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Central Station Solar: What’s the Future?

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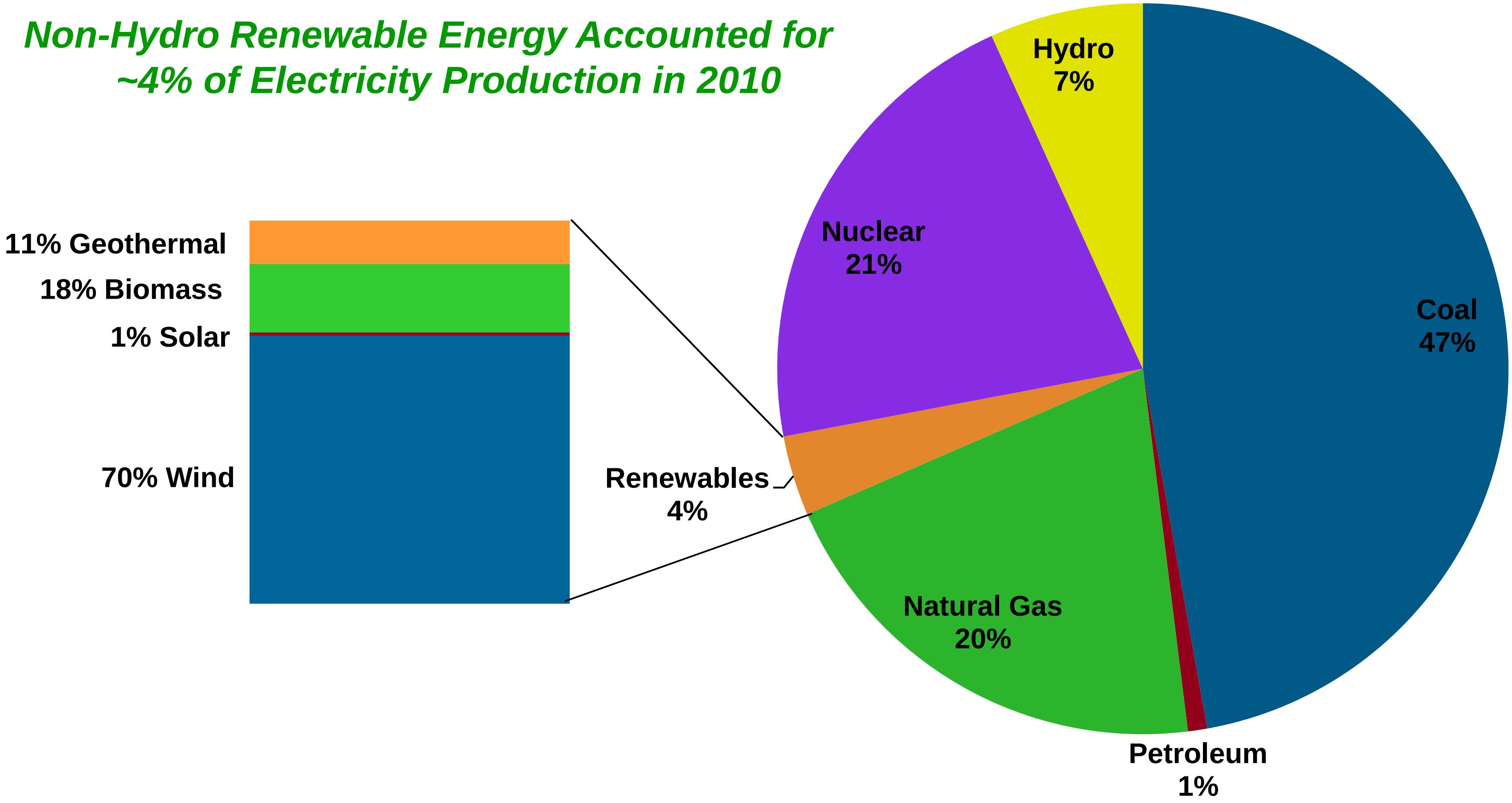
Outline

- Solar industry background and trends
- Central vs. distributed deployment
- Grid integration considerations
- Market outlook
- EPRI R&D focus

Source: BNL

U.S. Electricity Generation 2010

Non-Hydro Renewable Energy Accounted for ~4% of Electricity Production in 2010



Source: Energy Information Administration

Renewable Energy Generation 2010

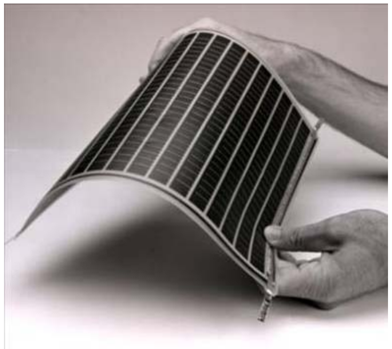
Technology	U.S. Growth Rate (World)	2010 U.S. Installed GW (World)
Wind	15% (25%)	40 (198)
Biomass Combustion	11% (7%)	10 (62)
Geothermal	0% (2%)	3.1 (11)
Solar PV	54% (74%)	2.5 (40)
Concentrating Solar Thermal	16% (83%)	0.5 (1.1)

- **2011 estimated U.S. PV deployment was 1.86 GW, a 74% increase (~70% world)**
- **Utility-driven growth increased ~185% from 2010 levels**

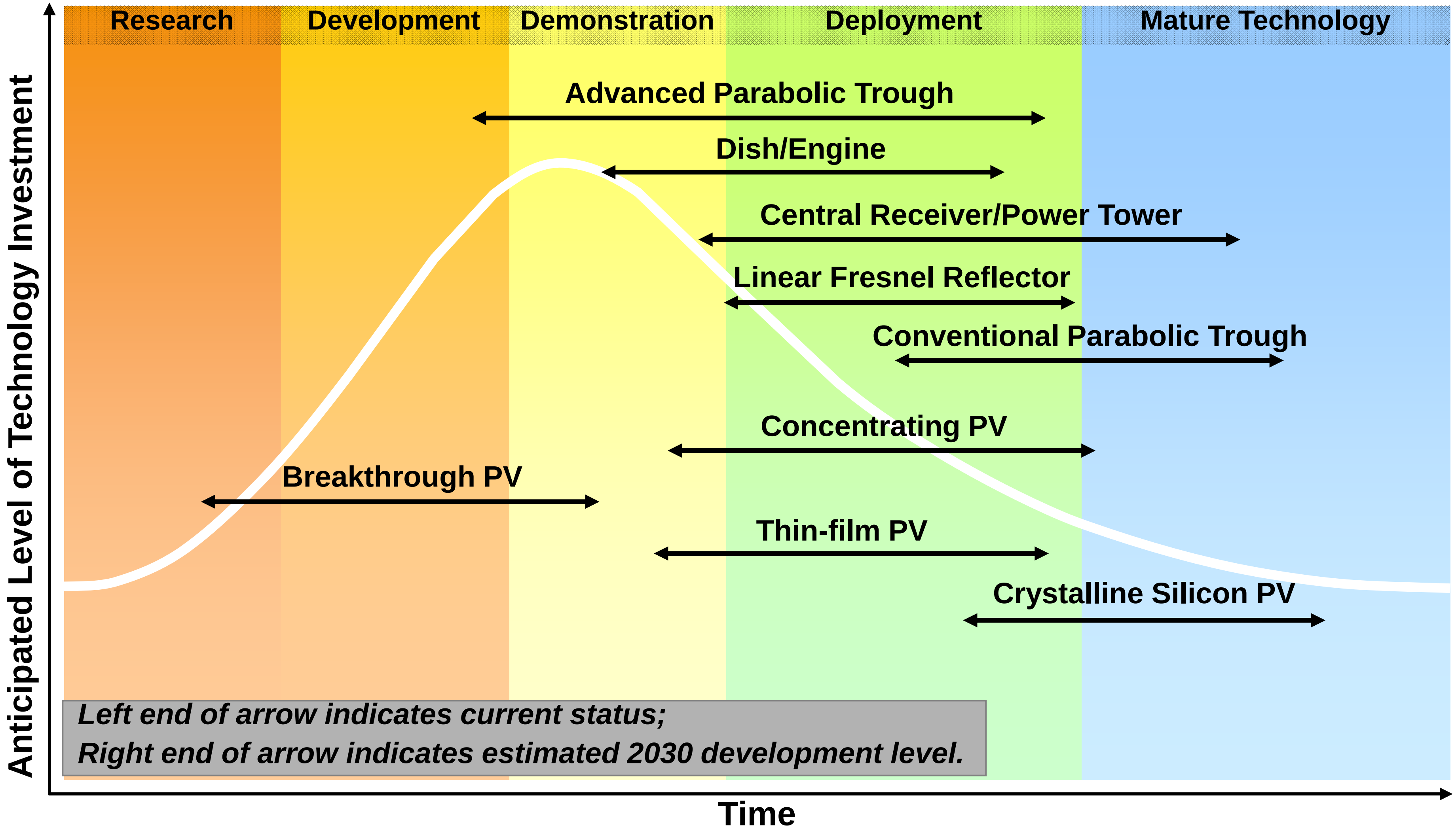
Source: Renewables 2011 Global Status Report, GTM, SEIA

PV Technology Overview

- Status
  - Crystalline silicon – commercial
  - Thin film – early commercial
  - CPV – early commercial
- Approximately 70 GW deployed worldwide
  - Largest central station plant: 214 MW in India
  - 20 projects of >50 MW each in operation worldwide
- Key attributes
  - Modular
  - Run-of-sun generation (no storage)
  - Large ramp rates possible



