NREL
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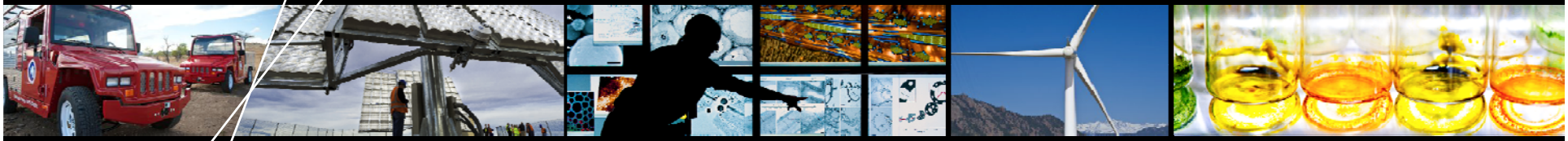
PV Manufacturing Cost Analysis:
Future Cost Reduction Opportunities



CESA Member Webinar:
Solar PV Manufacturing Costs

Alan Goodrich,
Michael Woodhouse,
Ted James

June 22, 2012

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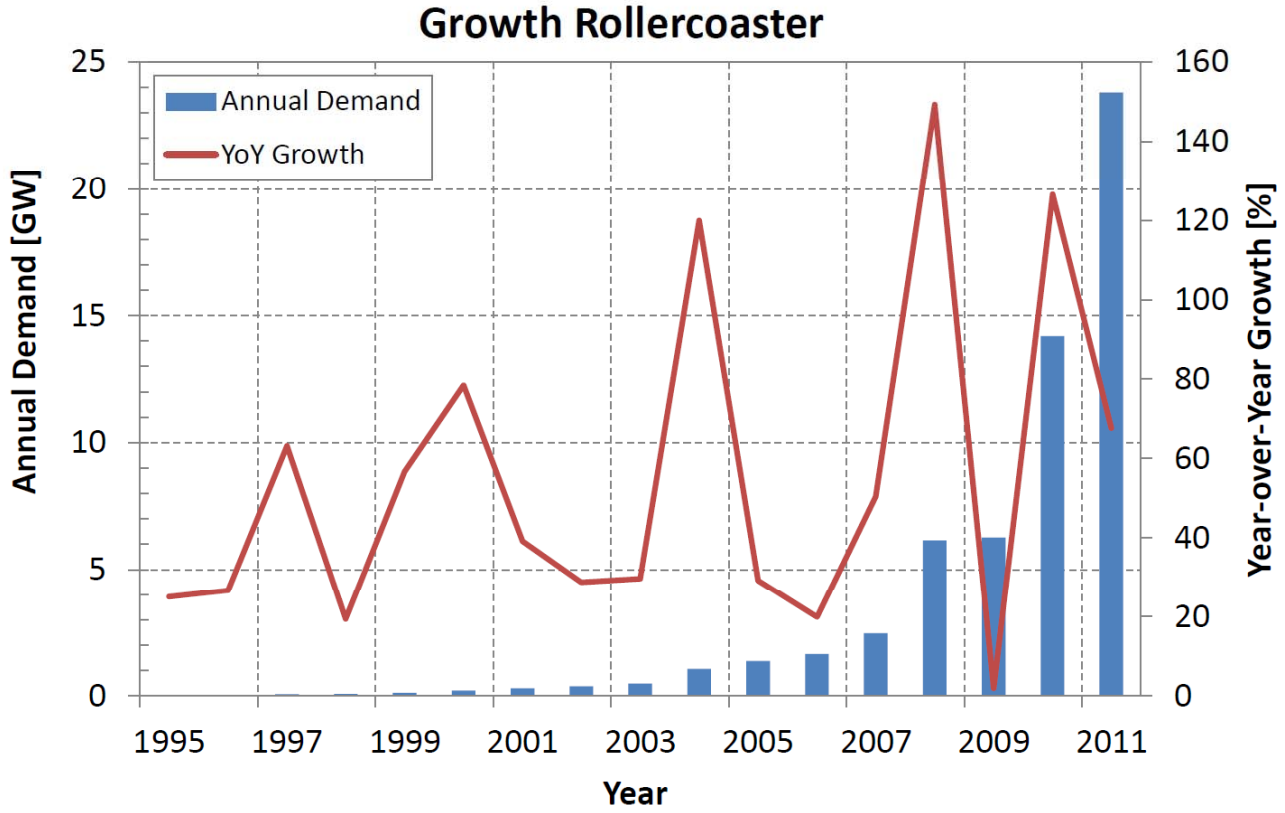
Overview

- **Reported Prices: Market Distortions**
  - Historic-cost reduction factors
  - The rising importance of innovation
  - The role of supply-side subsidies
- **Cost Analysis in-Support of R&D**
- **Future Cost-Reduction Opportunities**
  - Wafer based c-Si modules
  - SJ polycrystalline CdTe modules
- **System-Price Trends**

Top-Down (Reported) Prices

Useful for long-term strategic decisions?

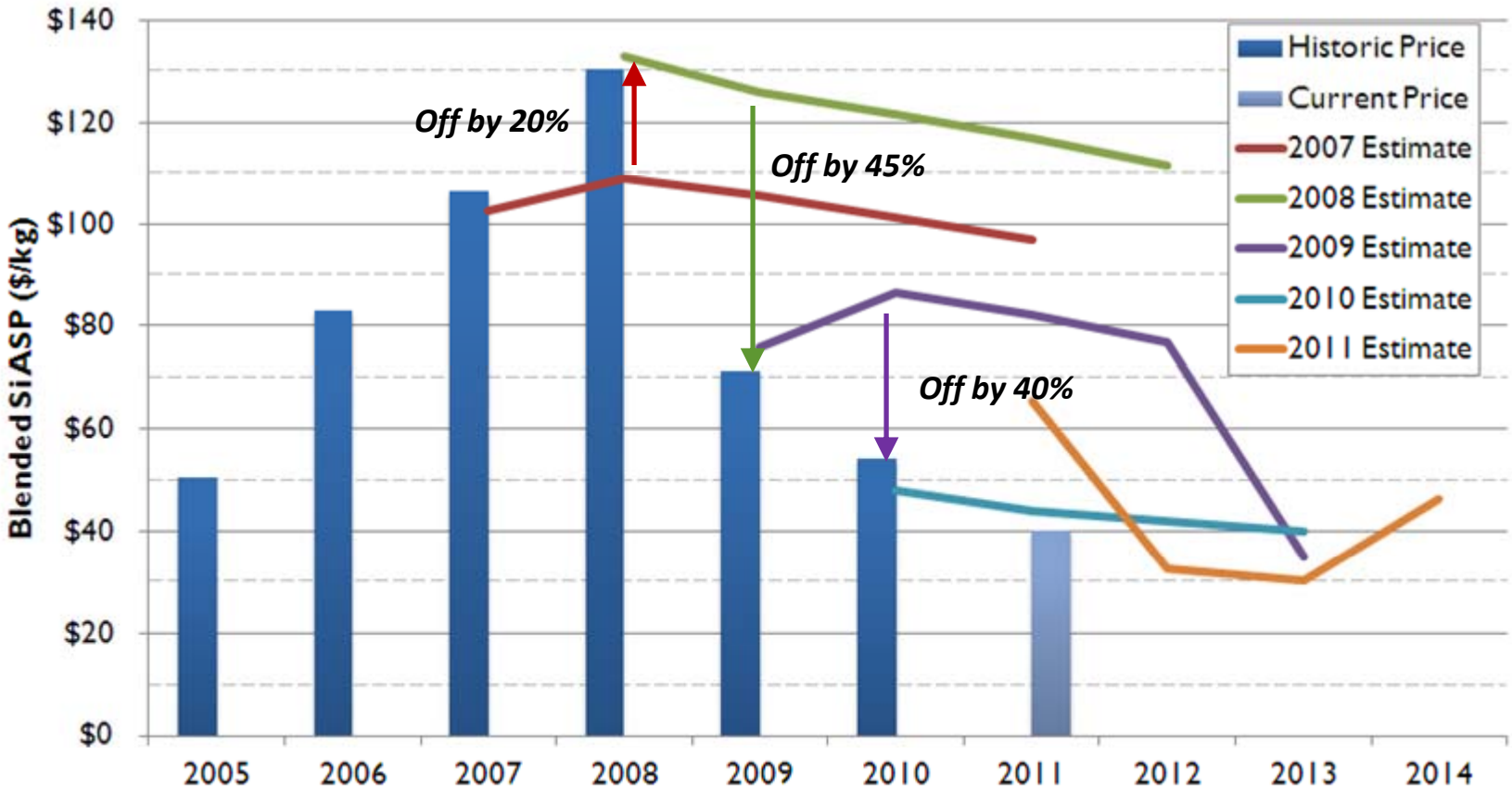
The Ups and Downs of the PV Market



- **PV is a nascent industry…prices generally reflect temporary shifts in buyer- or supplier-power**

Sources: Graph prepared by Douglas M. Powell, MIT using data from:I
EA, *Trends in Photovoltaic Applications,* (2011)
IHS, *PV Demand and Installation Surge in Q4,* (2011)

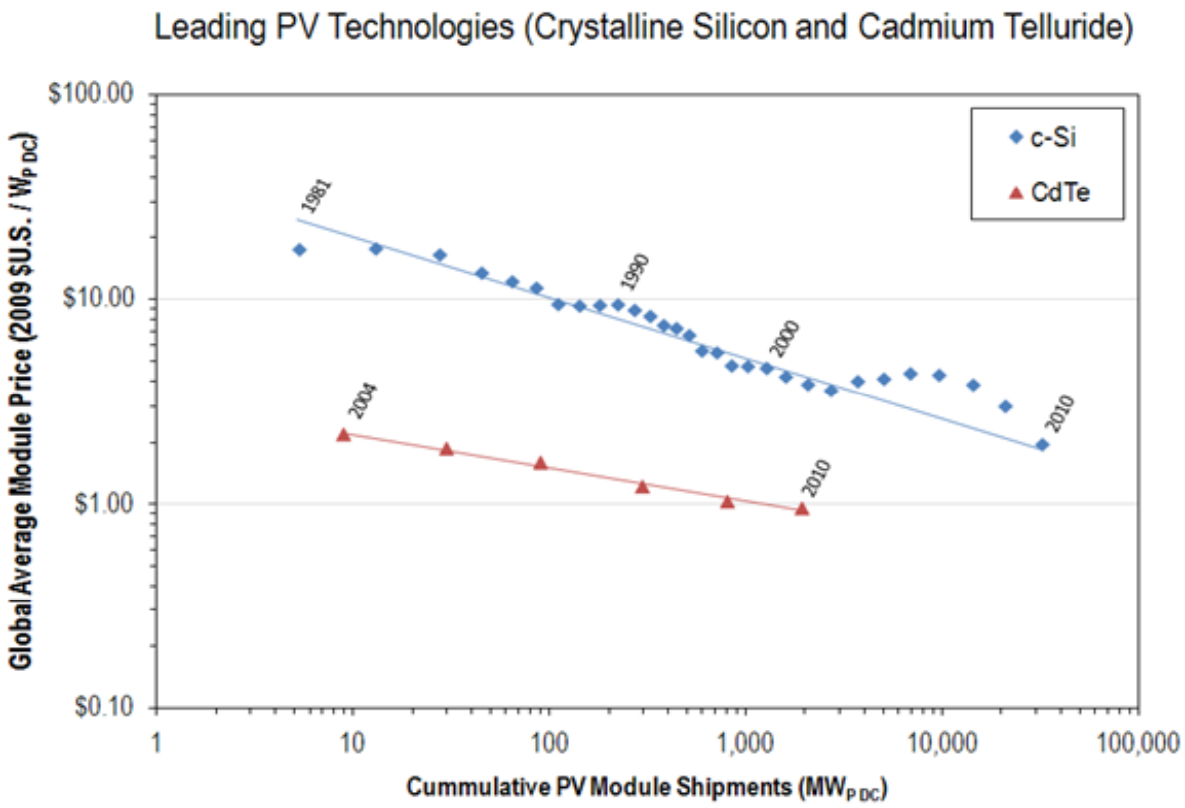
Market Distortions Throughout the Supply Chain



