# Solar Energy and Energy Storage: Current Challenges and Opportunities

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ORNL User Week 2010
September 14, 2010

# Lux Research profile

- We help clients capitalize on **science-driven innovation**
- We focus on **emerging technologies** in the chemicals and materials sector and the energy and environment sector (cleantech)
- We have practices in **Nanomaterials**, **Solar**, **Energy Storage**, **Water**, **Biosciences,** and **Green Buildings**
- We have clients on **five continents** – blue-chip corporations, government agencies and laboratories, universities, investors, and small/mid-cap companies
- We **source** our intelligence from the Lux Research Network: CEOs, CTOs, CSOs, and R&D execs at cutting-edge technology firms in our sectors of focus
- We draw on **our network** to:
  - Continuously monitor emerging technologies
  - Assist with company and technology evaluation
  - Identify discontinuities in technology commercialization
- We have **global research reach**, with offices in New York, Boston, San Francisco, and Amsterdam with 50+ employees: 67% scientists, 33% business analysts

LR Director Josh Wolfe present in the Oval Office during the signing of the 21st Century R&D Act

Matthew Nordan testifying before U.S. Congress

# Lux Research solar and energy storage coverage

## Lux Solar Intelligence – Technologies Assessed

- Multi- and mono-crystalline silicon
- Upgraded metallurgical grade silicon (UMG-Si)
- Amorphous and micro-crystalline thin-film silicon
- CdTe thin films
- CIGS/CIS thin films
- High concentrating PV (HCPV)
- Low concentrating PV (LCPV)
- Dye-sensitized (Grätzel) solar cells (DSSC)
- Organic photovoltaics (OPV)
- Concentrating solar power (CSP)
- Tracking systems, inverters, and other enabling tec
- Silicon thin-film (amorphous, microcrystalline, and
- Solar thermal
- Other novel technologies including nano-antennas, thin-film approaches

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## Lux Power Intelligence – Key Issues Addressed

- Transportation
  - Economic viability of full-sized hybrid and electric vehicles
  - Customized storage for light vehicles (e-bikes and scooters) and heavy vehicles (buses, trains, and trucks)
  - Consumer concerns – "range anxiety" and safety
- Grid
  - Benefits of smart-grid technologies such as AMI and demand response
  - Integration of storage with renewable generation (solar, wind)
  - Energy storage for frequency regulation and bulk energy storage
  - Advances in power electronics for inverters/transformers
- Overlap
  - Electric vehicle/grid integration
  - Improvements in existing technologies (e.g. increases in energy density for lithium-ion batteries)
  - Time frame of emerging technology commercialization
  - Raw materials supply
  - Investment trends (VC, IPO, M&A)
  - Environmental impact


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# Agenda

- Subsidy-driven volatility of supply and demand drives solar industry structure and outlook
- System level challenges present new opportunities for solar technologies

- Two applications drive grid energy storage
- Efficacy of grid-scale storage varies by region

- Who wins peak?
- The competition of solar, storage and smart grid to fill peak demand

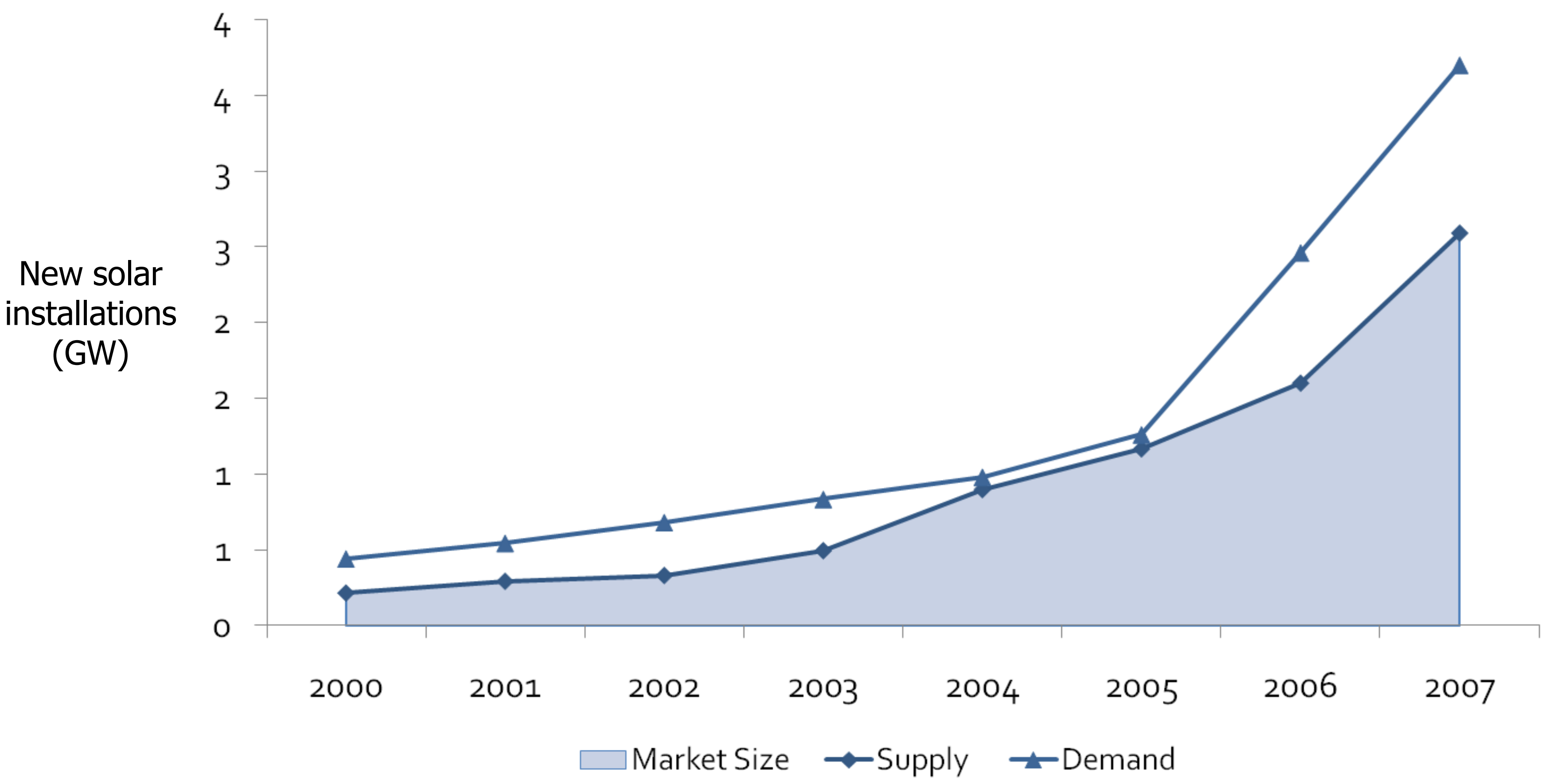
# Agenda

- Subsidy-driven volatility of supply and demand drives solar industry structure and outlook

# Subsidy-driven volatility determines industry structure to date

- Subsidies drive demand well beyond capacity, with upstream polysilicon the principal constraint between 2005 and 2008

# Subsidies Drive Demand Far Beyond Available Supply

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無錫尚德太陽能電力有限公司


Suntech Innovation

# Major Players "Reverse Integrate" to Capture Polysilicon Supply

Internal investment in polysilicon:

LDK — LIGHT OUR FUTURE 阳光照亮未来

ReneSola

SHARP

JV investment or cheap acquisition:

SUNTECH 尚德电力
JV → Asia Silicon, NITOL

SOLARWORLD — THE SUNPOWERED COMPANY
JV → Joint Solar Silicon Inc., Scheuten-SolarWorld Solizium

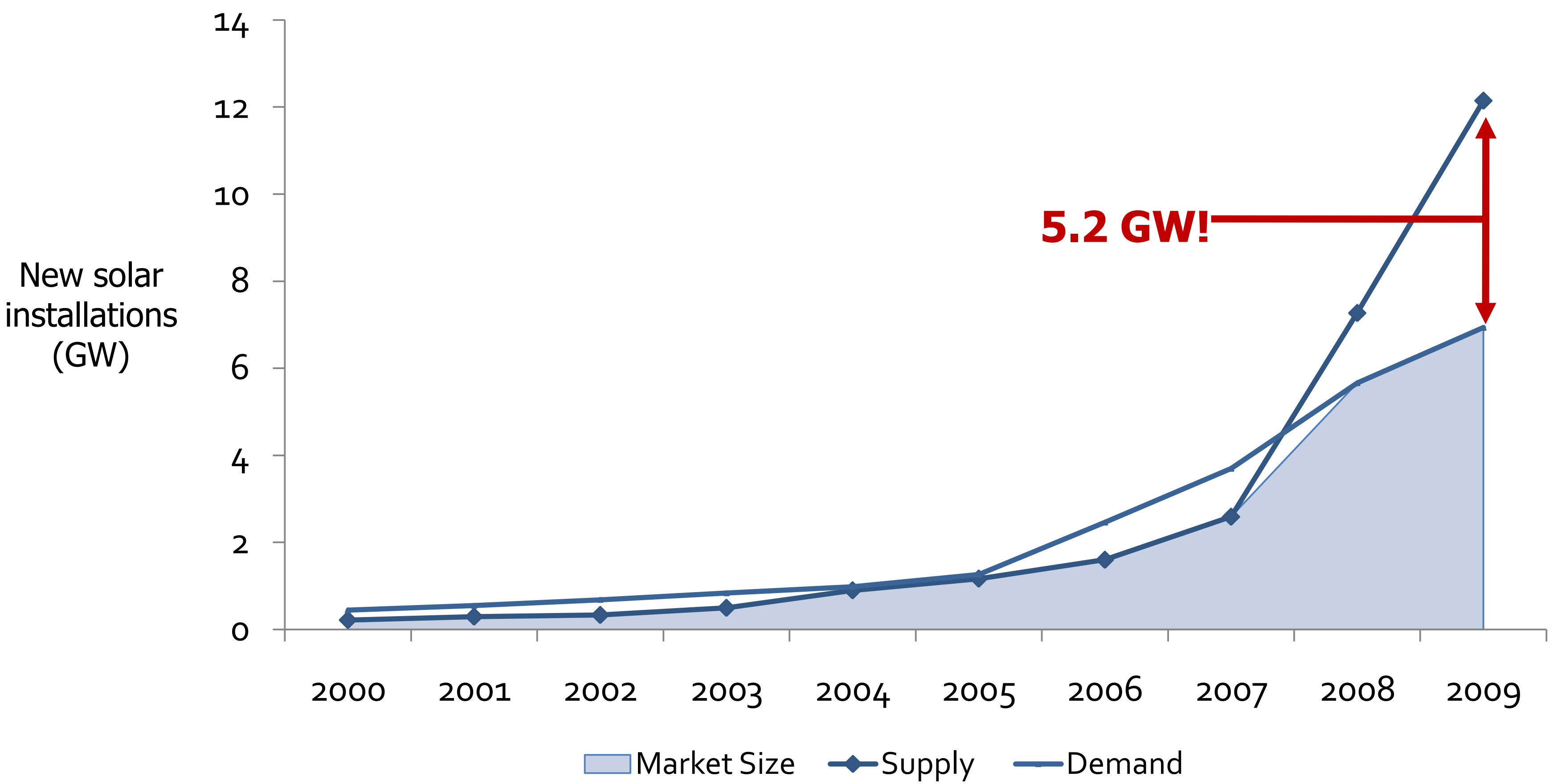
YINGLI SOLAR
M&A → Fine Silicon

# Subsidy-driven volatility determines industry structure to date

- Subsidies drive demand well beyond capacity, with upstream polysilicon the principal constraint between 2005 and 2008

- Subsidy cuts, rush of long-lead time capacity, and financial crisis trigger bust cycle in late 2008

# Long lead-time of capacity additions and limited demand result in ~2x overcapacity




Source: Lux Research Solar State of the Market, February 2009

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# Major players rely on downstream integration to gain long term visibility

Internal investment in project development:

REC Renewable Energy Corporation | SCHOTT solar | LDK LIGHT OUR FUTURE 阳 光 照 亮 未 来 | Q.CELLS

Acquisition or joint venture

SUNPOWER → M&A → SunRay Renewable Energy

First Solar → M&A → NextLight Renewable Power, LLC

MEMC TECHNOLOGY IS BUILT ON US → M&A → SunEdison simplifying solar

SUNTECH 尚 德 电 力 → JV → FOTOWATIO the power of the sun

# Subsidy-driven volatility determines industry structure to date

- Subsidies drive demand well beyond capacity, with upstream polysilicon the principal constraint between 2005 and 2008

- Subsidy cuts, rush of long-lead time capacity, and financial crisis trigger bust cycle in late 2008

- Solar market continues aggressive growth on the back of European demand…but subsidy uncertainty and price declines continue into the foreseeable future