Technology Development Assessment
Solar Photovoltaic (PV) and Solar Thermal



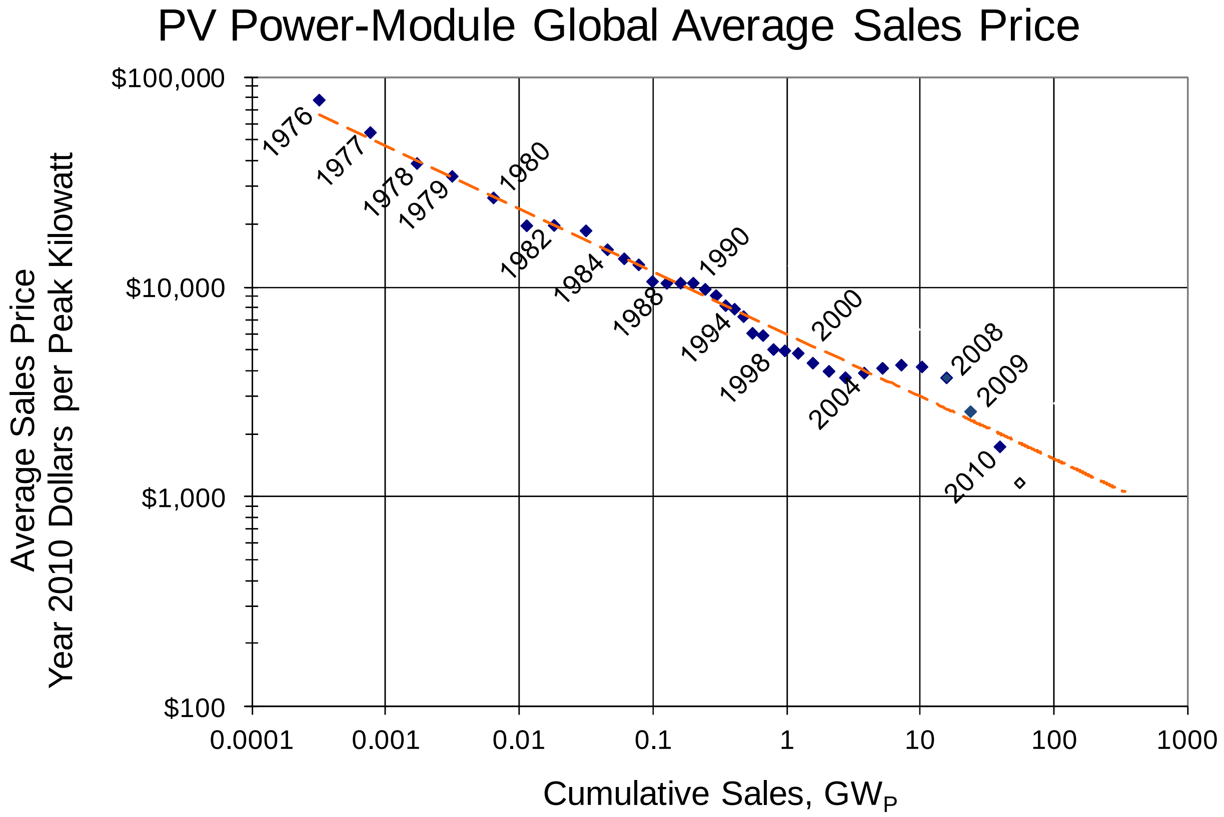
Left end of arrow indicates current status;
Right end of arrow indicates estimated 2030 development level.

What is the Future of PV Technology?

- Gen I (crystalline silicon) and Gen II (thin film) single-junction devices have max efficiencies of ~31%, limited by the Shockley-Queisser Limit
  - 41% efficiency feasible under concentration.
  - Incremental efficiency and cost improvements will continue
- Gen-III technologies side-step the S-Q efficiency limitations by utilizing more of the incident energy
  - Multijunction devices available today have achieved >40% in the field; only economical for CPV systems
  - Breakthrough devices can theoretically approach 68% (87% under max concentration) through use of novel materials (organic materials, carbon nanotubes, etc.) and manufacturing techniques

Whether or not breakthrough PV can realize those efficiencies, *when, and at what cost* remains to be seen.

PV Module Price Trends



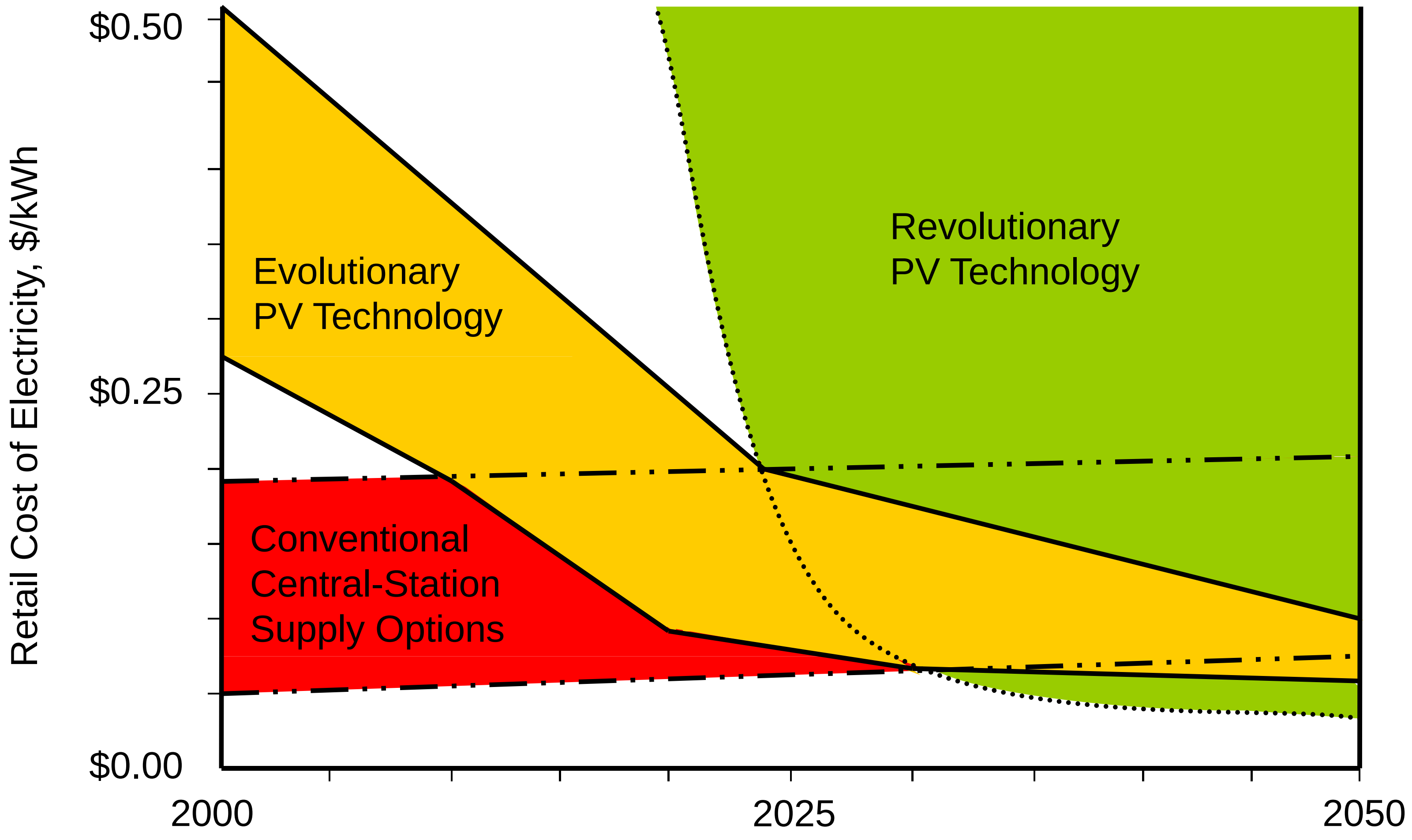
PV Power-Module Global Average Sales Price

ASP data source: P. Mints, Navigant Consulting PV Service Practice

T.M. Peterson, Solar Power Consulting, 10/31/11

- The chart, on logarithmic scale, illustrates how the average module price has declined by about 20% with each doubling of sales over several decades.
- Average selling price for modules dropped ~46% in 2011; installed costs dropped 20%

PV Cost Outlook



Comparison of Solar Technologies

Technology	Worldwide Market Share*	Capacity Factor	Install Cost ($/kW)	Projected Near-Term Global Growth
Flat-plate PV - Silicon-based	87% (~58 GW)	Up to 27%	~$3,200 [a]	20 GW+/year
Flat-plate PV - Thin Film	11% (~7 GW)	Up to 27%^	~$3,000 [b]	3.5 GW+/year
CPV	<0.01% (~33 MW)	Up to 31%	$3,600+[c]	~60 MW to be completed by mid-2012, ~700 MW in pipeline; outlook variable
Concentrating Solar Thermal Power (CSP)**	2% (2 GW)	Up to 28% (wo/storage); >70% (w/storage)	$4,100+ (wo/storage); $5,000+ (w/storage)	2.8 GW under construction; 12 GW pipeline (outlook variable)

* As of end-2011.

** Based on solar trough and central receiver technologies, does not include Stirling dish or linear Fresnel reflector.

[a] Based on the national weighted-average of installed utility system prices in the U.S. at end-2011.

[b] Based on average reported First Solar install costs

[c] Based on vendor-provided data

[†] Depends on whether storage is used; land use with 9 hrs storage is ~10.5 acres/MW.

^ Thin-film fixed solar PV (20 MW+)

Sources: EPRI, SEPA, NREL, CPV Consortium, GreenTech Media, McKinsey & Co., EPIA

Central vs. Distributed

Ground-Mounted vs. Rooftop PV

Central Station – Ground Mounted

- Pros
  - Lower upfront capital cost
  - Flexibility of location
  - Greater design flexibility, e.g., tracker vs. fixed
  - Lower power output variability
- Cons
  - Typically higher O&M costs
  - May require new/upgraded transmission
  - Potential environmental impacts
  - Potentially more difficult to finance

