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PVST 光伏科学与技术国家重点实验室
State Key Laboratory of PV Science & Technology

Cost analysis of current PV production and strategy for future silicon PV modules

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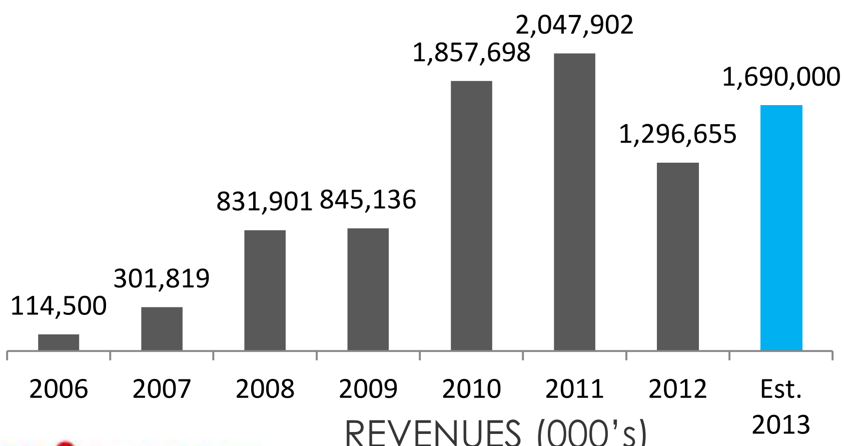
Presentation to UNSW
January 22nd, 2014

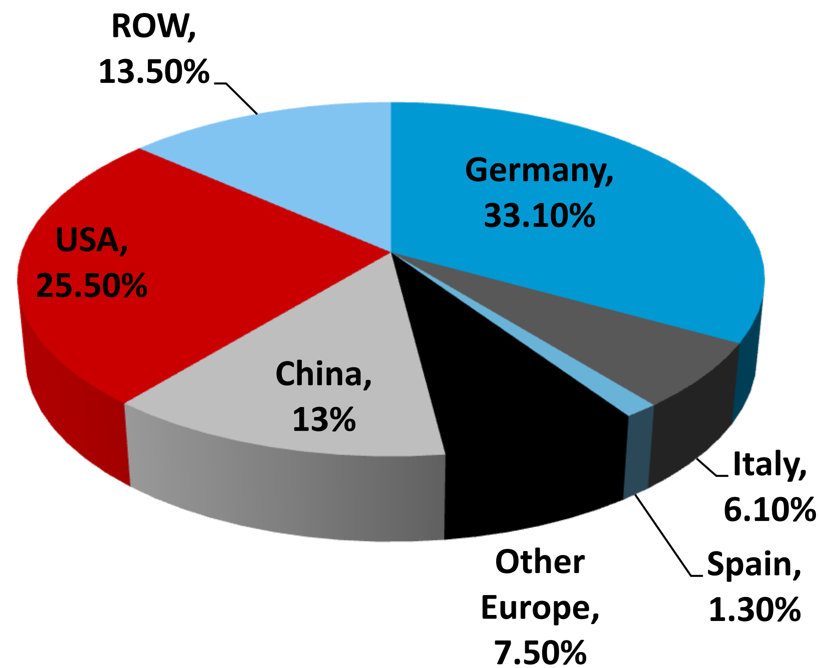
1. Trina Solar: A Global Solar Player
2. Where is the PV Industry going?
3. Cost Reduction Analysis
4. Future Challenges
5. Opportunities and Strategies
6. Sustainability
7. Conclusions

Company Snapshot

- Founded in 1997, in Changzhou, China
- $2,048 million 2011 net revenue[2]
- 22 offices worldwide
- Listed on the NYSE: TSL — TSL LISTED NYSE
- World's largest PV manufacturing campus[2]
- Over **7.5 GW shipped** since 2007[3]



Sales 2012



2012 SHIPMENTS – **1720 MW**[1]

Est. 2013 SHIPMENTS – **2600 MW**

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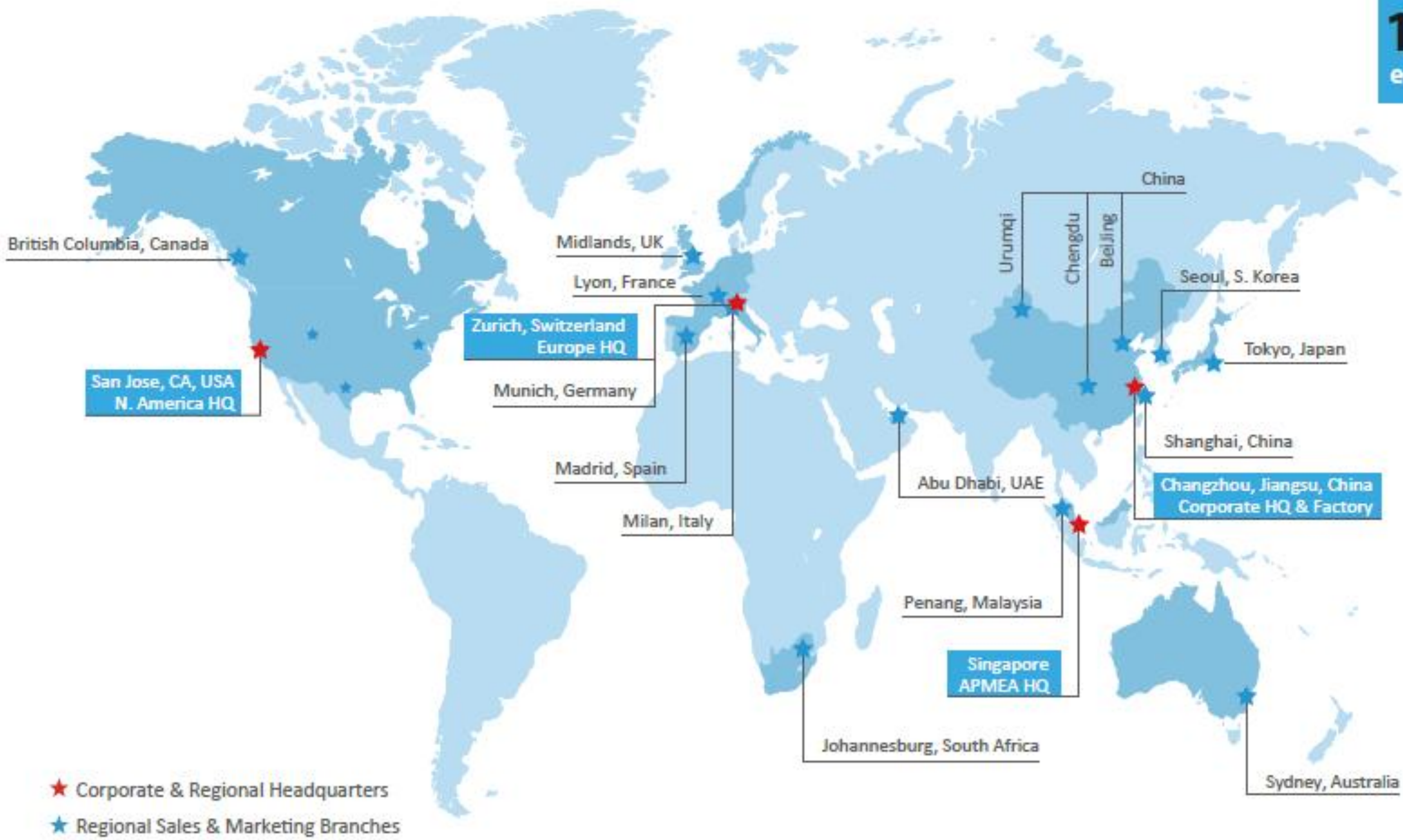
1. *Geographical breakdown, based on country record of sales, not end installation. Data as of Dec 31, 2012*
2. *As of February 23, 2012*
3. *As of January, 2014*