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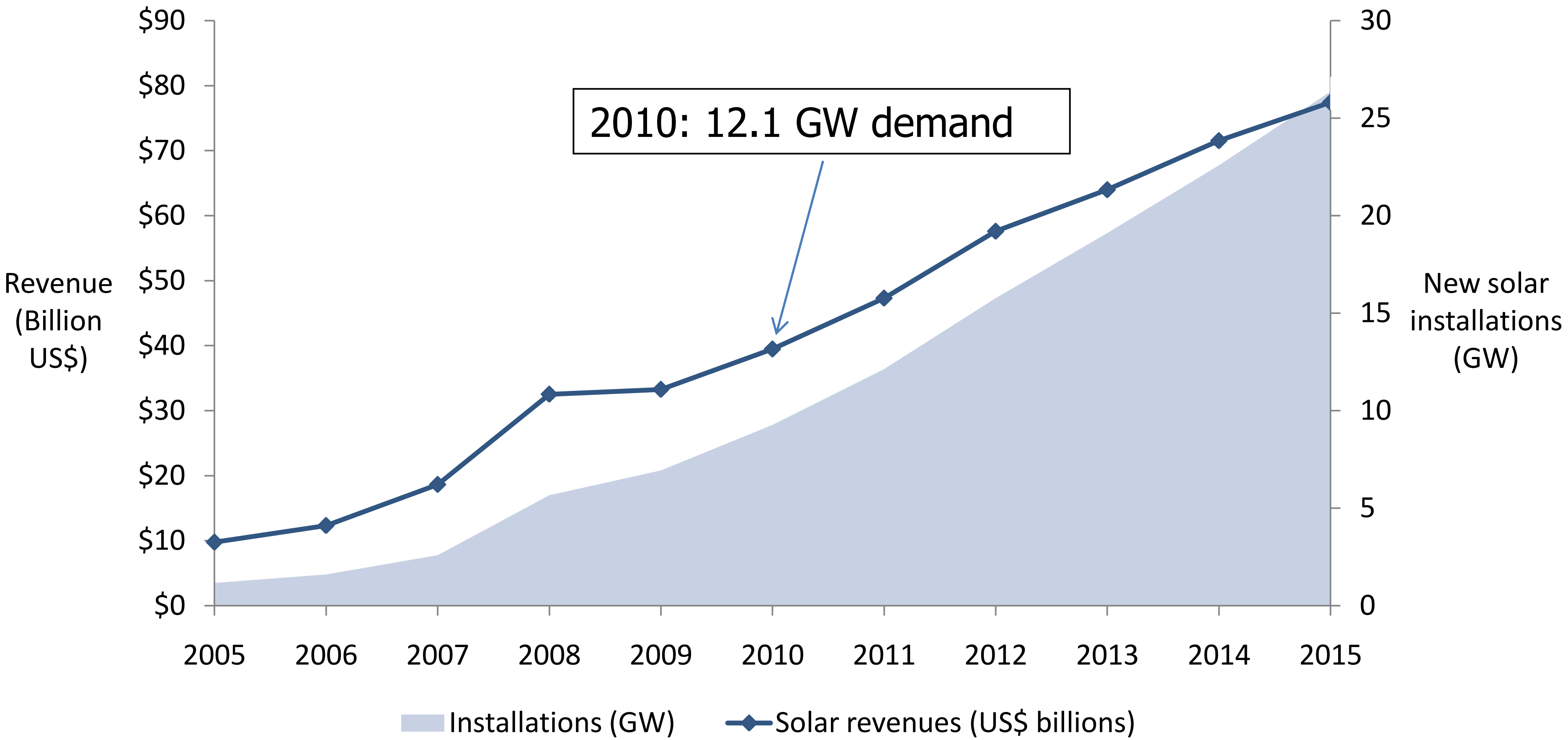
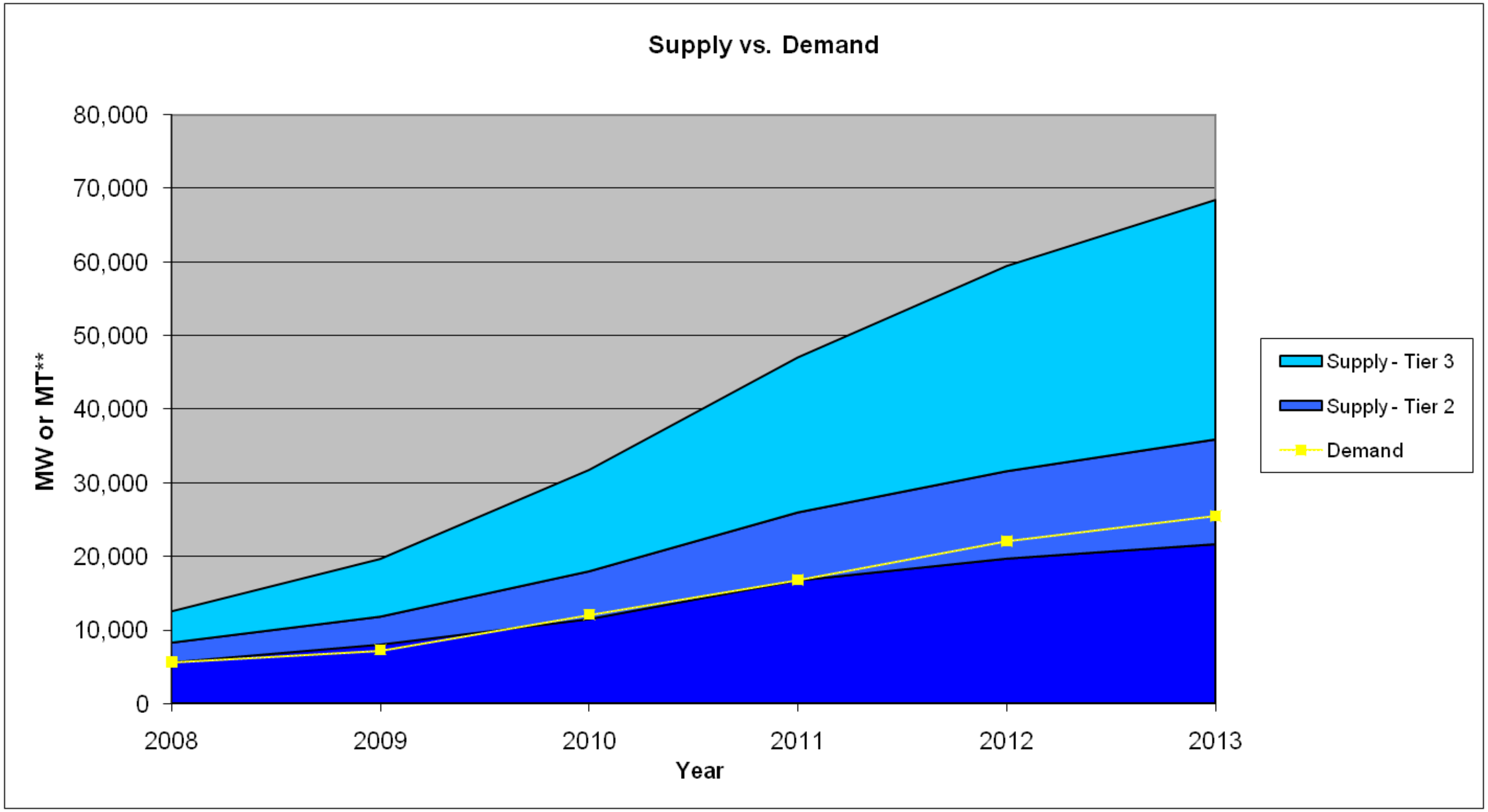
# Long term growth of the solar market driven by subsidies, difficult cost reductions




Source: Lux Research Solar State of the Market, February 2010

# Aggressive capacity expansions maintain excess capacity, pressuring long-term prices

- Top suppliers experience strong demand and supported pricing, but excess capacity limits market-entry opportunities for new firms




Source: Lux Research Solar Supply Tracker, June 2010

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# Sustained capacity oversupply conditions will drive future corrections

- Top tier players continue to “sell-out” production, with periods of limited supply for preferred modules and materials
- However, utilization rates at lower-tier firms sag as they seek to limit inventory
- Bottom-tier firms with little downstream networking and brand recognition become “zombies”, shutting down capacity indefinitely
- Due to steady overall declines in pricing, high-cost manufacturers are forced into outsourcing arrangements to drive down cost structures

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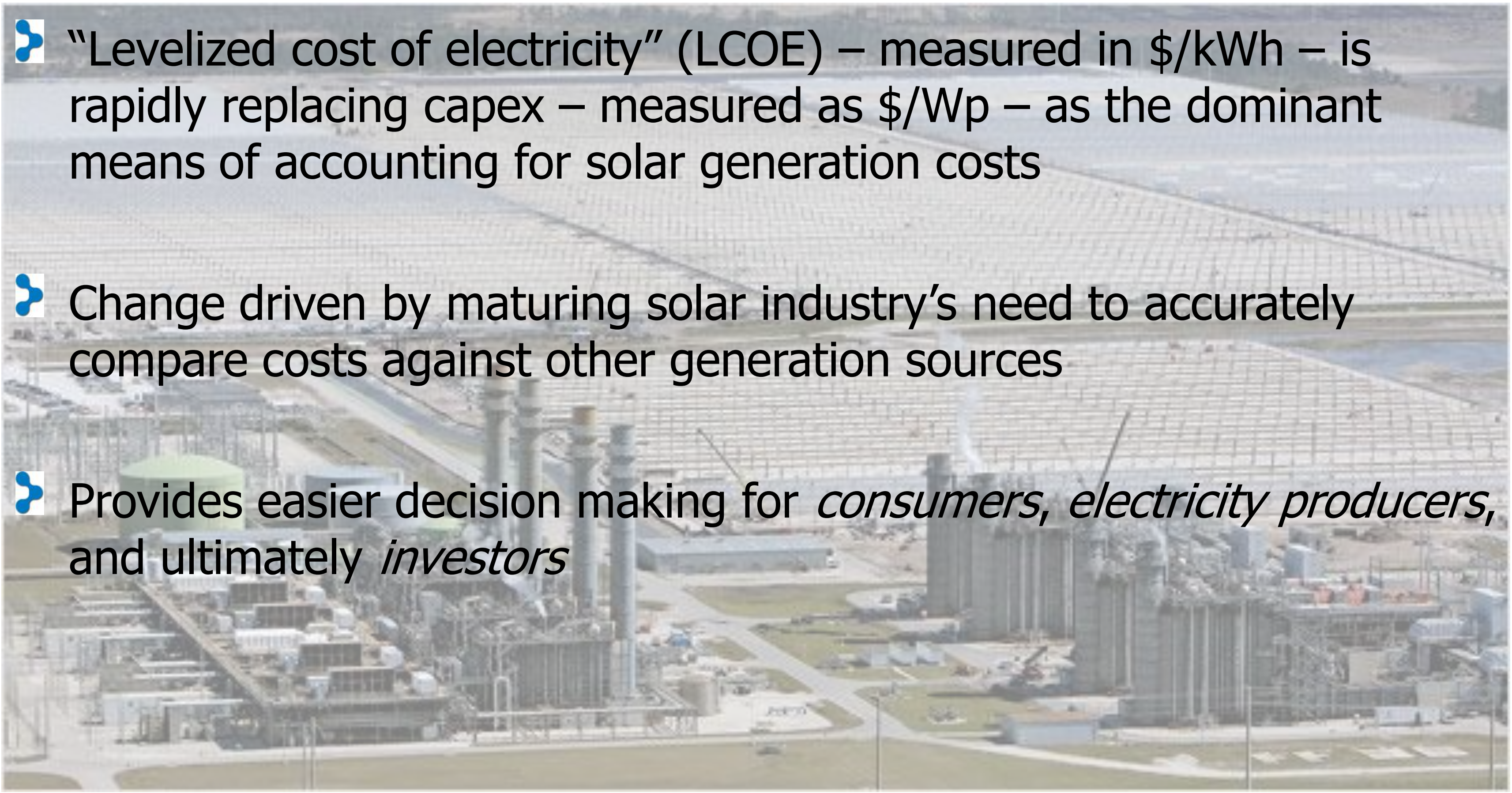
# Solar industry maturity is shifting the relevant metrics



- "Levelized cost of electricity" (LCOE) – measured in $/kWh – is rapidly replacing capex – measured as $/Wp – as the dominant means of accounting for solar generation costs
- Change driven by maturing solar industry's need to accurately compare costs against other generation sources
- Provides easier decision making for *consumers*, *electricity producers*, and ultimately *investors*

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# Overcoming a simplistic view of "grid parity"

***Grid Parity: "The solar LCOE at which an electricity customer is indifferent to buying electricity from the grid or from a solar system."***

- Grid parity is a sliding scale and varies widely by <u>country</u>, <u>application</u>, <u>technology</u>, and <u>electricity rate regime</u>

- Grid parity will be a <u>gradual process</u> leading to a gradual increase in demand as more countries and applications are "unlocked" at lower price points – it will not be a "hockey stick" inflection point

# LCOE reflects the net present value of future production and costs

- LCOE is the NPV of all future costs divided by the NPV of future electricity production (kWh)

$$LCOE\left(\frac{\$}{kWh}\right) = \frac{\sum_{t=1}^{t} Annual\ Costs_t/(1+r)^t}{\sum_{t=1}^{t} kWh_t/(1+r)^t}$$

- Costs include: Upfront capex, financing costs, operations and maintenance (O&M) costs, land lease, and taxes
- Key assumptions:
  - System residual value is equal to the NPV of all future electricity generation ($/kWh) minus future costs at year of contract (PPA, FIT, etc.) termination – typically year 20
  - Discounting the value of future electricity production is *critical* to reflect its true economic value; beware of any LCOE analysis that ignores this, as it will make solar look artificially cheap

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# A properly configured and located system is key to maximizing output

| Category | Description | Input Factors | Specific Example |
|---|---|---|---|
| **Module Performance** | The kWh output (DC) of a module per kWp depends on its performance under specific geographic conditions | Module temperature and temperature coefficient, output current and voltage, annual performance degradation, performance under different light spectra | Most thin film modules have a better DC yield (kWh/kWp) than crystalline silicon under low light conditions |
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# System level challenges present new opportunities for solar technologies

LCOE as the key metric drives **system-level concerns** for costs and performance:

- Crystalline-silicon maintains the lead in installation volume, but new technologies gain market acceptance through concentration on targeted applications

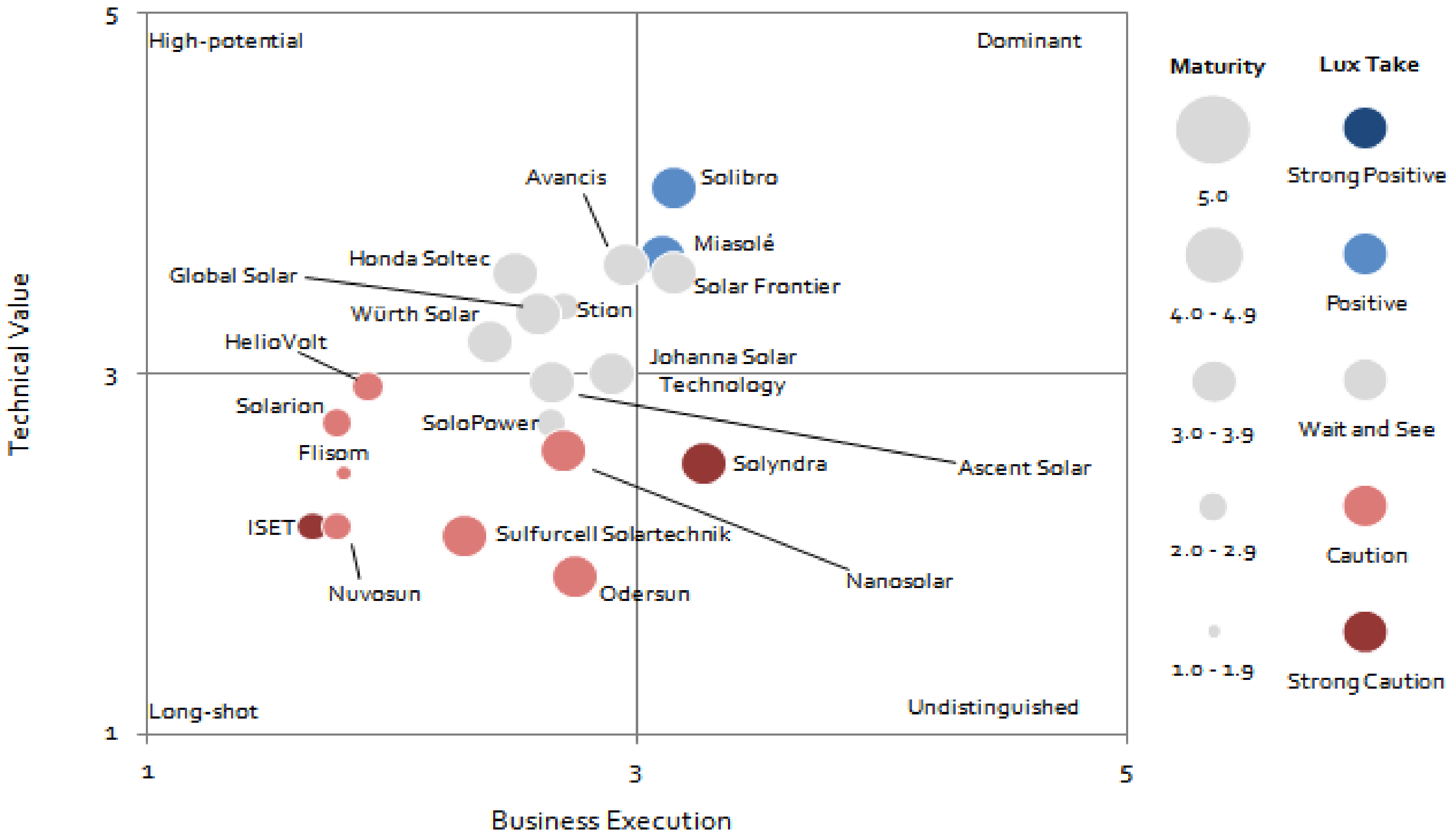
# Crystalline silicon technologies maintain largest market share

Falling prices of incumbent crystalline silicon (x-Si) technologies has **reduced the economic advantage of new technologies**

# Alternative PV technologies must surpass an ever rising bar set by crystalline silicon

Developers of new PV technologies **must meet strict cost targets**, and offer system-level advantages over crystalline silicon

# Lux Innovation Grid: Ranking CIGS developers



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LCOE as the key metric drives **system-level concerns** for costs and performance:

- Crystalline-silicon maintains the lead in installation volume, but new technologies gain market acceptance through concentration on targeted applications
- Balance of systems – the “less exciting side of solar” – offers significant, but slow moving cost savings

# BOS example: Power electronics increase capital costs, but improve residential LCOE

- Micro-inverters and maximum power point tracking (MPPT) units cut system derate factors – essential in the calculation of the levelized cost of electricity (LCOE) – especially in poorly-designed or placed installations (for example, residential).
- MPPT may edge micro-inverters due to due to lower unit cost, higher inverter efficiency
  - SolarEdge backed by GE and OEM agreement with Flextronics
- However micro-inverters from are gaining traction in residential market today
  - Enphase claims significant share of CA residential market in Q1 2010
  - SMA acquires OKE-services in its first steps into market
- String-level MPPT solutions – such as Satcon's Solstice – are also starting to surface as compromise offerings for larger-scale systems.