- **Opportunity for low- to non-Si techs turned out to be limited**
- **Consider long-term competitive prices**

Sources: Graph prepared by David Feldman, NREL using data from:
Graph prepared by David Feldman, NREL, using data from:
Photon Consulting, "Solar Annual 2007", "Solar Annual 2008", "Solar Annual 2009", "True Cost of Solar 2010", "Solar Annual 2010-11"

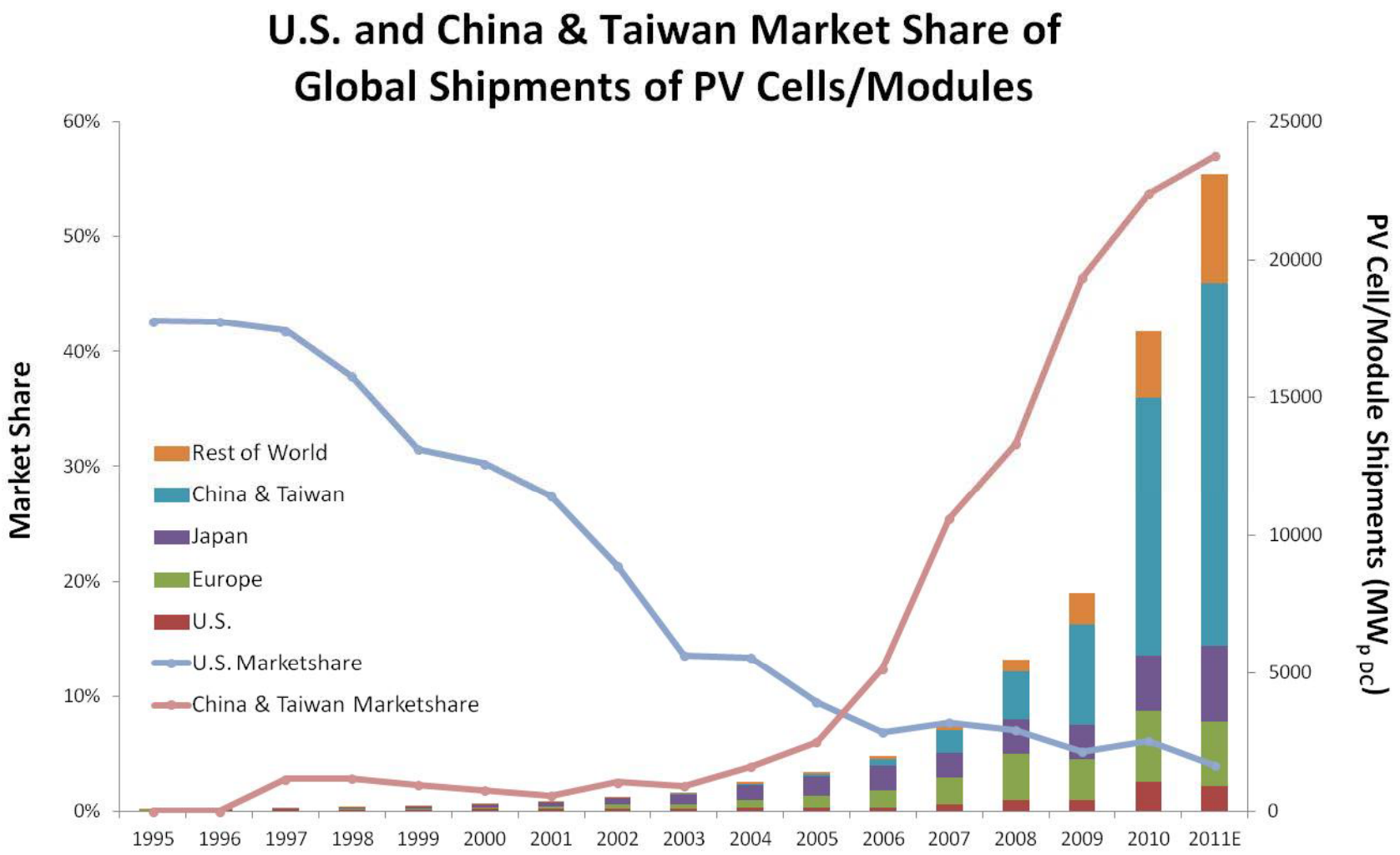
Historic Solar PV Module Prices – Top Down



- **Historic factors: scale (43%), efficiency gains (30%)**

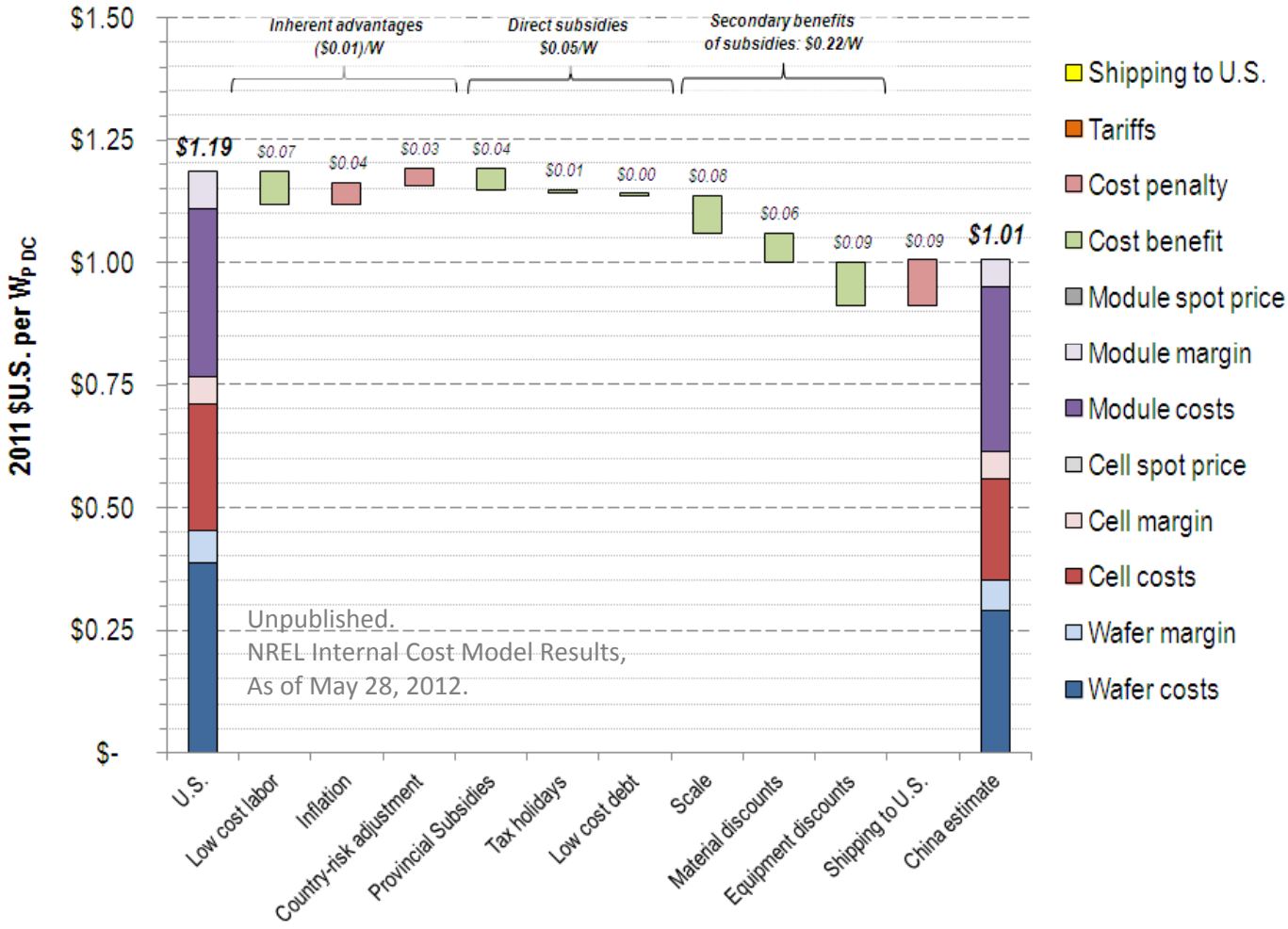
Sources: Graph courtesy of David Feldman, NREL; data sources:
For 1980-1984: "Large Quantity Buyers", Navigant Consulting (2006), Photovoltaic Manufacturer Shipments 2005/2006, Report NPS-Supply1 (August 2006); For 1985-2011: "Large Quantity Buyers", Navigant Consulting (2011), Photovoltaic Manufacturer Shipments 2010/2011, Report NPS-Supply VI (April 2011). For inflation: Implicit Price Deflators for Gross Domestic Product, Bureau of Economic Analysis (9/29/11). For UBS Module ASP '11: UBS Global Solar Industry Update 2011 Volume 11 (June 2011). For Sep. '11 Chinese c-Si Spot Price: UBS Global Solar Industry Update 2011 Volume 13 (September 2011).
Nemet, G.F. (2006). "Beyond the learning curve: factors influencing cost reductions in photovoltaics." Energy Policy 34(17): 3218-3232.

Recent, Dramatic Shift in the Origin of Production



Sources: Graph prepared by Ted James, NREL using data from:
NREL chart using data from Mints, P.; Donnelly, J. (2011). "Photovoltaic Manufacturer Shipments, Capacity and Competitive Analysis 2010/2011." Report NPS-Supply 6, Navigant Solar Services Program. Palo Alto, CA.

The Impact of Supply-Side Subsidies



Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). "A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map:Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs." NREL (in preparation)

Bottom-Up Cost Analysis

Long-term competitive pricing

Methodology Overview

Technical Cost Models (Busch 1987)

Relate technical details to costs (according to GAAP)

Direct Manufacturing Cost Summary: CIGS, Coevaporated on glass (Annual production volume: 600 MW_{PDC})

	$/Wp	$/module	$/year	percent	investment
VARIABLE COST ELEMENTS					
Material Cost	$0.61	$72.03	$363,572,081	56.0%	
Direct Labor Cost	$0.09	$10.71	$54,059,605	8.3%	
Utility Cost	$0.02	$1.95	$9,823,730	1.5%	
FIXED COST ELEMENTS					
Equipment Cost	$0.15	$17.58	$88,740,016	13.7%	$621,180,110
Tooling Cost	$0.00	$0.00	$0	0.0%	$0
Building Cost	$0.00	$0.02	$94,102	0.0%	$2,733,073
Maintenance Cost	$0.05	$5.90	$29,772,831	4.6%	
Overhead Labor Cost	$0.00	$0.09	$467,282	0.1%	
Cost of Capital	$0.17	$20.45	$103,221,567	15.9%	
TOTAL COSTS	**$1.08**	**$128.73**	**$649,748,214**	**100.0%**	**$623,913,183**

Example data for illustration purposes only.

Cost of Goods Sold

Non-cash Expense
- Depreciation

Interest Expenses
- Less non-cash expenses

Capex requirements
- For a target prod. volume
- Equipment, facilities

Not pictured:

Calculate minimum sustainable (long-term competitive) price

Pro forma income statement, discounted cash flow analysis

Sources: J.V. Busch, Technical cost modeling of plastics fabrication processes, PhD Thesis, Massachusetts Institute of Technology, (1987).