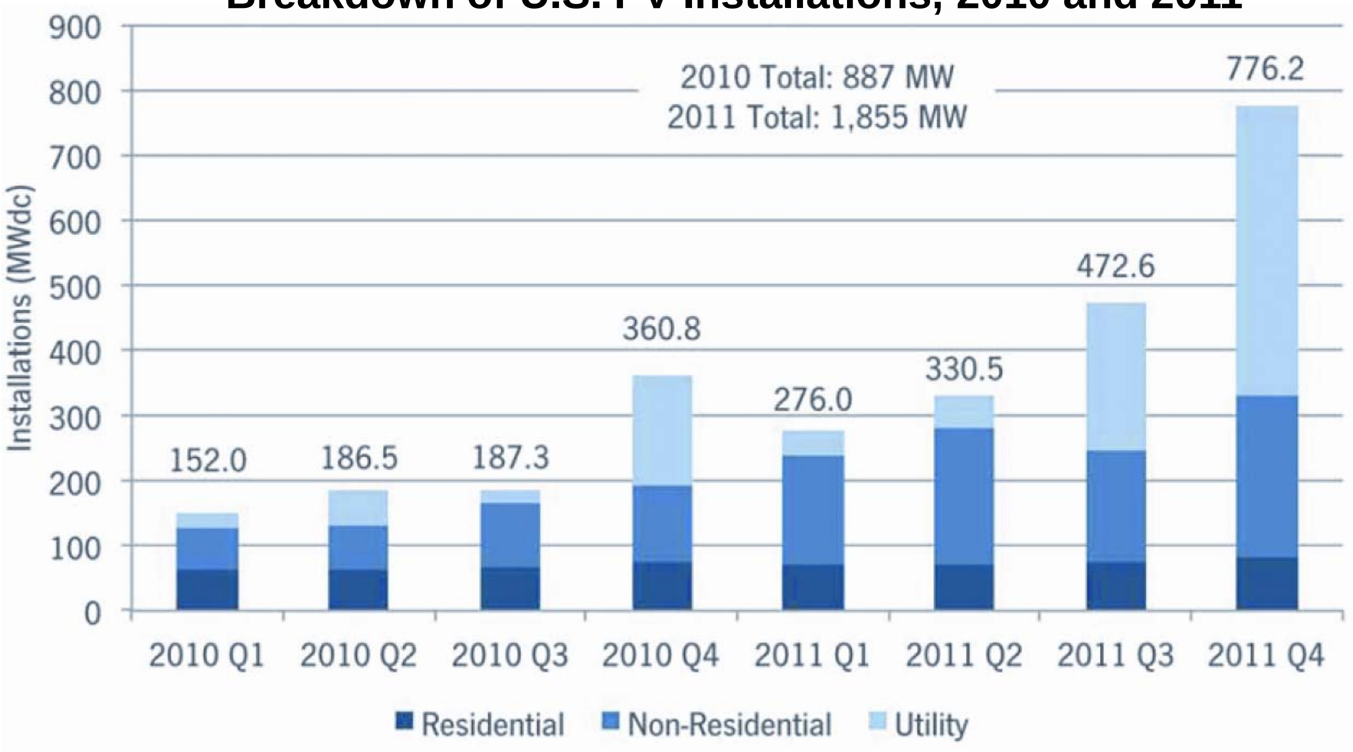
Distributed – Rooftop

- Pros
  - Generation closer to load
  - Environmentally friendly
- Cons
  - Labor, transaction, and implementation costs are higher
  - Customized designs drive up cost
  - Requires relatively new roof with sufficient structural integrity
  - Potentially limited usable space
  - Potential for shading issues
  - Requires willing owner
  - Intermittency

PV's modularity is applicable to both central and distributed plants and allows rapid deployment. Large plants are often brought online in phases.

Go Big or Go Home

Breakdown of U.S. PV Installations, 2010 and 2011



- Utility-owned projects represented 39% of new deployment in 2011 and central station projects are expected to dominant the future market
- In early 2012 utility activity includes >9 GW under contract, >3 GW under construction, and ~32 GW pipeline

Source: GTM Research and SEIA

Recent U.S. Utility-Scale PV Projects

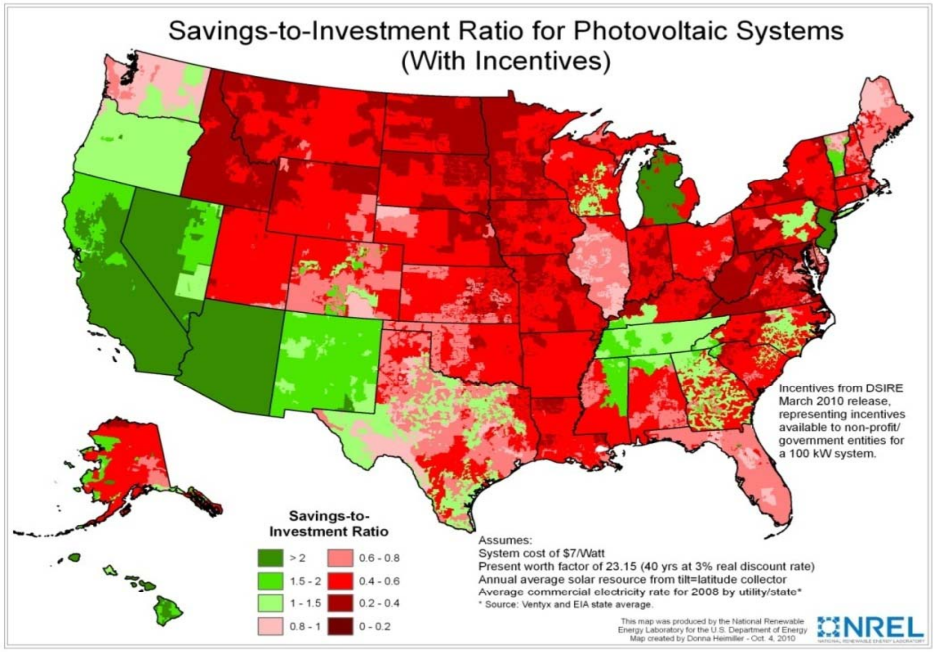
28 utility-scale PV projects (>10 MW) were placed in service in 2011

Plant Name	Capacity (MW$_{DC}$)	Location	Technology	Op. Date	Constr. Start
PV - Placed in Service					
Mesquite Solar 1	42	Arlington, AZ	Multi c-Si	**Dec-11**	Jun-11
Agua Caliente	38	Yuma County, AZ	CdTe	**Jan-12**	Aug-11
San Luis Valley Solar Ranch	38	Alamosa County, CO	Mono c-Si	**Nov-11**	Dec-10
Long Island Solar Farm LLC	37	Upton, NY	Multi c-Si	**Nov-11**	Oct-10
FRV Webberville Plant	34	Webberville, TX	Multi c-Si	**Dec-11**	Apr-11
Paloma Solar Plant	21	Gila Bend, AZ	CdTe	**Oct-11**	Mar-11
Cotton Center Solar Plant	21	Gila Bend, AZ	Mono c-Si	**Oct-11**	Jan-11
Bagdad Solar Project	19	Bagdad, AZ		**Dec-11**	Aug-11
McGraw Hill	14	East Windsor, NJ	Multi PV	**Jan-12**	Aug-11
APS - Prescott	13	Prescott, AZ	Multi c-Si	**Nov-11**	Dec-10
SPS - Lea	11	Lea, NM	Multi c-Si	**Dec-11**	Dec-10
SPS - Monument	11	Lea, NM	Multi c-Si	**Dec-11**	Dec-10
Hartz Solar Hamilton	9	Hamilton, NJ	Multi c-Si	**Dec-11**	Jun-11
Alamogordo Solar Energy Ctr	7	Deming, NM	CdTe	**Oct-11**	Jan-11
Las Vegas Solar Energy Ctr	7	Las Vegas, NM	CdTe	**Nov-11**	Jan-11
Stanton Solar Farm	6	Orange County, FL		**Dec-11**	Apr-11
Sky Harbor Airport	5	Phoenix, AZ	Mono c-Si	**Dec-11**	Oct-11
Arizona Western College	5	Yuma, AZ	Mixed	**Dec-11**	May-11
PV - Beginning Construction					
First Solar, Inc. (Topaz)	688	San Luis Obispo County, CA	CdTe		**Nov-11**
Copper Mountain 2	188	Boulder City, NV	CdTe		**Dec-11**
Imperial Energy Center S.	163	Imperial County, CA	CdTe		**Jan-12**
Matinee Energy	120	Benson, AZ			**Dec-11**
Recurrent -SMUD	50	Sacramento, CA			**Oct-11**
Sorrento Solar Farm	50	Lake County, FL	Mono c-Si		**Nov-11**
McHenry Solar Farm	31	Modesto, CA	Mono c-Si		**Dec-11**
Cupertino - Huron	25	Huron, CA	Multi c-Si		**Oct-11**
Grand Ridge Solar Plant	23	LaSalle County, Il	CdTe		**Dec-11**
Tinton Falls Solar Farm	20	Tinton Falls, NJ			**Nov-11**
Utech Solar Plant	20	New Jersey	Multi c-Si		**Feb-12**
NAWS China Lake	14	China Lake, CA	Mono c-Si		**Jan-12**
LADWP Solar Project	12	Los Angeles, CA	Multi PV		**Dec-11**
UA Tech / Astrosol	6	Tucson, AZ	a-SI		**Dec-11**
Lawrenceville School	6	Lawrence Township, NJ			**Oct-11**
Canton Solar Farm	6	Canton, MA	Mono c-Si		**Dec-11**
Princeton University	5	Princeton, NJ	Mono c-Si		**Oct-11**

Source: NREL

Distributed PV Markets

Savings-to-Investment Ratio for $7/W PV before *Incentives*



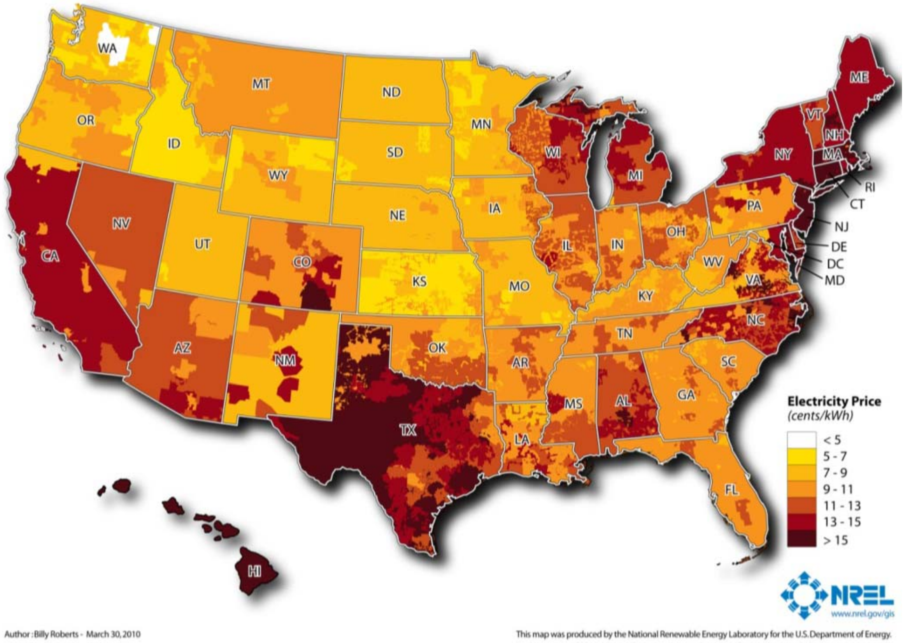
Savings-to-Investment Ratio for Photovoltaic Systems (With Incentives)

Incentives from DSIRE March 2010 release, representing incentives available to non-profit/ government entities for a 100 kW system.