# Solar Outlook

- Subsidy-driven volatility continues to drive short-term demand for solar components, but long term subsidy step downs must be expected
- Therefore, long term growth of the market depends upon cost reductions achieved through intense competition among PV firms, and requires using PV LCOE as the relevant metric for comparison with conventional resources
- Technology developers, materials providers, investors, and system integrators must capitalize on targeted opportunities with system-level cost and performance improvements to bring new technologies to market

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- Two applications drive grid energy storage
- Efficacy of grid-scale storage varies by region

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# Two main applications for grid-scale storage: Power and Energy

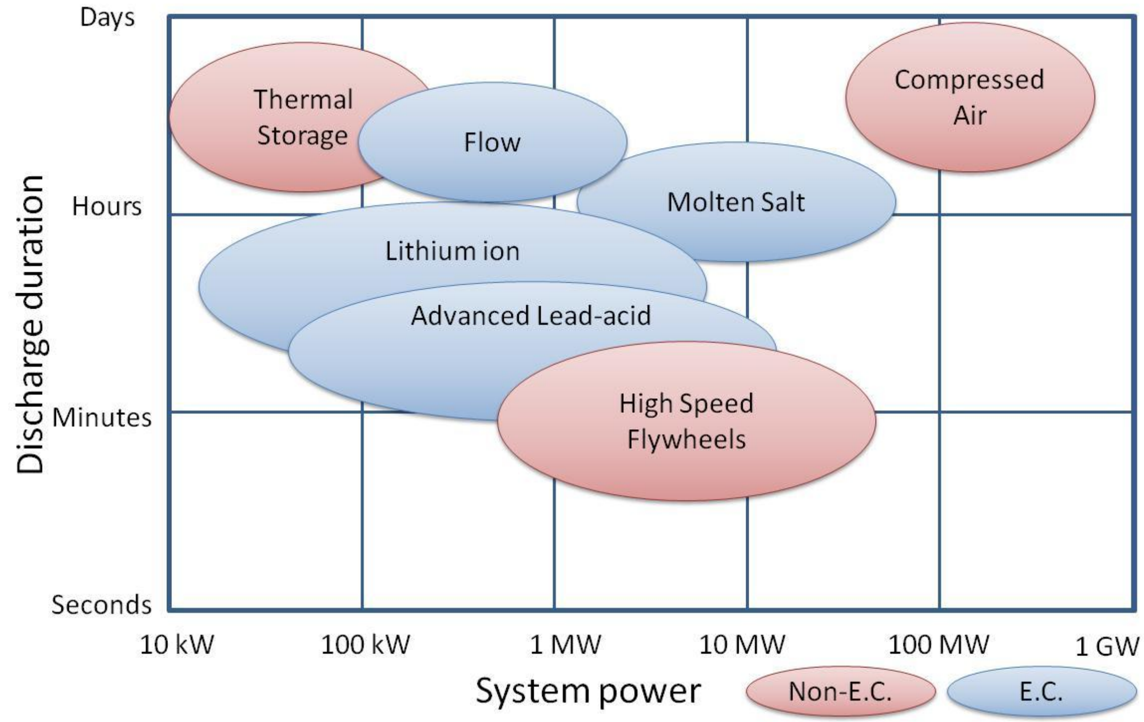
- First, an analogy for review:
  - Energy storage is to water capacity as…
  - Power delivery is to water flow


- Comes down to short discharges (power function) or long discharges (energy-type)
  - Some possibilities for overlap too

# Available Technologies Span a Range of Capabilities

- Electrochemical (batteries)
  - Molten Salt
  - Lithium Ion
  - Advanced Lead-acid
  - Flow Batteries

- Non-electrochemical
  - Compressed Air Energy Storage
  - Thermal Storage
  - High Speed Flywheels

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# So many choices for grid storage…what makes sense?

| Technology choices | Power vs. Energy Applications | Centralized vs. distributed siting |
|---|---|---|
| Molten Salt<br>Lithium Ion<br>Advanced Lead-acid<br>Flow Batteries<br>Compressed Air<br>Energy Storage<br>Thermal Storage<br>High Speed Flywheels<br>& Additional subcategories | End-user rate reduction<br>Energy arbitrage/commodity storage<br>T&D upgrade deferral<br>Ancillary services<br>• Spinning reserve<br>• Frequency regulation<br>Renewables shifting<br>Renewables firming<br>& Additional Applications | Centralized<br>Moderately distributed<br>Distributed<br>Extremely Distributed |
| **Regional generation mix** | **Geographical influences** | **Fully regulated vs. restructured regulations** |
| Regionally unique | Regionally unique | Regionally unique |

# Energy storage deployment will depend on: technology + application + location

- In the U.S., more developed compensation scenarios and government-supported installations encourages a wide of applications and technologies
  - ARRA funds drive growth in new installations, including a range of technologies
- In Germany, renewables expansion may open opportunity for grid energy storage installations to support distribution-level instabilities
  - *The biggest problem will come at the distribution level – not the transmission level – with renewables. For instance, if you have similar weather in a single area (particularly with solar), voltage problems will develop. One solution is to add small storage in the distribution network.* – German utility
- In China, the rapid expansion of wind installations points to the opportunity for renewables shifting/firming. Meanwhile, politically-based trends influence compensation opportunities
  - *Most of the wind [shifting] bids in China are for 2-4 hours because of the Li-ion firms. In order to make wind installations profitable, they will need longer discharge times, but Li-ion can't do it. The timing for changing this trend is uncertain, however.* – Energy storage developer, China

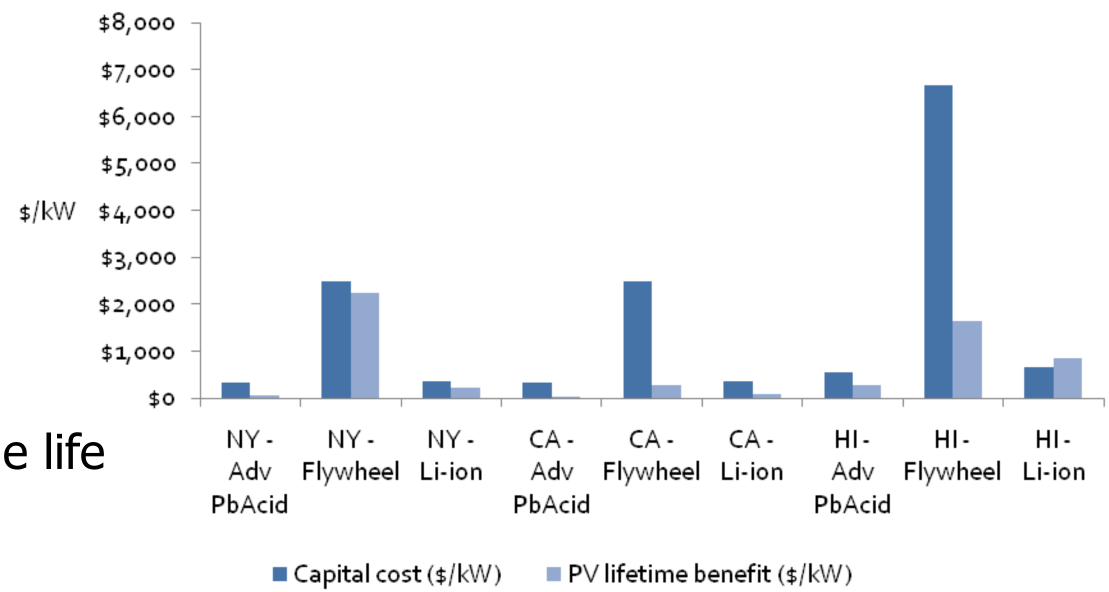
# Efficacy of grid-scale storage varies by region – a look at the U.S.

| Region | Generation mix (major energy source(s)) | Geography | Regulation | Comparable regions |
|---|---|---|---|---|
| **New York** | Limited renewables; (31% natural gas, 29% nuclear) | Long transmission lines, congestion in urban area | Restructured | England, Russia |
| **California** | High renewables and aggressive RPS; (55% natural gas) | Long transmission lines in protected land, congestion in urban areas | Partially restructured | Spain, Argentina |
| **Hawaii** | High renewables and expensive fossil fuels; (83% oil) | Small island grids, no interconnections | Fully regulated, with some merchant power | Japan, Indonesia |

- Two different near-term feasible scenarios modeled for each region

# Power applications are only economical in very limited markets

- Specific scenarios without incentives based on capital cost and lifetime benefit PV
  - New York - Frequency regulation on open wholesale market
  - California - Frequency regulation on open wholesale market
  - Hawaii - Stabilizing wind farm output on PPA
- Li-ion is attractive in specific markets now, and has opportunities in more with price reduction and cycle life improvement
- Flywheels may be cost effective in high value frequency regulation markets with cost reduction
- Hybrid supercapacitor-type Advanced Lead-Acid batteries' low price does not make up for their lack of cycle life

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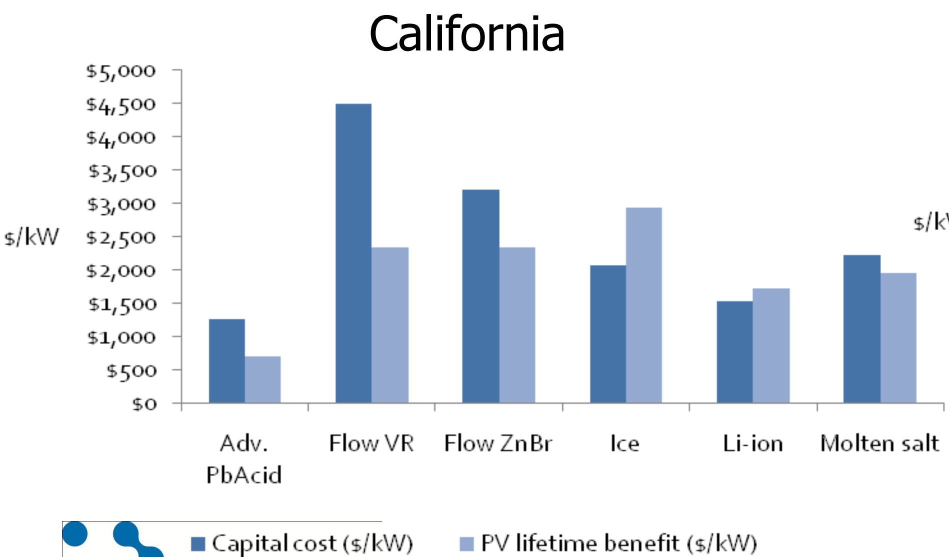
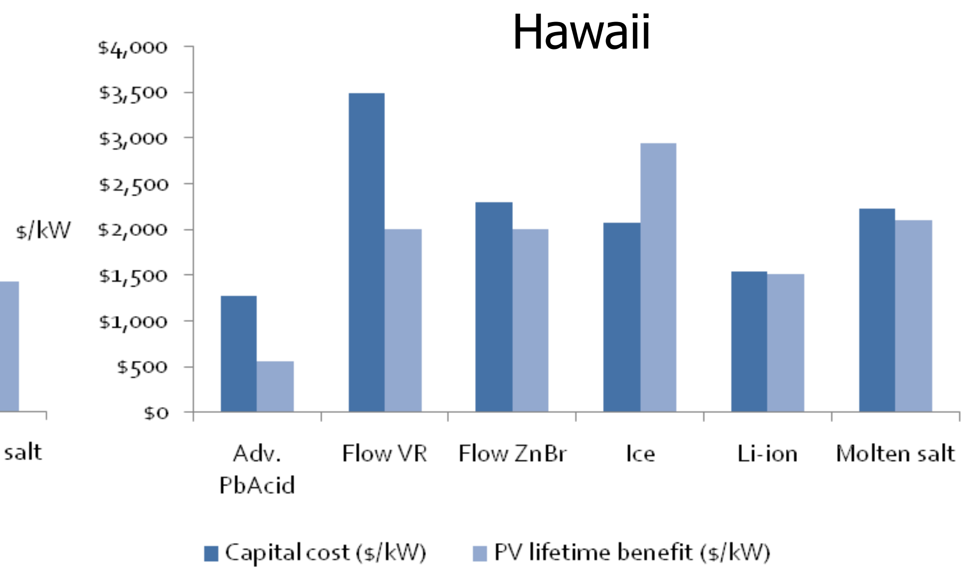
# Economics for energy applications – CA/HI

- Specific scenario without incentives based on capital cost and lifetime benefit PV
  - California – Time-of-use pricing and demand charge in PG&E
  - Hawaii – Time-of-use pricing and demand charge on Oahu
- Ice is very attractive due to long life and modest up-front cost
- Li-ion is somewhat attractive

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- Who wins peak?
- The competition of solar, storage and smart grid to fill peak demand