DCF Analysis: Minimum Sustainable Price

Sales
Cogs
Contribution margin

SG&A
Overhead labor
R&D
Regulatory
Warranty
Working capital
Depreciation
EBIT

Taxes
Unlevered net income

Plus: depreciation
Less: capital expenditures
Less: NWC
Plus: after tax salvage value
Free cash flow

Greenfield analysis

- Construction, ramp-up periods
- Operating expenses: %-revenue method (industry comparables)
- Accelerated depreciation
- Internal hurdle rate = total cost of capital (including debt):
  exclude interest expense

Price that satisfies NPV = 0, using the "Internal hurdle rate" as the discount rate = Minimum Sustainable Price

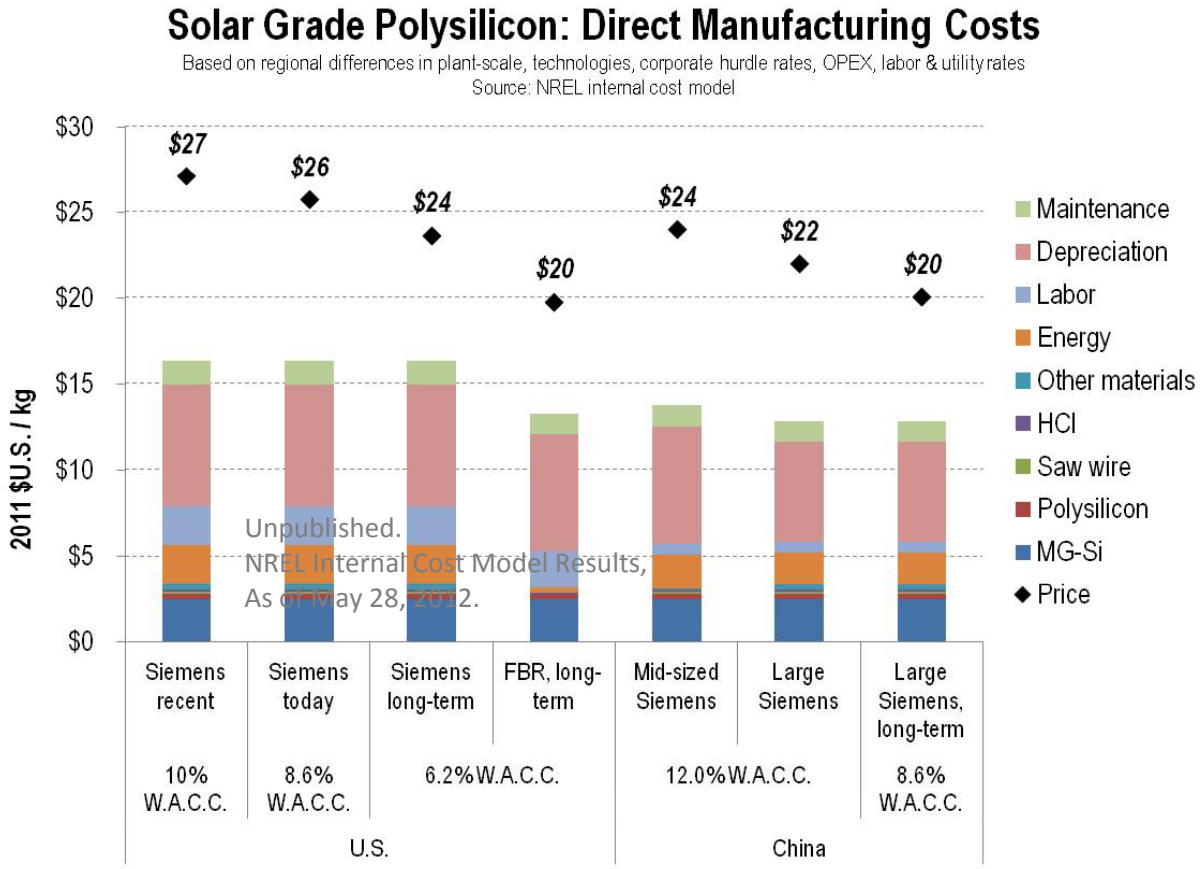
Technology Road Maps

The competitive price of alternative tech. pathways:

Wafer based c-Si

SJ poly CdTe

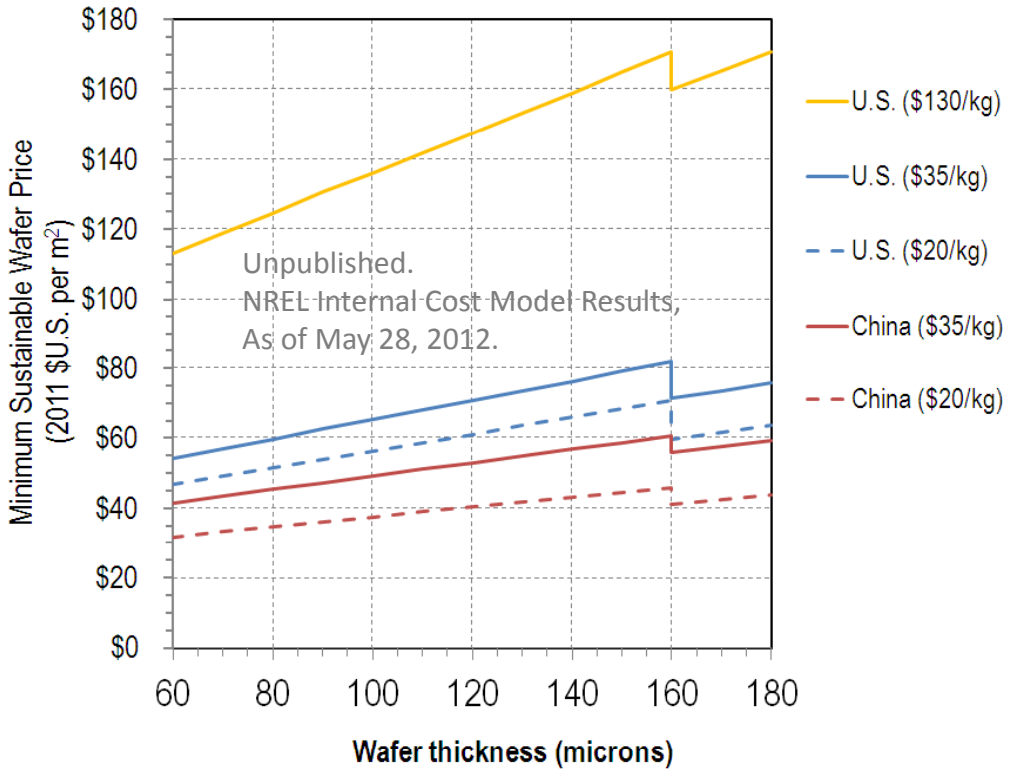
Poly Costs: Capital, Energy Intensive



- **Today's *competitive* price ($27/kg) may approach $20/kg in the long-term**

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). "A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map:Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs." NREL (in preparation)

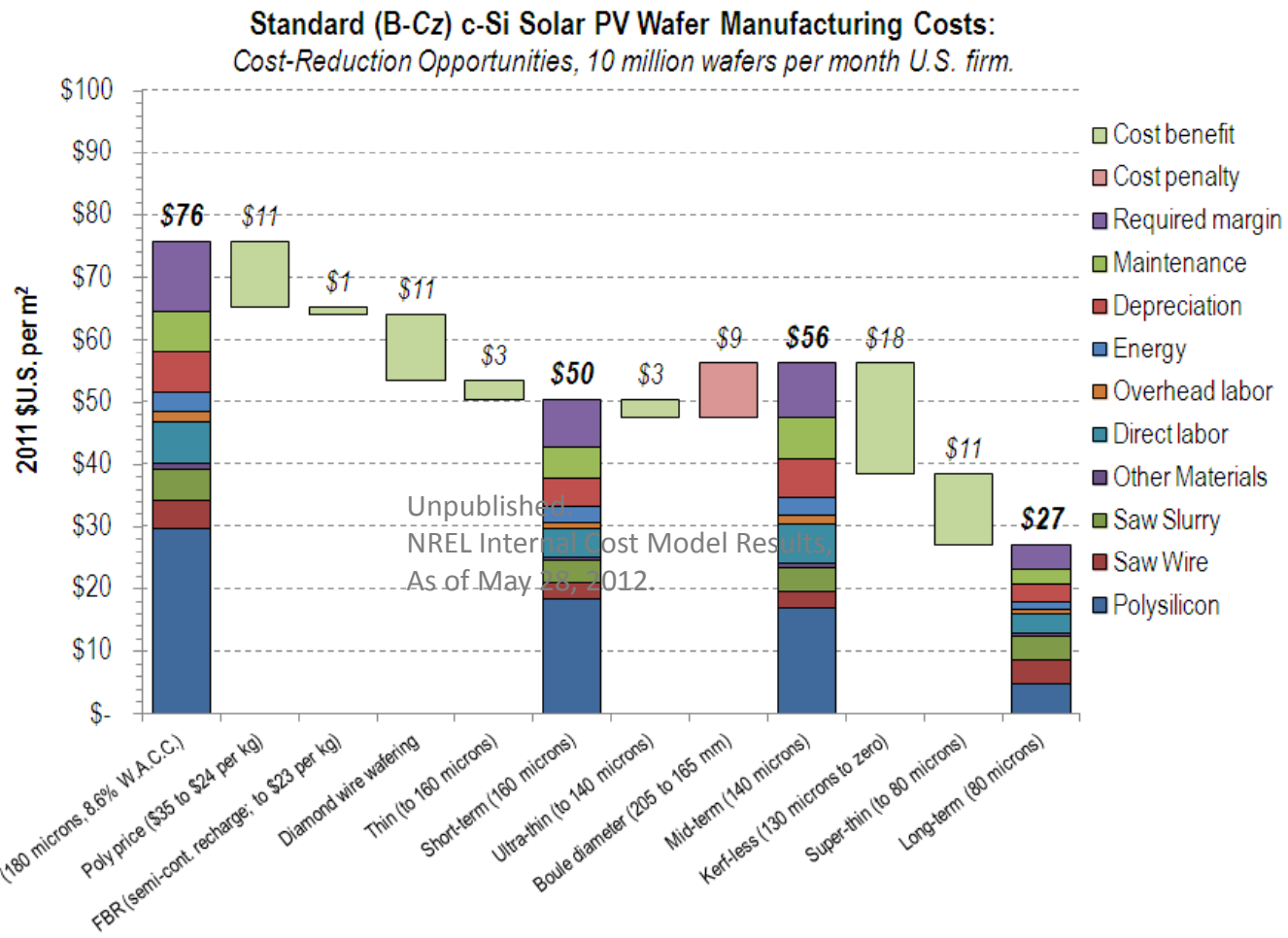
The Value of Thin Wafers



- **Potential cost disadvantages:**
  - Mechanical yield losses, surface passivation requirements

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). "A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map:Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs." NREL (in preparation)

U.S. Bulk c-Si Wafers: Cost Road Map



Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). "A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map:Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs." NREL (in preparation)

Many known pathways to higher efficiencies

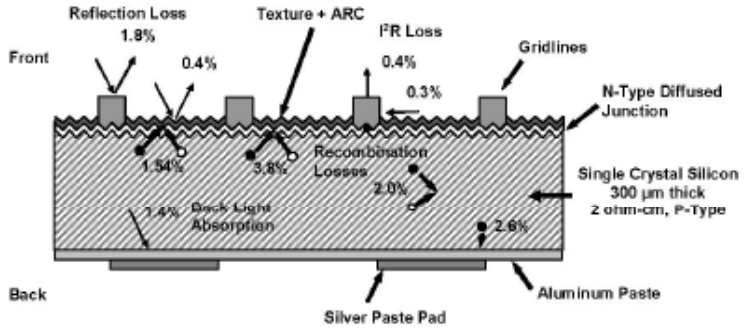
…but, at what cost?