GLOBAL FOOTPRINT

APPROX. **20** branch locations,

15,000 employees



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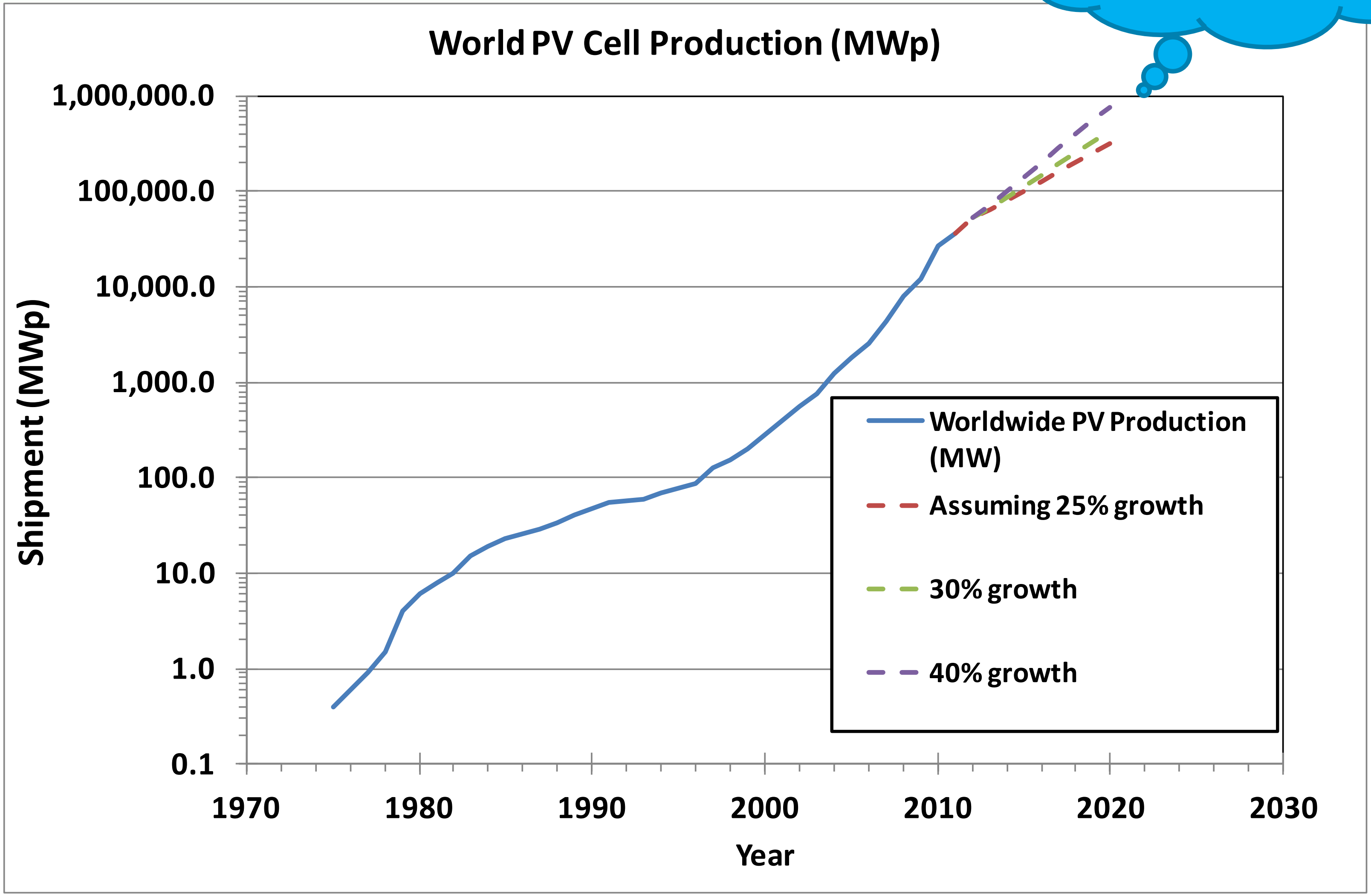
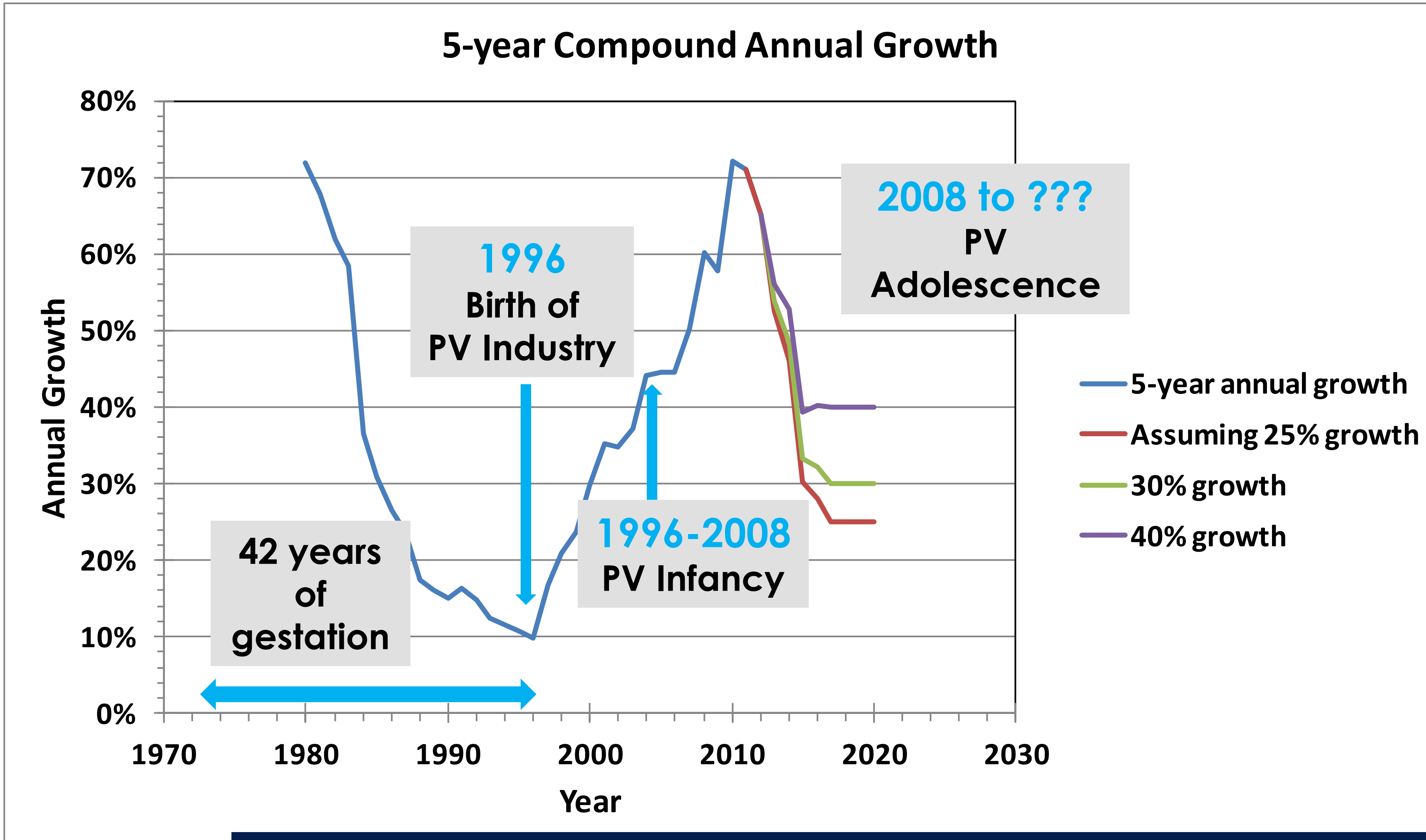
A Steady Growth …