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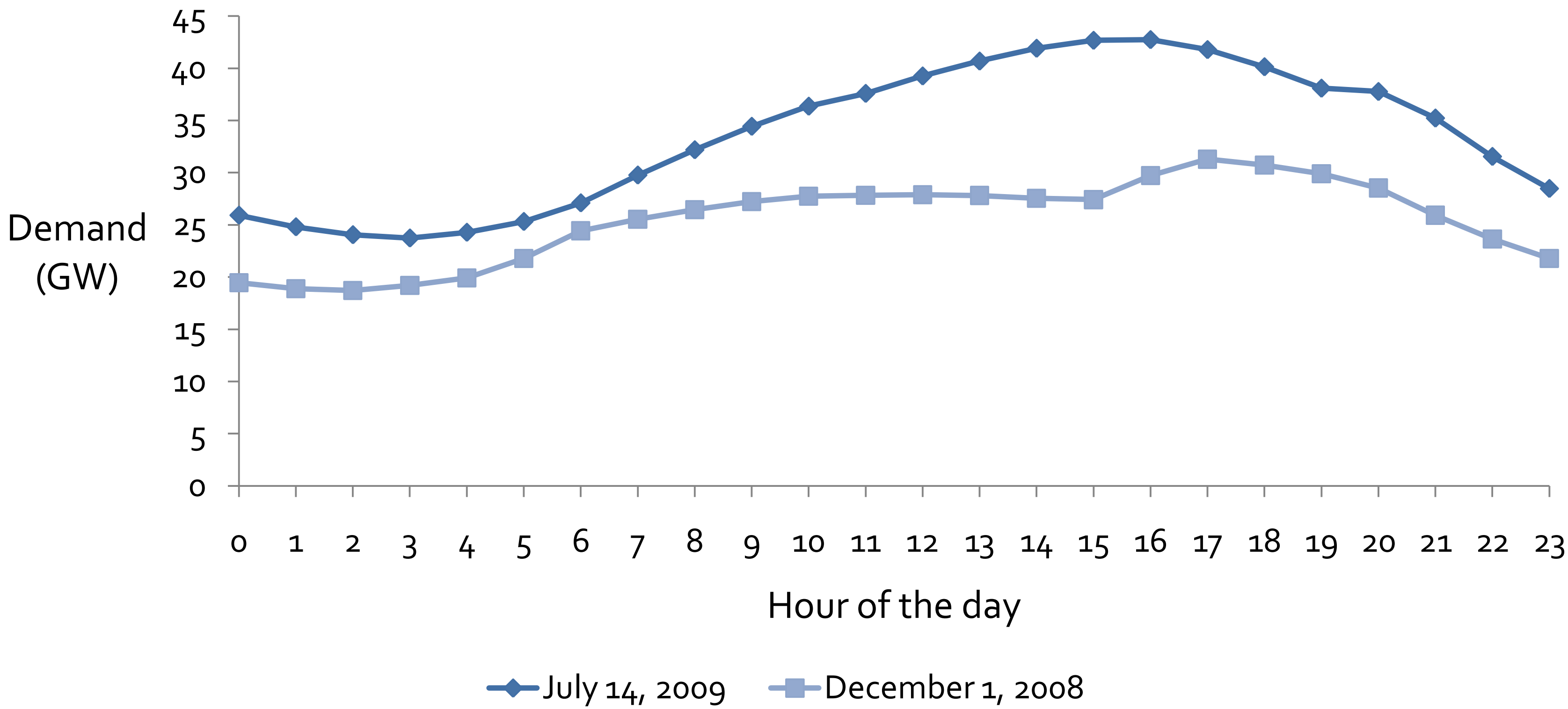
# Who wins peak?

- Electricity demand is greatest during the late afternoon during summer months

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Source: California ISO

# New technologies to address peak demand are both competitive and complementary

- Developers of demand response, solar thermal, and energy storage solutions offer solutions to limit the need for natural gas peakers

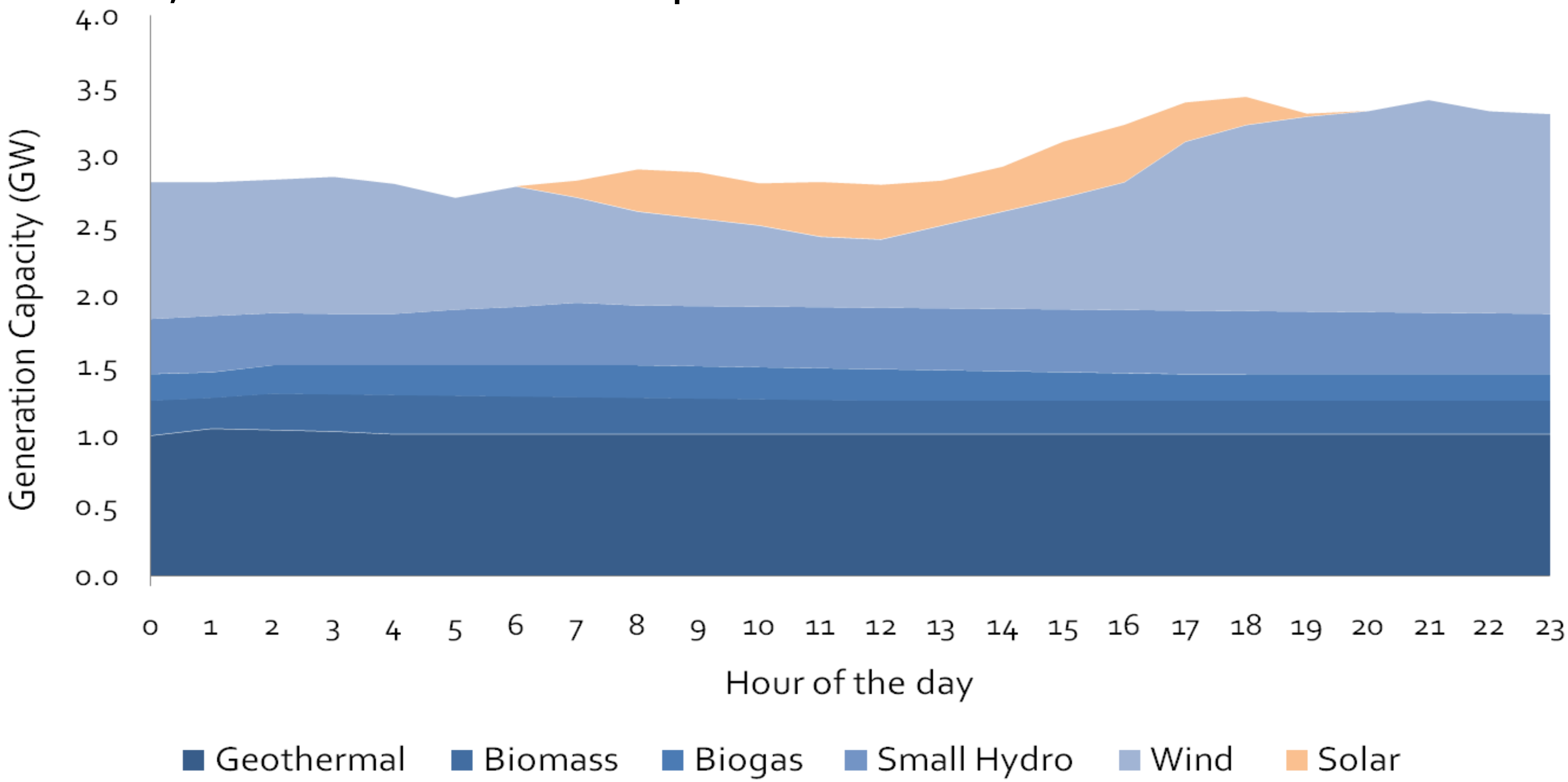
| | Description | Buyer | Key Technology Developers |
|---|---|---|---|
| Demand response | Demand-side technology that is a subset of "smart grid" applications; smart metering that enables load "curtailment" during periods of high demand | Regulated utilities | EnerNOC, Comverge, CPower |
| Solar generation | Generation technology that produces when the sun is shining, conveniently producing when A/C loads and thus peak demand are high | Regulated utilities, residential and commercial customers | SunPower, First Solar, Suntech Power |
| Energy storage | Supply-side technology that, when combined with baseload generation, can store electricity at night when generation costs are cheap and shift its supply back to peak hours when prices and high | Regulated utilities | Ice Energy, General Compression, Energy Storage and Power Corporation (ESPC), GE |

# Who wins peak?

- Multiple inputs must be considered to examine a technology’s potential to “win peak”
  - Capacity factor, dispatchability, capex cost, opex cost, compensation structures, time-of-use pricing, etc.

# The solar example to meet peak demand

- Though it is not dispatchable and requires relatively high capital costs, solar matches well to peak demand



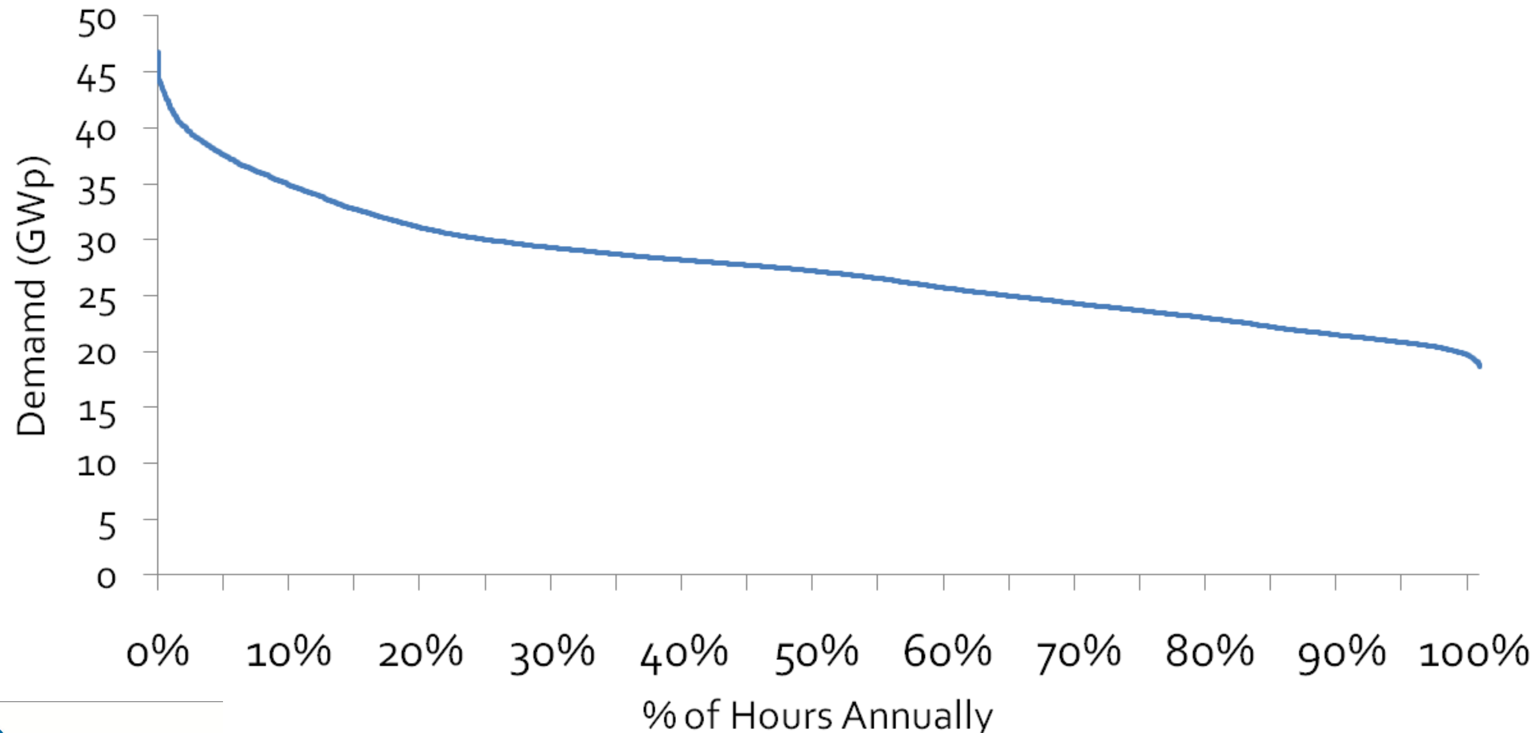

Source: California ISO

# Who wins peak?

- Multiple inputs must be considered to examine a technology's potential to "win peak"
  - Capacity factor, dispatchability, capex cost, opex cost, compensation structures, time-of-use pricing, etc.
- Capacity factor and dispatchability are key consideration for utilities

# Capacity factor and dispatchability are key consideration for utilities

- The load duration curve
  - Serves as the basis for high LCOE at small capacity factors
  - Exemplifies the opportunities for complementary technologies




Source: California ISO

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# Who wins peak?

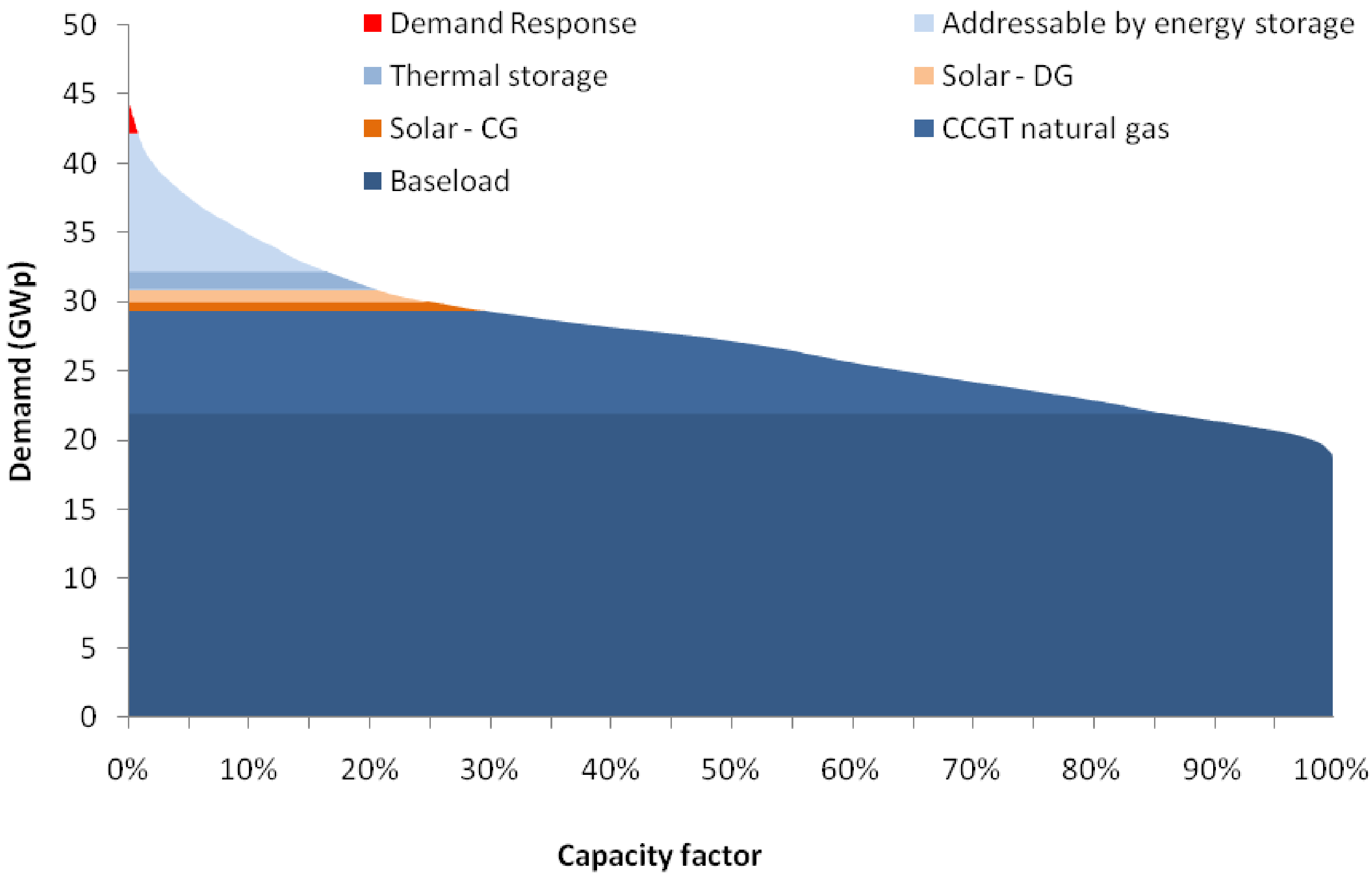
- Multiple inputs must be considered to examine a technology's potential to "win peak"
  - Capacity factor, dispatchability, capex cost, opex cost, compensation structures, time-of-use pricing, etc.
- Capacity factor and dispatchability are key consideration for utilities
- Demand response, solar energy, and energy storage best serve different regions of the load duration curve