Assumes:
System cost of $7/Watt
Present worth factor of 23.15 (40 yrs at 3% real discount rate)
Annual average solar resource from tilt=latitude collector
Average commercial electricity rate for 2008 by utility/state*
* Source: Ventyx and EIA state average.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy
Map created by Donna Heimiller - Oct. 4, 2010

Residential Retail Electricity Rates



Author: Billy Roberts - March 30, 2010

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

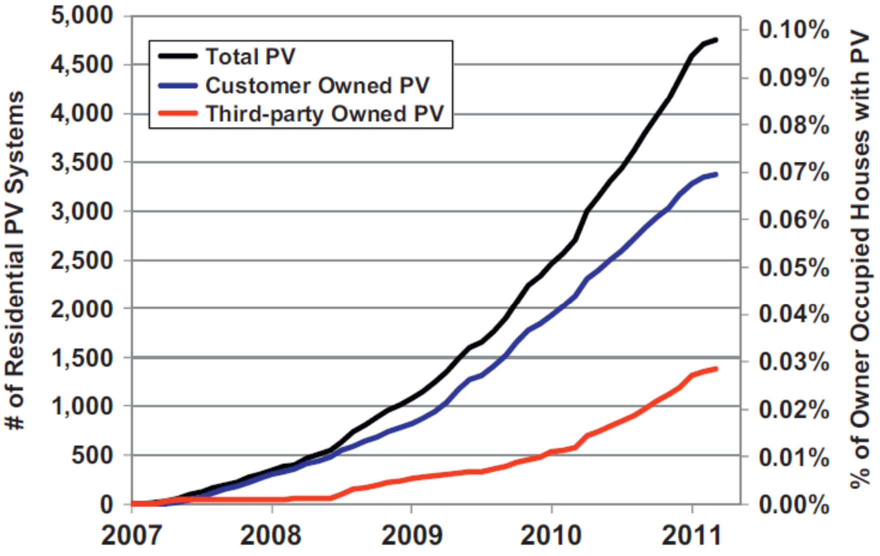
- With incentives, DG PV can represent a profitable investment in several states
- Unclear what economic thresholds are required to entice adoption and what barriers to customer adoption may exist after ‘breakeven’ is reached

Source: Denholm et al. 2010 (NREL)

Distributed PV Ownership Also Growing

Third-party owned PV gaining market share in LA and Orange counties, CA

- Distributed PV economics depend on incentives, retail rates and rate design, e.g., net metering
- Third party residential PV markets growing rapidly, > 60% market share in CA in 2012
- PV leasing products appear to be enticing new demographics to adopt PV in LA
- Third-party adoption trends likely to extend to other states



CA Market only

Source: Drury et al. 2012 (NREL)

Cost as a Function of System Size

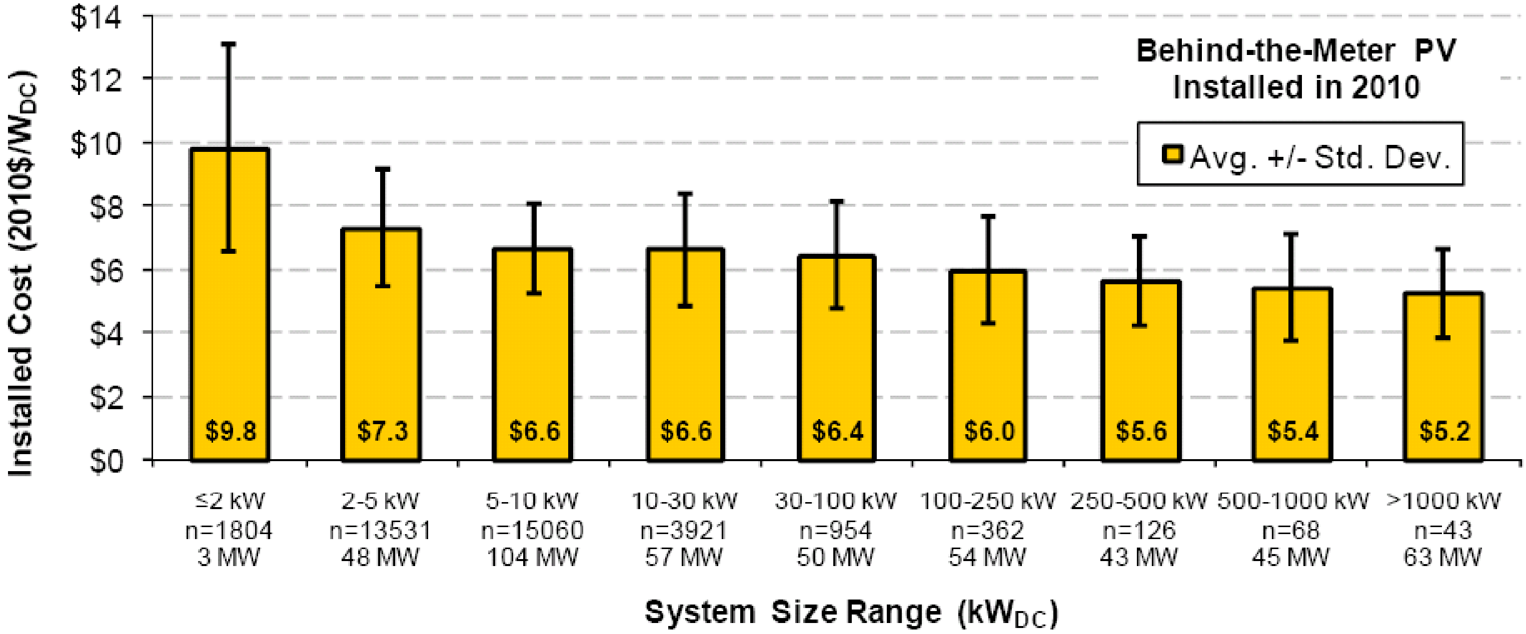
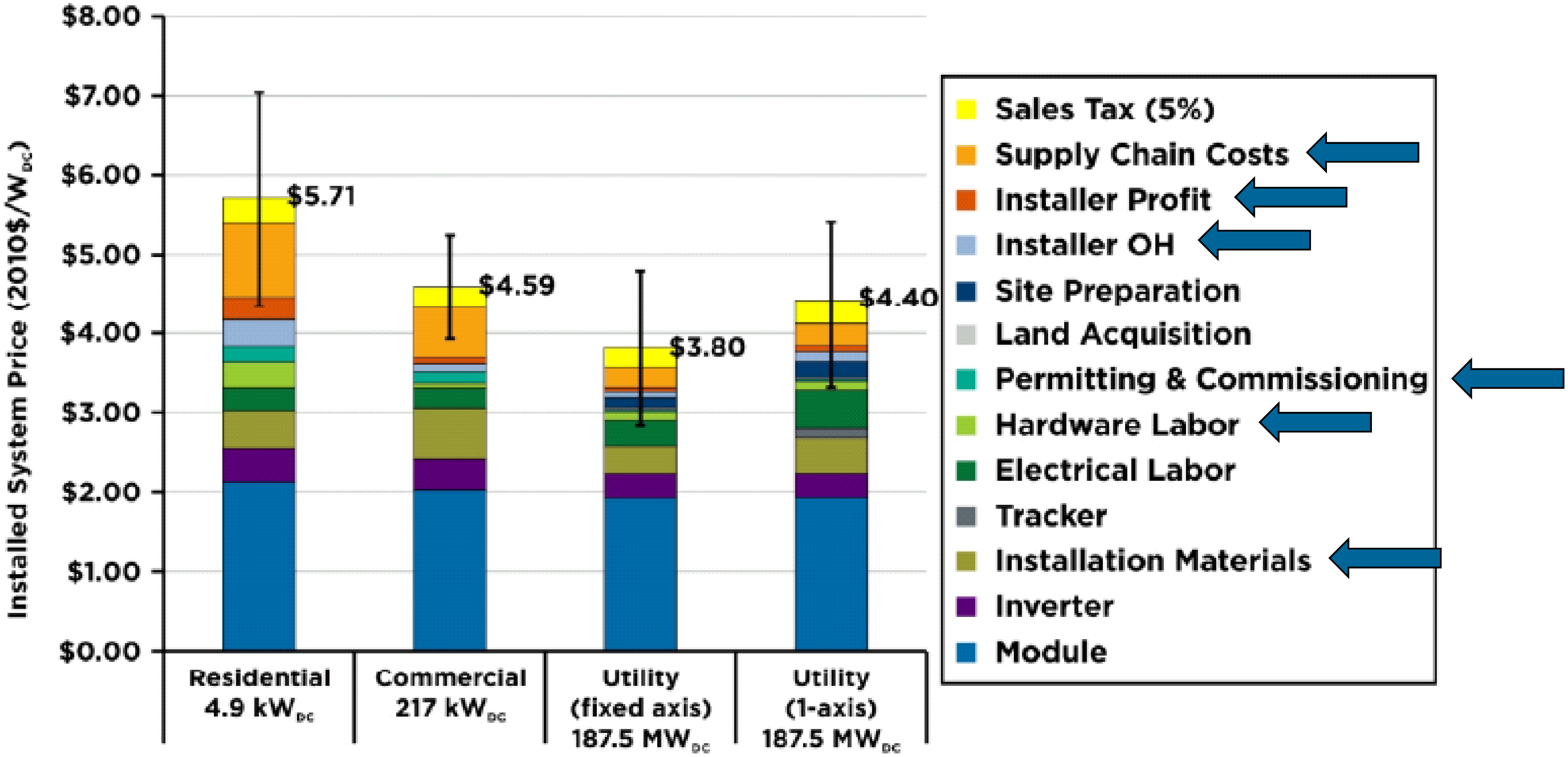


Figure 11. Variation in Installed Cost of Behind-the-Meter PV According to System Size (All Sizes)

Source: LBNL

- Systems with trackers have higher upfront costs, but may achieve lower LCOE
- Larger projects benefit from volume purchases and the ability to spread fixed project costs and transaction costs over more electricity generation
- 10-250 kW systems may have higher costs due to lower levels of standardization, but larger plant sizes experience economies of scale