TeraWatt/year
by 2025 +/- 5?



Various sources: Paul Maycock's PV News, Photon International, Navigant

Industry History



What are the conditions required for PV to reach adulthood?

5 Conditions Required for PV to reach “adulthood”

1. Cash-flow Sustainability
   - Profitable and generate enough cash for growth
2. Subsidization-free market
   - PV must become a “no-brainer” (an obvious choice) even without subsidies
3. Material Sustainability
   - No material supply issue up to TW/year level
4. Energy Sustainability
   - PV must have a positive impact on the reduction of fossil fuel consumption
5. Grid-management Sustainability
   - PV must become a “Voltage source”, as well as a “Power source”, in a smart grid environment, with efficient storage

Learning Curve Model

- Every manufactured product exhibits a reduction in cost following a learning curve model

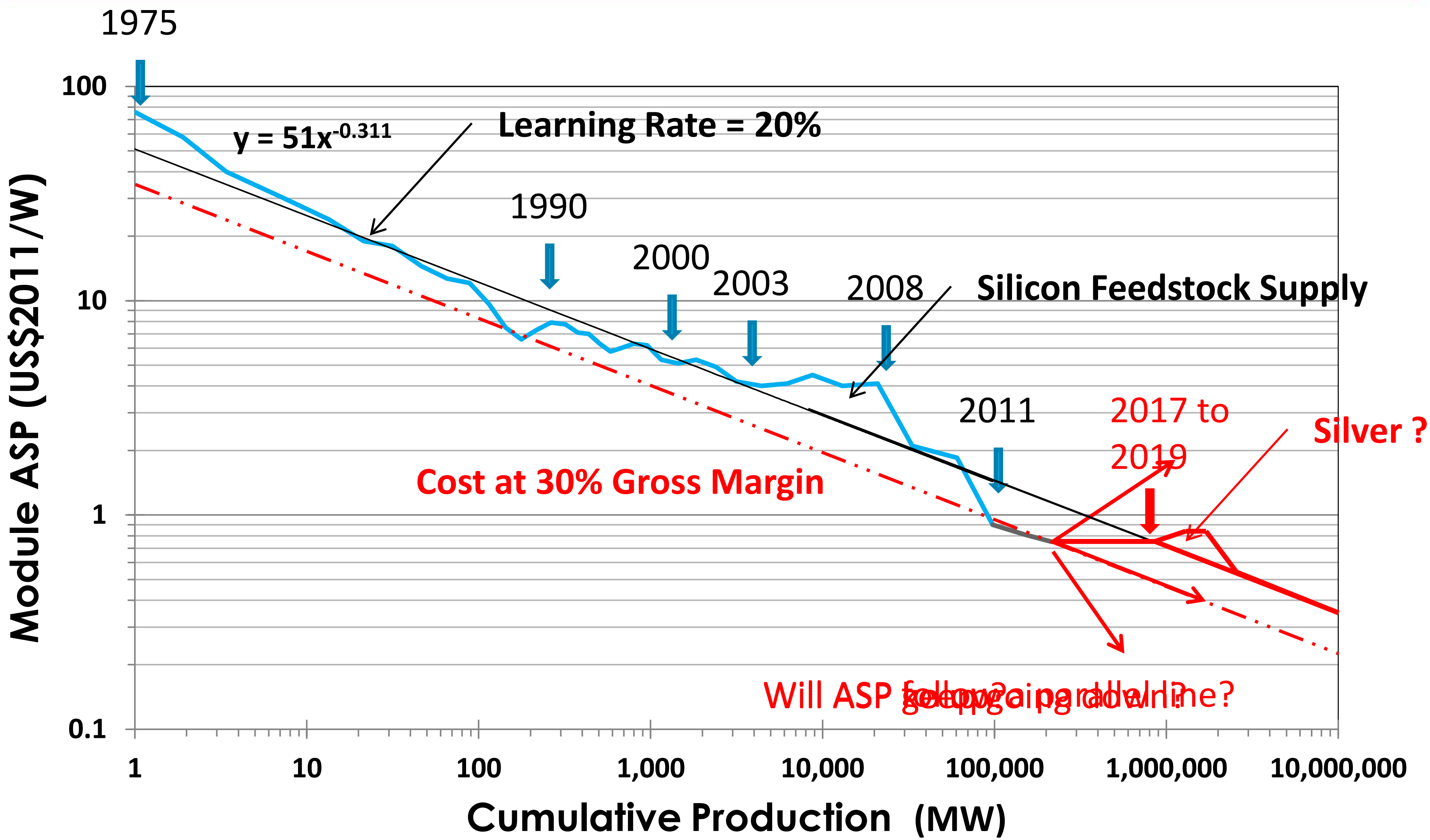
$$C_t = C_0\left(\frac{q_t}{q_0}\right)^{-b}$$

- ➢ q is cumulative production
- ➢ "learning by doing"

- Progress Ratio $PR = 2^{-b}$

- Learning Rate $LR = (1 - PR)$

1975-2012 Module Prices ($2011)



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Price, Cost and Cumulative Production

- Between 2008 and 2012, the price of PV modules has plummeted. But what really happened to the cost of manufacturing?

