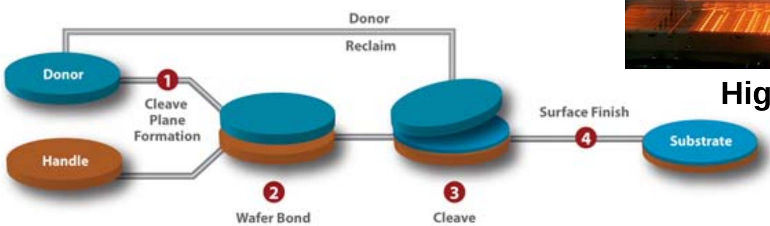
Drivers for non-module cost reduction plays

- Increasing proportion of non-module costs will increase margins and volumens for best-in-class downstream players
- Potential module oversupply scenario could lead to BOS being an even larger portion of total installed system cost
- Innovation is currently fairly limited in the BOS cost reduction area – examples are SunPower "pod" systems, Akeena Andalay system, & BP Solar Integra system

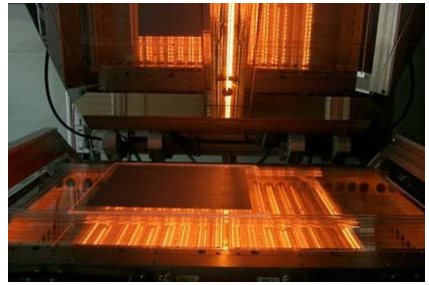
"Opportunity 4": Crystalline Silicon Thin Films



Epitaxial



Lift-off



High Temperature

- Evolutionary approaches such as string ribbon (Evergreen) and thick re-crystallization (CSG) have shown initial progress
- Moving forward, a diverse set of advanced thin crystalline silicon approaches promise a 10x reduction in silicon intensity

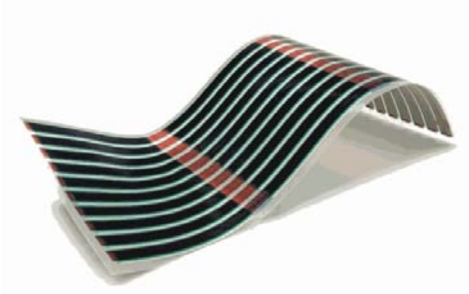
- **May remove several process constraints of the traditional wire saw approach**
  - No kerf loss (reduces polysilicon 2x)
  - Thinner cells (reduces polysilicon 3-10x)
  - Greater process integration (reduced capex alternative poly feedstock)

Approach

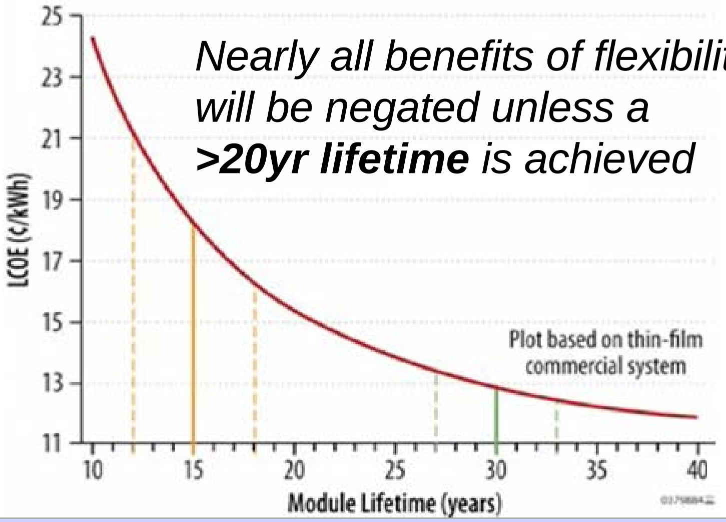
Challenges→	Surface Tension	Crystallization	Impurity Migration	Through-put	Area Scalability	Yield	Sufficient Thickness	Capex	Coef T. Expan	Light Trapping	Over Thickness
High Temp	X	X	X		X	X			X	X	X
Epitaxial		X		X	X	X	X		X	X	
Lift-off			X	X	X	X		X		X	X

"Opportunity 5": Flexible Encapsulants / BIPV Entry

Value Proposition – Marginal module cost increases allow for significant reductions in installation costs



Moisture barrier levels of **10^{-6}g/m^2/day** or better need to be achieved



Nearly all benefits of flexibility will be negated unless a ***>20yr lifetime*** *is achieved*

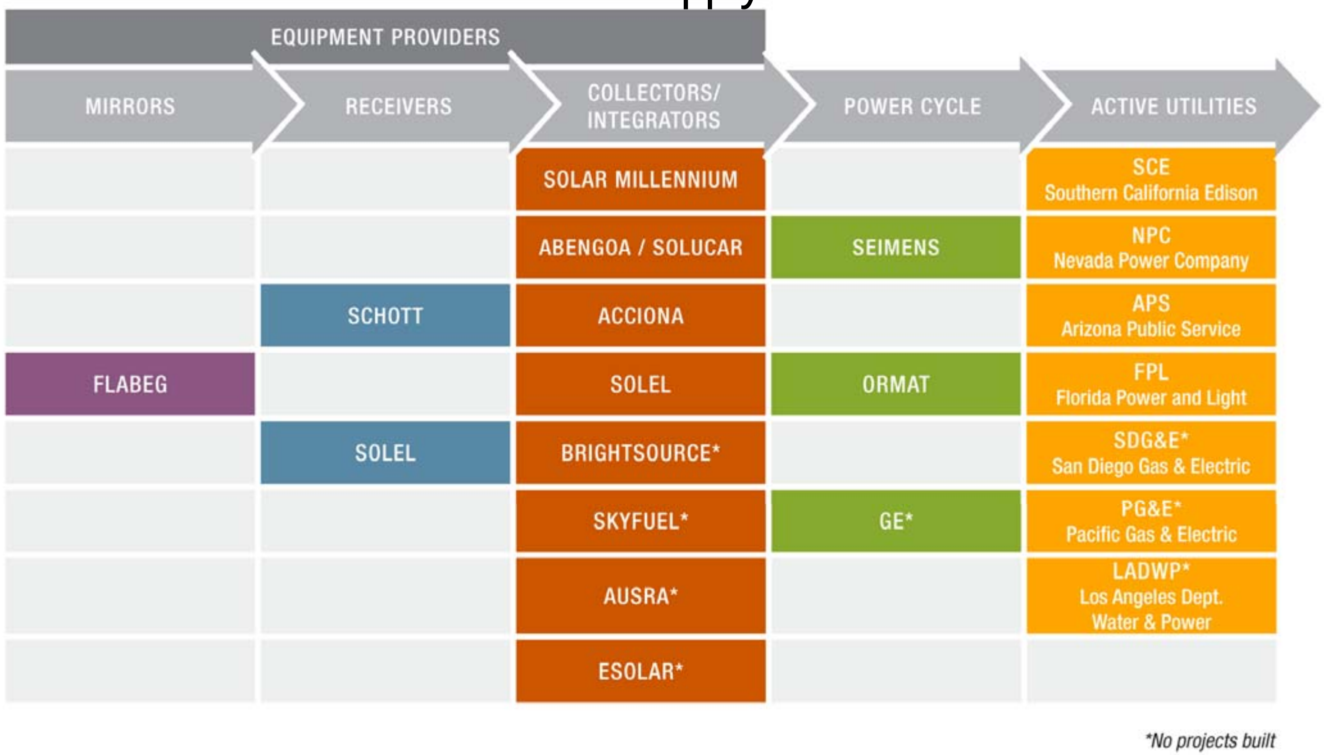
Substrate	Benefits	Difficulties
• **Glass**	Excellent barrier, Smooth, Thermal Expansion, Vacuum compatible	Rigid, Heavy
• **Flexible**	Low kg/W, Durability, Removable, Potential low cost with high throughput	Curling, Stress, Poor adhesion
– Polyimid	Monolithic integration	Worst efficiency, Low-temp deposition
– Flexible metal	High deposition temp	Pin holes (roughness), Impurity diffusion

- Lower kg/W can significantly reduce manufacturing, shipping (weight, breakage) and installation cost
- Flexible thin films allow for a *true* roll-to-roll process
- Flexible form factors may open up new markets for PV installations.