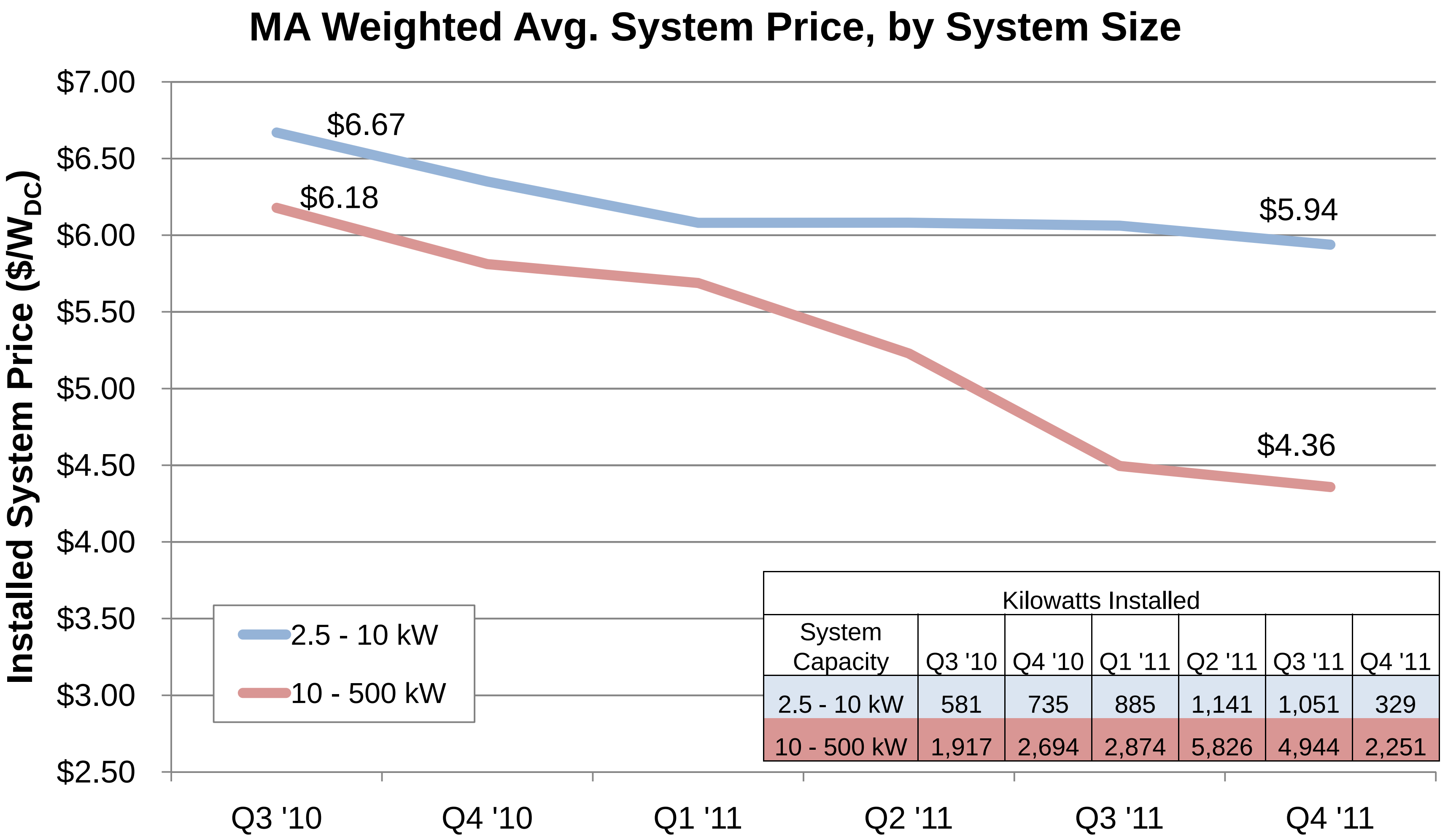
System Costs as a Function of Project Size



- **Utility scale plants have lowest costs, but this has an effect on margins**
- **Residential scale systems have value-efficient panels and high margins**

Source: Goodrich et al. 2012 (NREL)

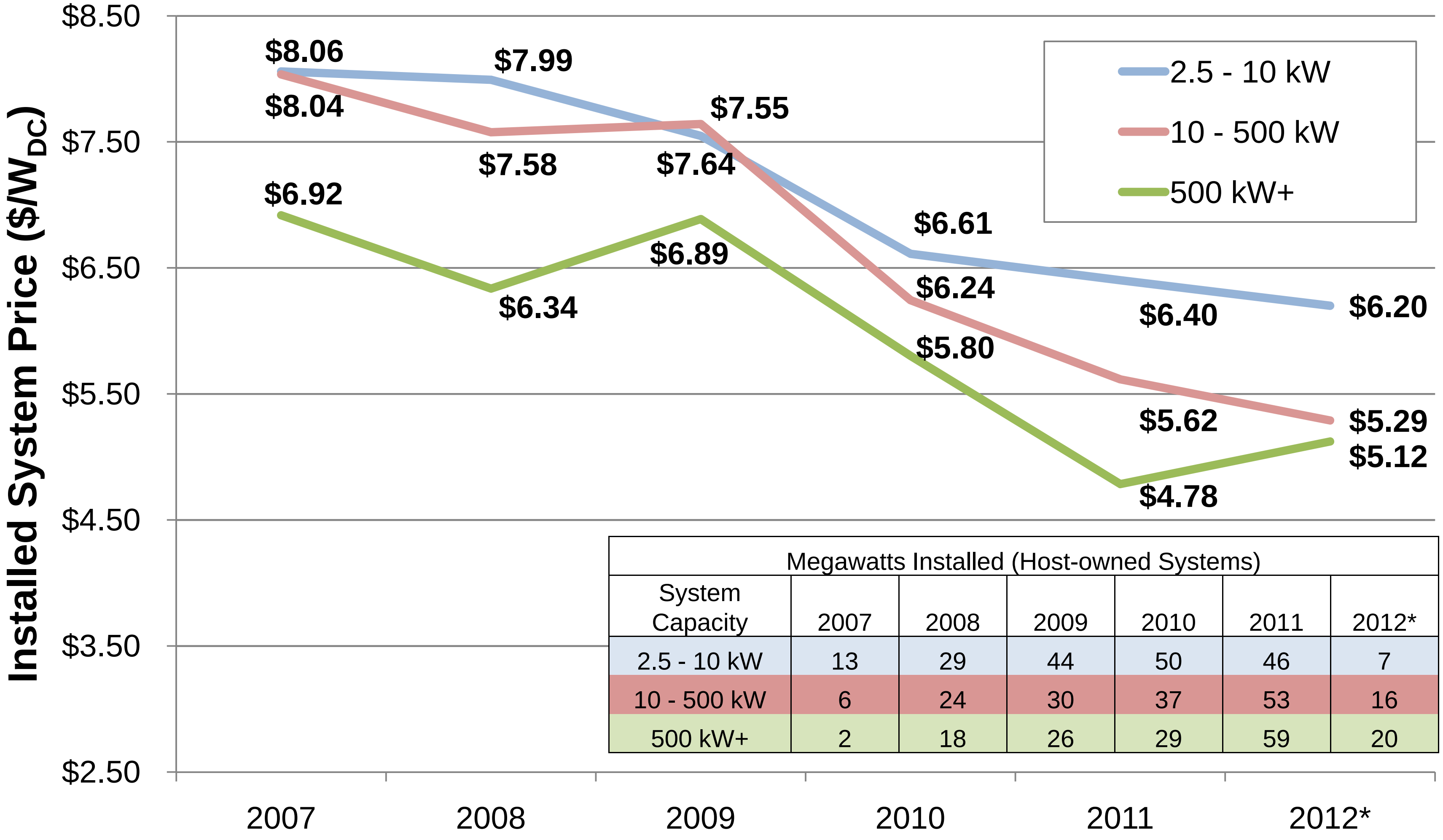
Massachusetts Pricing Trends


MA Weighted Avg. System Price, by System Size

	Kilowatts Installed					
System Capacity	Q3 '10	Q4 '10	Q1 '11	Q2 '11	Q3 '11	Q4 '11
2.5 - 10 kW	581	735	885	1,141	1,051	329
10 - 500 kW	1,917	2,694	2,874	5,826	4,944	2,251

Source: Massachusetts Solar Carve-Out Program (accessed 03/09/12), as reported by NREL

California Pricing Trends



Megawatts Installed (Host-owned Systems)

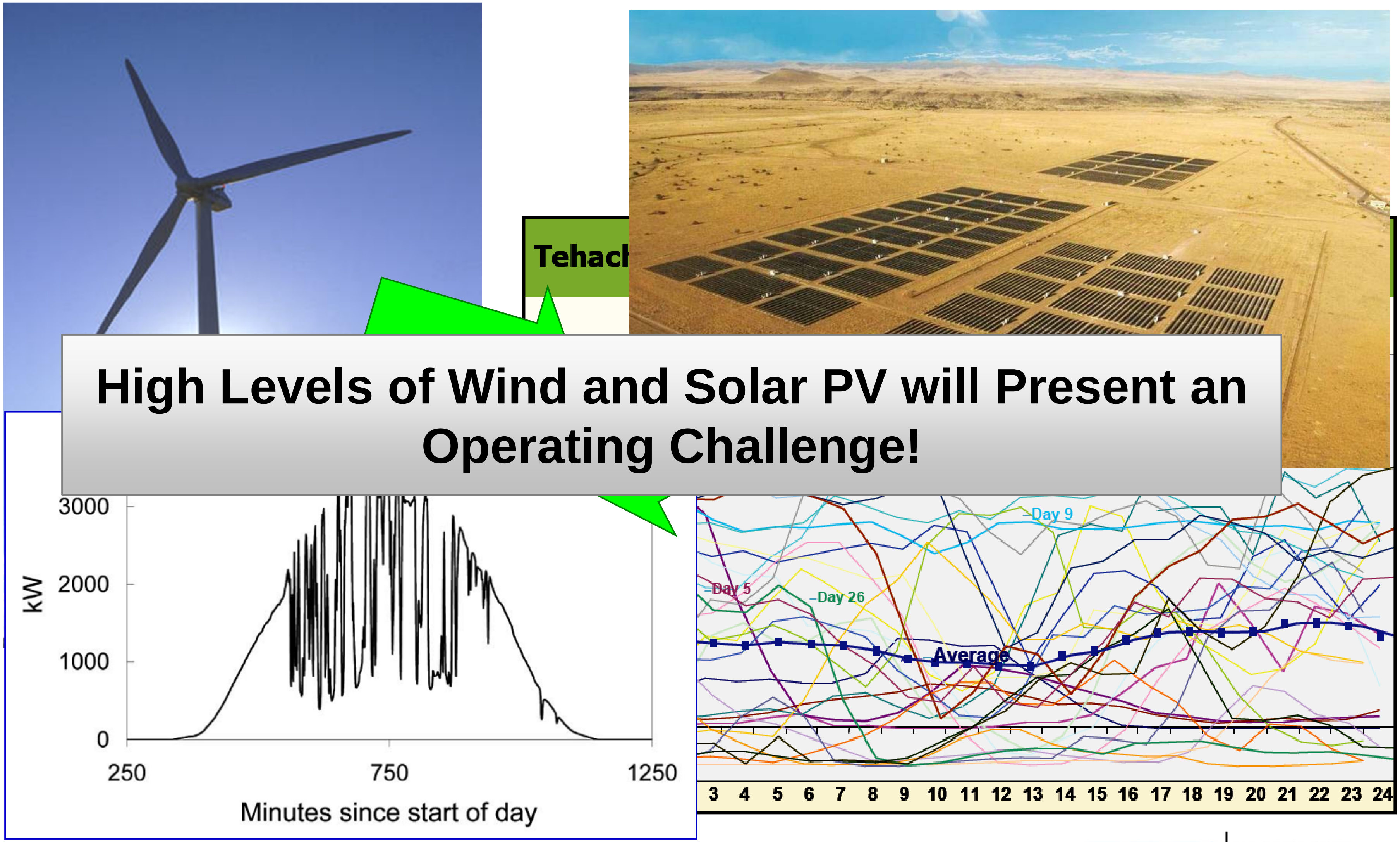
System Capacity	2007	2008	2009	2010	2011	2012*
2.5 - 10 kW	13	29	44	50	46	7
10 - 500 kW	6	24	30	37	53	16
500 kW+	2	18	26	29	59	20