# New technologies best serve different regions of the load duration curve

- Significant factors assessed: capacity factor, intermittency vs dispatchability, variable vs capital costs, capacity vs energy payment

| | Description | Specific application |
|---|---|---|
| Demand response | Demand-side technology that is a subset of "smart grid" applications; smart metering that enables load "curtailment" during periods of high demand | On-demand curtailment, up to 50-80 1 hour "events" per year |
| Solar generation | Generation technology that produces when the sun is shining, conveniently producing when A/C loads and thus peak demand are high | Distributed generation<br>Centralized generation |
| Energy storage | Supply-side technology that, when combined with baseload generation, can store electricity at night when generation costs are cheap and shift its supply back to peak hours when prices and high | Thermal storage (ice)<br>Compressed Air ES (CAES)<br>Alternative energy storage (electrochem) |

# Opportunity for energy storage to "fill the gap" between demand response and solar



# Outlook

- Driven by government subsidies, solar offers a valuable offset to peak-demand, and demand for solar installations continues fervently in 2010 on the back of European demand

- Energy storage – in all its technologies, applications, and locations – is still immature both in terms of technology as well as compensation structure and implementation

- The complex drivers for the utilization of energy generation or storage options *require* that technologists, producers, developers, and end-users weigh the key factors of demand for these new technologies

# Thank you

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# System level challenges present new opportunities for solar technologies

LCOE as the key metric drives **system-level concerns** for costs and performance:

- Crystalline-silicon maintains the lead in installation volume, but new technologies gain market acceptance through concentration on targeted applications

- Balance of systems – the "less exciting side of solar" – offers significant, but slow moving cost savings

- Power electronics and monitoring address system derate factors to drive overall system performance

# Power electronics: Addressing system-level performance through the derate factor

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| **Module Performance** | The kWh output (DC) of a module per kWp depends on its performance under specific geographic conditions | Module temperature and temperature coefficient, output current and voltage, annual performance degradation, performance under different light spectra | Most thin film modules have a better DC yield (kWh/kWp) than crystalline silicon under low light conditions |
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# Power electronics increase capital costs, but improve LCOE for residential installations

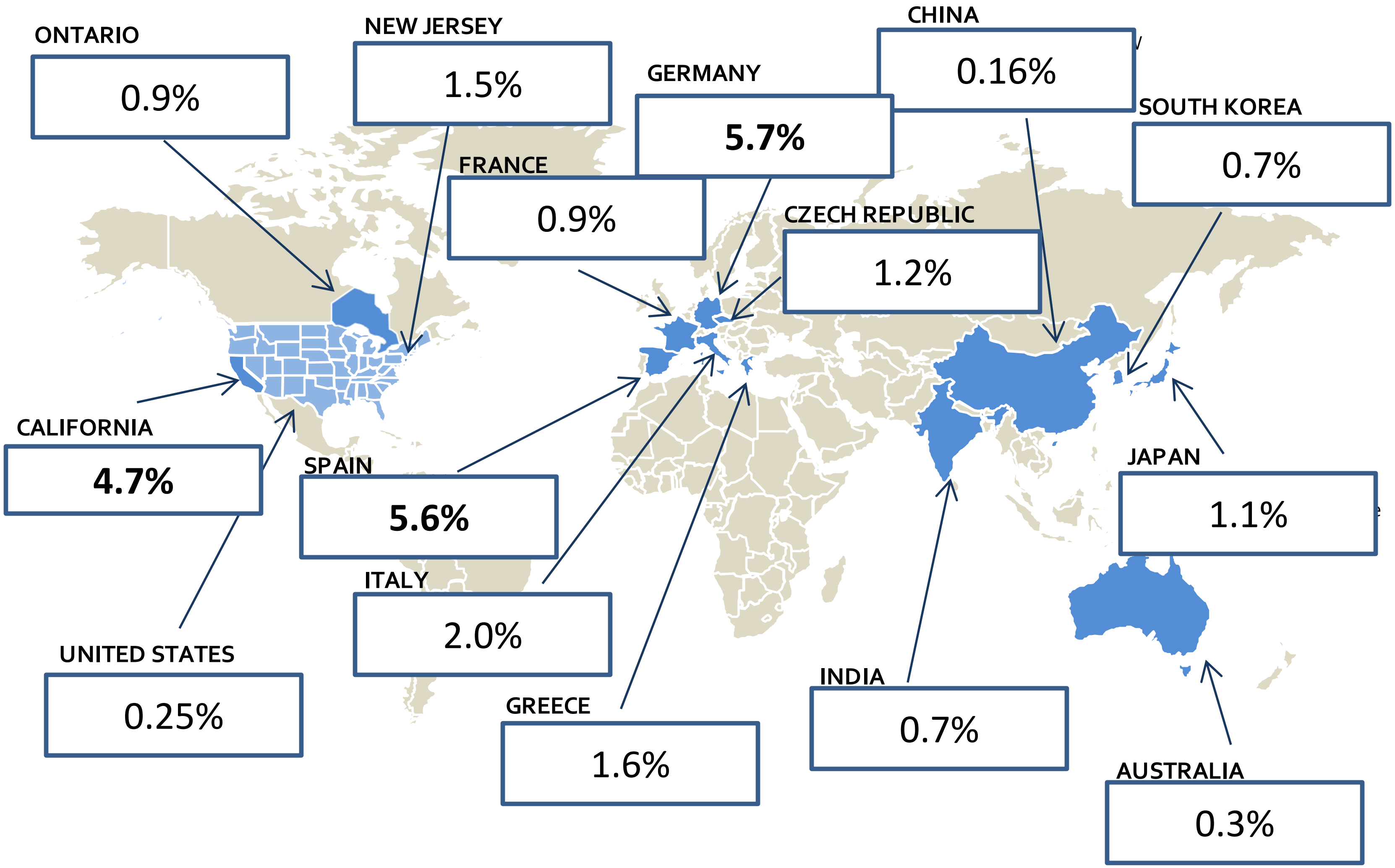
- Micro-inverters and maximum power point tracking (MPPT) units cut system derate factors especially in poorly-designed or placed installations

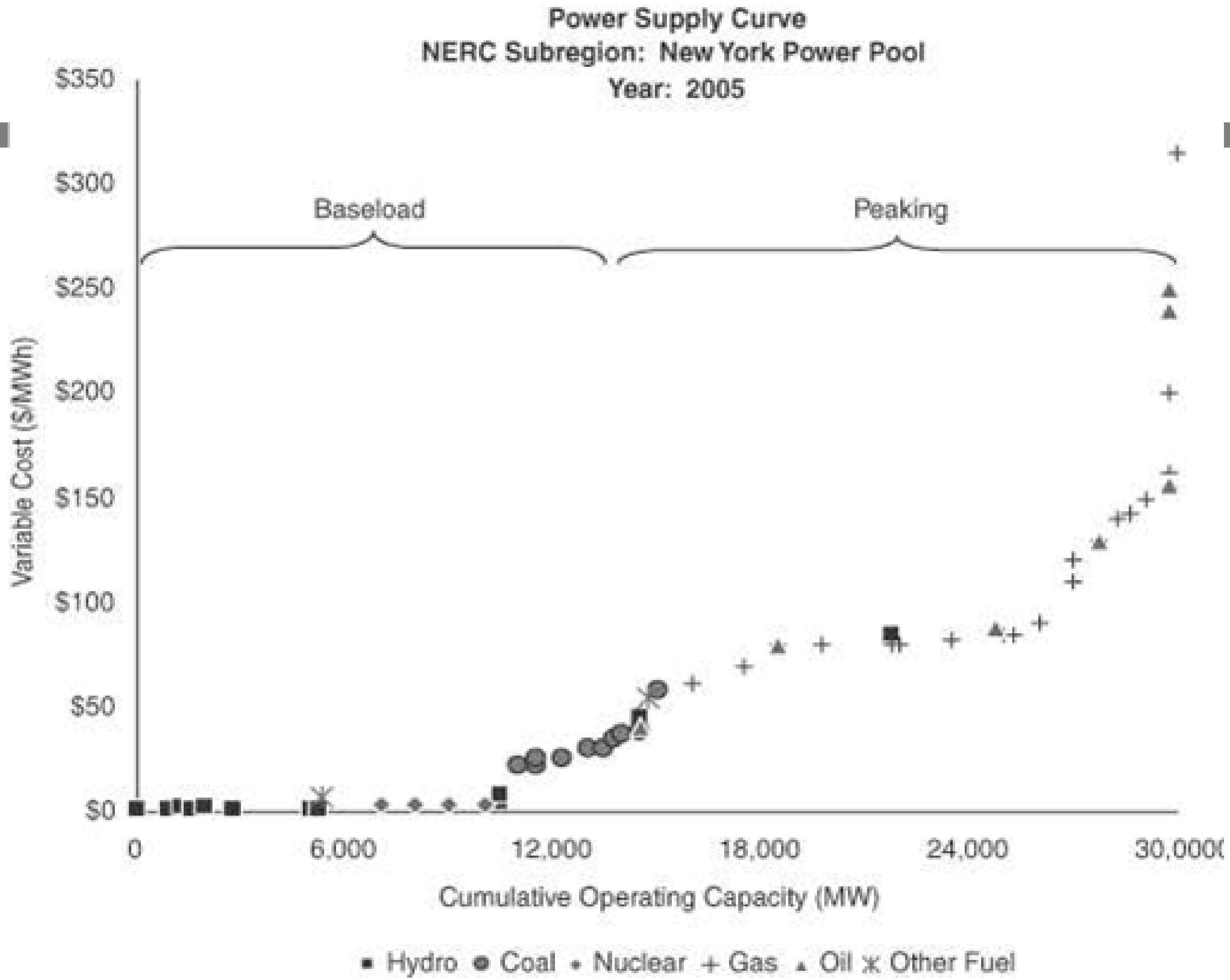
- MPPT may edge micro-inverters due to due to lower unit cost, higher inverter efficiency

- However micro-inverters from are gaining traction in residential market today

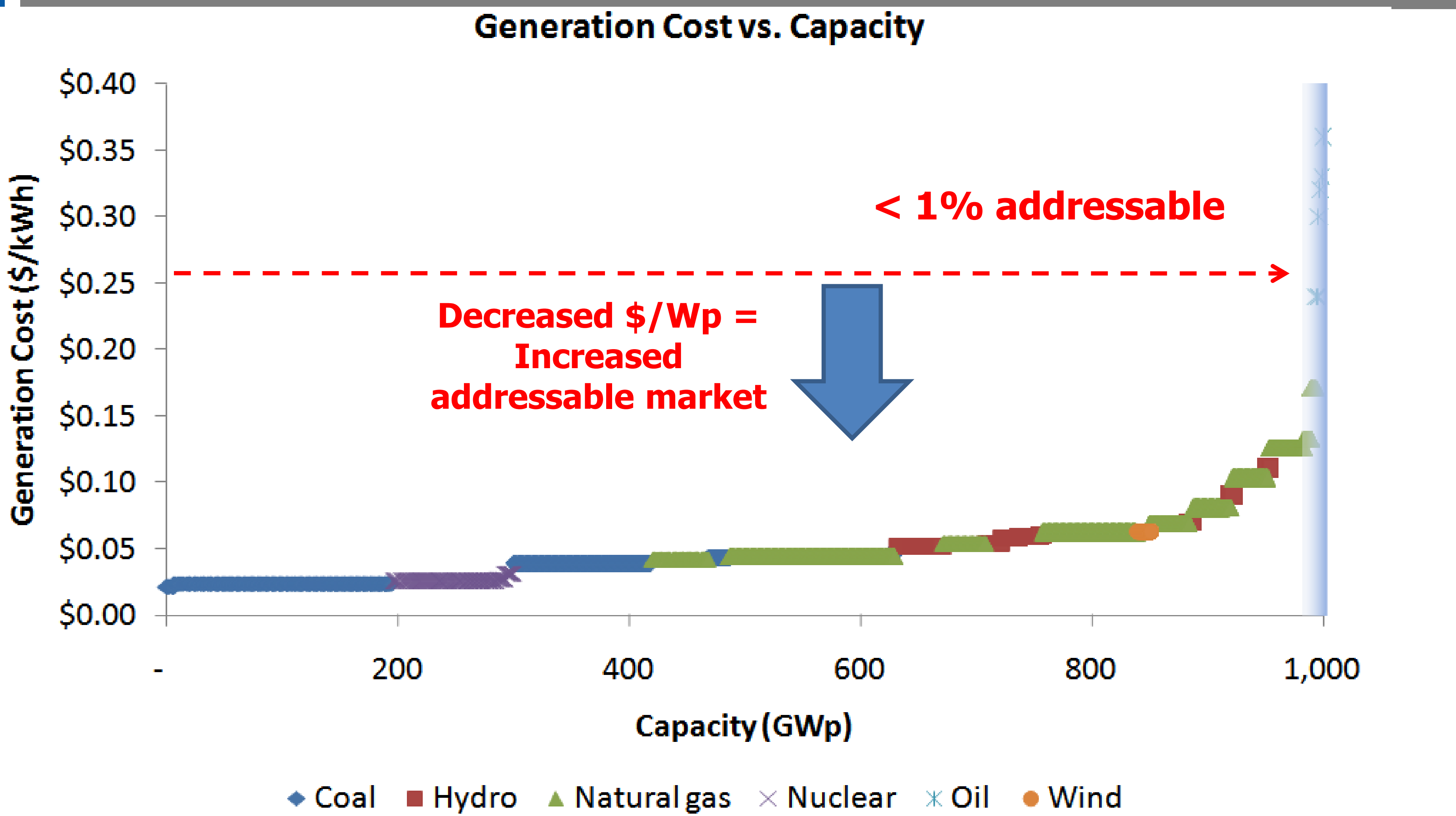
- String-level MPPT solutions – such as Satcon's Solstice – are starting to surface as compromised offerings for larger-scale systems.