"Opportunity 6": CSP supply chain gaps

Value Proposition – Competition is limited at key spots

CSP Supply Chain



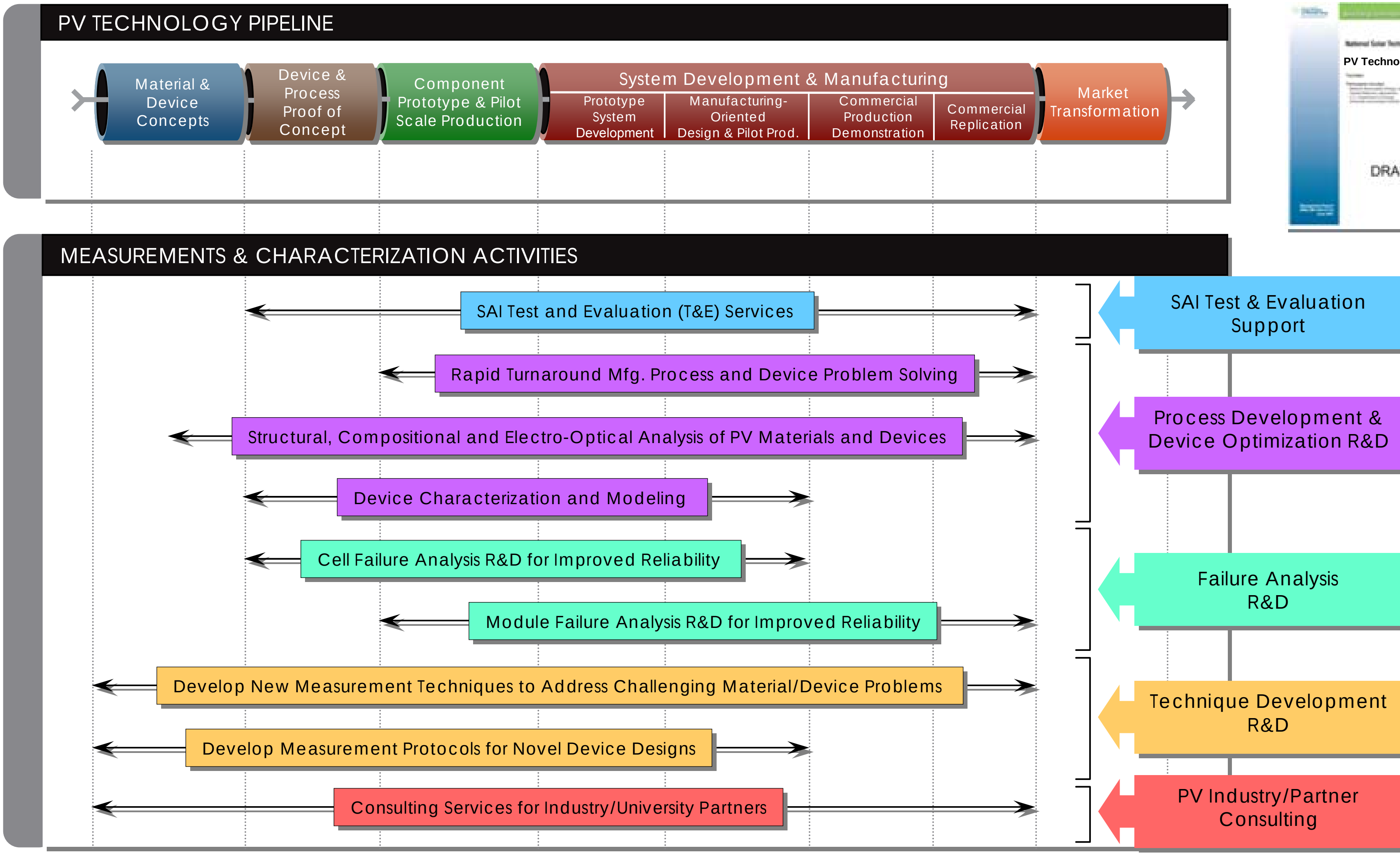
Component	Specifications	Barriers / Hurdles
• **Curved Mirrors**	Durable, high reflectivity, anti-soiling, low cost	Manufacturing difficulties of sagging glass to spec, reflective layer durability
• **Receiver Tubes**	High absorption, low heat loss, high durability	Specialized coatings and encapsulants

Agenda

- Program Objectives
- Industry Landscape
- Investment Opportunities
- Technology Commercialization Opportunities

DOE Programs Facilitating Commercialization:

NREL Measurements & Characterization (M&C) Project



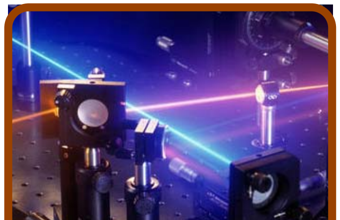
NREL M&C Core Competencies

Additional Information: www.nrel.gov/pv/measurements or contact Peter Sheldon (peter_sheldon@nrel.gov)

Analytical Microscopy

A-M

- Utilize high-resolution techniques to obtain structural, chemical and morphological information of materials and devices on an atomic scale. Techniques include:
  - ✓ Scanning Electron Microscopy (SEM)
  - ✓ Transmission Electron Microscopy (TEM)
  - ✓ Cathodoluminescence (CL)
  - ✓ Electron Backscattered Diffraction (EBSD)
  - ✓ Scanning Probe Microscopy (AFM, STM, SKPM, C-AFM, etc.)
  - ✓ Electron Probe Microanalysis (EPMA)



Electro-Optical Characterization

E-O

- Utilize electro-optical techniques to relate PV device performance to the methods and materials used to produce them. Techniques include:
  - ✓ Photoluminescence Spectroscopy (PL)
  - ✓ Minority Carrier Lifetime (TRPL, RC-PCD, and μW-PCD)
  - ✓ Fourier Transform Infrared Spectroscopy (FTIR)
  - ✓ Spectroscopic Ellipsometry VASE and RTSE
  - ✓ Capacitance Techniques (C-V, DLTS, AS, and DLCP)
  - ✓ Computational Modeling

Surface Analysis

S-A

- Surface analytical techniques determine the chemical, elemental, and molecular composition and electronic structure of materials surfaces and interfaces. Techniques include:
  - ✓ Auger Electron Spectroscopy (AES)
  - ✓ X-ray Photoelectron Spectroscopy (XPS)
  - ✓ Ultraviolet Photoelectron Spectroscopy (UPS)
  - ✓ Dynamic Secondary Ion Mass Spectrometry (SIMS)
  - ✓ Time-of-Flight SIMS

Cell & Module Performance

CMP

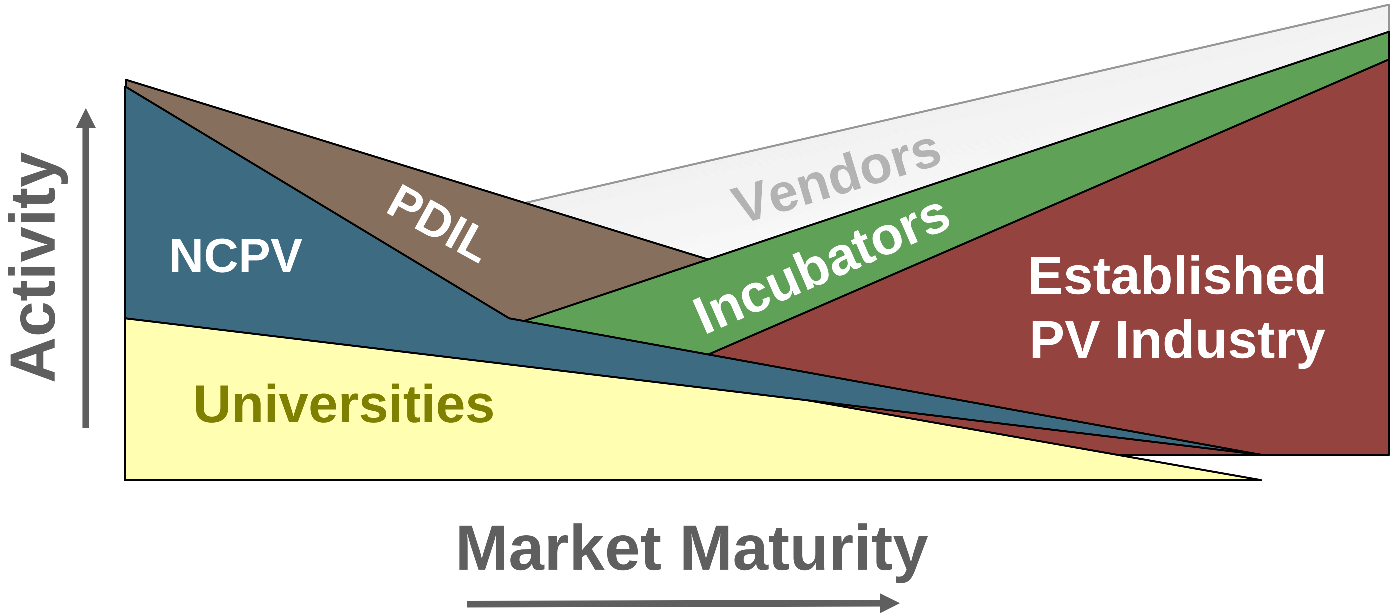
- Independent facility for verifying device and module performance for the entire PV community
- ISO 17025 accredited for primary reference cell, secondary reference cell and secondary module calibrations
- Provide the U.S. PV industry with a calibration traceability path (reference cell calibrations for the entire US terrestrial community)
- Develop hardware, software and procedures to accommodate new cell and module technologies.