Note: excludes all 3rd-party owned systems

Source: CSI Database (accessed, 03/07/12), as reported by NREL

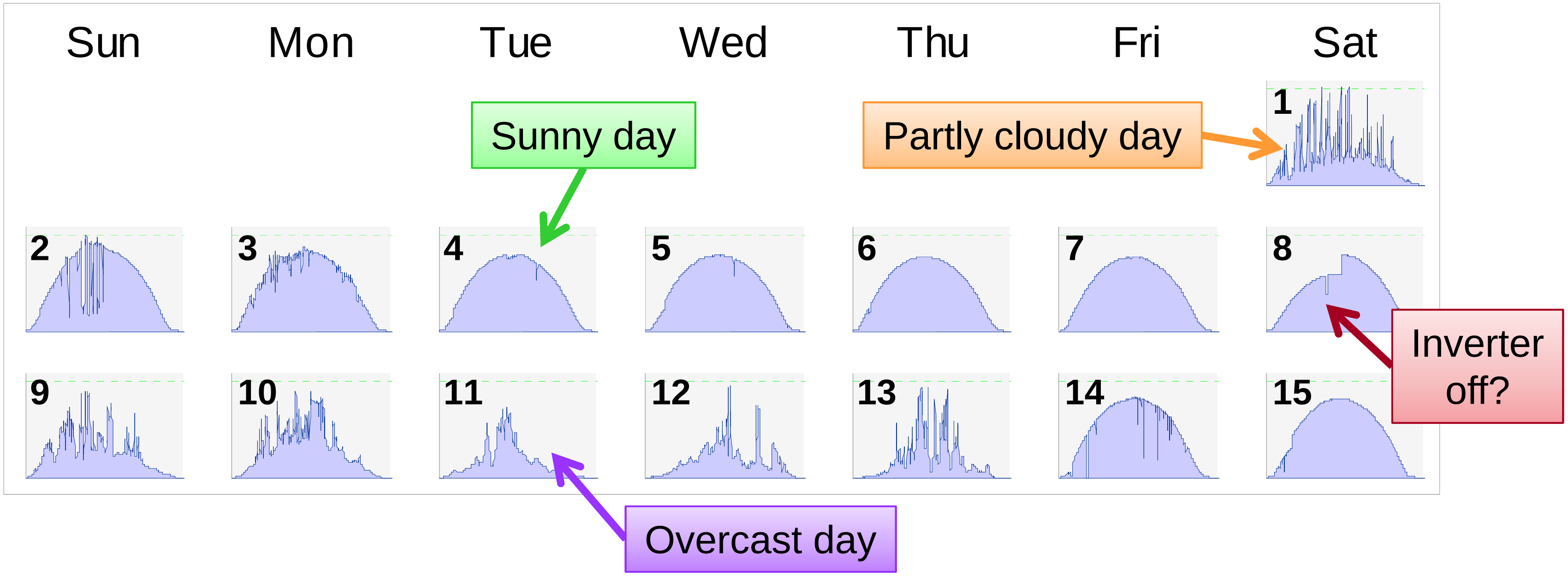
Solar Integration

Variability & Uncertainty
Bulk Power Issues



High Levels of Wind and Solar PV will Present an Operating Challenge!

Sample AC Power Production – 1MW PV System (Oct 1-17, 2011) in Tennessee



Sunny day

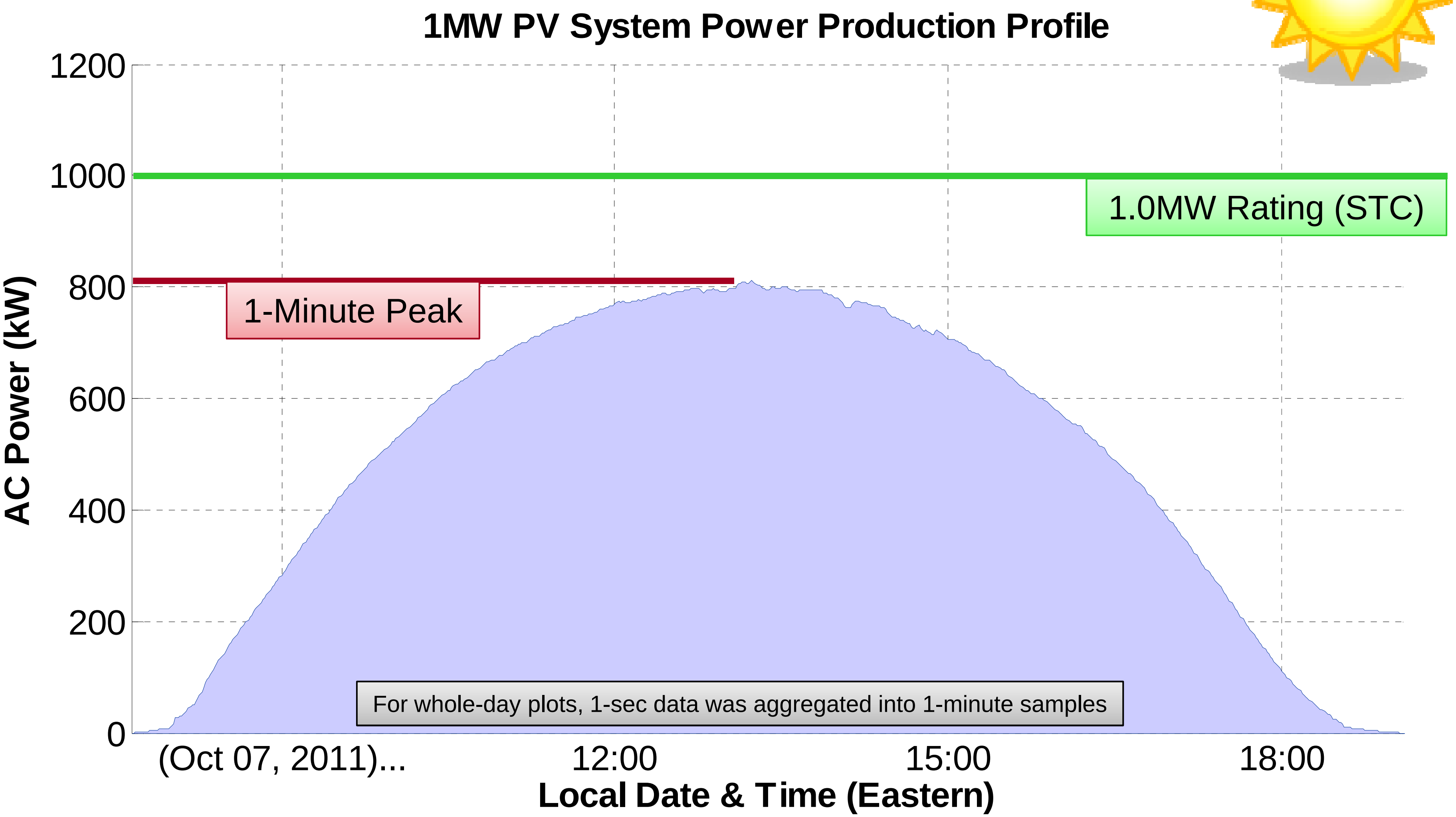
Partly cloudy day

Inverter off?