# Outlook: Solar as a Percentage of Generation in 2015

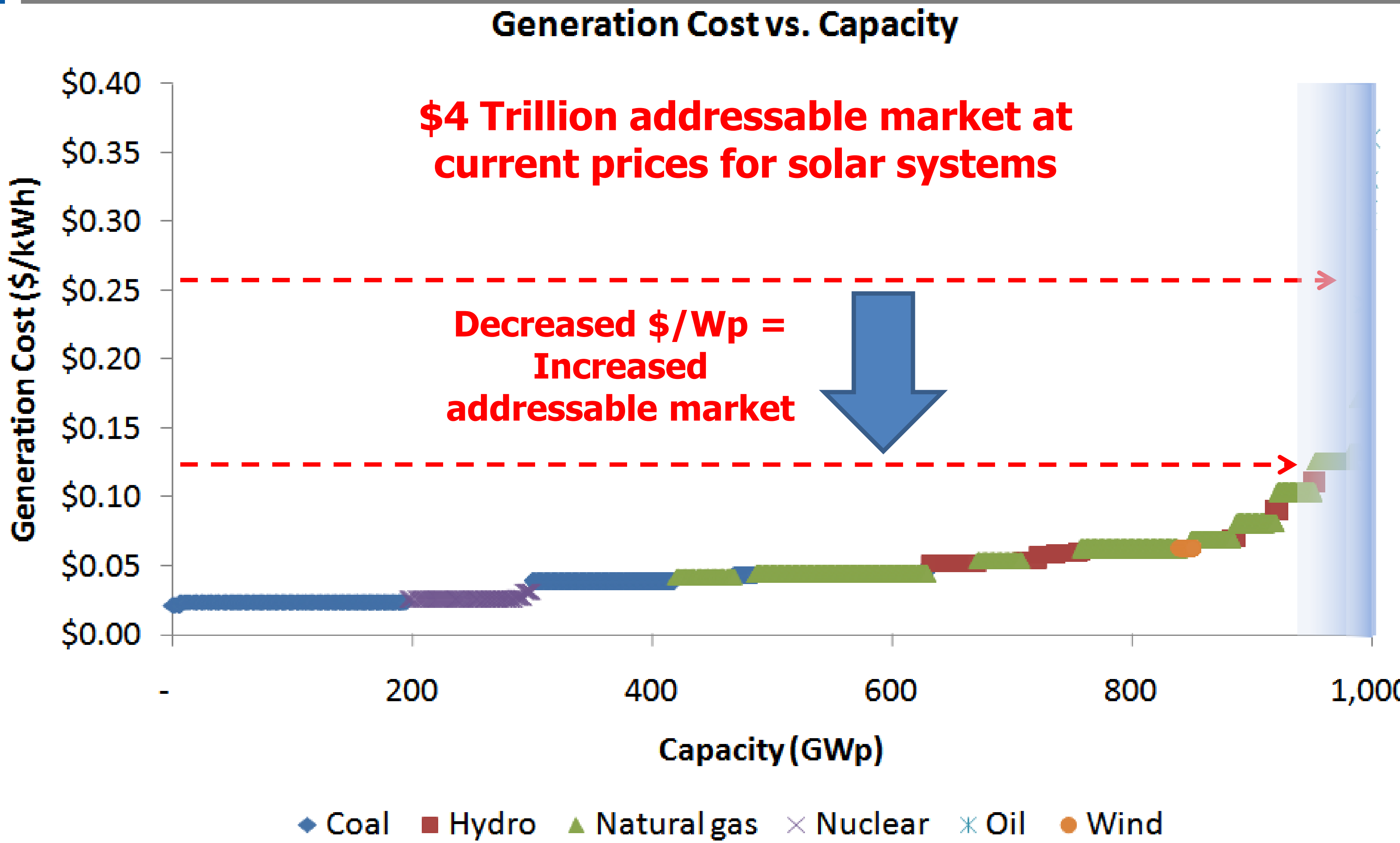



Power Supply Curve
NERC Subregion: New York Power Pool
Year: 2005
Baseload
Peaking
Variable Cost ($/MWh)
$350
$300
$250
$200
$150
$100
$50
$0
0
6,000
12,000
18,000
24,000
30,000
Cumulative Operating Capacity (MW)
Hydro
Coal
Nuclear
Gas
Oil
Other Fuel

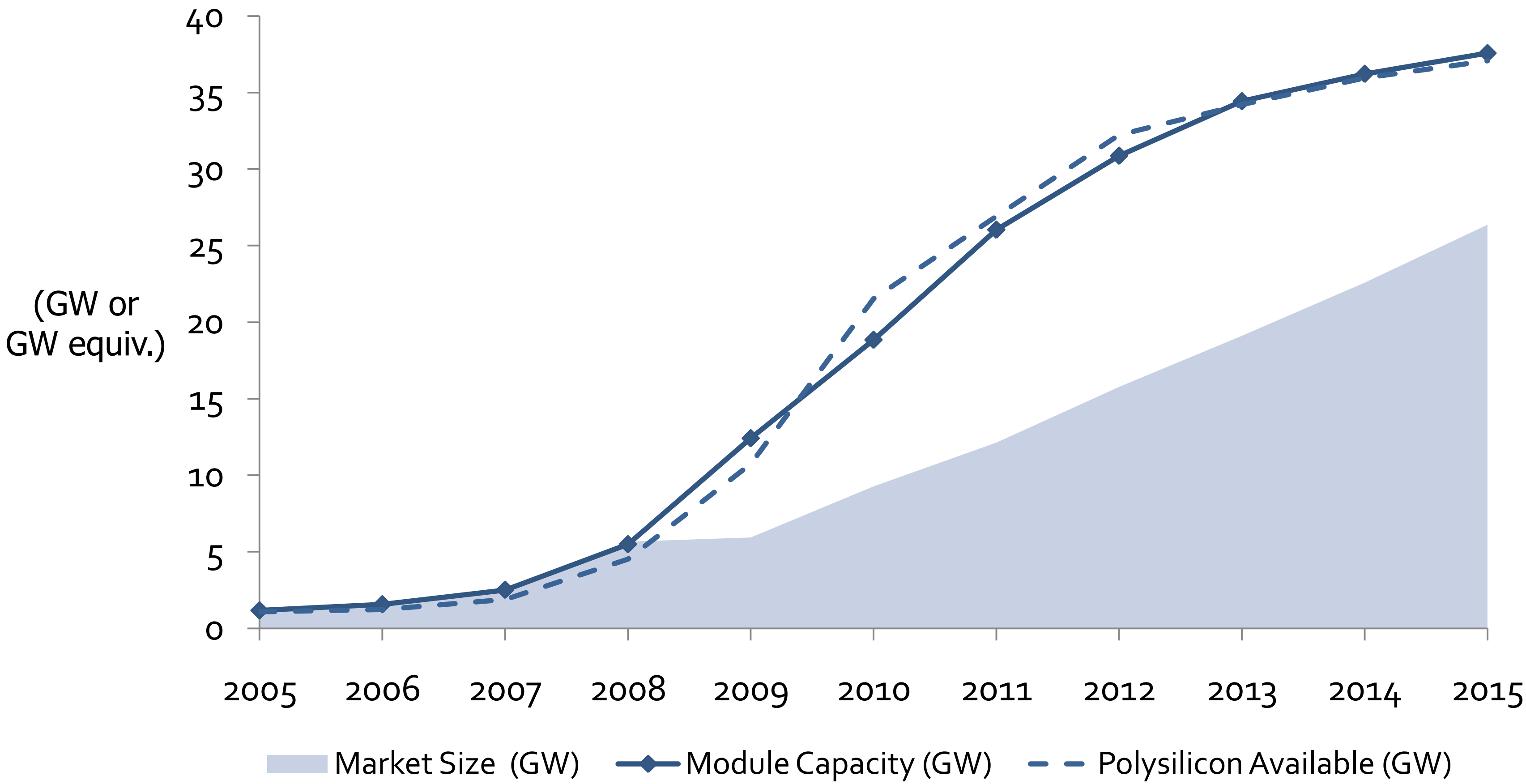
# Solar Generation Cost Determines Addressable Market



# Outlook: Cost reductions drive continued penetration of solar power



# Aggressive Capacity Expansions Perpetuate Oversupply Throughout the PV Value Chain




Source: Lux Research Solar State of the Market, February 2010

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# Lux Research - Sample companies covered

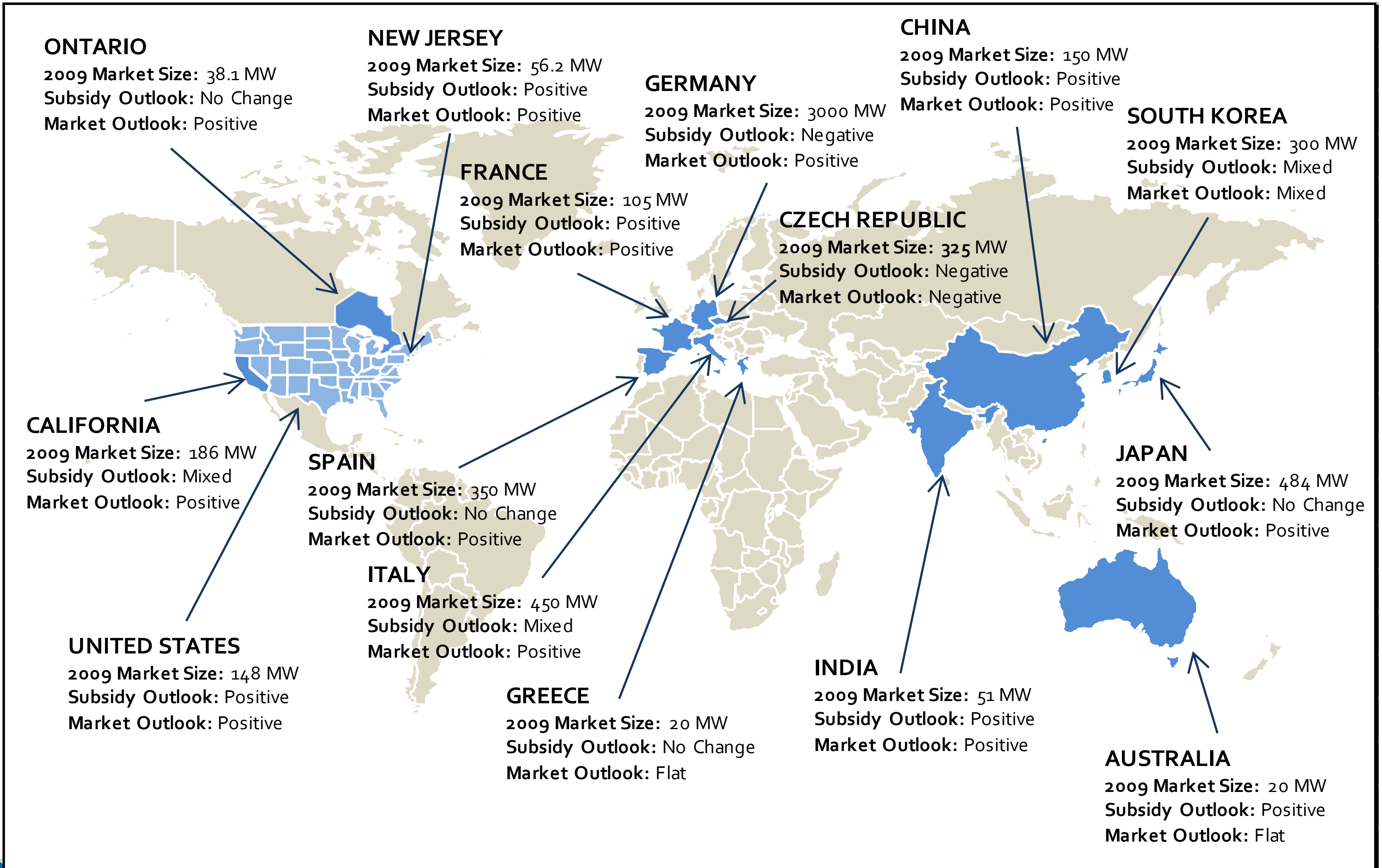
Over 300 companies profiled in primary research today. Some examples:

## Start-Ups

## Mid-sized Companies/Subsidiaries

## Large Corporations

# Subsidies Continue to Drive Volatility



# Maturing Asian and North American Markets Drive Growth through 2015

- German demand continues to buoy the global PV demand through 2010, but subsidy reductions prelude transition to emerging European markets
  - Germany hits 3.7 GW in 2010 as investors race anticipated mid-year subsidy cuts
  - While emerging PV markets work to address market limitations
    - — Italy works to overcome bureaucratic hurdles
    - — A positive revision to the French feed-in-tariff for ground-mounted installations
    - — The Czech Republic market cools due to halted interconnection by the country's largest utility in February 2010
- Moving forward, the maturing Asian and North American markets drive growth as Europe markets saturate
  - China's subsidies drive growth in volume to support domestic producers
    - — China's subsidies begin to impact overall global volume in 2010, aggressively driving forward through 2015
  - The North American market emerges at last to drive growth
    - — Ontario becomes a new darling destination for PV installations
    - — U.S. market reaches 1.1 GW in 2010 as government investment tax credits and loan guarantee programs begin to come online

# Crystalline silicon cost and efficiency improvements set an "ever rising bar"

Low cost crystalline silicon manufacturers will take full advantage of low cost polysilicon in 2010, while also making slower, but steady reductions in non-silicon conversion costs…while First Solar steadily leads in cost reduction efforts.