Year	ASP (2011US$)	Cumulative Production (GW)	Cost from Learning Curve Model	Real Cost
Begin. 2008	**4.0**	**13.0**	**100%**	**100%**
End 2012	**0.73**	**150.3**	**46.7%**	**?**
Δ=5 years	**-81.75%**	**Ratio = 11.56**	**-53.3%**	

$$C_t = C_0 \left(\frac{q_t}{q_0} \right)^{-b}$$

with b = -0.311

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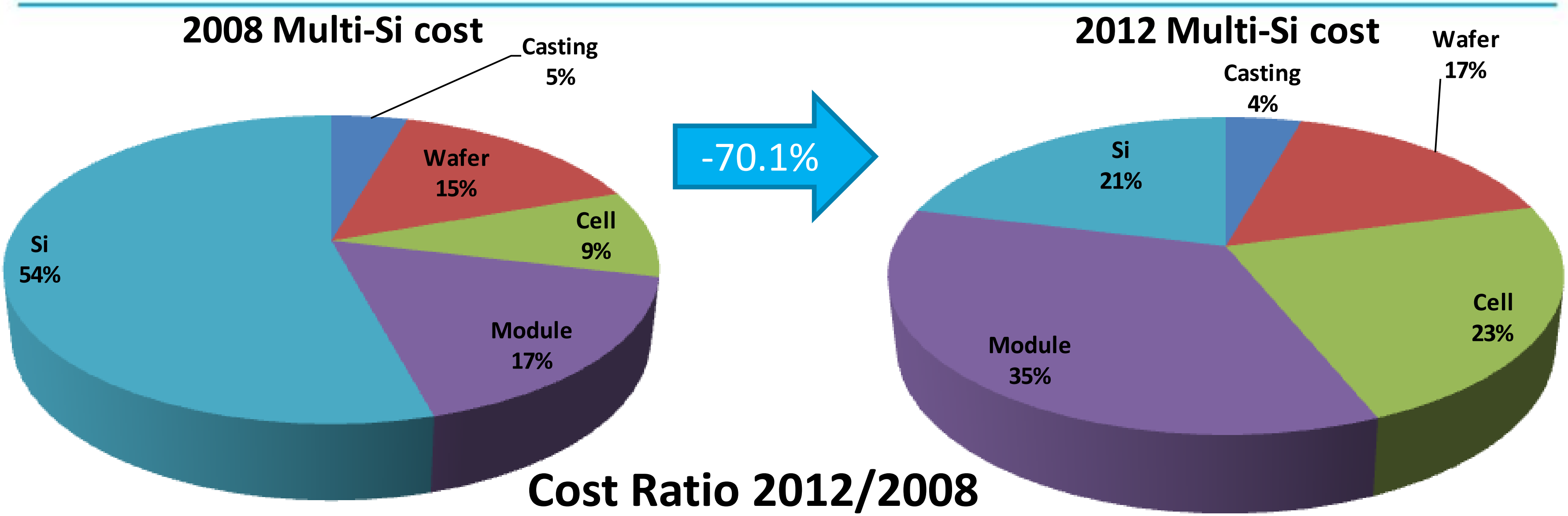
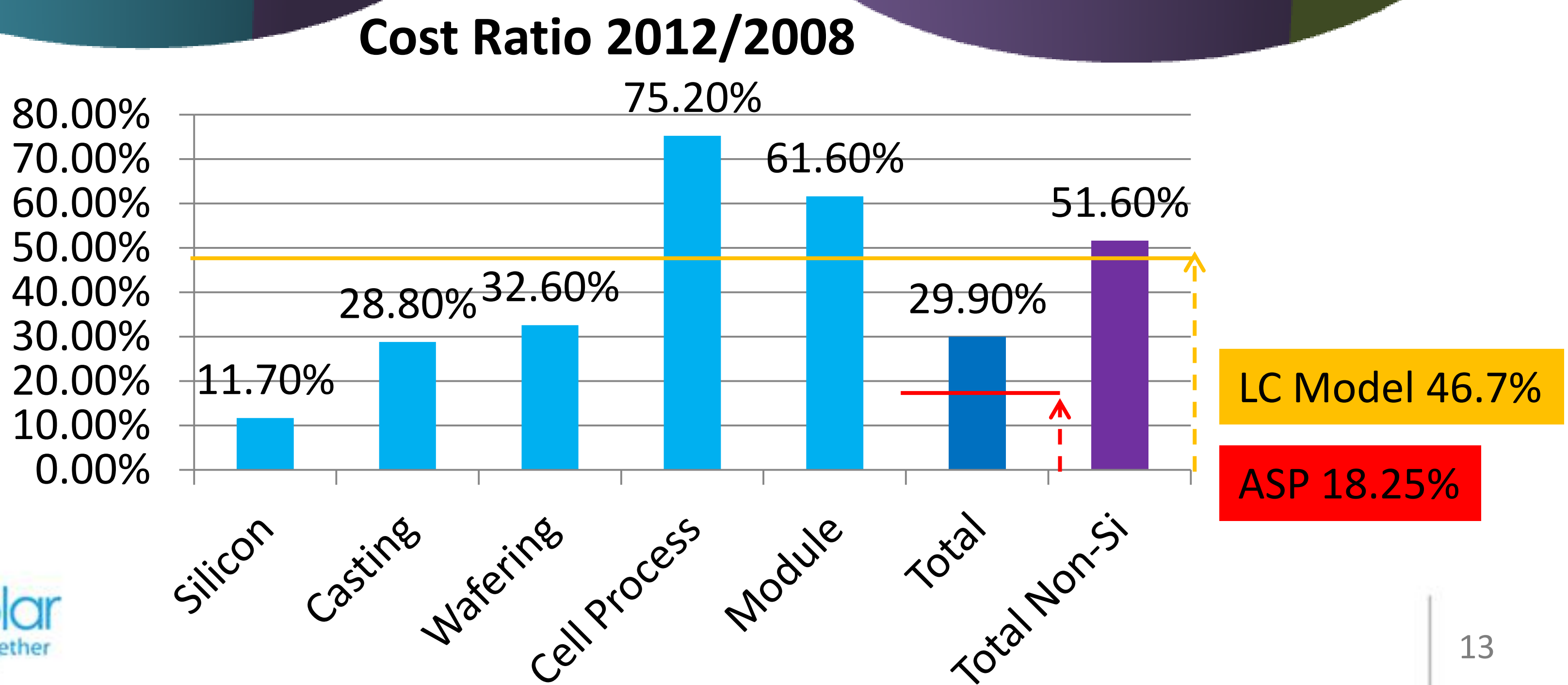
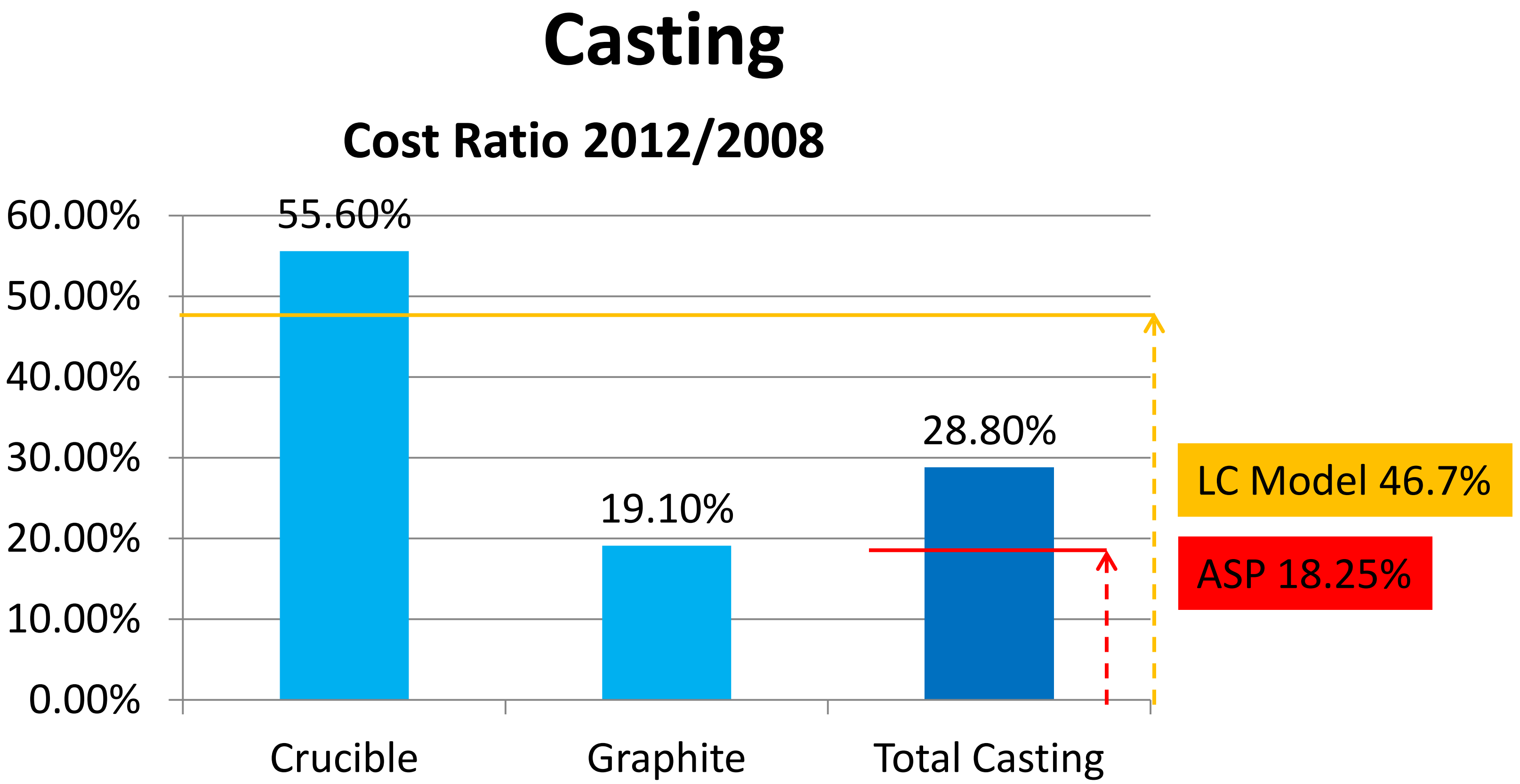
Manufacturing Cost of Multi-Crystalline Si PV Modules