Overcast day

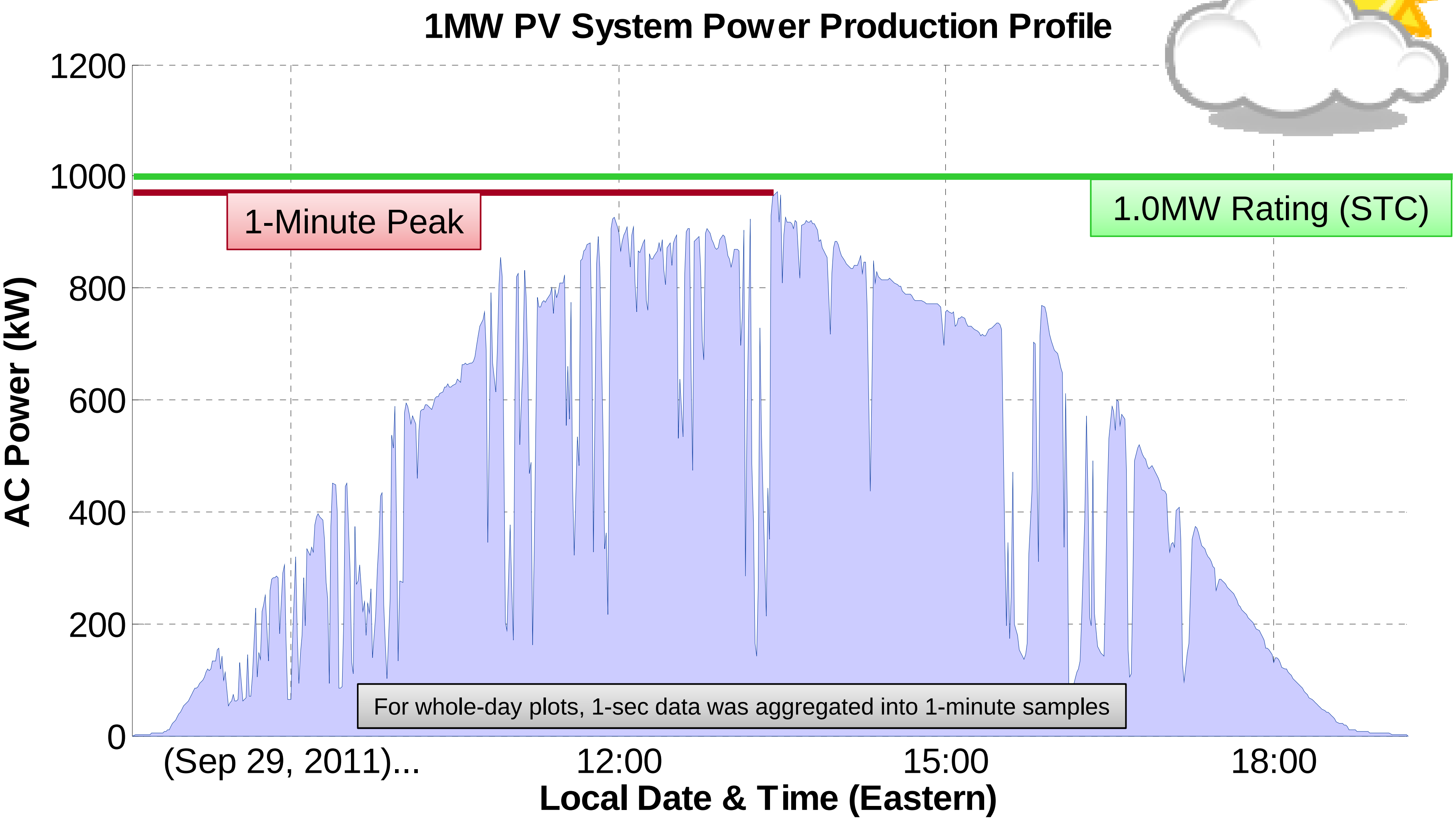
Cloudless Day in October

Power profile shows 1-min average ac output during daylight



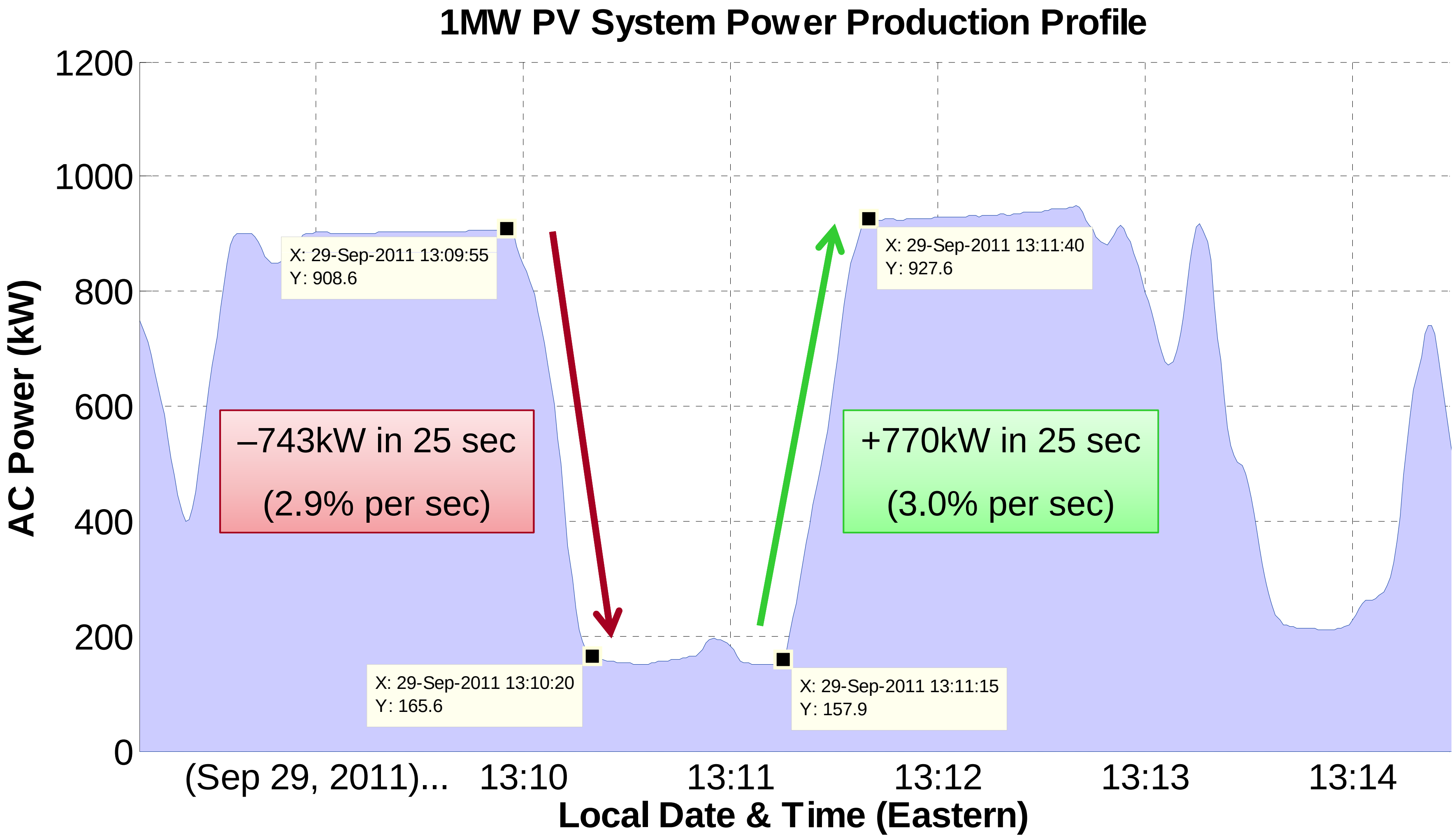
Partly Cloudy Day in September

Power profile shows 1-min average ac output during daylight



Power Ramp Events on Partly Cloudy Day

High definition power profile of 1MW system at 1-sec resolution



–743kW in 25 sec

(2.9% per sec)

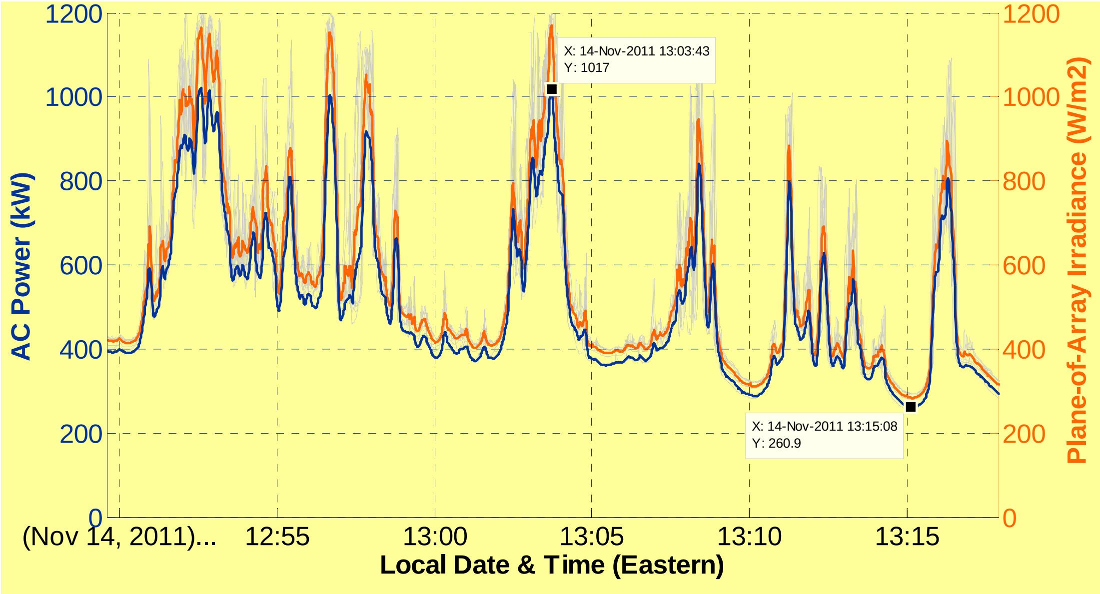
+770kW in 25 sec

(3.0% per sec)

Informed Plant Design and Siting to Reduce Cloud-Induced Variability

- Cloud shading may cause fast ramps exceeding 50% of capacity
- Cloud transients are smoothed by geographic diversity and larger plant sizes
- EPRI R&D to evaluate design and siting options to reduce variability
  - Selection of PV technology and mounting configuration
  - Inverter sizing
  - Project siting/sizing

Variability for 1-MW Plant Over 30 Minutes Based on 1-Second Irradiance Data



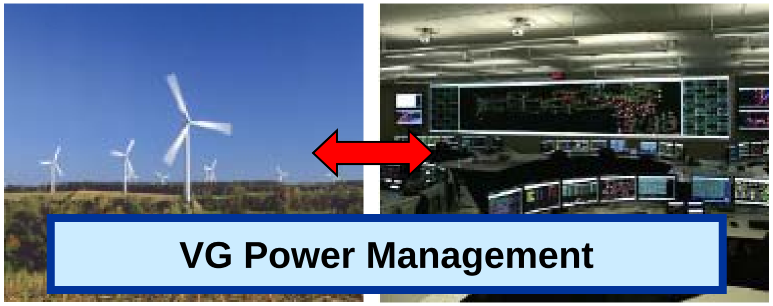
Grey lines show sensor irradiance measurements

Orange line shows average irradiance

Blue line shows AC power production

Many Sources of Flexibility to Address Variability

- Conventional Resources
  - Peaking and cycling units
- Emerging Resources
  - Demand response
  - Energy storage
  - Plug-in electric vehicles
- VG Power Management
  - Control VG output
- Institution/Market Flexibility
  - Coordination among Balancing Authorities (BAs)
  - Shorter scheduling
- More Transmission



EPRI Working with Industry to Meet Challenges - Renewable Integration Research

Bringing together collaborative engagement, technical resources and lab capabilities