Process Development Integration Laboratory (PDIL) : From Basic Science to Mini-Modules

National Center for Photovoltaics outputs
- small area
- high efficiency
- laboratory processes
- independent equipment
- no standards
- exposure of interfaces
- data islands
- low sample throughput
- no module prototyping

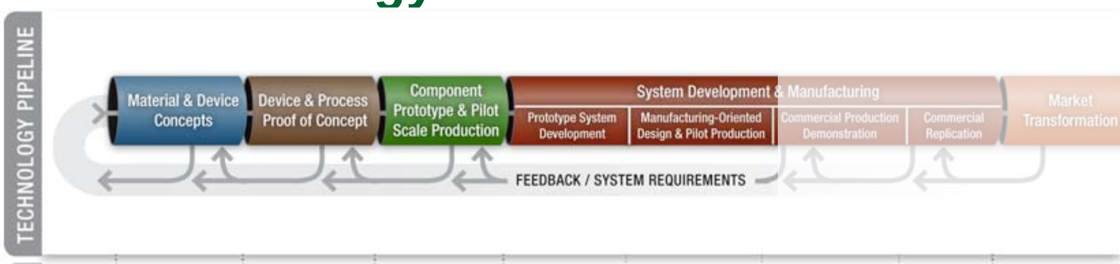
PDIL investigates
- commercially viable area
- **bridge the efficiency gap**
- **bridge the cost gap**
- integrated, flexible equipment
- standardized size and transport
- controlled ambient between steps
- automated data systems
- accelerated throughput
- potential **mini-module** processing (basic science still possible size)

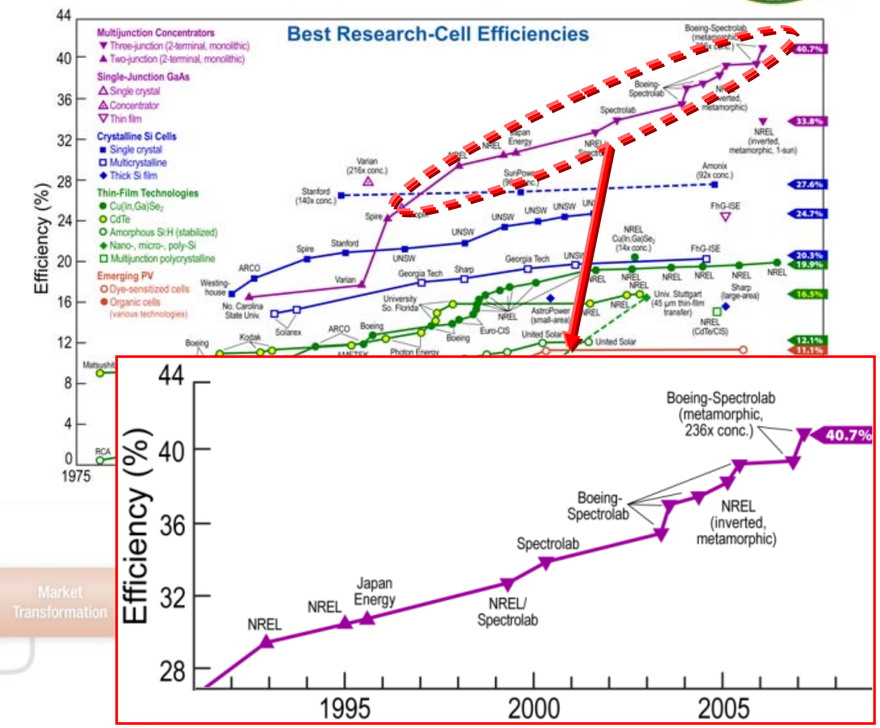
Industry
- large area
- lower efficiency
- low-cost processes
- rigid processes
- no standards
- no interface studies



Inverted Metamorphic Multijunction (IMM) cells for CPV

- **Description**
  - Method for fabricating ultra-high-performance concentrator cells
- **Impact**
  - Improved efficiency, heat management, and materials use
- **Technology Readiness**





Conversion efficiencies for record multi-junction devices have risen by 10% over the past decade and this trend is forecast to continue. Moreover, record efficiency devices in CPV bear relevance to commercial products.

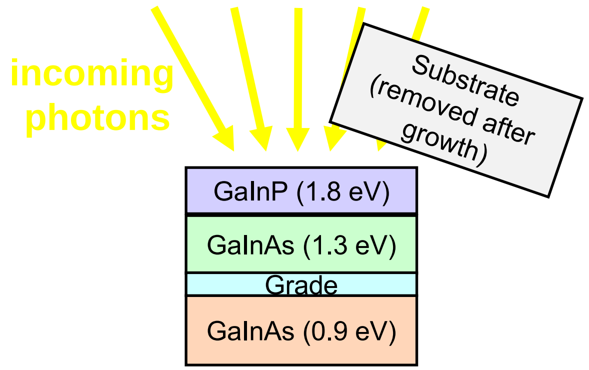
- **Estimated Time to Market**
  - 1 to 2 years
- **Estimated Commercialization Cost**
  - $50M

Daniel Friedman | NREL | Phone: 303-384-6472 | daniel_friedman@nrel.gov

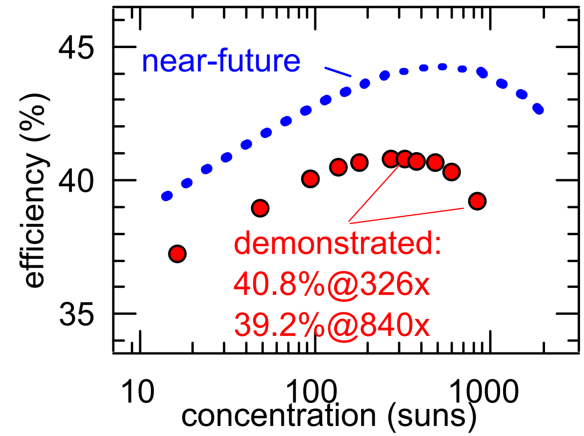
Inverted Metamorphic Multijunction (IMM) cells for CPV

- PROBLEM: **The CPV industry is calling for continual improvements in solar cell power output.** The standard commercially-available multijunction cell design is bumping up against performance limits due to challenges in making the junctions with the optimal band gaps.
- DESCRIPTION OF INVENTION/TECHNOLOGY: The IMM cell uses a new approach to fabricating the junctions with the optimal band gaps while maintaining the required high materials quality. The basic idea is to grow the layers of the cell in reverse order compared to the conventional approach, resulting in the lowest-bandgap, most highly strained junction being grown last. This keeps strain-induced defects away from the higher-bandgap cells (which produce most of the power in the device). Combined with a carefully-engineered composition grading scheme, the low-junction cell can be grown with high quality as well. Finally, the substrate is removed to enable light to enter the cell from the required direction, entering the highest-bandgap junction first. The substrate removal, while introducing an additional processing step, results in an extremely thin cell which enhances heat removal, and has the potential for manufacturing cost savings as high as 25%.
- IMPACT: This cell will likely become the standard cell for the entire CPV industry.
- IP POSITION: NREL has three patents pending, and has extensive know-how.
- TECHNOLOGY STATUS: Demonstrated at NREL: the cell has set new benchmarks for efficiency at high concentrations – 40.8% at 326 suns and 39.2% at 840 suns – and further significant performance improvements to near 45% are likely near-term. Furthermore, we also have a longer-term four-junction concept under development for efficiencies ultimately approaching 50%. This technology is already being transferred to several companies.
    - **Application in CPV Systems**: We anticipate that this technology will reduce CPV LCOE by ~10-25%.
    - **Special needs to implement**: Requires an additional processing step not routine in the solar cell industry, but nowhere near the sophistication of the microelectronics industry. Standard epi growth facilities are used, although with additional know-how to develop the required growth recipes.