Canadian Solar

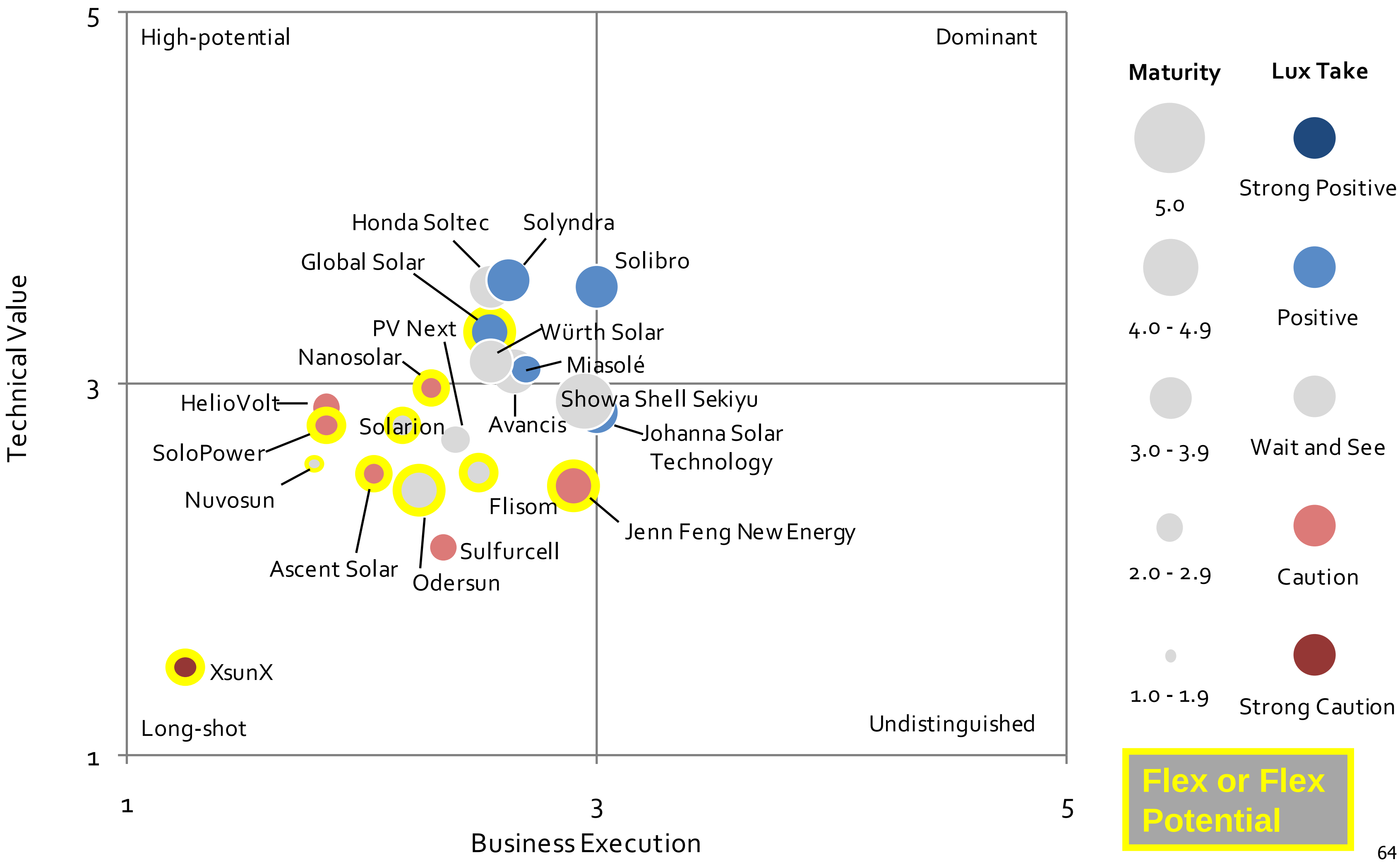
…while First Solar steadily leads the PV field with its cost reduction roadmap for its cadmium telluride modules, targeting costs as low as $0.52/W to $0.63/W by 2014

# New technologies must adapt to the rapidly changing "rules of the game"

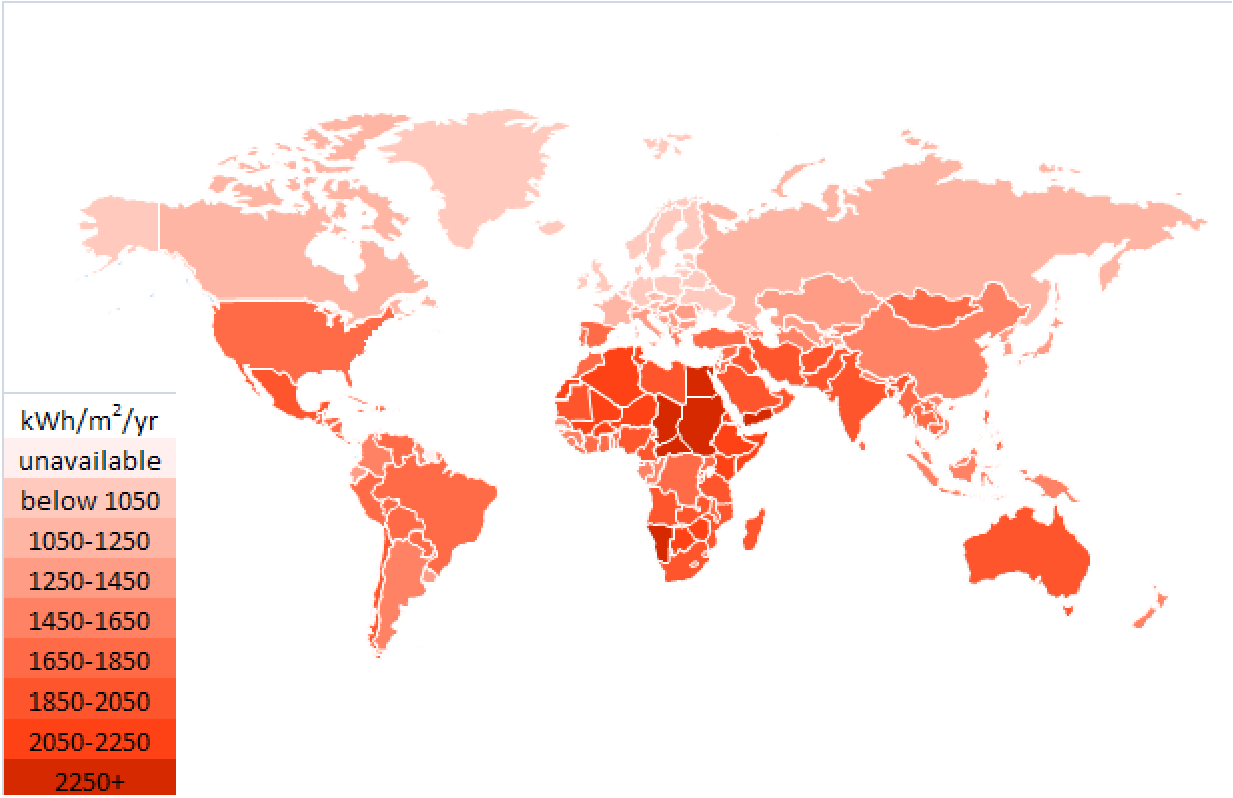
- High potential, high risk technologies – including copper indium gallium diselenide (CIGS), high concentration PV (HCPV), cadmium telluride (CdTe), and flexible thin film technologies – still hold potential to successfully enter the PV market

- However, targets and short-term expectations must be tempered

# Outlook among CIGS developers: Lux Innovation Grid



# Insolation and system performance determine system output – and thus revenue




*System Revenue = Insolation (hours/year) x [DC system capacity (kWp) x Inverter efficiency (%)] x System derate factor x PPA or FIT rate ($/kWh)*

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# A properly configured and located system is key to maximizing output

| Category | Description | Input Factors | Specific Example |
| --- | --- | --- | --- |
| **Module Performance** | The kWh output (DC) of a module per kWp depends on its performance under specific geographic conditions | Module temperature and temperature coefficient, output current and voltage, annual performance degradation, performance under different light spectra | Most thin film modules have a better DC yield (kWh/kWp) than crystalline silicon under low light conditions |
| **Inverter Performance** | The kWh output (AC) of a PV system depends on the efficiency of the inverter to convert the DC power output of the solar modules | Inverter efficiency (DC to AC) | Traditional inverters perform better under high current, requiring configuration in series – sacrificing system performance for inverter performance |
| **System Architecture Performance or "Derate" Factor** | The kWh output (AC) of a group of modules depends upon how the system is configured | Module shading or soiling, module mismatch, wiring in series or parallel, etc. | When wired in series, losses due to shading and module mismatch can result in series resistance that limits the performance of a string of modules to the output of the weakest module |

# New technologies must adapt to the rapidly changing "rules of the game"

- High potential, high risk technologies – including copper indium gallium diselenide (CIGS), high concentration PV (HCPV), cadmium telluride (CdTe), and flexible thin film technologies – still hold potential to successfully enter the PV market
- However, targets and short-term expectations must be tempered
- Overall, developers of new technologies will take one of three main routes to market:

# Route #1: Conserve Cash if You Have It

Those pursuing this strategy tend to fall into two categories: the **smart** and the **wealthy.** Which is better?

- WEALTHY: Aggressive developers who raised war chest but have disappointed on over-aggressive timelines

SolFocus MIASOLÉ nanosolar

- SMART: Conservative developers who have taken the long view from the beginning and conserved cash

GLOBAL SOLAR AMONIX NanoGram corporation

# Route #2: Exit Early for Long-term Capital

Attract a strategic buyer to provide long-term technology incubation, or seek an IPO soon – but both likely at lower terms than anticipated by investors

- M&A: Players with high capital costs and long timeline and uncertain timeline to commercial adoption

- IPO: Players with lower capital costs and/or starting to see commercial traction

# Route #3: Cheap M&A by Strategic Buyer

One of the last options for investors seeking to recoup capital, but only after Route #1 and #2 have failed.

- Recent examples:

# Largest Global Companies Buy Into Solar Aggressively

- Technology giants make advantageous investments into firms that require long technology development lead times.
- Firms with large-scale project and distribution experience layout large sums to diversify into solar thermal
- Now is the time to buy…but who's next?

intel → PrimeStar Solar (Making It Happen)

BOSCH → aleo, ersol, Johanna Solar Technology

# Agenda

- Volatility of supply and demand drives  vertical integration strategies – first "reverse integration" then "forward integration"
- Overview of "levelized cost of electricity" (LCOE) calculation
- As demand shifts from Europe to emerging solar markets, aggressive capacity expansions will set up stark future corrections
- The success of new technologies will depend upon their developers' strategies for waiting out the storm

# Module cost and performance: Improved system performance with PV technologies

| Category | Description | Input Factors | Specific Example |
|---|---|---|---|
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**→ Technology developers and investors must base expectations on penetration via targeted applications with focus on overall system cost and performance**

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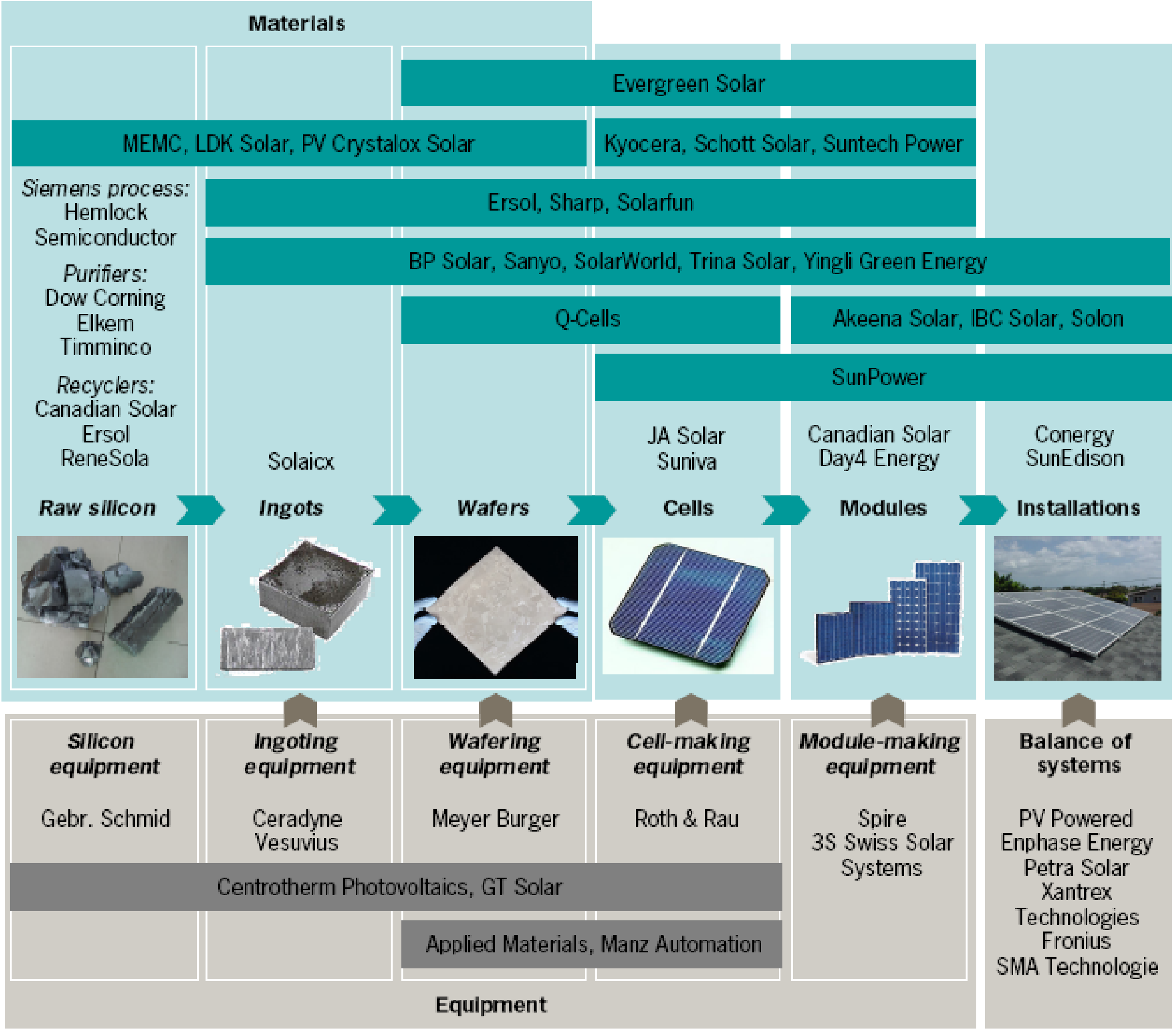
# Lux Research Solar covers the value chain – from materials to installations

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Source: Lux Research, Solar State of the Market Q1 2008

# Lux Research Solar - Technologies assessed

- Multi- and mono-crystalline silicon
- Upgraded metallurgical grade silicon (UMG-Si)
- Amorphous and micro-crystalline thin-film silicon
- CdTe thin films
- CIGS/CIS thin films
- High concentrating PV (HCPV)
- Low concentrating PV (LCPV)
- Dye-sensitized (Grätzel) solar cells (DSSC)
- Organic photovoltaics (OPV)
- Concentrating solar power (CSP)
- Tracking systems, inverters, and other enabling technologies
- Silicon thin-film (amorphous, microcrystalline, and nanocrystalline)
- Solar thermal
- Other novel technologies including nano-antennas, organic solar concentrators, and exotic thin-film approaches