Major Material Cost 2012 compared to 2008



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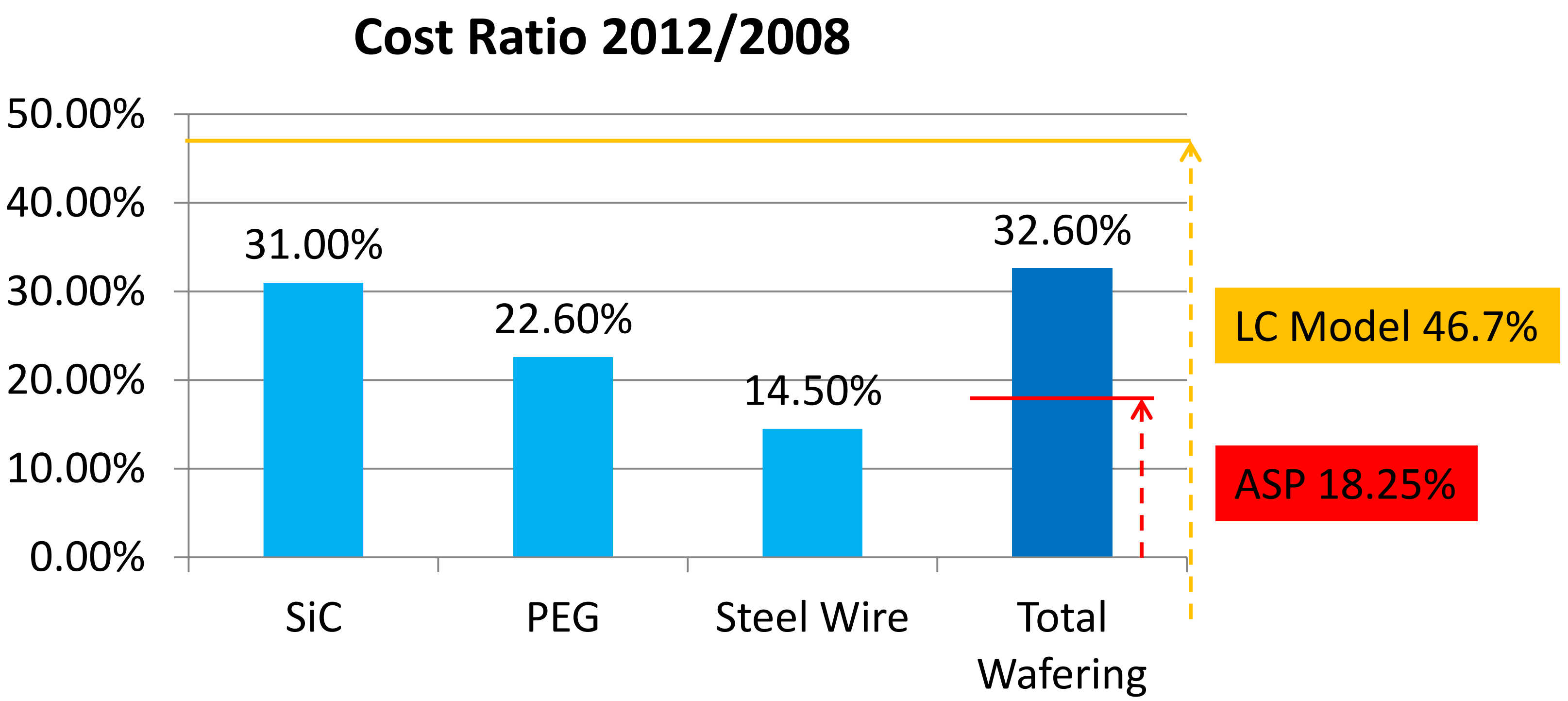