Technology Concept

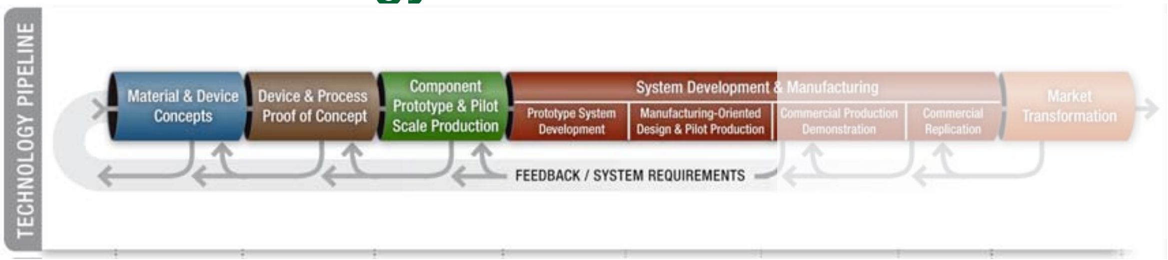


Demonstrated Performance



Fast, low-cost process for making high quality Copper-Indium-Gallium Diselenide (CIGS) photovoltaics

- **Description**
  - Fast, low-cost process for making high quality Copper-Indium-Gallium Diselenide (CIGS) photovoltaics
- **Impact**
  - Low cost / high yield CIGS manufacturing
- **Technology Readiness**

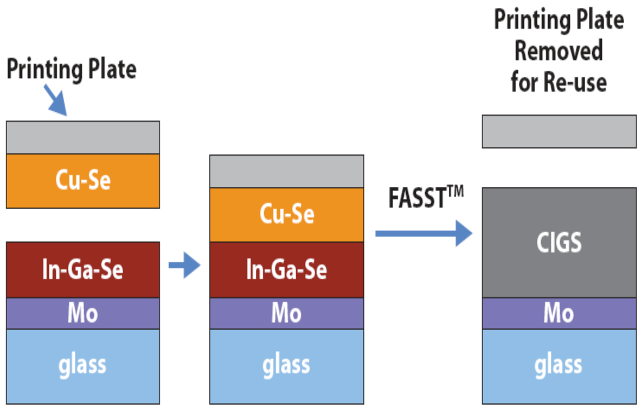


- **Estimated Time to Market**
  - 3 years
- **Estimated Commercialization Cost**
  - $50M

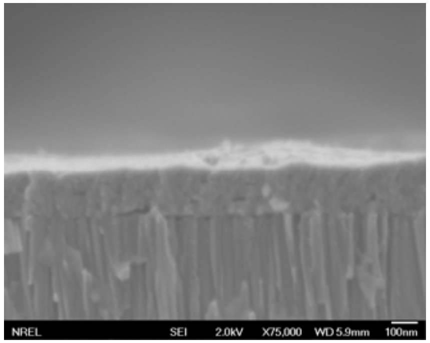
Fast, low-cost process for making high quality CIGS PV

- PROBLEM: Vacuum based approaches to CIGS deposition have proven difficult to scale up to manufacturing due to yield problems largely due to compositional uniformity. Non-vacuum approaches have still required selenization, which is a time consuming treatment in H_2Se.
- DESCRIPTION OF INVENTION/TECHNOLOGY: Together with Heliovolt, NREL has developed a system of solution based selenium containing precursors to formation of CIGS with FASST (Field Assisted Simultaneous Synthesis and Transfer) rapid thermal processing to rapidly produce high-performance large area cells.
- IMPACT: Potentially very large since this is a general technology for enhanced CIGS deposition that is potentially applicable to many thin film solar cell manufacturers.

- IP POSITION: NREL has a series of 4 patents and 2 recent disclosures in the area available for licensing. HelioVolt holds the rights for their use in FASST processed materials. These can be licensed for use in other processes for deposition of modification of CIGS layers.
- TECHNOLOGY STATUS: Currently available. Heliovolt is currently developing their proprietary FASST technology at their new manufacturing facility in Austin, TX. It is anticipated that these could be licensed to other CIGS manufacturers for use in their manufacturing processes.
  - **Reduction to practice**: We anticipate that this technology could have impacts on surface modification of CIGS films to improve electronic performance or in direct rapid thermal processing of precursor films composed of a compositionally balanced mixture of the liquid sources.
  - **Special needs to implement**: No special needs; involves straightforward atmospheric deposition like that already employed in solar cell fabrication and annealling.



Using FASST™ to Produce High-Quality CIGS

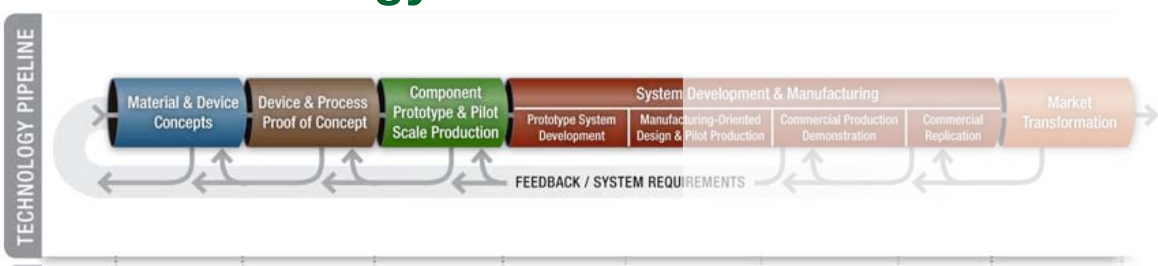


Dense, but small grain, CIGS film formed by RTP of solution based precursors

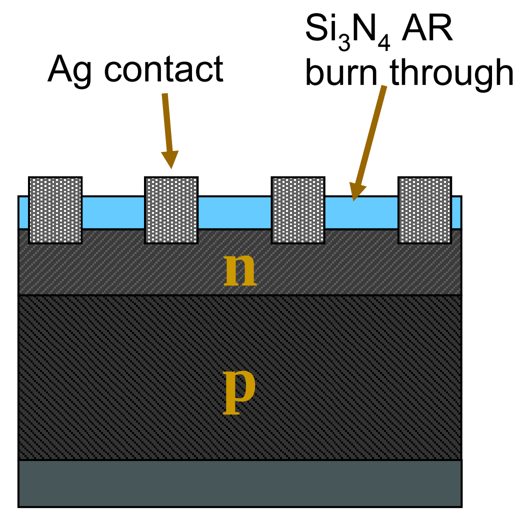
David Ginley | NREL | Phone: 303-384-6573 | david_ginley@nrel.gov

Ink jet deposition of solar cell

- **Description**
  - Ink jet deposition of solar cell
- **Impact**
  - Increased aspect ratio reduces shadow loss
  - Low breakage
  - High throughput
- **Technology Readiness**



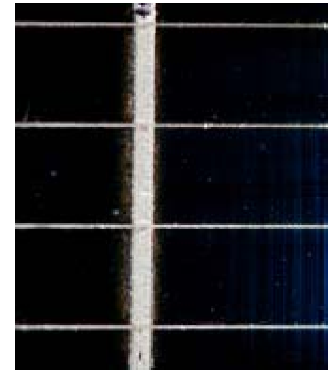
- **Estimated Time to Market**
  - 1 years
- **Estimated Commercialization Cost**
  - $10M Printing Process
  - $ 25M Ink production



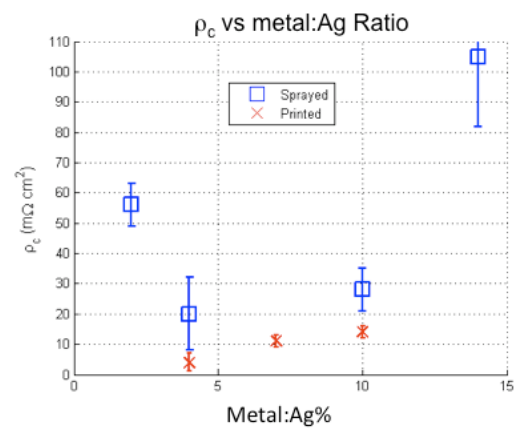
David Ginley | NREL | Phone: 303-384-6573 | david_ginley@nrel.gov

Ink-Based Direct Write Contacts for Solar Cells

- PROBLEM: Current contact methods for Si and other solar cells suffer from a lack of resolution, need to pattern with screens or photolithography, and mechanical contact with the cells.
  - Many next generation cells will require new approaches to doping and metallization of contacts. (interdigitated back contacts)
- DESCRIPTION: A series of inks have been developed for metallizations (Ag, Cu, Ni, Al etc.) & burn through agents & dopants, that can be printed with high resolution (<40 μm) using inkjet cassettes.
- IMPACT: Direct write contacts offer improved resolution, have better materials utilization, are low cost, allow ready process integration, low capitalization cost, and are broad applicability to PV and other electronic technologies.
- IP: NREL has a series of 5 patents and 3 recent disclosures in the area available for licensing.
- STATUS: The technology has been demonstrated for a number of solar cell systems.
  - There are 7 related inventions available for license.
  - The technology has been reduced to practice for Si with initial demonstrations as well for CIGS and OPV.
  - Currently Available
  - No special needs
  - Ink synthesis, direct write printer, thermal processing.