Performance opportunities

- Front side shadowing
- Bulk recombination
- Surface recombination

However, cost trade-offs exist

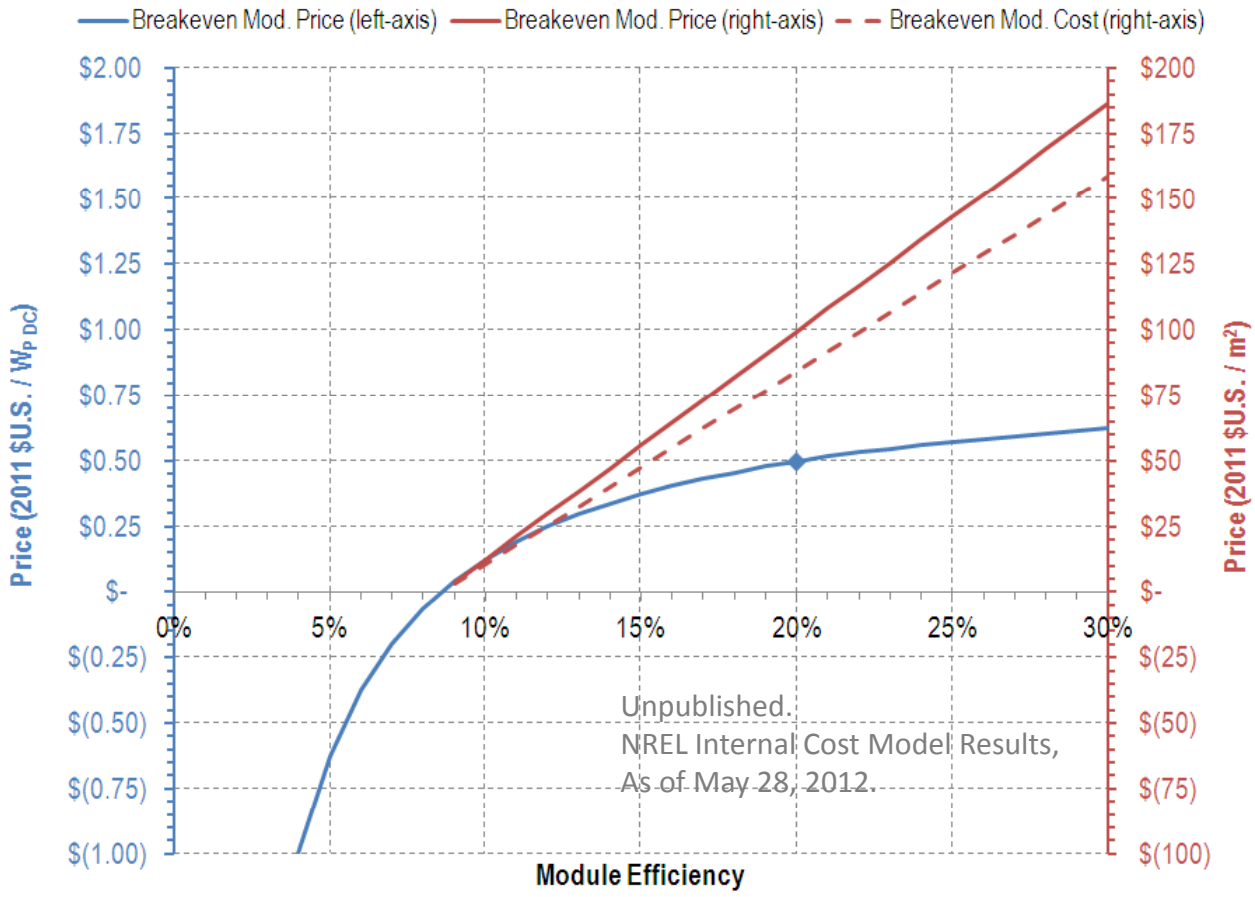
- Trina: 17.2% cells, $1.16/W module costs[1]
- Sunpower: 24% cells, $1.48/W module costs[2]



Standard c-Si Cell loss mechanisms[3]	
c-Si Module Efficiency (Potential)	**29%**
Front surface recombination	(3.8%)
Rear surface recombination	(2.6%)
Bulk recombination	(2%)
Front grid shadowing	(1.8%)
Diffused junction recombination	(1.5%)
Rear contact absorption	(1.4%)
Resistive losses	(0.7%)
Front surface reflection	(0.4%)
Ending Cell Efficiency	**14.8%**

[1]Trina Q2 2011 Earnings Call. August 23, 2011.
[2]Herron, J. (2010). "Shining the Light." Photon International. September 2010.
[3]R.Swanson, "Developments in Silicon Solar Cells", Electronic Devices Meeting, 2007.IEDM, IEEE International

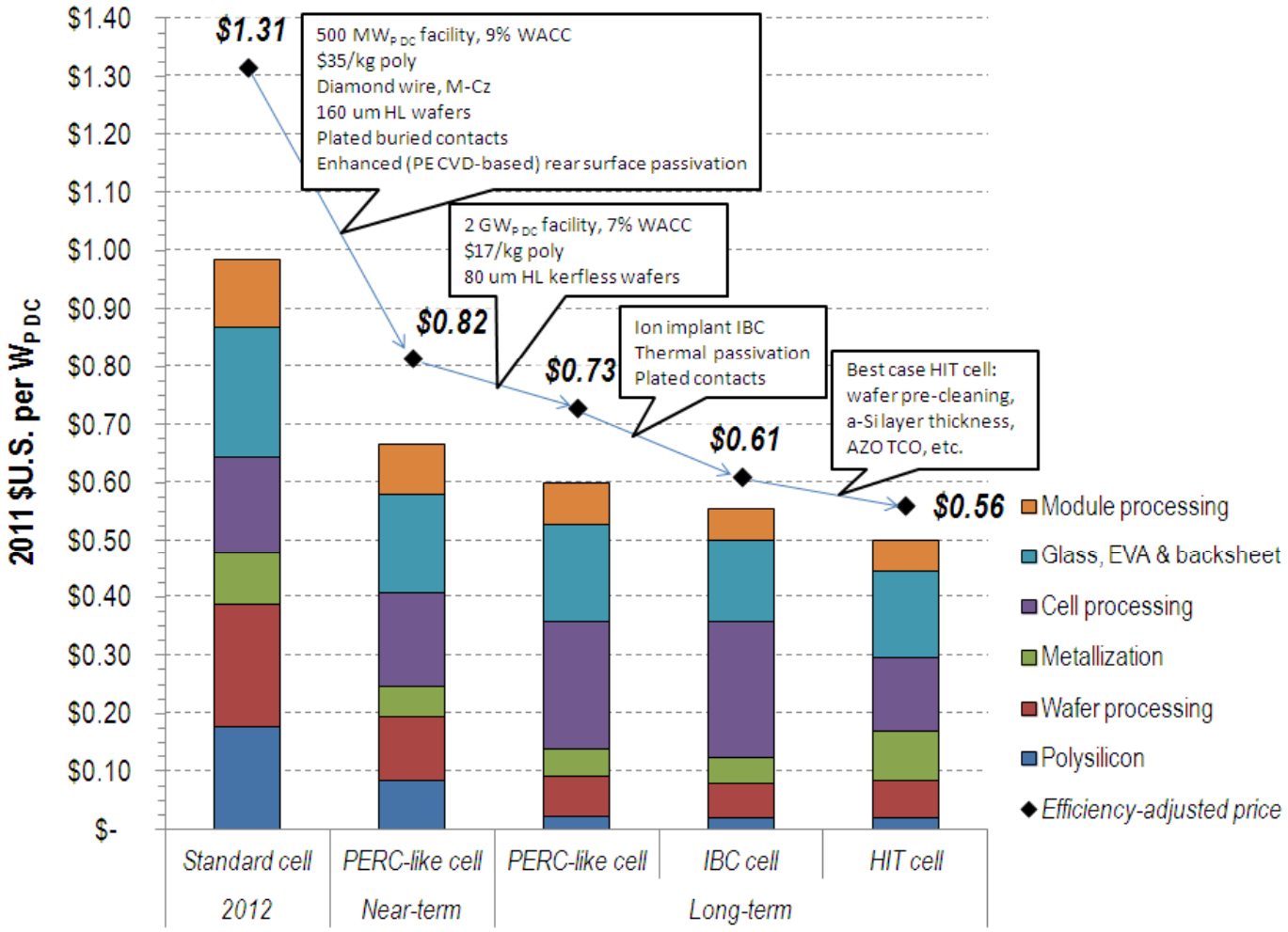
Efficiency Adjusted Module Prices (rel. to SunShot)



- **To achieve SunShot, 15% module may not exceed $47/m² (cost)**
  - **Based on ground mount system costs; efficiency penalty greater for rooftop systems**
  - **15% BoS penalty (rel. to 20% modules) = ~$40/m²**

Sources: NREL internal cost models.

U.S. Wafer Based c-Si PV Road Map



Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). "A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map:Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs." NREL (in preparation)

CdTe Technical Improvement Pathways

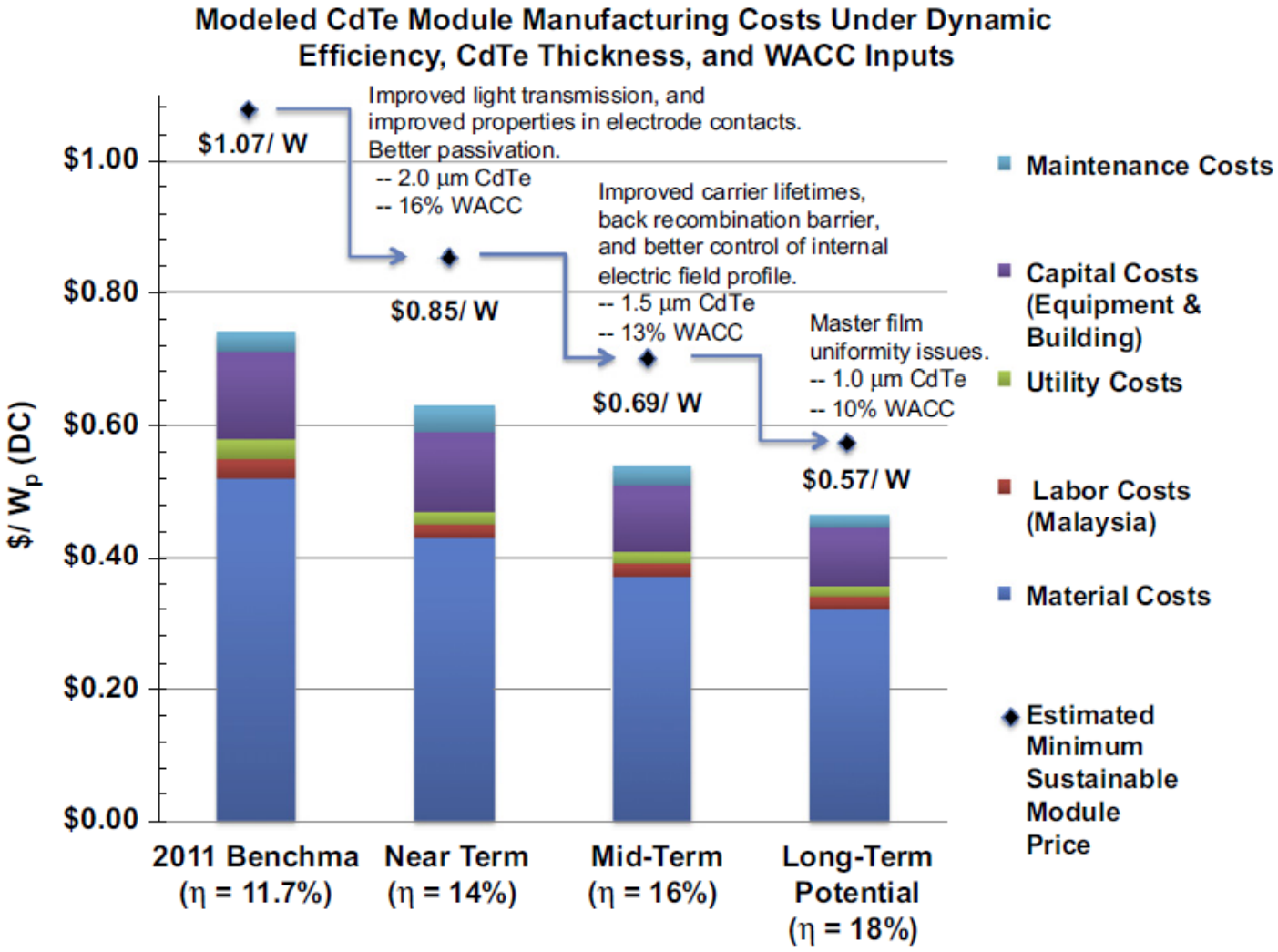
(Single-junction polycrystalline cells. 89% cell-to-module derate)

Cell Performance Parameters	Baseline (2011)	Near term	Midterm	Full potential
Short-Circuit Current Density: J_{SC} (mA/cm^2)	**23**	**24**	**25**	**26**
		Improved light transmission through the front glass: thinner glass; lower Fe content, Sb doping [52, 53]	Improve TCO transmission (reduce NIR absorption from free carriers) [52, 54-56]	Reduce window layer absorption: • Thin or replace CdS [57, 58] • Substrate architecture
Open-Circuit Voltage: V_{OC} (V/cell)	**0.80**	**0.90**	**1.0**	**1.0**
		Improve minority-carrier lifetimes in CdTe: grain size, crystallinity, grain boundary passivation [50]	• Reduce CdS/ CdTe junction recombination via doping [59] • Resistive Oxide TCO Buffer Layers [50, 53, 60]	•Improve film uniformity [57, 61, 62] •Electron back reflector [63, 64]
Fill Factor: FF (%)	**70**	**75**	**80**	**80**
		• Improve ohmic contact to back electrode assembly [64, 65] • Improve minority-carrier lifetimes in CdTe [50]	•Improve charge-carrier mobility in TCO[50, 53, 56, 66-68] • Resistive Oxide TCO Buffer Layers [50, 53, 60, 69]	•Improve film uniformity [57, 61, 62] •Electron back reflector [63, 64]
AM 1.5 Power Conversion Efficiency (%):	**13% Cells (11.7% modules)**	**16%**	**20%**	**21% cells (18% modules)**

Sources: Woodhouse, M.; Goodrich, A.; Margolis, R.; James, T.; Dhere, R.; Gessert, T.; Barnes, T.; Eggert, R.; Albin, D. (2012). "Perspectives on the Pathways for Cadmium Telluride Photovoltaic Module Manufacturers to Address Expected Increases in the Price for Tellurium." Solar Energy Materials & Solar Cells (in press).