Distributed
Renewables

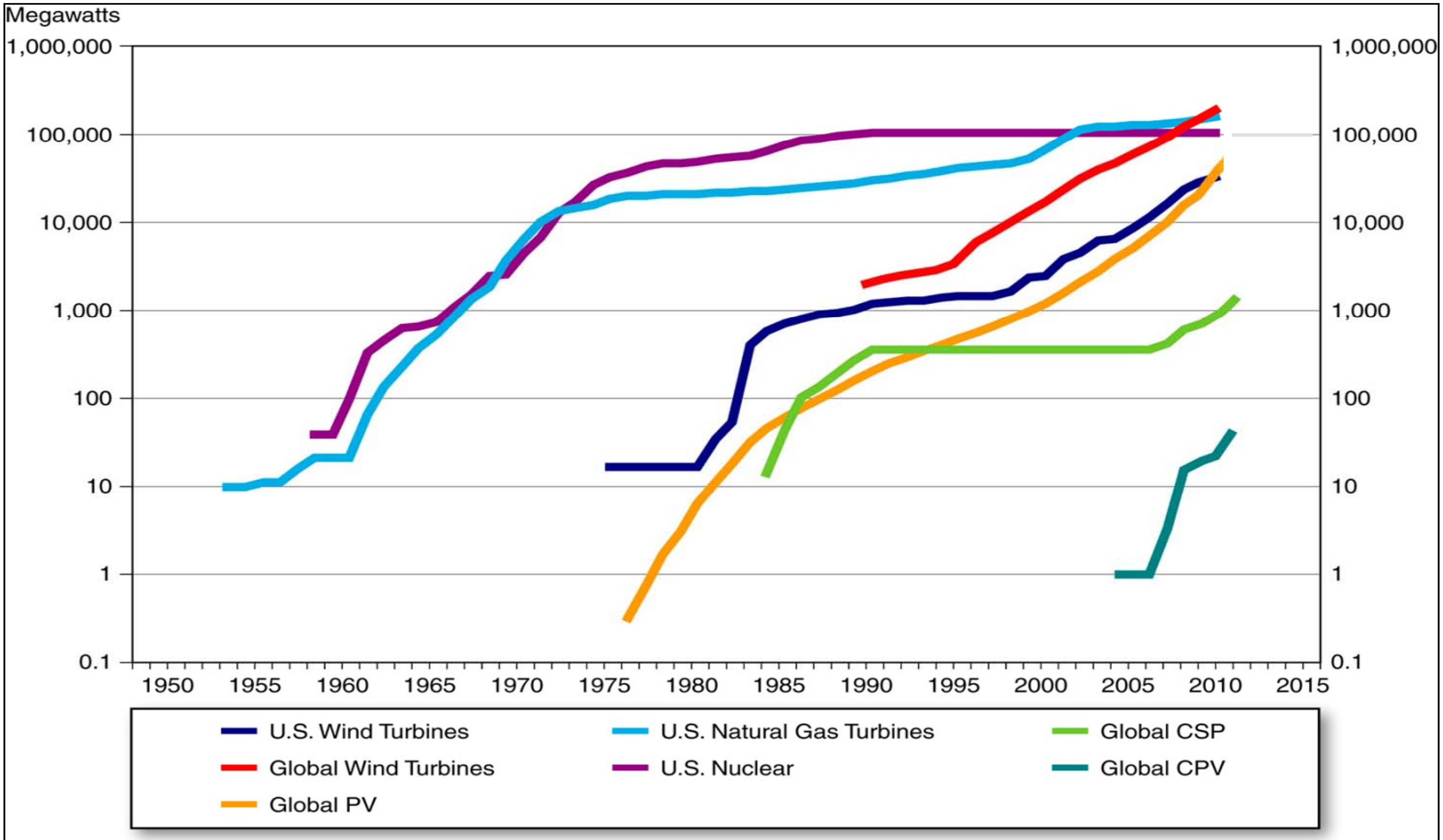
Integration Variable Generation
& Controllable Loads

P94
Energy Storage

Smart Grid as Virtual Power Plant
& Compressed Air Energy
Storage
(CAES) Demonstrations

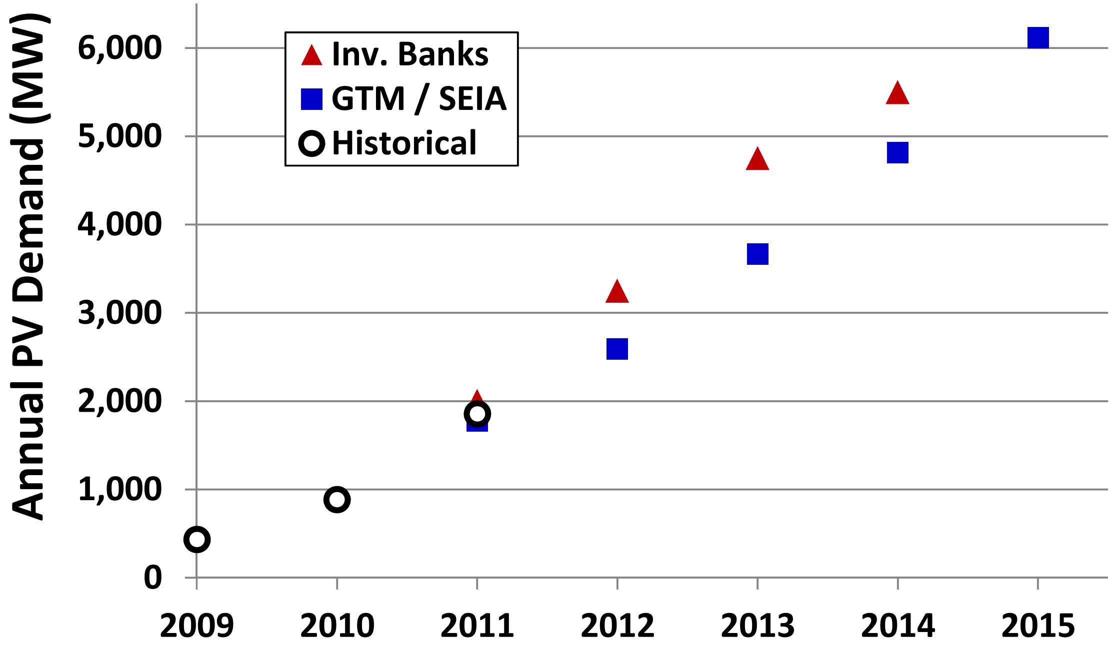
Industry Outlook

PV Trajectory Follows Nuclear, Gas, Wind Industries



Sources: Figure based on data from EIA (U.S. Nuclear, Natural Gas, and Wind), European Wind Energy Association (Global Wind), NREL (Global CPV), EPRI (Global CSP), and Navigant Consulting PV Service (Global PV, historic and forecasted – based on modules shipped).

U.S. PV Market Forecast

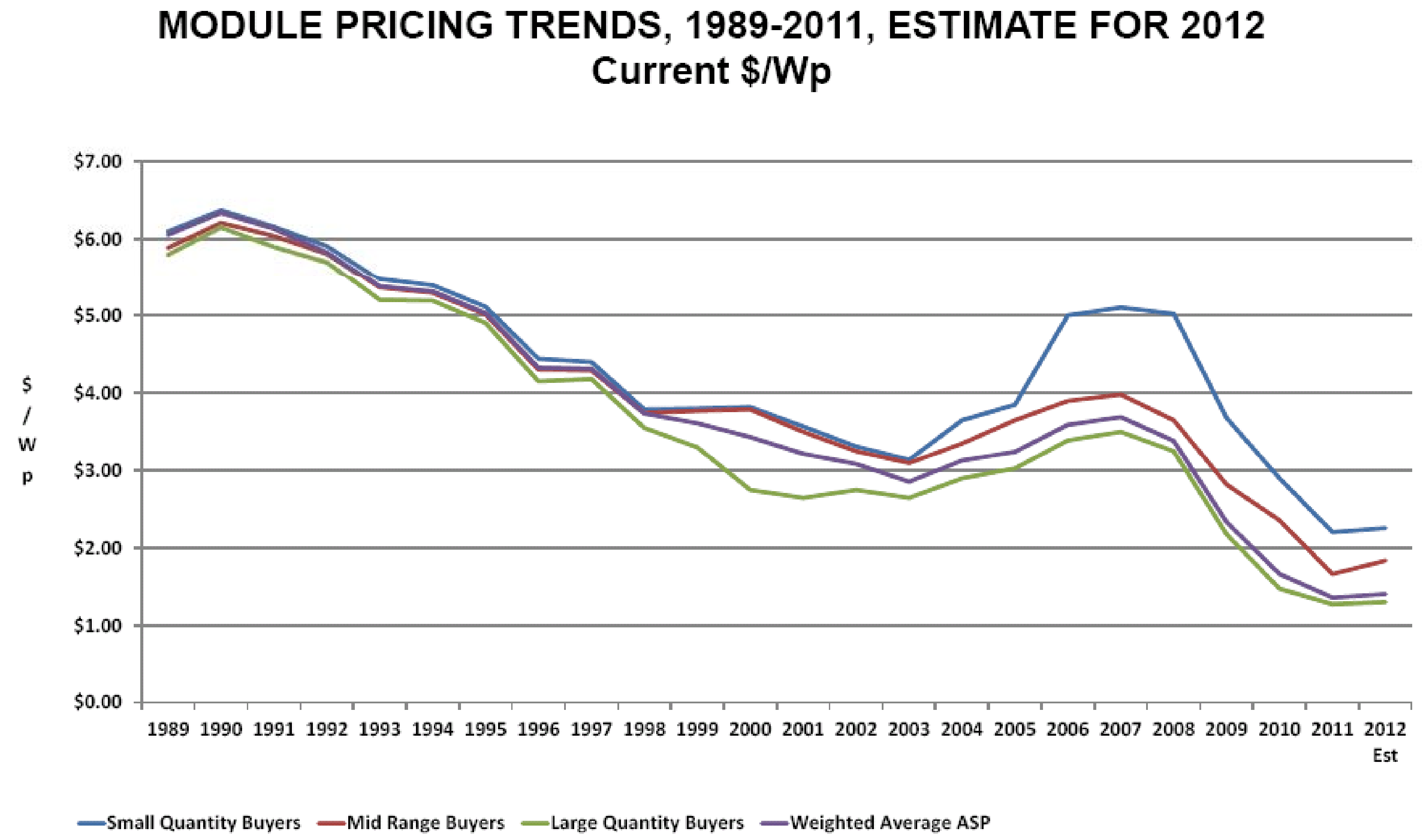


Inv. Banks: Barclays Capital (2/14/11), Citigroup Global Markets (5/11/11), Goldman Sachs Group (5/16/11), Jefferies & Co. (6/2011), Lazard Capital Markets (4/13/11), Macquarie (4/1/11), Piper Jaffray (1/2011), Stofel Nicolaus & Co. (5/5/11), UBS Securities, LLC (3/31/11), Wedbush Securities (2/8/11)
GTM/SEIA: GTM/SEIA 2011

- Projections consistent with about a 1 GW/yr increase in U.S. PV demand through 2015
- Several projections dominated by utility PV markets
- Could lead to about 20 GW PV by 2015 (~1% of US electricity demand)

Source: NREL

Historic and Near-term Pricing Trends



Source: Paula Mints – Navigant PV Services Program

Outlook

- Utilities will increasingly lead the way in spurring new U.S. PV capacity additions
- PV pricing is not likely to rebound in 2012 given the widely mismatched supply/demand equation
- Growing PV installations will require U.S. utilities to devise strategies for managing grid penetration that maintain overall network reliability
- The consolidating PV market in 2012 through 2014 will beget a new technology landscape
- Uncertainty due to polarized political situation which affects incentives

EPRI Approach to Address PV R&D Gaps

Technology Development & Systems Improvements

Develop third generation PV cell designs

- Monitor technology developments
- Partner with academic institutions, national laboratories and industry to accelerate technology development
- Review PV stakeholder technology roadmaps to understand potential efficiency improvements and cost reductions

Optimize plants to maximize output and reduce variability

- Model effects of location, sizing, PV module, balance of system components, module layout and mounting configurations on plant output
- Verify with field testing

EPRI Approach to Address PV R&D Gaps
Reliability & Performance Improvements

Assess long-term performance and reliability

- Provide independent, third-party test data to guide technology assessment and inform resource planning
- Conduct independent, long-term field testing to assess reliability of key PV system components

Optimize PV O&M

- Provide comprehensive assessment of O&M needs for PV generation connected to utility grid systems
- Identify best practices employed for utility-owned systems vs. customer- or third-party-owned assets

Together…Shaping the Future of Electricity