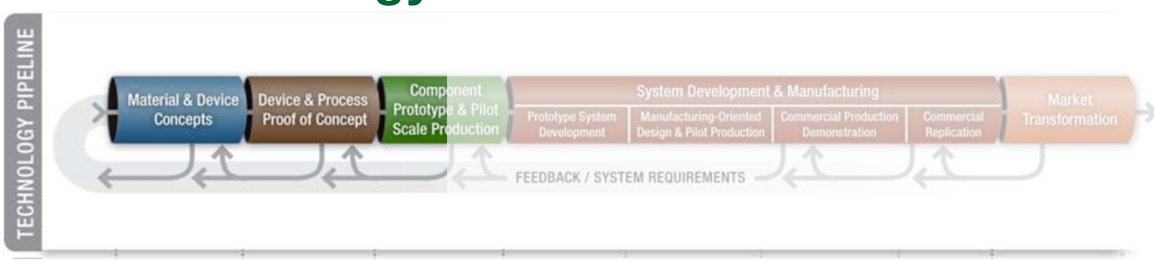


Line thickness:	**10 μm**
Line width:	**40μm**
Dep. temperature :	**180°C**
Ann. temperature:	**750°C**
Cell efficiency	**13%+**
On Evergreen Solar Silicon	

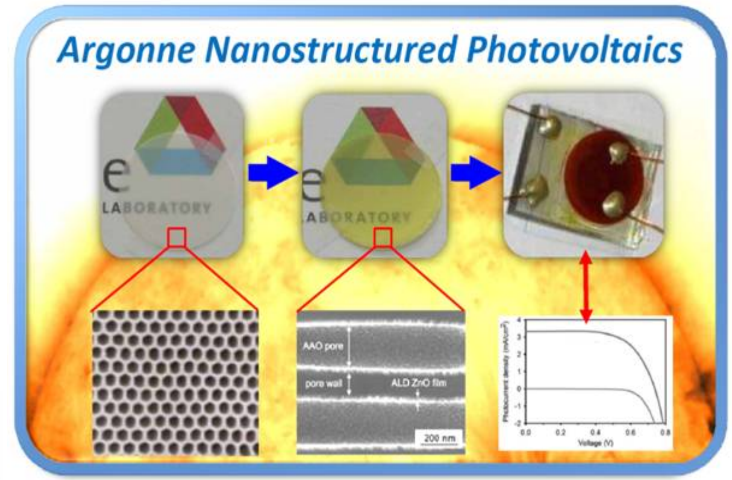


Low cost, low temperature fabrication of nanostructured, dye-sensitized solar cells

- **Description**
  - Low cost, low temperature fabrication of nanostructured, dye-sensitized solar cells
- **Impact**
  - Inexpensive, scalable design and manufacturing technology
- **Technology Readiness**



- **Estimated Time to Market**
  - 5 years
- **Estimated Commercialization Cost**
  - $100MM



Jeffrey Elam | Argonne | Phone: 630-252-3520 | jelam@anl.gov

Argonne Nanostructured Photovoltaics

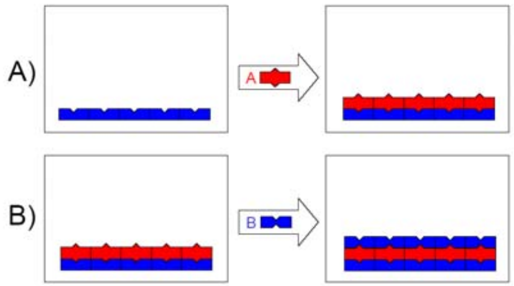
- PROBLEM: Existing photovoltaics using crystalline silicon requires costly, high-temperature manufacturing. Dye sensitized solar cells (DSSCs) are cheaper to produce, but their solar efficiency is too low for commercial adoption. Argonne Nanostructured Photovoltaics utilize atomic layer deposition (ALD) technology to overcome the limitations of DSSC performance.

- DESCRIPTION OF INVENTION/TECHNOLOGY: Argonne's patented ALD technology allows precise, conformal layers of material to be applied to high surface area, nanostructured templates to synthesize high performance dye sensitized solar cells. A revolutionary new architecture developed at Argonne allows enhanced charge collection and improved solar efficiency for inexpensive DSSCs that will facilitate wide scale commercialization.

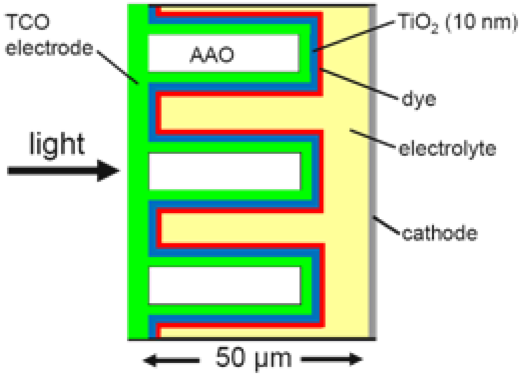
- IMPACT: The potential impact is very large since this is a general technology for synthesizing and engineering nanoscale structures with applications in photovoltaics, solid state lighting, catalysis, separations, sensors, fuel cells, and much more.

- IP POSITION: Argonne has a series of 13 patent applications covering ALD technology.

- TECHNOLOGY STATUS: We currently have working prototype devices of the Argonne Nanostructured Photovoltaics. We are continuing to develop and improve these PVs, and we are in the process of securing funding for further development and scale up.



ALD uses alternating reactions between gaseous precursors (A and B) to deposit layers of nearly any material with atomic precision

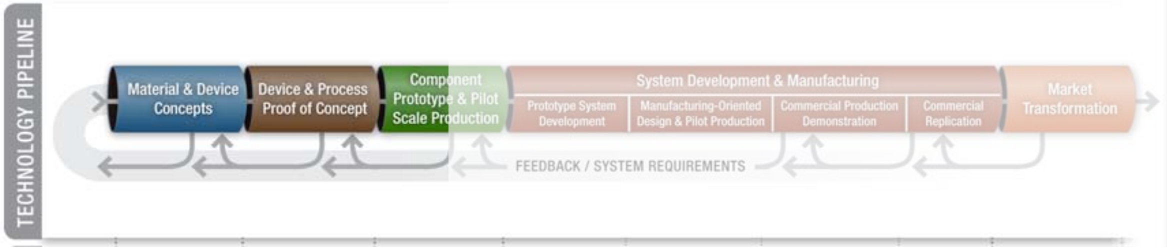


Sequence of ALD layers (TCO, TiO_2) deposited on nanoporous anodic aluminum oxide (AAO) support generate solar cell with improved performance.

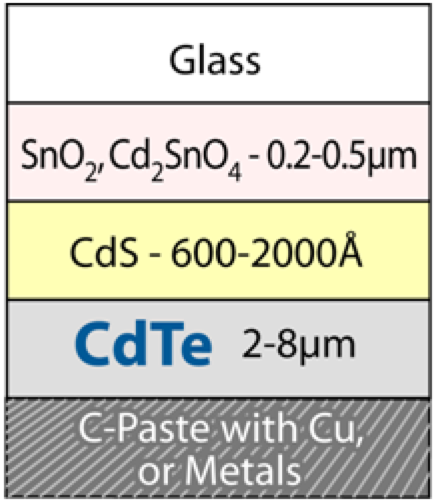
Jeffrey Elam | Argonne | Phone: 630-252-3520 | jelam@anl.gov

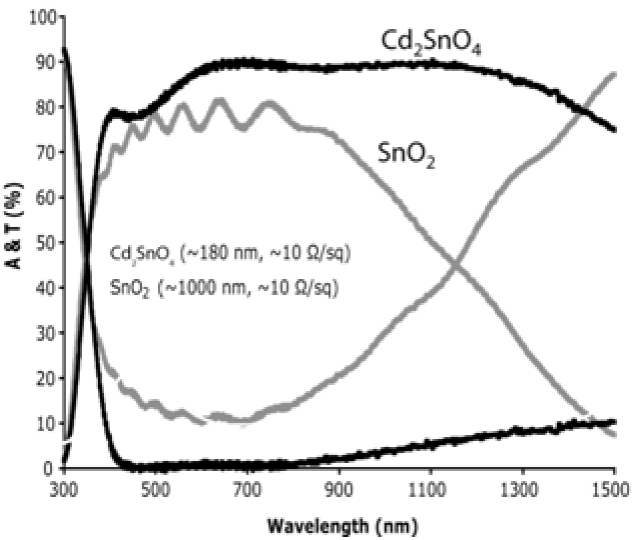
Improved transparent conducting oxides for CdTe modules deliver higher IR transmission