Malaysia CdTe (on-glass) Module Prices

(Single-junction polycrystalline cells. 89% cell-to-module derate)



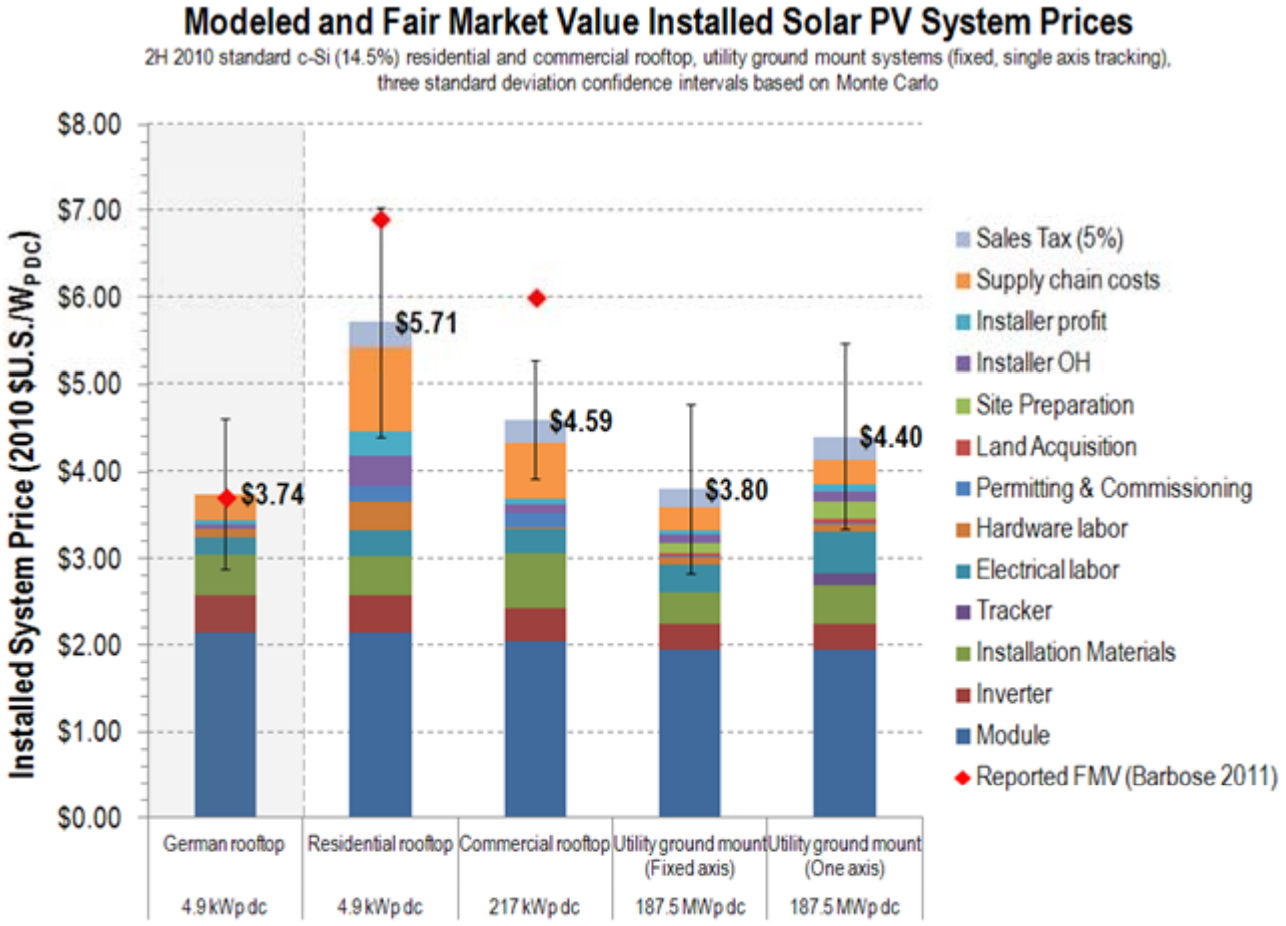
Sources: Woodhouse, M.; Goodrich, A.; Margolis, R.; James, T.; Dhere, R.; Gessert, T.; Barnes, T.; Eggert, R.; Albin, D. (2012). "Perspectives on the Pathways for Cadmium Telluride Photovoltaic Module Manufacturers to Address Expected Increases in the Price for Tellurium." Solar Energy Materials & Solar Cells (in press).

System Price Trends

Market Distortions

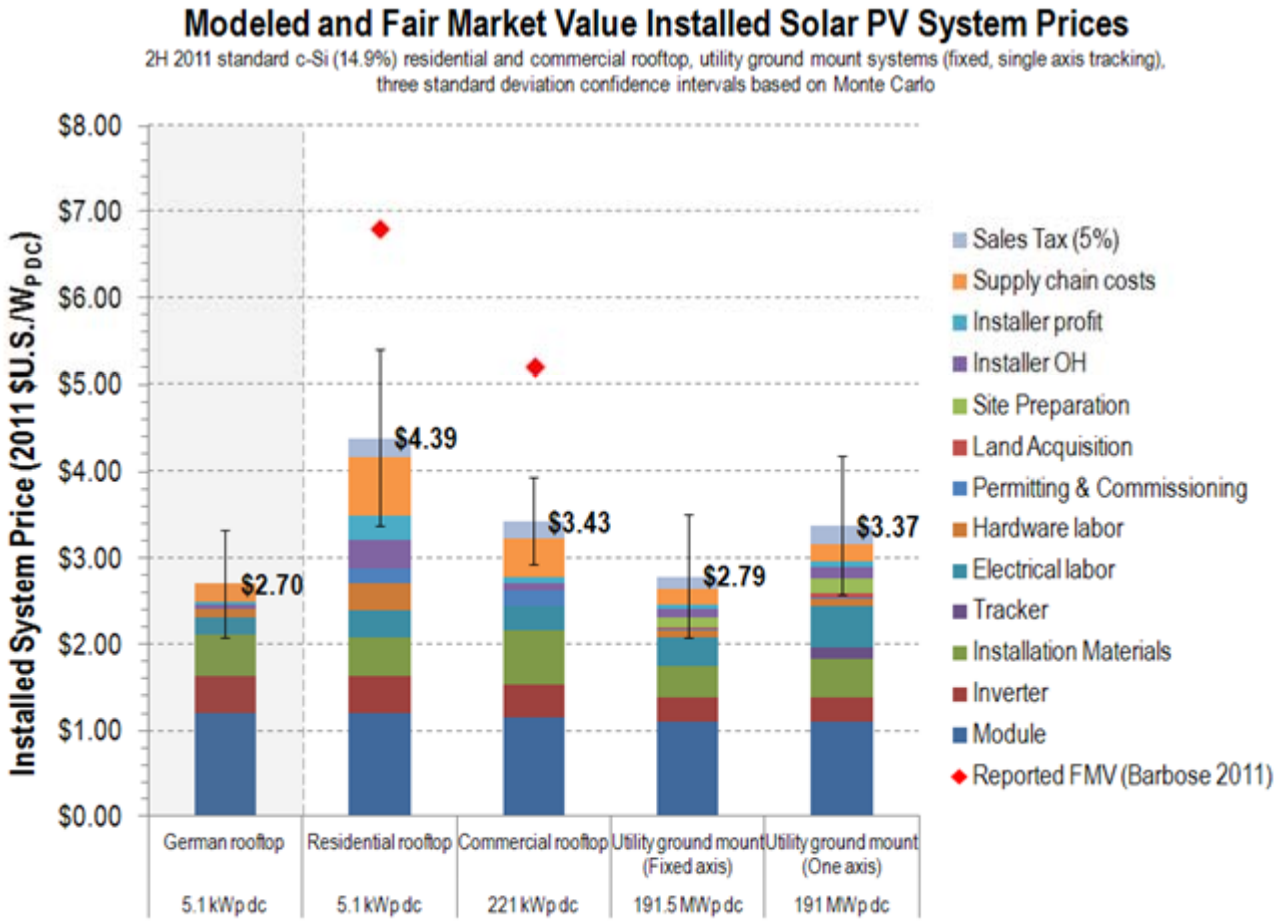
Regional Variations

2010 NREL-System Price Estimates



Sources: Goodrich, A.; James, T.; Woodhouse, M. "Residential, Commercial, and Utility Scale PV System Prices in the U.S.: Cost Reduction Opportunities" NREL Technical Report (in preparation), 2011 Partial year (2011) Fair Market Value (FMV) system prices:
Barbose, G.; Darghouth, N.; Wiser, R.; Seel, J. (2011). Tracking the Sun IV: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2010. Berkeley, CA: Lawrence Berkeley National Laboratory.

1H 2011 NREL-System Price Estimates



Sources: Goodrich, A.; James, T.; Woodhouse, M. "Residential, Commercial, and Utility Scale PV System Prices in the U.S.: Cost Reduction Opportunities" NREL Technical Report (in preparation), 2011 Partial year (2011) Fair Market Value (FMV) system prices:
Barbose, G.; Darghouth, N.; Wiser, R.; Seel, J. (2011). Tracking the Sun IV: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2010. Berkeley, CA: Lawrence Berkeley National Laboratory.