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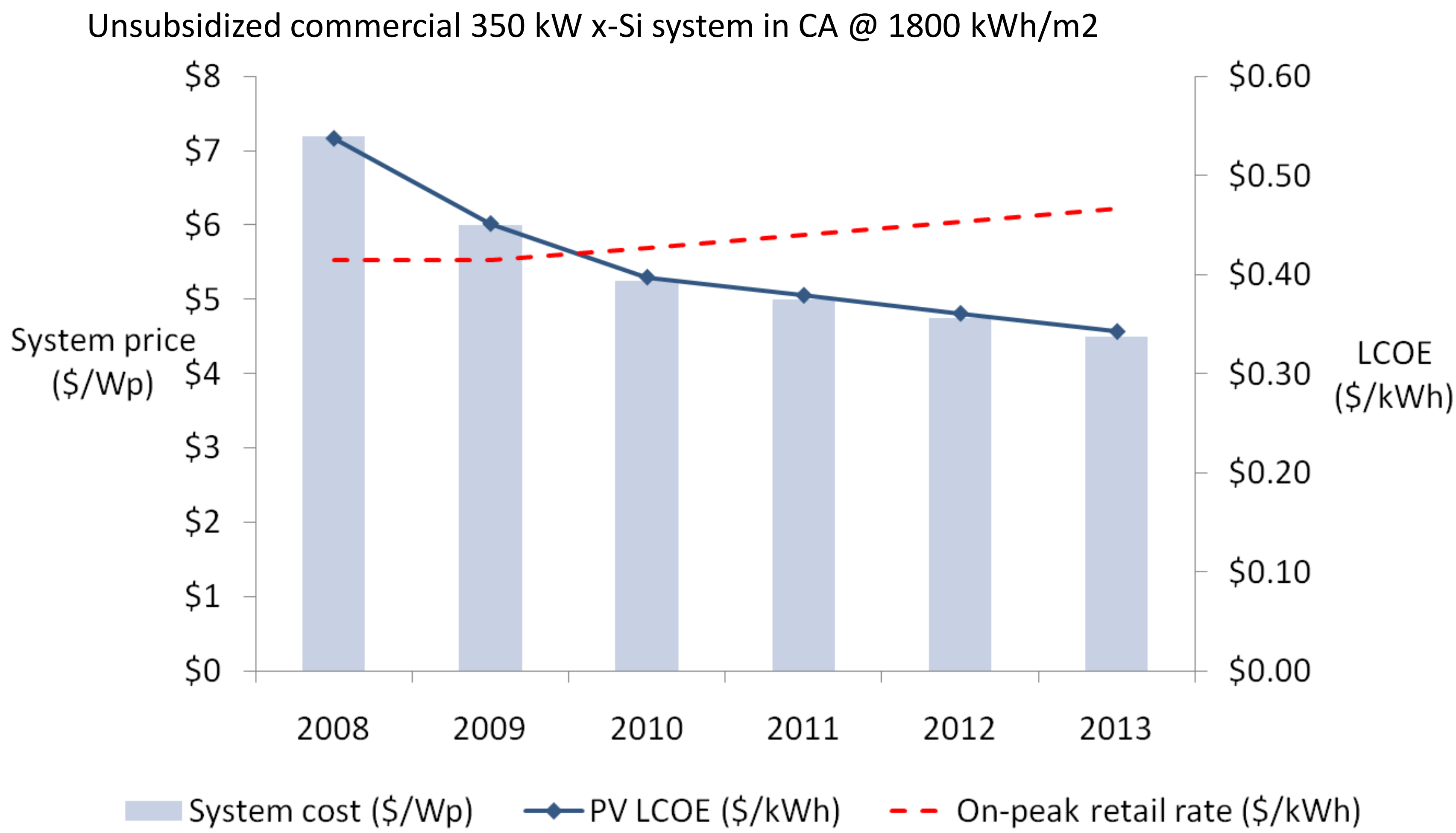
# California commercial x-Si PV systems are close to grid parity at peak rate

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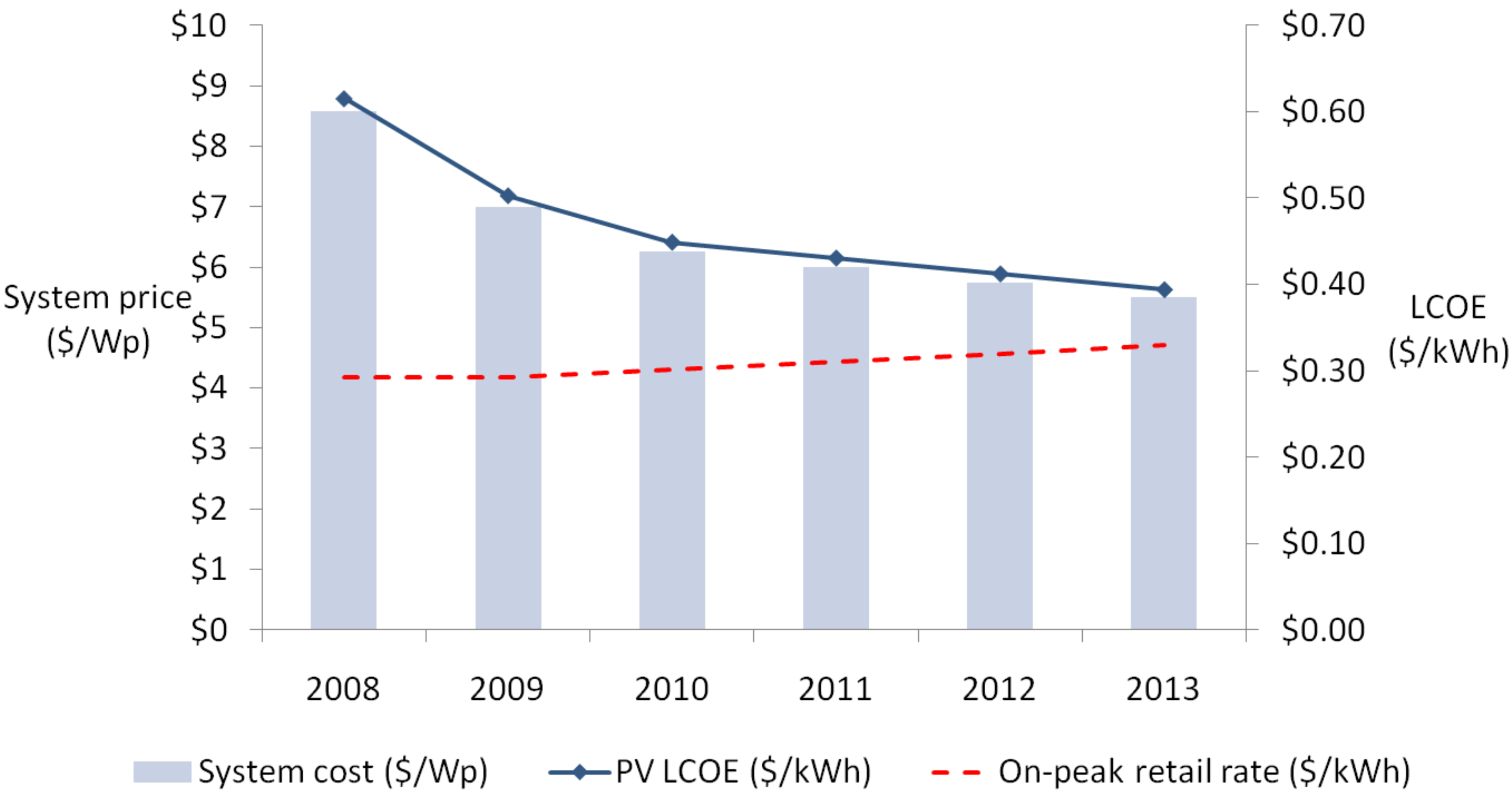
# Price cuts due to oversupply put residential "grid parity" within striking distance

Unsubsidized residential 5 kW x-Si system in CA @ 1800 kWh/m2

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# System cost: the "less exciting side" of solar is an equal partner in system cost reduction

**Case study**: BOS costs for a 5 kW c-Si installation with a standard string inverter

| | 2009 Price ($/W) | Annual cost reduction (%) | Net impact on a c-Si residential installation |
|---|---|---|---|
| Racking | $41/m$^2$ | -2% | $4.70/m$^2$ cost reduction from 2009 to 2015 |
| Wiring | $32/m$^2$ | -2% | $3.60/m$^2$ cost reduction from 2009 to 2015 |
| String-level inverters | $0.58/W | -3% | $0.11/W cost reduction at residential level from 2009 to 2015; slightly improved electricity output |
| Engineering and design | $8.20/m$^2$ | -2% | $1.46/m$^2$ or $0.01/W cost reduction at residential level from 2009 to 2015 |
| Labor (mounting and electrical connection) | $180/m$^2$ | -4% | $78/m$^2$ or $0.44/W cost reduction at residential level from 2009 to 2015 |
| Regulatory, sales, and general admin (SG&A) | $184/m$^2$ | -2% | $21/m$^2$ or $0.12/W cost reduction at residential level from 2009 to 2015 |

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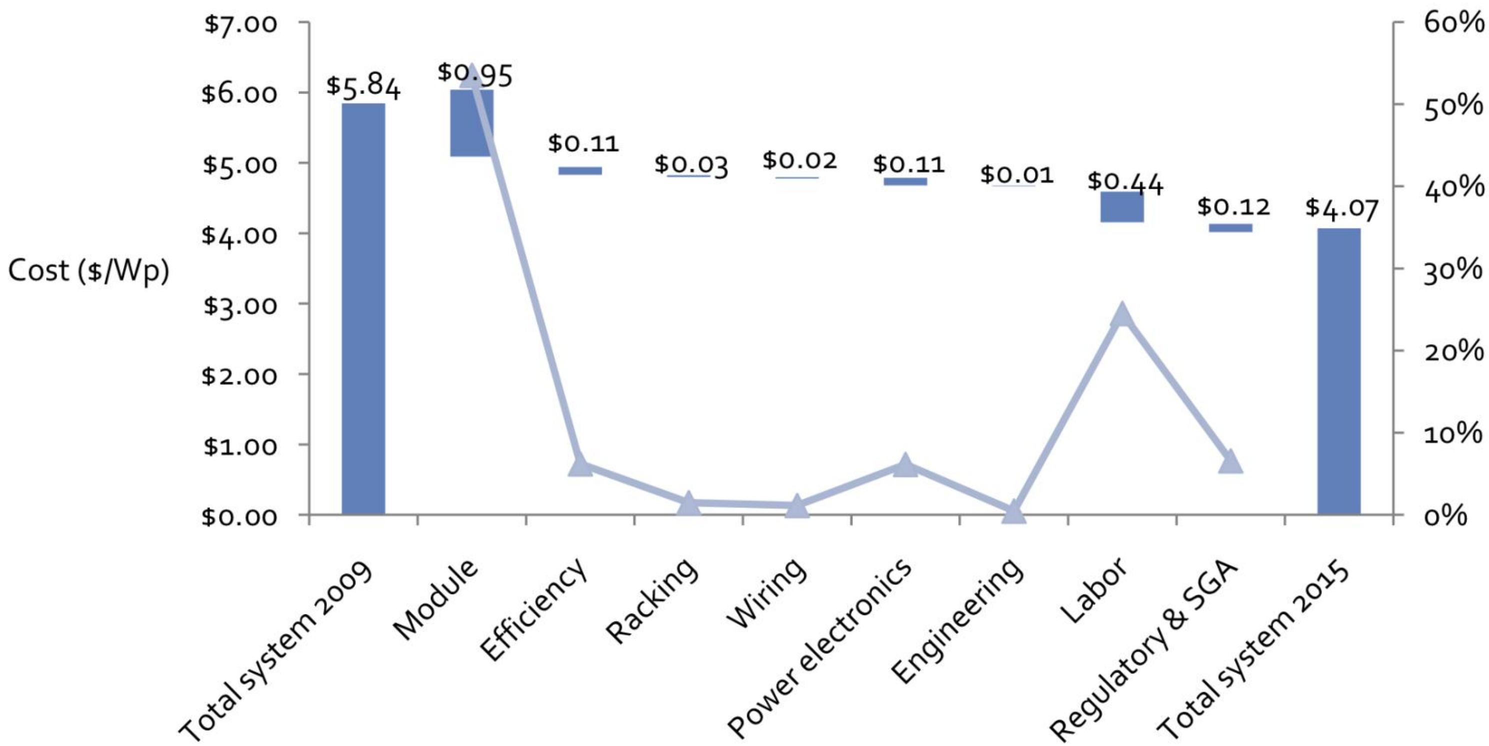
# System cost: Often overlooked, labor costs offer the highest potential for BOS savings

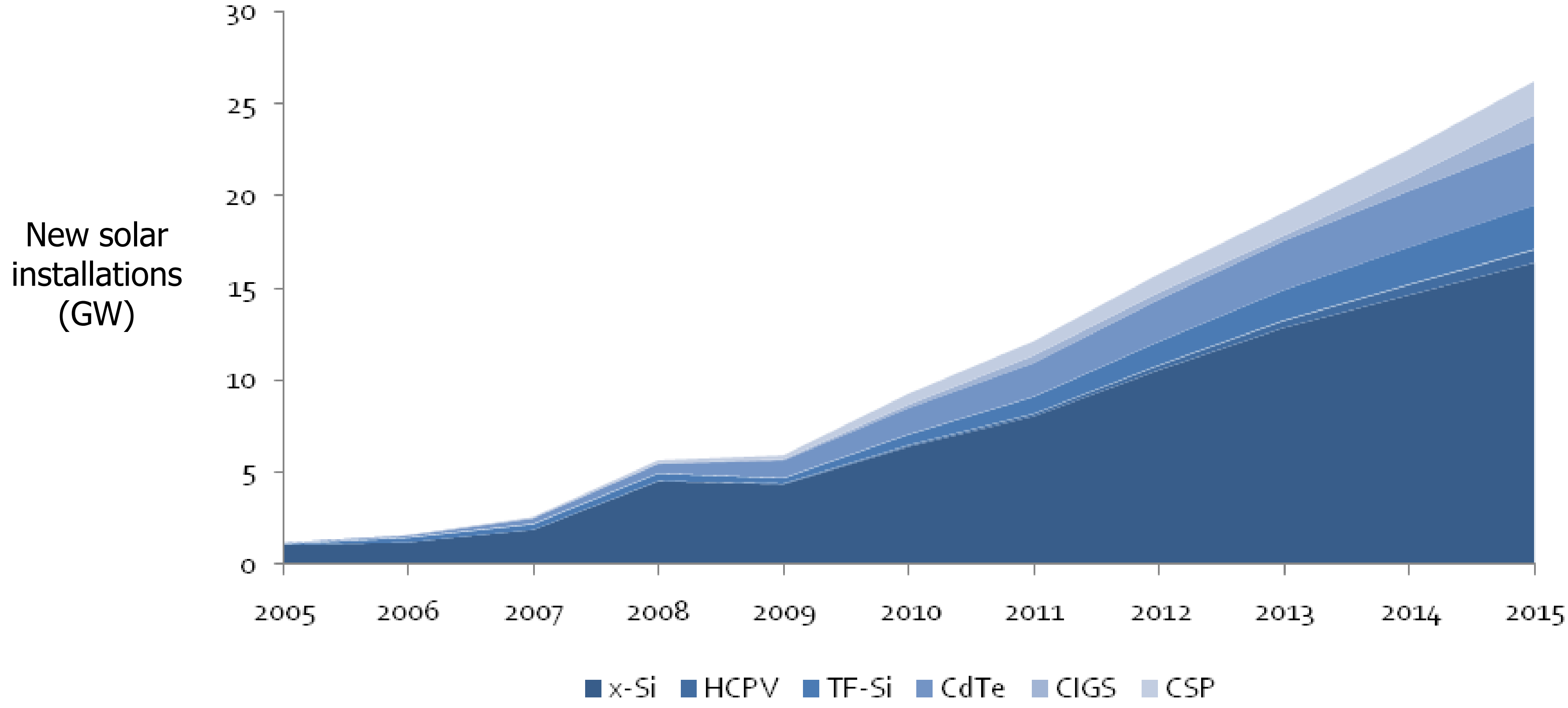
- Labor savings account for 25% of *total system* cost reductions through 2015, driven by standardization and improved engineering that lead to a reduction in the quantity and skill of labor required.




Based on 2009 pricing for a residential 5 kW c-Si system with a string level inverter

# Module cost and performance: x-Si stays on top; solar thermal, thin film make gains

New technologies expand market share through success in specific applications where they can surpass an **"ever rising bar"** to adoption




Source: Lux Research Solar State of the Market, February 2010