- **Description**
  - Improved transparent conducting oxides for CdTe modules deliver higher transmission in the IR
  - Wider processing window that other alternative TCOs
- **Impact**
  - 10.4% production modules become 11.2% modules
  - Improved Low-e glass
- **Technology Readiness**



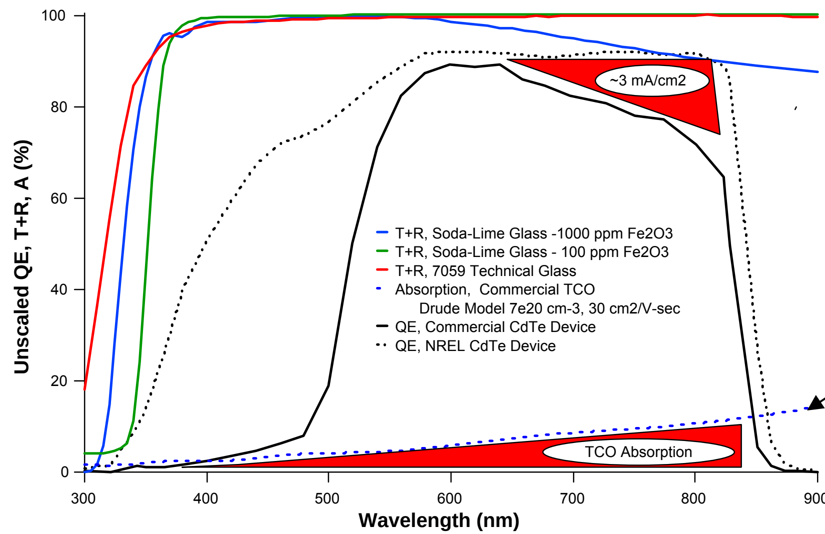
- **Estimated Time to Market**
  - 2 years
- **Estimated Commercialization Cost**
  - $20M



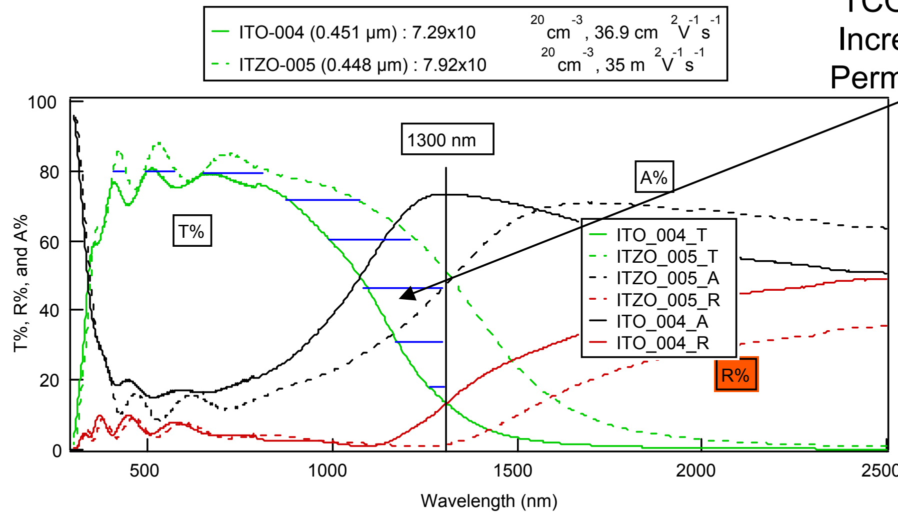


High Transmission TCO for CdTe

- PROBLEM: Industry standard TCOs (e.g. fluorine doped SnO_2) have excessive absorption in the IR resulting in a substantial reduction in module efficiency. TCO's with improved optical performance require complex processes for deposition.
- DESCRIPTION OF INVENTION/TECHNOLOGY: Control of the dielectric permittivity of the TCO provide another tool to engineer the desired optical characteristics. We have developed technology to increase permittivity through modest modification of conventional TCOs.
- IMPACT: Potentially very large since this can replace current commercial TCOs with moderate adjustment to production tools.
  - 10.4% production modules become 11.2% modules
  - Improved Low-e glass
- IP POSITION: NREL has two patent applications addressing the material and methods of fabrication.
- TECHNOLOGY STATUS:
  - Presently developing materials based on industrial chemistries
  - Expect results with new chemistries by end of 08



TCO IR Absorption ~1.5 mA/cm^2

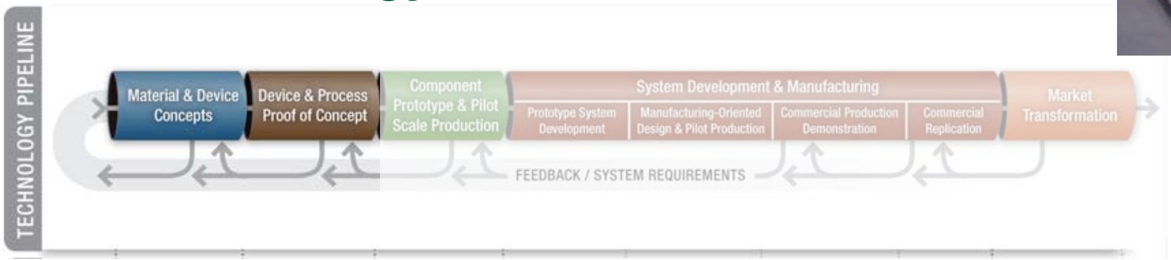


TCO with Increased Permittivity

Tim Gessert | NREL | Phone: 303-384-6451 | Tim_Gessert@nrel.gov

Design/Develop Improved Photoelectrode Architectures

- **Description**
  - Design/Develop Improved Photoelectrode Architectures
- **Impact**
  - Enhance Sensitized Solar Cell (SSC) device stability and performance
- **Technology Readiness**

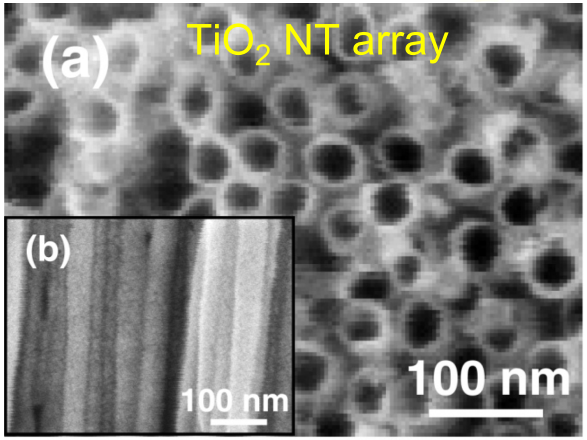


- **Estimated Time to Market**
  - 5 to 10 years
- **Estimated Commercialization Cost**
  - $25-50M

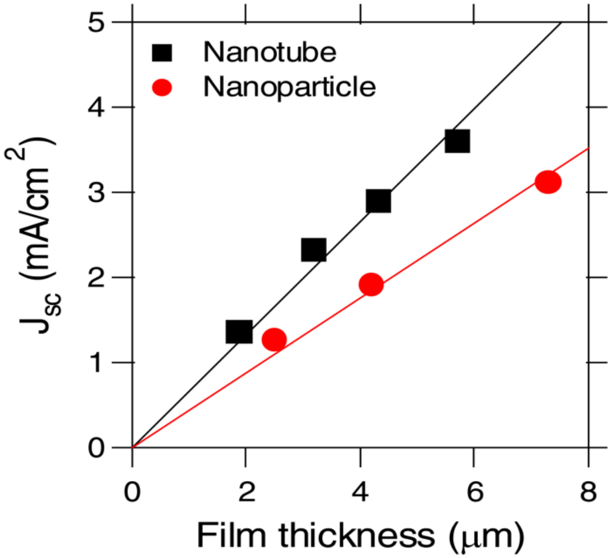
Photo Toyota/Aisin Seki

Design/Develop Improved Photoelectrode Architectures for SSC PV

- PROBLEM: **The electrical and optical properties of the current nanostructured thin film architecture in sensitized solar cells (SSCs) limit device performance and stability.** The major advantages of SSCs relative to other PV technologies are their high impurity tolerance and inexpensive scale-up to non-vacuum- and low-temperature-based high-volume manufacturing via continuous processes. State-of-the-art SSC prototypes and manufactured modules utilize disordered nanoparticle thin film photoelectrodes, which restrain light-harvesting & charge-collection efficiencies. In addition, the tortuous pore network in such disordered films is difficult to fill completely with quasi-solid and solid-state charge-conducting phases and, consequently, limits their application using some non-liquid devices.
- DESCRIPTION OF INVENTION/TECHNOLOGY: NREL has replaced the current disordered nanocrystalline architecture with an ordered (oriented) nanotube array. Thin films of oriented nanotube arrays in dye-sensitized solar cells improved the photocurrent by at least 20% owing to higher light-harvesting and charge-collection efficiencies. With thicker films, a larger improvement is possible.
- IMPACT: Potentially large since this is a general technology that could directly replace the current nanocrystalline particle-based film photoelectrodes in manufactured modules while also using low-cost fabrication techniques familiar to industry (e.g., electrochemical anodization).
- IP POSITION: NREL has a recent disclosure under review.
- TECHNOLOGY STATUS: Device Process & Proof of Concept. NREL is currently developing the technology to demonstrate improved stability and efficiency using ordered (oriented) nanotube arrays in SSC devices.
  - **Reduction to practice**: We anticipate that this technology could enhance device photocurrent (and overall efficiency) by >20% and allow more facile development of quasi-solid and solid-state devices having high stability and performance.
  - **Special needs to implement**: No special needs; involves straightforward deposition processes like those already employed in sensitized solar cell fabrication.