Status of the U.S. Solar Industry

Justin Baca
Senior Research Manger
Solar Energy Industries Association

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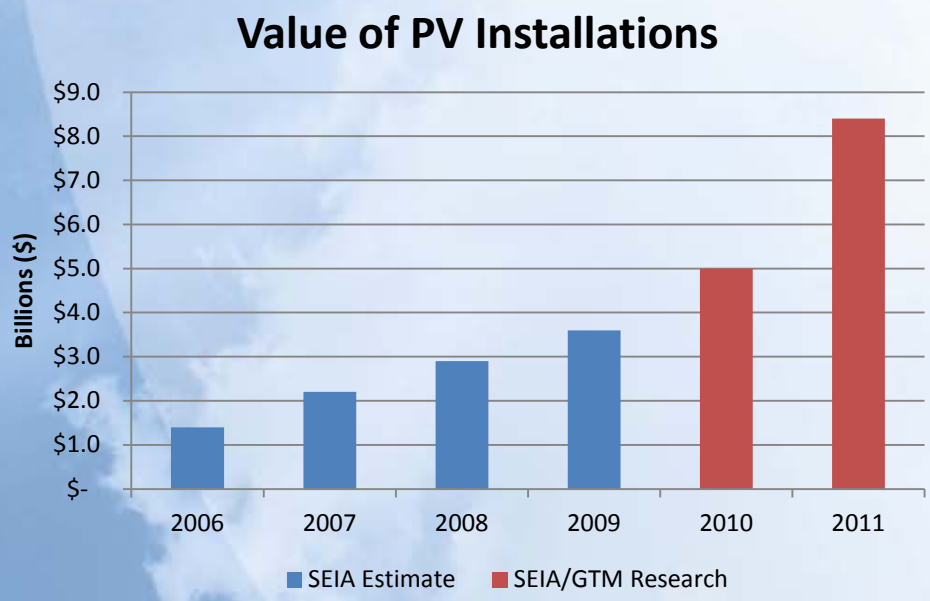
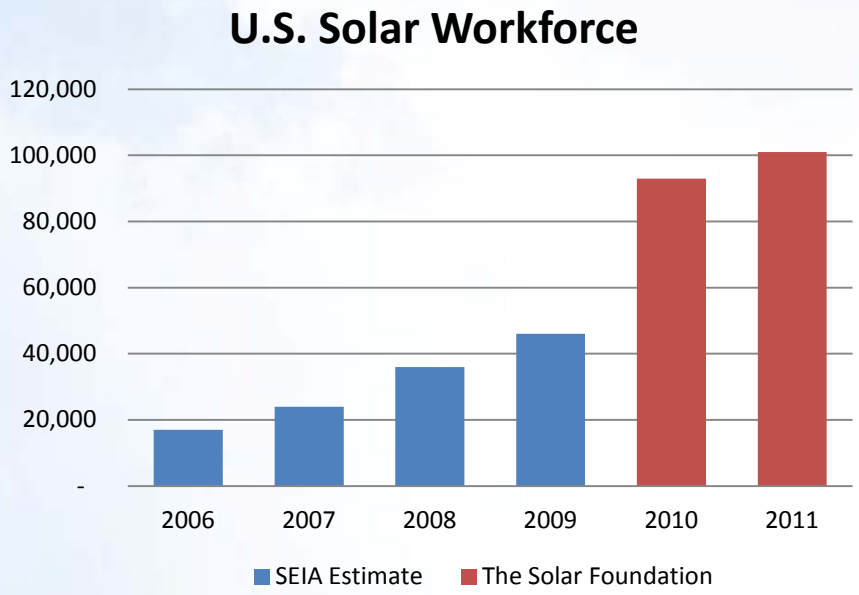
About SEIA

- Founded in 1974
- U.S. National Trade Association for Solar Energy
    - 1,000+ member companies from around the world
    - Members from across 50 states
    - Largest companies in the world as well as small installers
- Our Mission: Build a strong solar industry to power America
- Our Goal: 10 gigawatts (GW) of annual installed solar capacity in the U.S. by 2015

Industry Overview

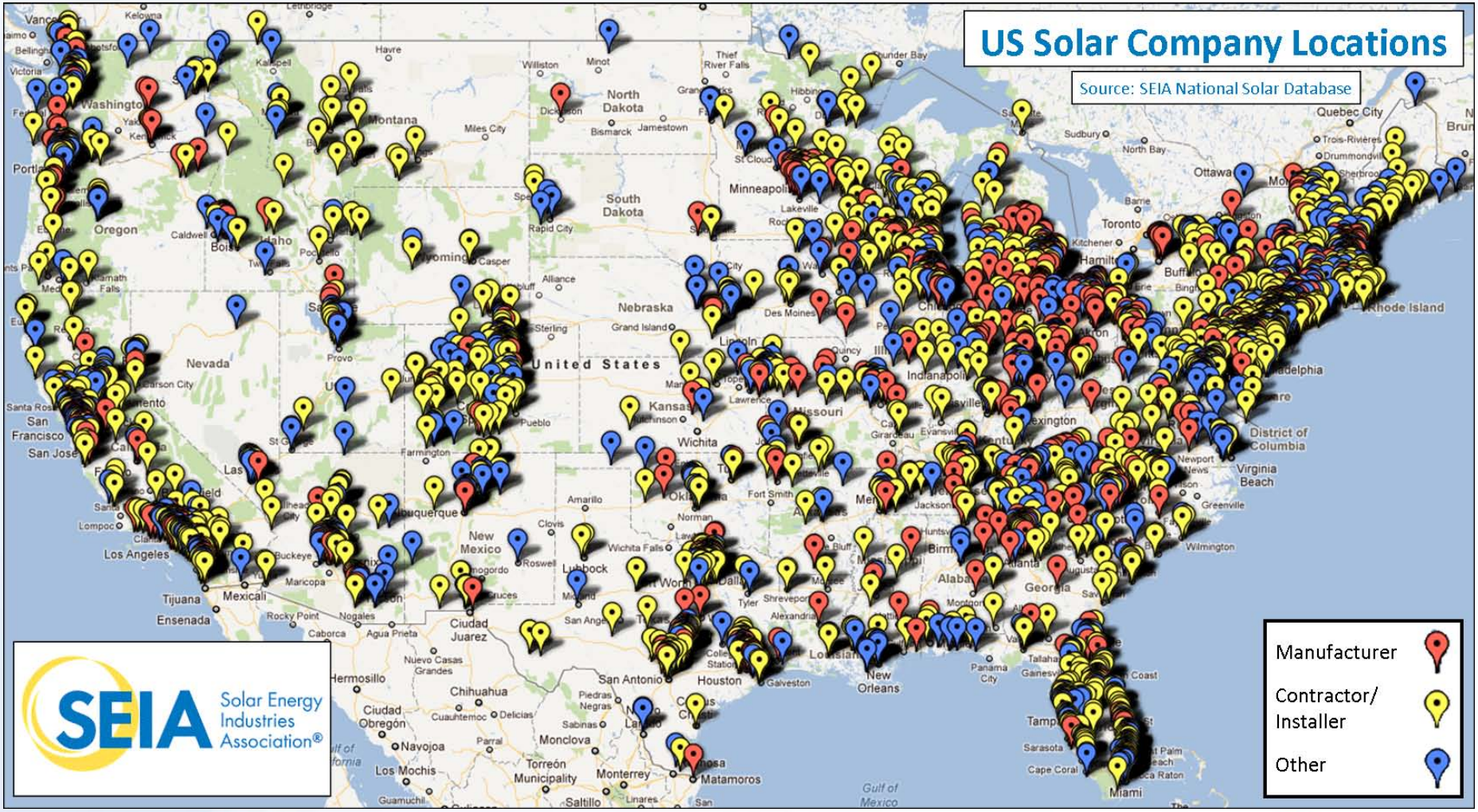
- The value of solar installations grew to $8.4 billion in 2011, up from $6 billion in 2010
- Solar employment more than doubled from 2009 to 2011, topping 100,000 American workers





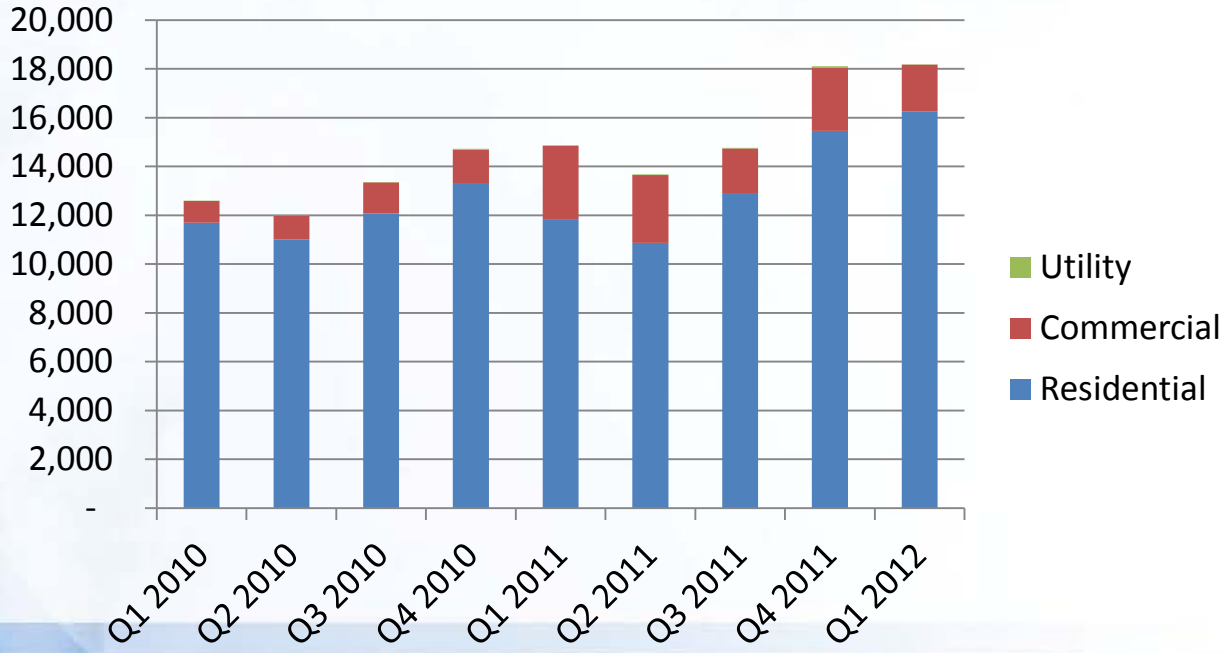
SEIA/GTM Research U.S. Solar Market Insight: Year In Review

U.S. Solar Business Locations



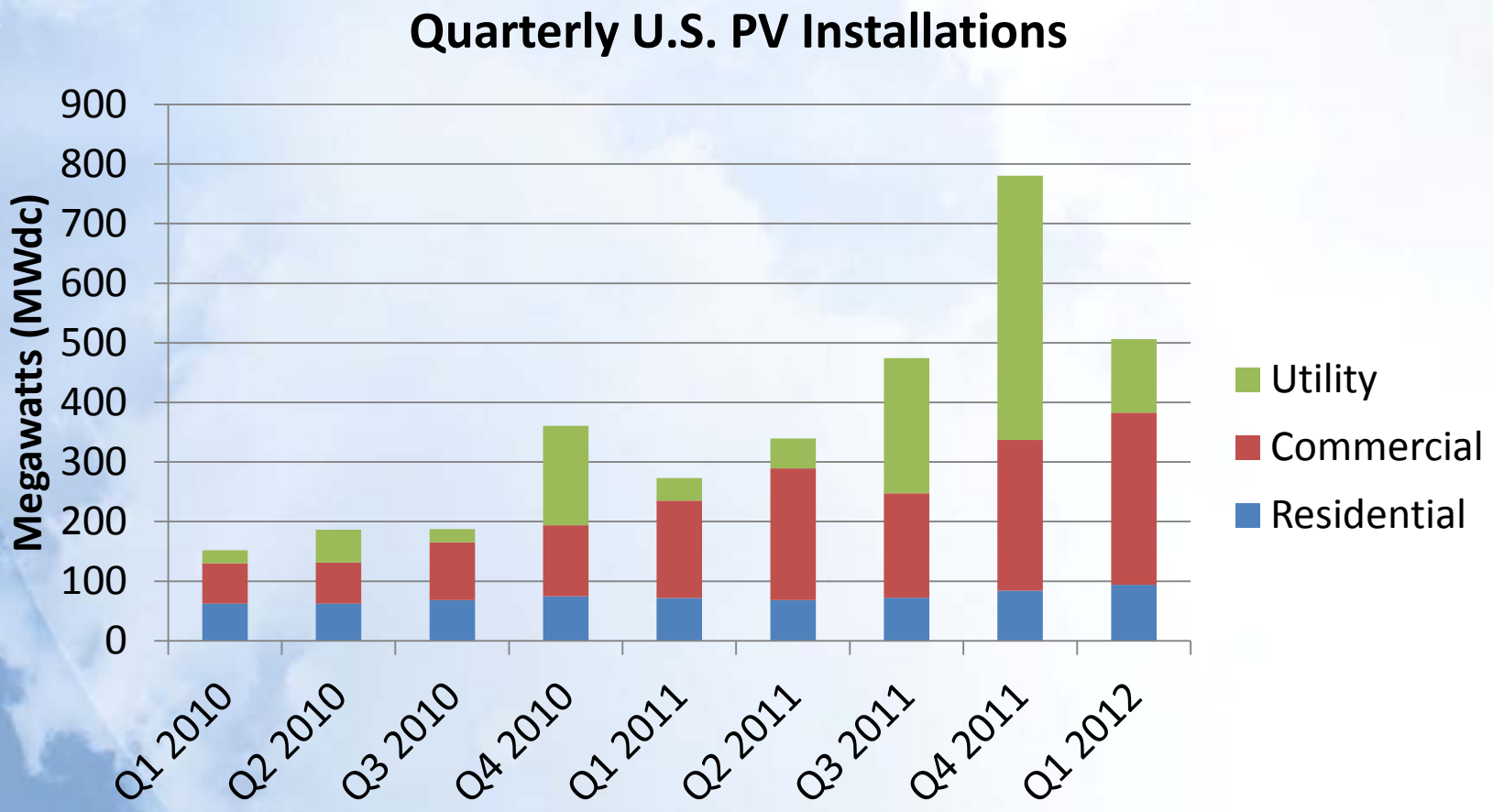
230,000 PV Systems in the U.S.