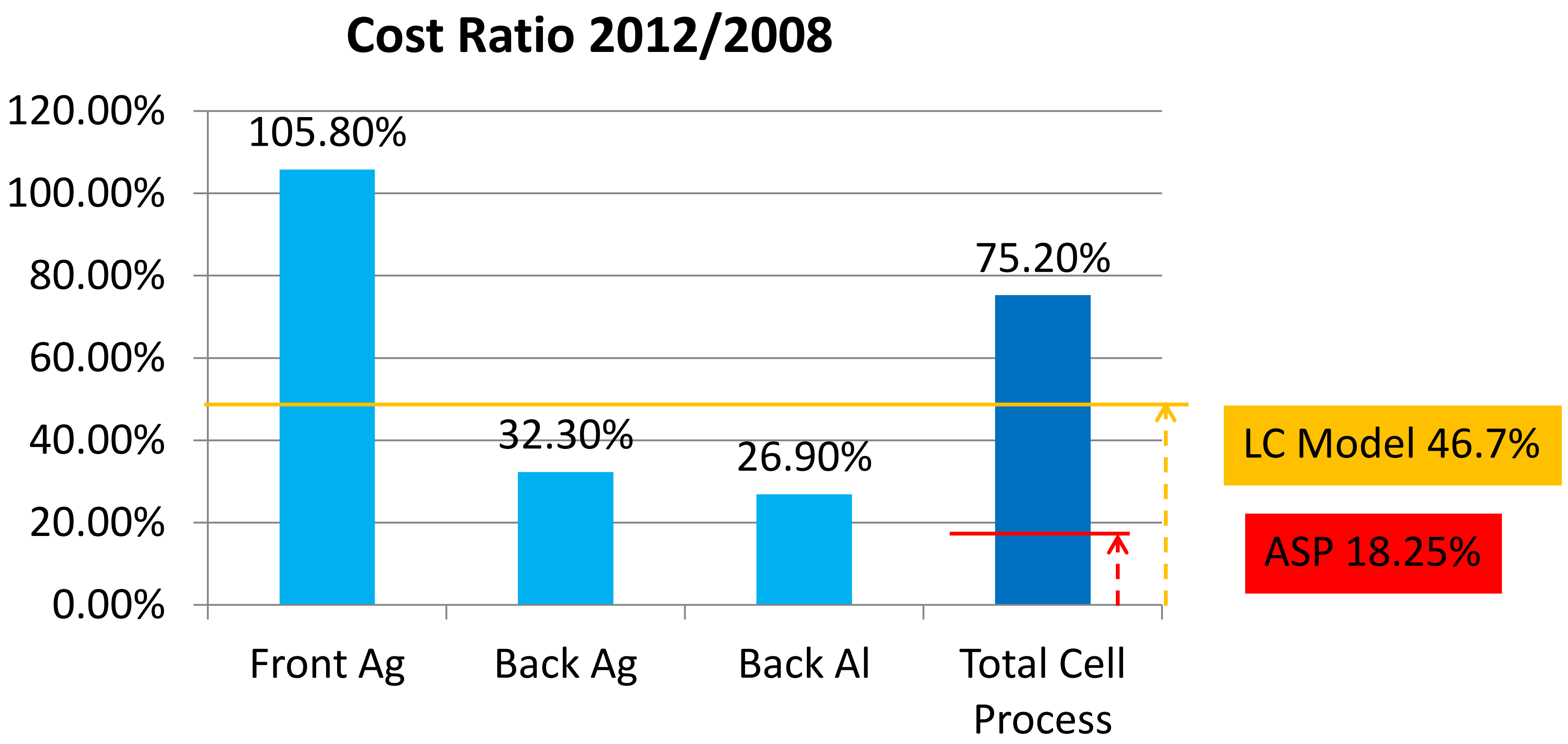
Major Material Cost 2012 compared to 2008

Wafering



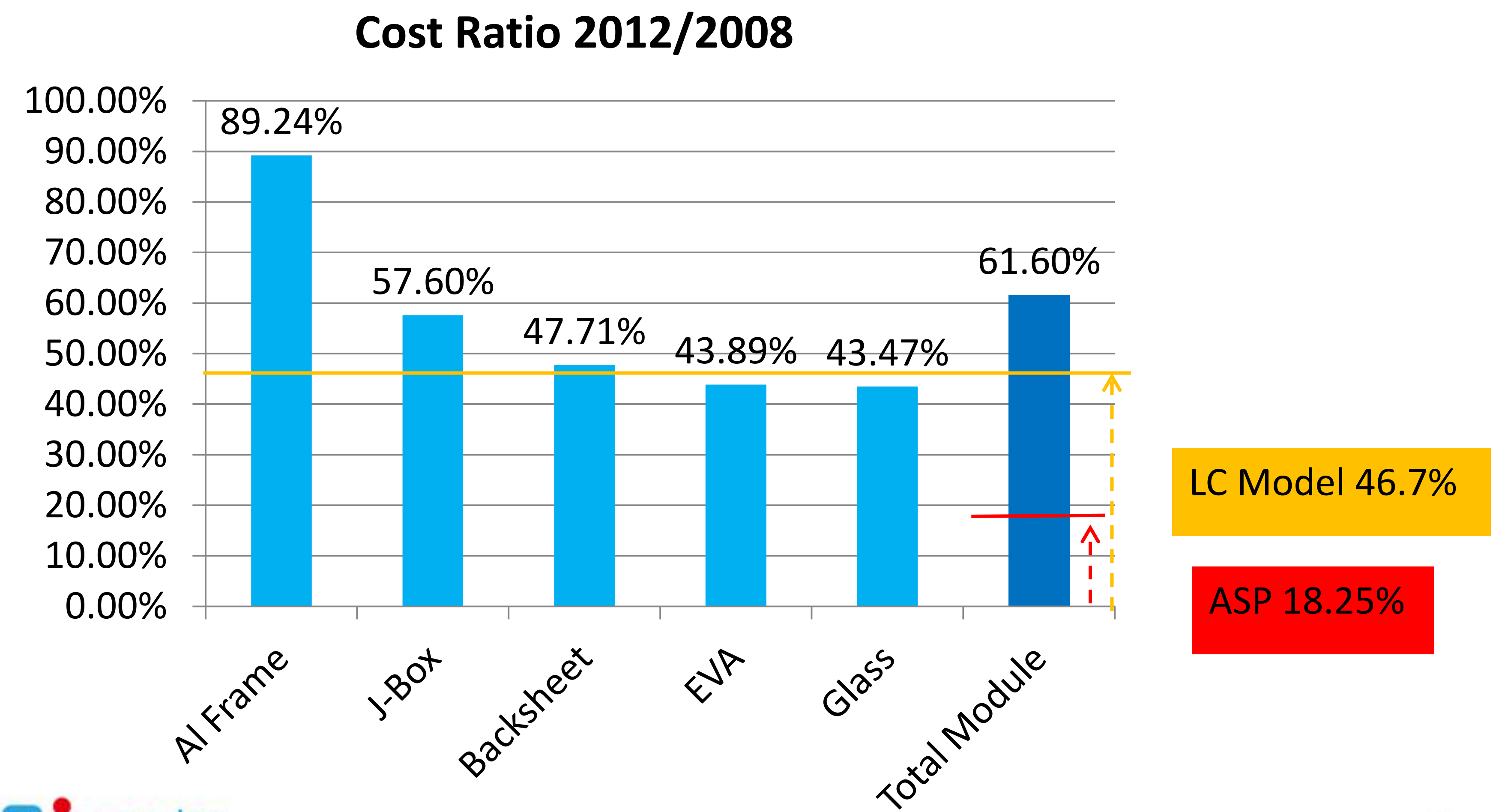
Major Material Cost 2012 compared to 2008