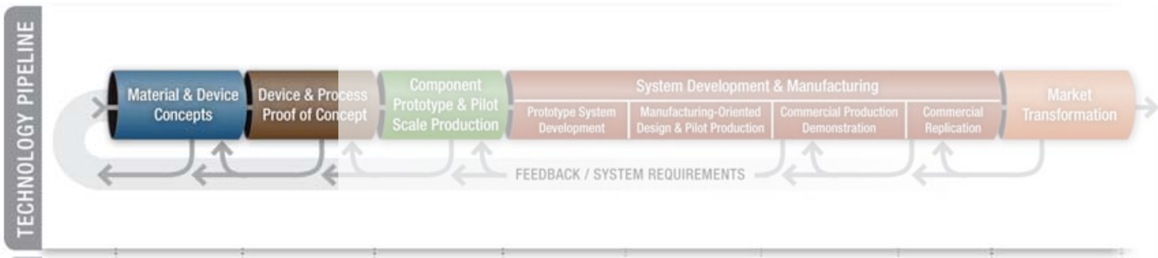
K. Zhu et al., *Nano Lett.* **2007**, *7*, 69

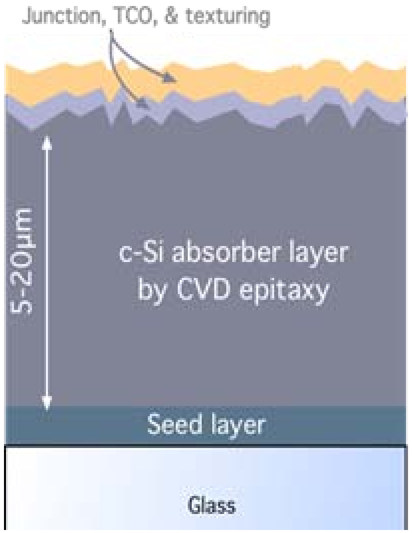


AJ Frank| NREL| Phone: 303-384-6262; e-mail: arthur_frank@nrel.gov

Thin crystal Si films grown epitaxially from gas of an inexpensive seed-layer substrate

- **Description**
  - Thin crystal Si films grown epitaxially from gas of an inexpensive seed-layer substrate
- **Impact**
  - Wafer-based c-Si performance at thin film manufacturing costs
- **Technology Readiness**

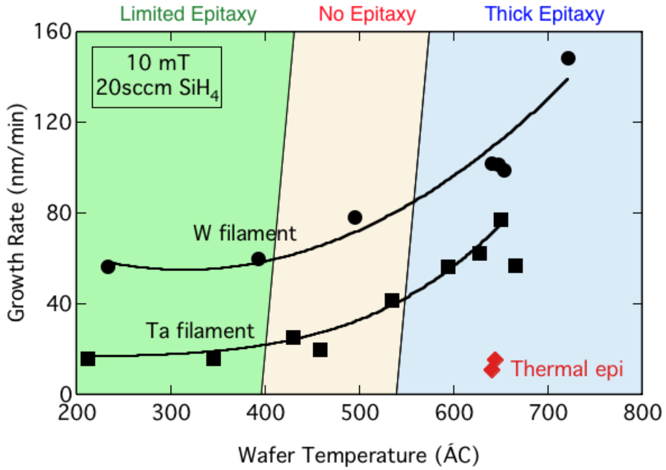


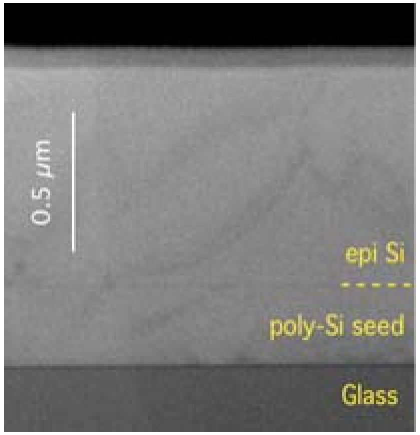


- **Estimated Time to Market**
  - 5 years
- **Estimated Commercialization Cost**
  - $50-$100M absorber layer process replacement

Wafer-replacement Silicon for Efficient, Low-cost PV

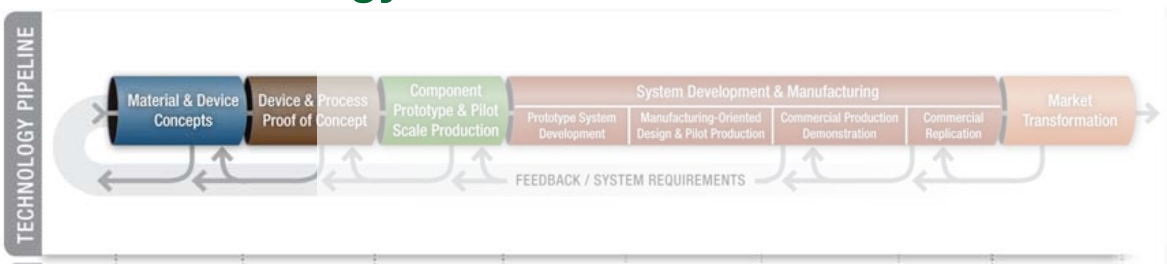
- PROBLEM: Costly energy & materials waste in wafer. Raw material alone currently over 0.5$/W - need to achieve 1$/W modules. Even when feedstock crisis ends, cost is too high.
- DESCRIPTION: Reduced costs by eliminating feedstock and melt, replacing 200μm wafers with ~10μm films. Devices can be grown over large areas with in-line CVD. Fabrication of an inexpensive seed layer is followed by subsequent epitaxial device growth
- IMPACT: Dramatic cost reductions associated with reduced material usage and large area deposition. Transition to industry will leverage existing expertise and equipment from both thin-film and c-Si industry
- IP POSITION: NREL has low-T epitaxy patent and several others in preparation
- TECHNOLOGY STATUS:
  - High-quality seeds in industry, collaborations underway
  - Fast epitaxy HWCVD demonstrated
  - Devices expected in 12 months
  - Products ~5 years from market





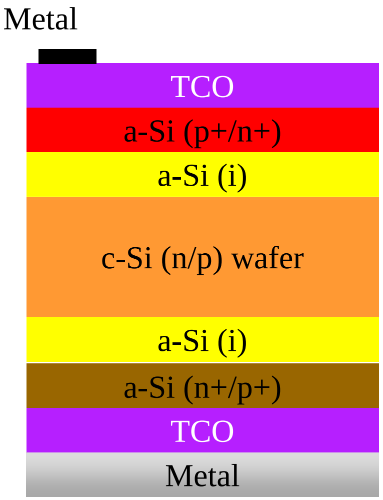
High performance device for p-type Si wafers

- **Description**
  - High performance device for p-type Si wafers
  - Low thermal budget and balanced strain ideal for thin wafers
- **Impact**
  - Increased efficiency and reduced Si consumption for advanced modules
- **Technology Readiness**



- **Estimated Time to Market**
  - 2 years
- **Estimated Commercialization Cost**
  - $10-50M