- 18,000 installed in Q1 alone
- Average system sizes slowly growing
  - Residential :5-6 kW
  - Commercial: ~80 kW
  - Utility: 5.7 MW

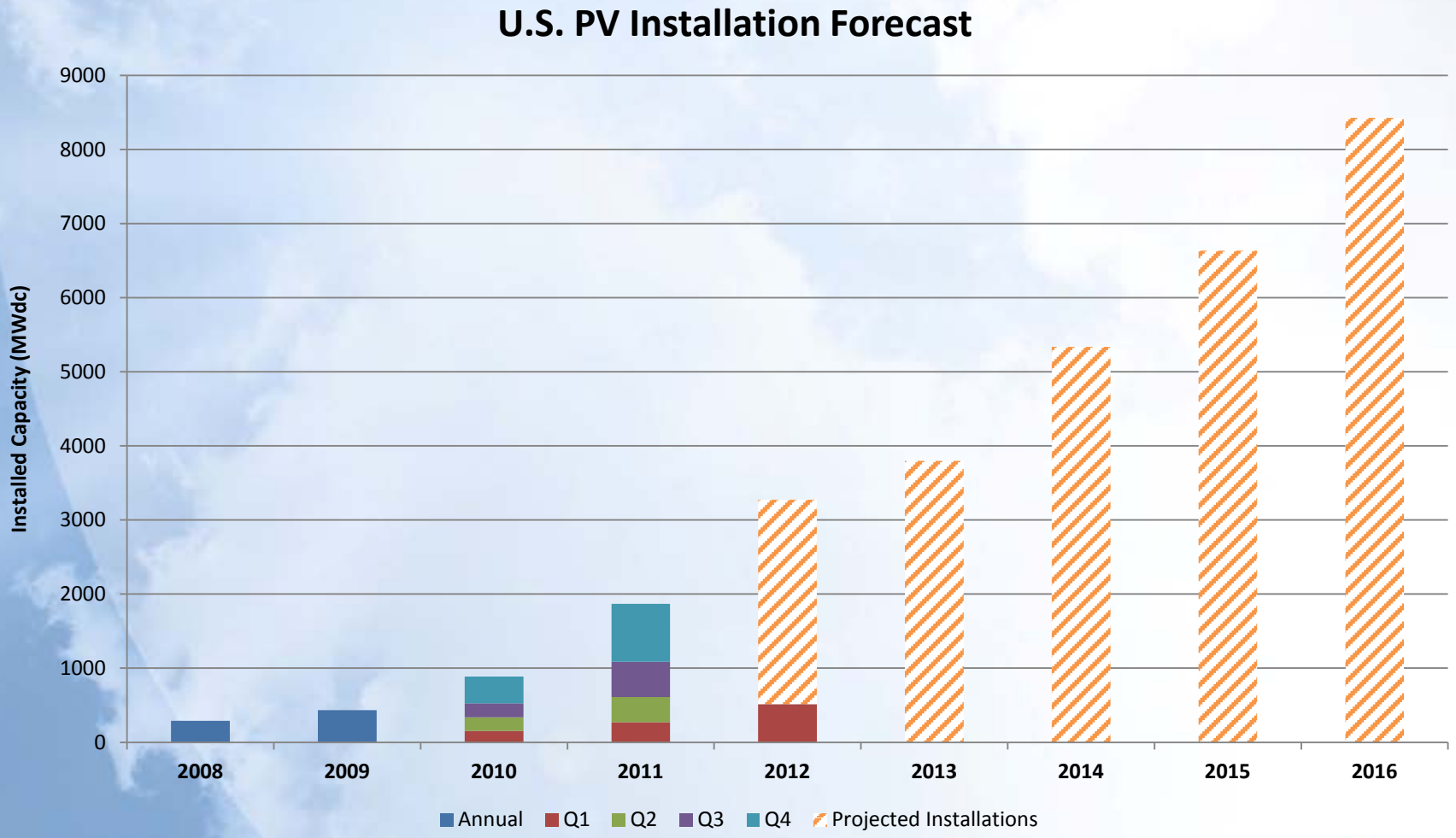


U.S. Solar Industry Continues Strong Growth

- PV demand grew 85% in Q1 2012 over Q1 2011

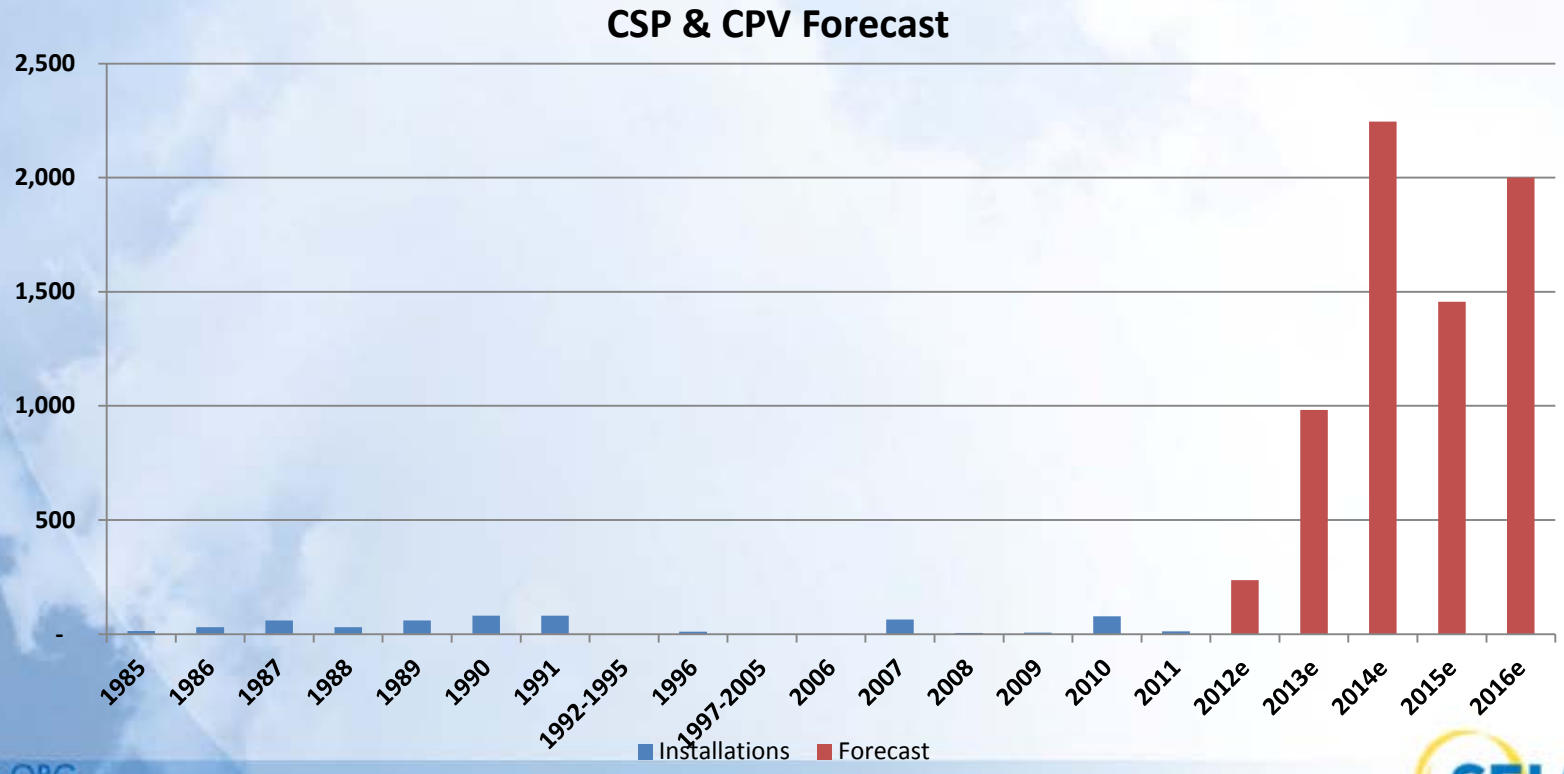


U.S. PV Demand Forecast to Grow 75% in 2012 to Nearly 3.3 GW



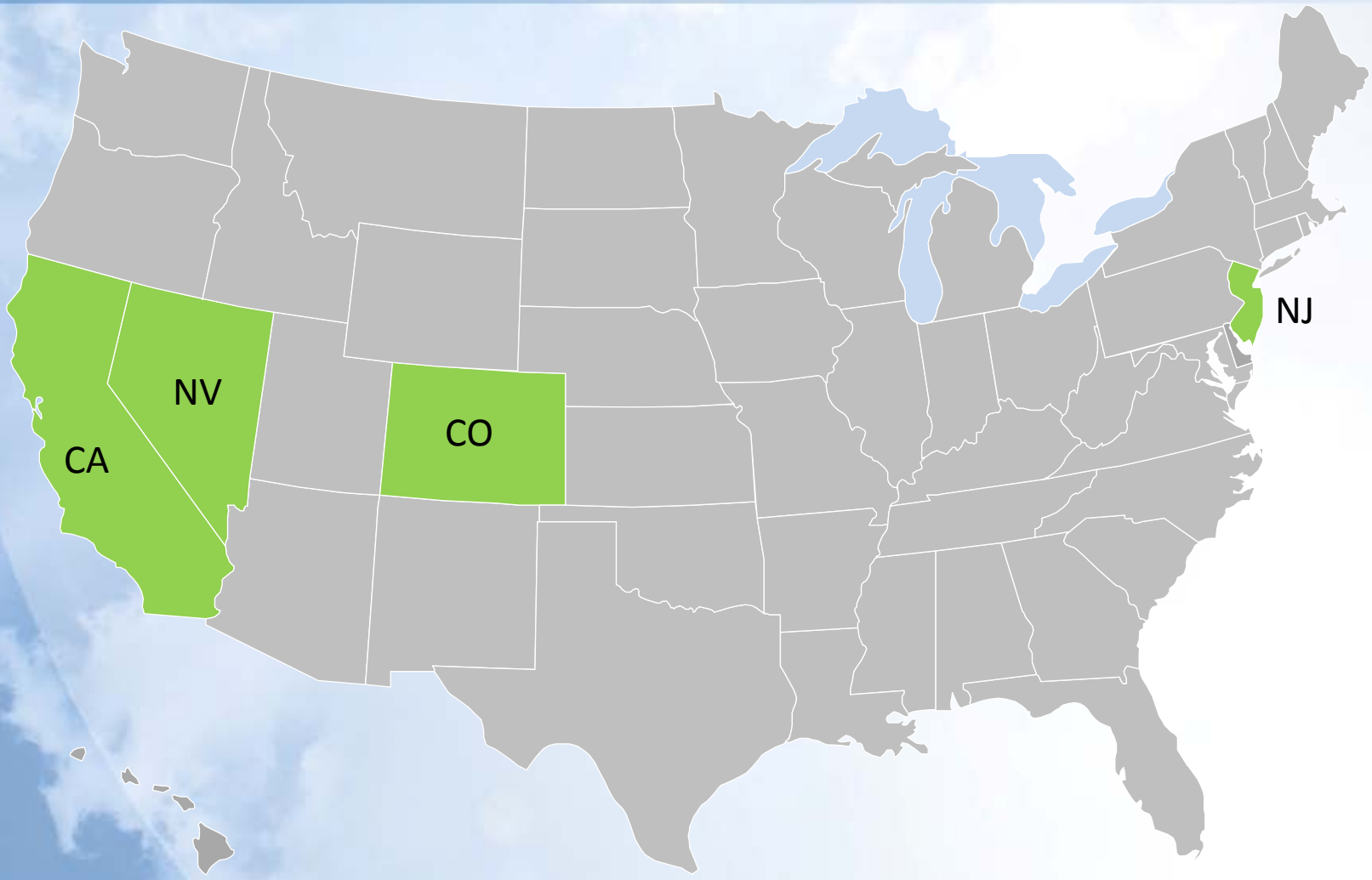
U.S. to Lead in CSP

- California, Arizona and Nevada are leading states for CSP
- The current CSP pipeline contains some 5,700 MW of projects with signed PPAs
- 1,300 MW under construction