Cell Processing

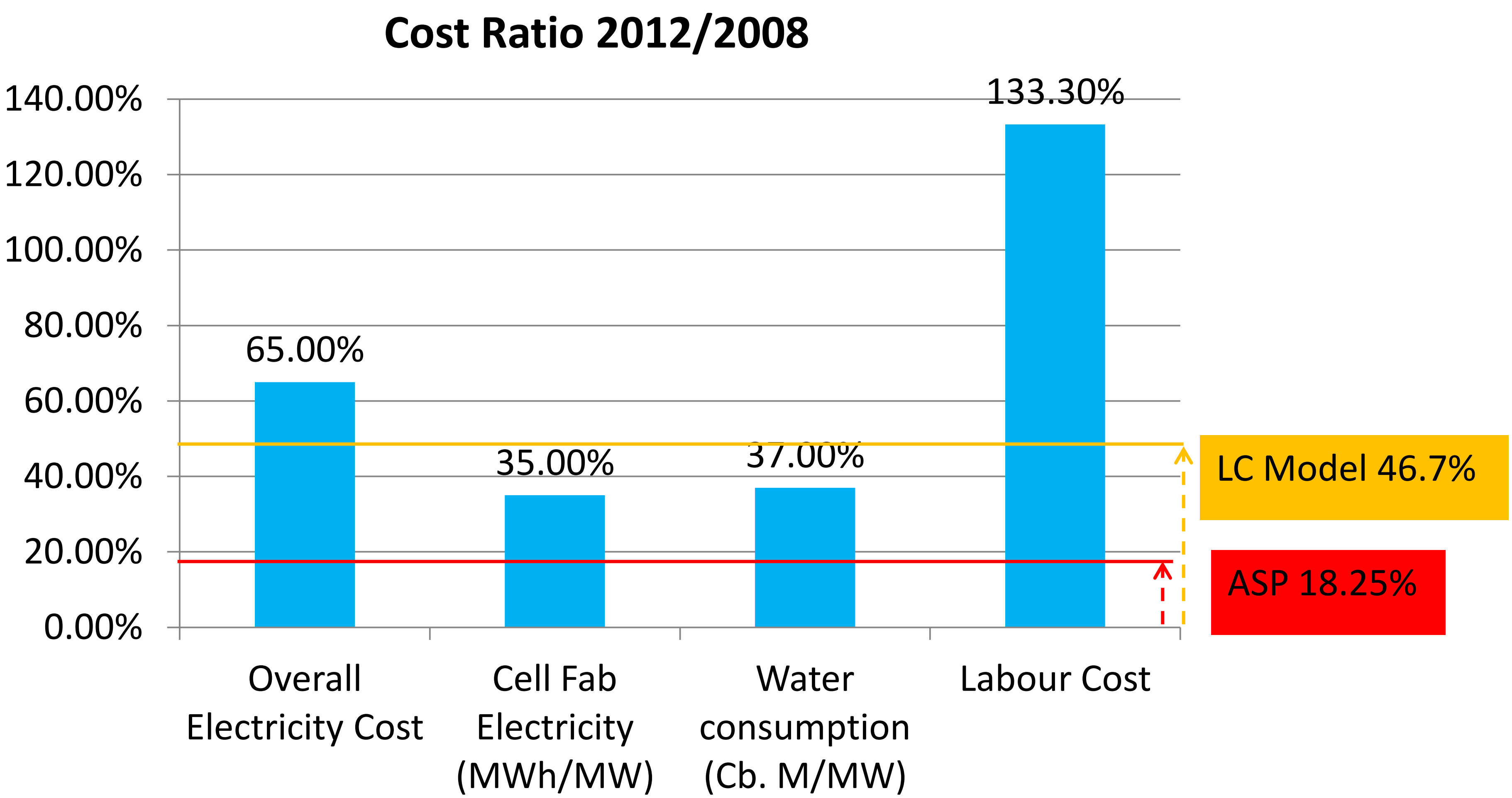


Major Material Cost 2012 compared to 2008

Module



Other Major Costs: 2012 compared to 2008



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Cash Flow and Energy Sustainability

1. Increase EBITDA to be able to invest for growth

$$Growth \le \frac{ASP}{ACB} \times EBITDA(\%)$$

2. Energy Pay-Back Time (EPBT)

$$Growth \le \frac{1}{EPBT\left(in\_years\right)}$$

*ASP = Average Sales Price
ACB = Average Cost to Build
EPBT = Energy Pay-Back Time
EBITDA = Earning Before Interest, Tax, Depreciation and Amortization