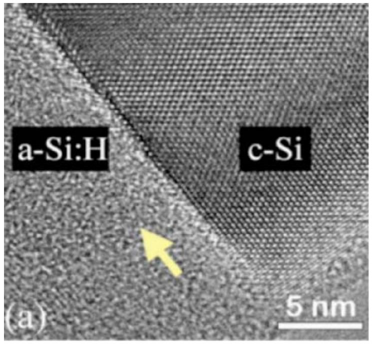
Structure



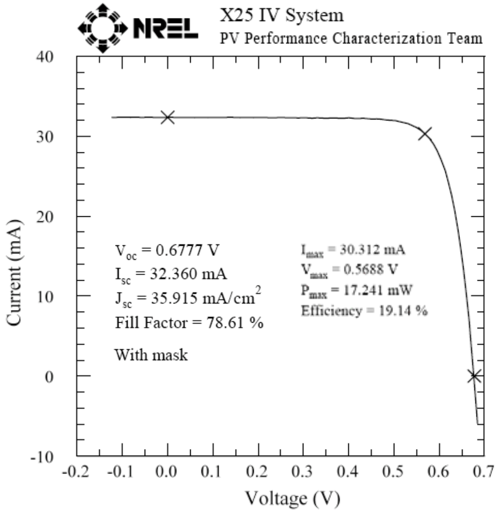
Qi Wang | NREL | Phone: 303-384-6681 | qi_wang@nrel.gov

High performance device for p-type Si wafers

- PROBLEM: Low efficiency on widely available *p*-type c-Si wafers and wafer bowing on thin wafers



- DESCRIPTION OF INVENTION/TECHNOLOGY: Heterojunctions were widely believed to be limited to applications with n-type Si. Through control of the interface and film deposition, we have achieved high performance in p-type Si, the lower cost and more abundant material.
  - Achieved high voltage of 0.677 V and 19.1% on *p*-type FZ c-Si
  - 18.7% on *p*-type CZ c-Si



- IMPACT: Potentially very large since this can be substituted into the production of most silicon PV lines.

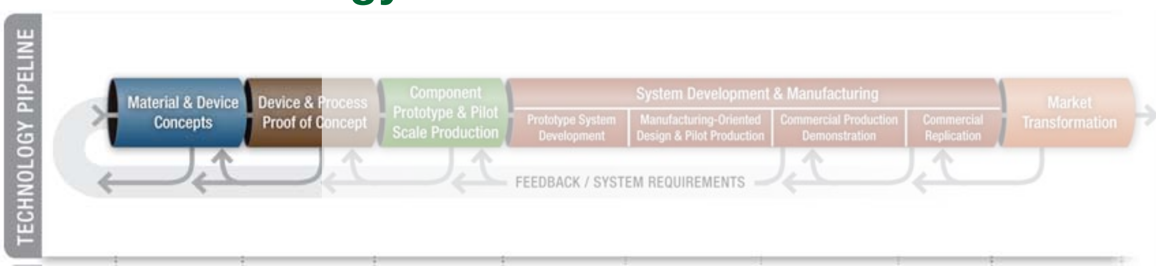
- IP POSITION: NREL has disclosures and patents on the methods for control of the interface and on the necessary deposition process.

- TECHNOLOGY STATUS: Currently available. Working with one partner for evaluation in larger areas and exploration of scale-up of deposition process.

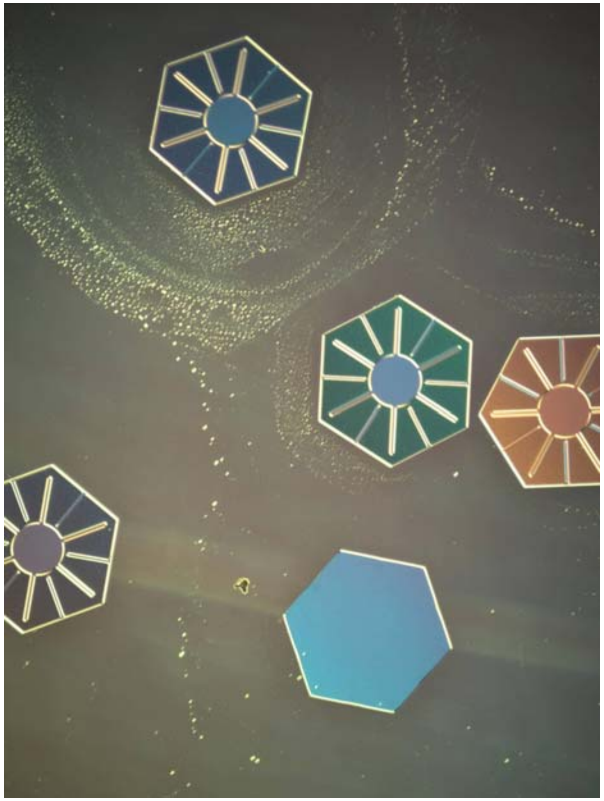
Qi Wang | NREL | Phone: 303-384-6681 | qi_wang@nrel.gov

Leveraging MEMS/Microsystem Technologies for PV Systems with Thin c-Si/III-V Cells

- **Description**
  - Leveraging MEMS/Microsystem Technologies for PV Systems with Thin c-Si/III-V Cells
- **Impact**
  - Significant reductions in total system cost
  - High-efficiency modules (>20% c-Si, >40% III-V)
  - Building integrated PV
- **Technology Readiness**



- **Estimated Time to Market**
  - 3 Years
- **Estimated Commercialization Cost**
  - $100M

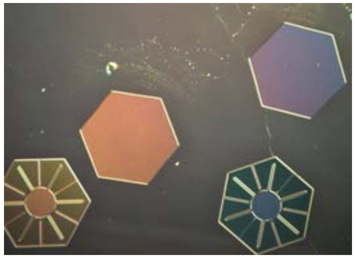


Crystalline silicon PV cells with backside contacts. These cells are 20 μm thick and 500 μm across and are manufactured in a manner that allows highly efficient use of c-Si material.

Gregory N. Nielson | SNL | Phone: 505-284-6378 | gnniels@sandia.gov

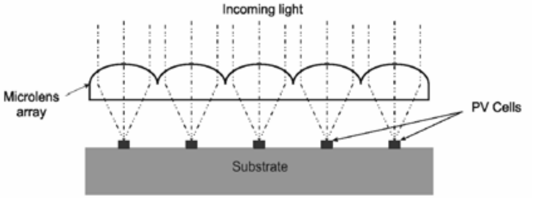
Leveraging MEMS/Microsystem Technologies for PV Systems with Thin c-Si/III-V Cells

- **PROBLEM:** In breaking out component PV system costs, it is clear that many component costs need to be reduced. The five most expensive components of a PV system are silicon material, installation labor, module assembly, inverter, and cell fabrication. Together, these comprise approximately 90% of the system cost. Of these components, the highest cost is less than about 25% of the total system cost. Therefore, to achieve grid parity (2-4 times reduction in system cost) requires a system approach that addresses many components simultaneously.
- **DESCRIPTION OF INVENTION/TECHNOLOGY:** We are leveraging MEMS/Microsystems technologies and ideas to reduce costs across many component cost areas of PV systems. The fundamental technology is the creation and use of thin (~20 μm) and small (on the order of ~100 μm) PV cells of c-Si and III-V materials. These small cells allow highly optimized use of the expensive crystalline semiconductor materials and, when combined with massive parallel assembly concepts under development within the MEMS/Microsystems communities, provides for very low cost modules. Further, these small cells enable other concepts that will further reduce costs. These concepts include optical concentration at the millimeter scale, new tracking methods for thin (<3 cm) flat plate modules mounted flat on roofs, incorporation of electrical functionality (e.g. health monitoring, power conditioning) in modules, and building integrated PV.
- **IMPACT:** This is a new approach to creating PV modules/systems with reduced cost and new functionality. If successful, the impact of this technology will be very large.
- **IP POSITION:** SNL has filed one patent application with approximately six new disclosures filed and under review. All IP is available for licensing.
- **TECHNOLOGY STATUS:**
  - Currently developing thin c-Si and GaAs PV cells. We have demonstrated functional 20 μm thick PV cells using methods that allow reuse of the remaining substrate with 1-2 μm of kerf loss. We anticipate c-Si cells of ~20% efficiency in 1-2 years (at current funding levels, quicker development possible with more funds).
  - Next significant development effort is bringing parallel assembly concepts to the point of commercialization. With proper funding, we anticipate this can be accomplished in 2-3 years.
  - Remaining concepts are relatively straightforward (i.e. no additional development time).



Create highly efficient thin/small cells (20 μm thick, 500 μm across).

Large numbers of cells can be assembled in parallel.



Combined with high-quality (refractive), small scale optics to increase efficiency and lower cost. (One-sun concepts also possible.)

Gregory N. Nielson | SNL | Phone: 505-284-6378 | gnniels@sandia.gov

Questions and Resources:

DOE Solar Program/Analysis: http://www.eere.energy.gov/solar/solar_america/
PV Value Clearinghouse: www.nrel.gov/analysis/pvclearinghouse/
SNL PV Systems R&D: www.sandia.gov/pv
NREL Solar Research: www.nrel.gov/solar

Sign up for our Newsletter and Market Analysis: Send email to solar@ee.doe.gov

Questions & Follow-up:

John Lushetsky - john.lushetsky@ee.doe.gov - 202-287-1685