Continued U.S. Market Diversity: Creating Opportunity

U.S. States With >10 MW of PV Installations, 2007



Source: SEIA/GTM Research: Solar Market Insight Q3 2011

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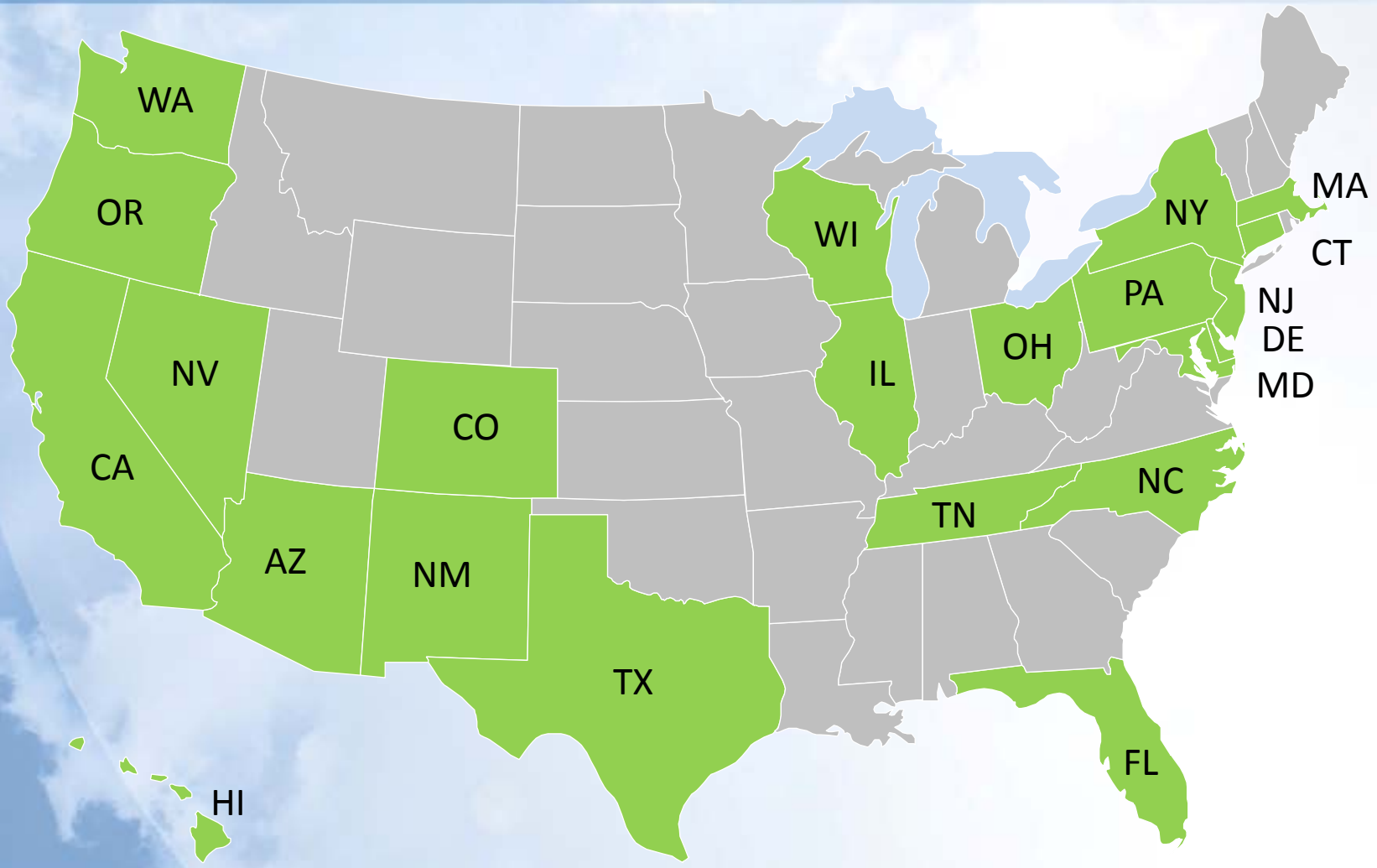
Continued U.S. Market Diversity: Creating Opportunity

U.S. States With >10 MW of PV Installations, 2011



Source: SEIA/GTM Research: Solar Market Insight, "2011 Year in Review"

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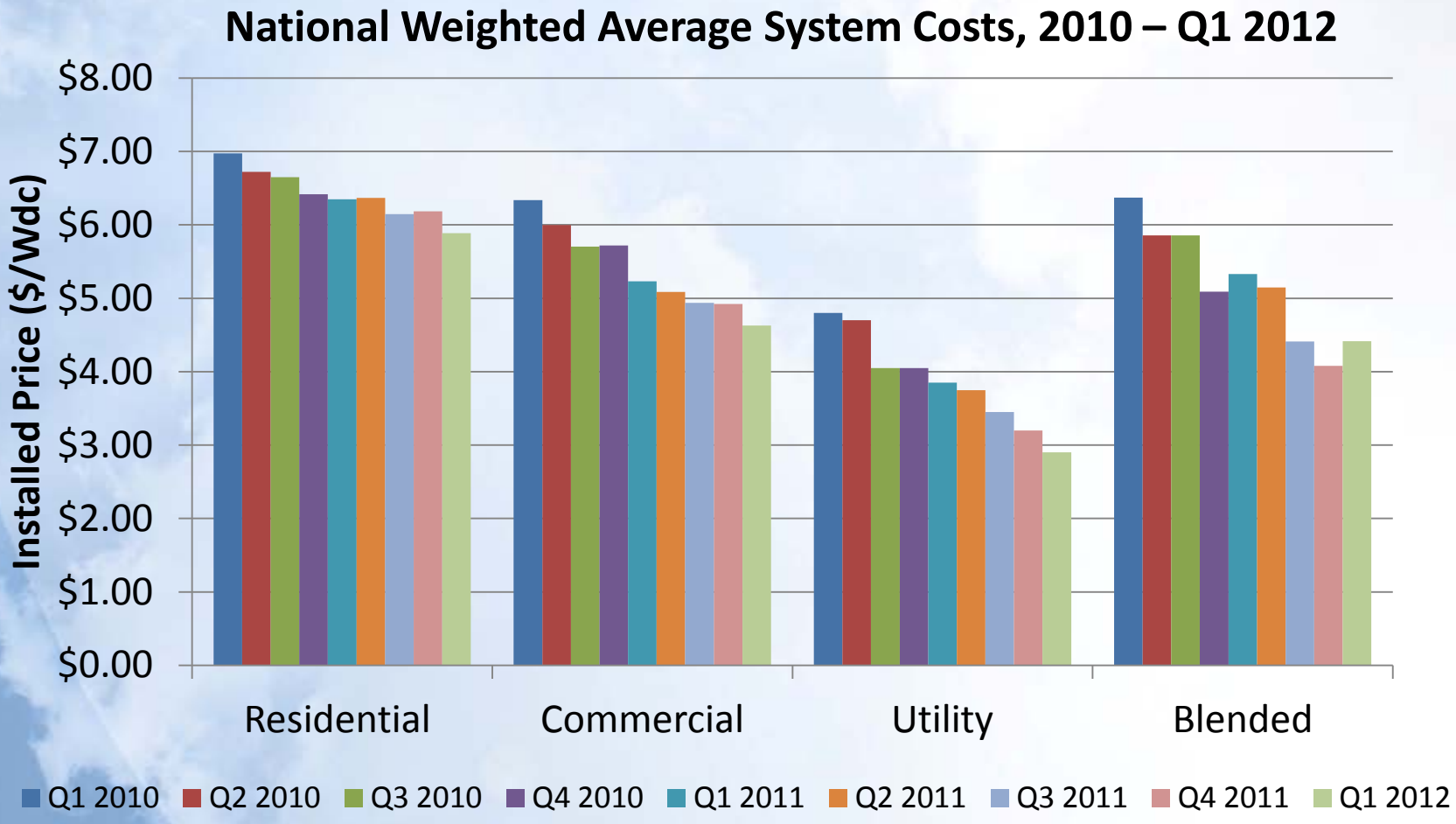
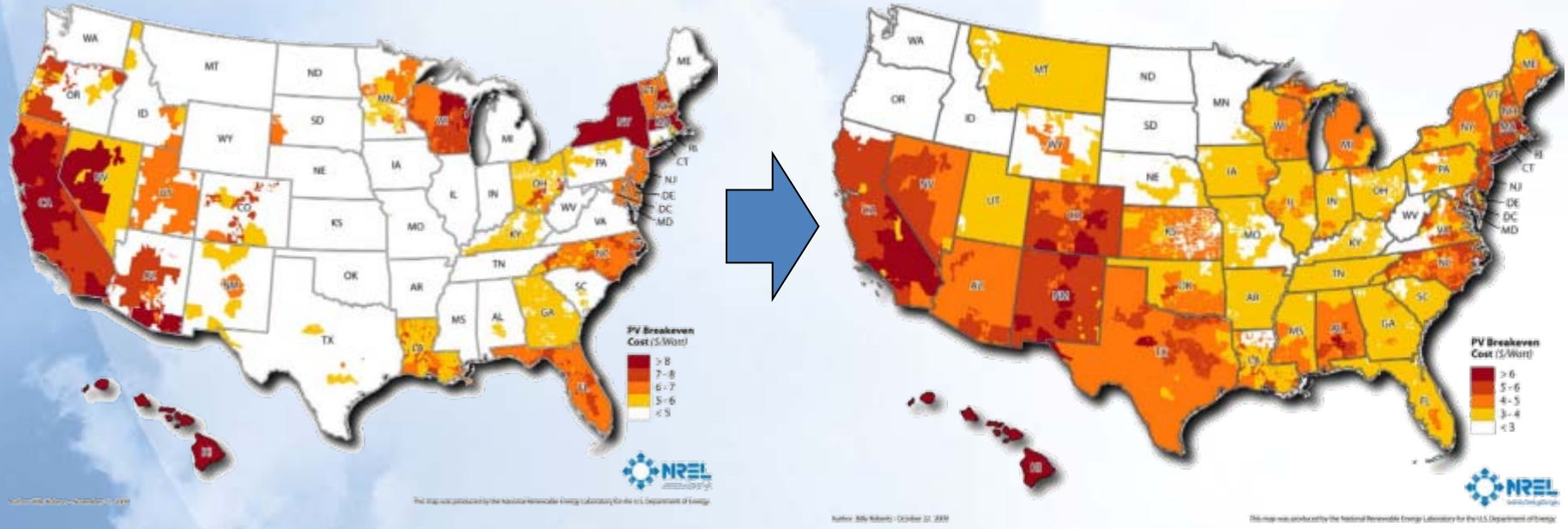
Solar Continues To Become More Affordable and More Competitive



More Markets Developing in Next 4 Years

Residential PV break-even installed price in **2008** assuming full retail net metering, state incentives and 30% ITC.

Residential PV break-even installed price in **2015** assuming full retail net metering and 30% ITC.



Source: Denholm, Margolis, Ong, Roberts "Break-Even Cost for Residential Photovoltaics in the United States: Key Drivers and Sensitivities" NREL 12/2009

Other Issues

- SolarWorld trade case against Chinese cell manufacturers
- Expiration of 1603 Treasury program at end of 2011 and tax equity supply
- Expiration of 30% Investment Tax Credit at the end of 2016
- Soft Costs

THANK YOU

Justin Baca

Senior Research Manager

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