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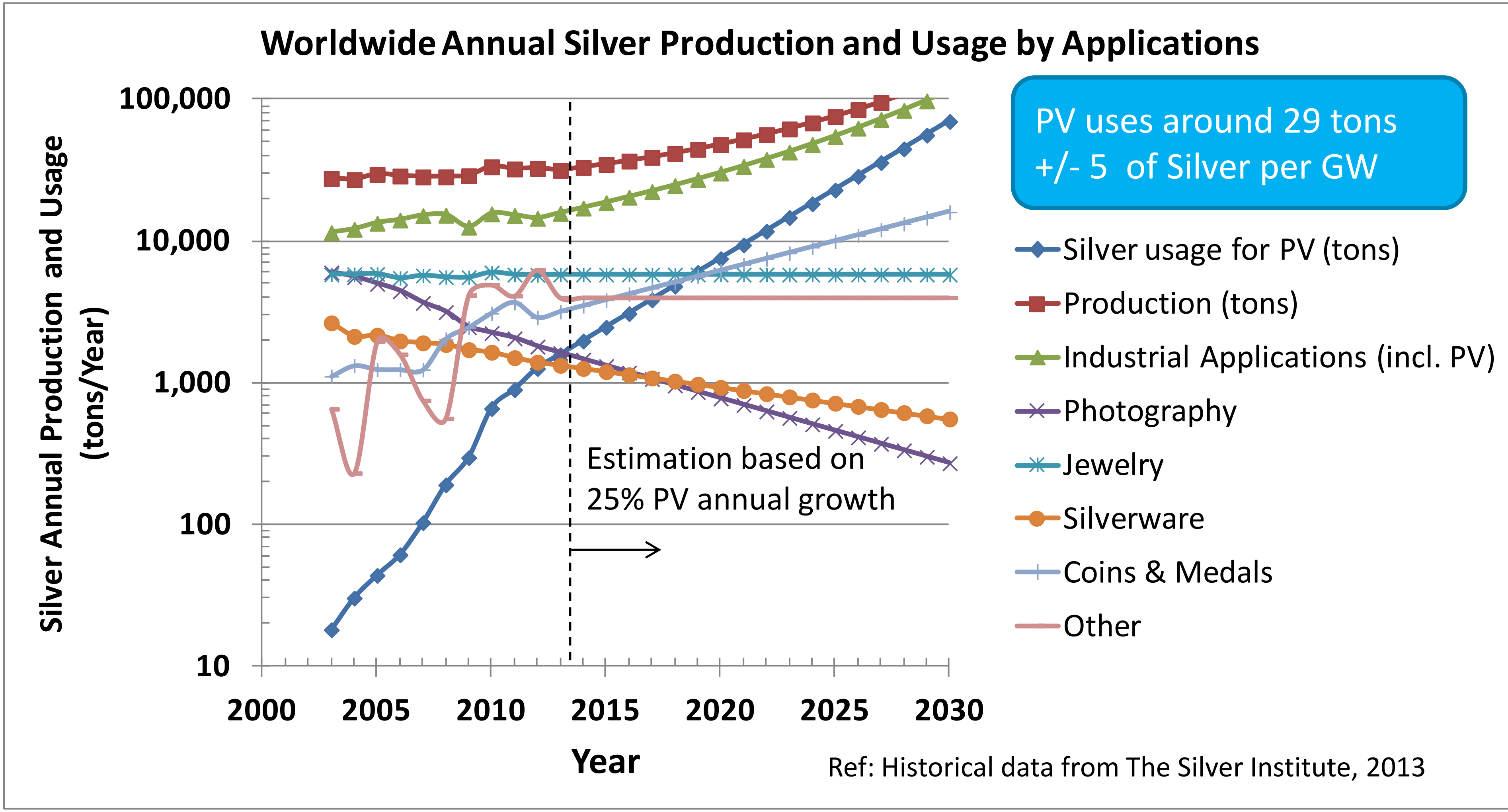
Material Sustainability: Silver Production and Usage



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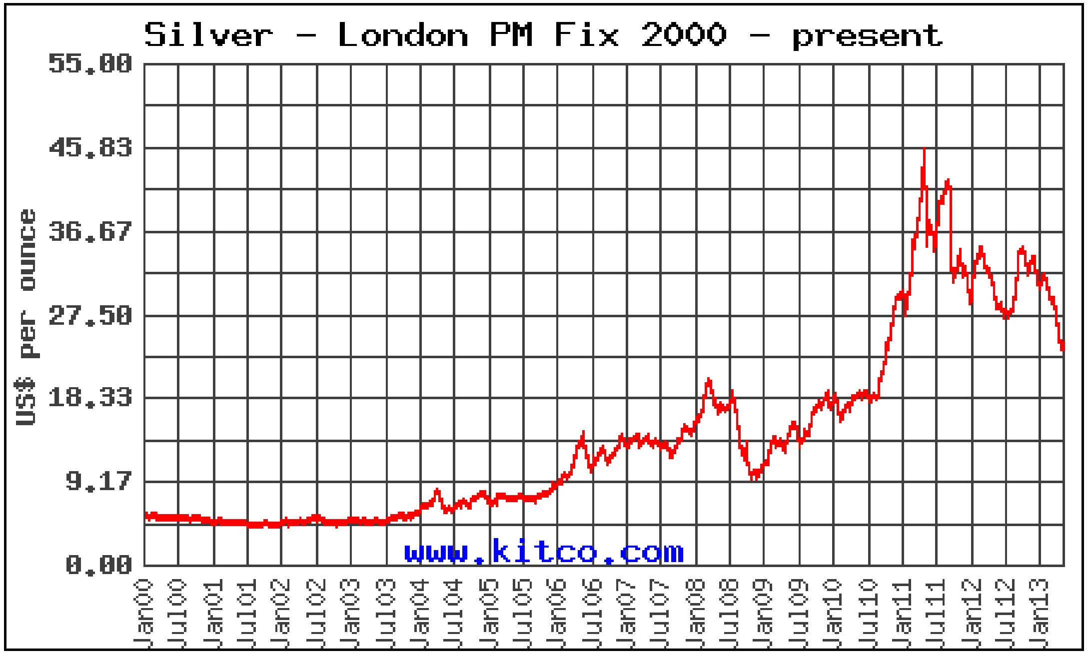
Historical Price of Silver



Yearly chart of silver price (2000 - 2013)

- At US$45 per ounce, the cost of Silver in PV represents US$0.035 to 0.049/W

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Decision Factors: Quality and LCOE

Customer decisions will now be based on two main factors:

1. **Product Reliability**
2. **L**evelized **C**ost **o**f **E**lectricity (**LCOE**)

$$\frac{\text{TOTAL COST}}{\text{PRODUCED ENERGY}}$$

Impacted by:

a) Cost of installation, Interest rate, Operation and Maintenance, …

b) Energy Production Rate, Energy Rating kWh/(kWh/m^2) or Energy efficiency

Temperature coefficients, Low-Irradiance efficiency, etc.

c) Annual performance degradation and hardware lifetime

INDUSTRY STRATEGY MOVING FORWARD

1. Improve Product Quality
2. Innovations to reduce LCOE

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LCOE is the only Value for the customer

LCOE = Levelized Cost Of Electricity

$$\frac{\text{TOTAL COST}}{\text{PRODUCED ENERGY}}$$

High Energy Production Rate + High Reliability + Low Cost of Installation O&M = Low LCOE and High Value for Customers

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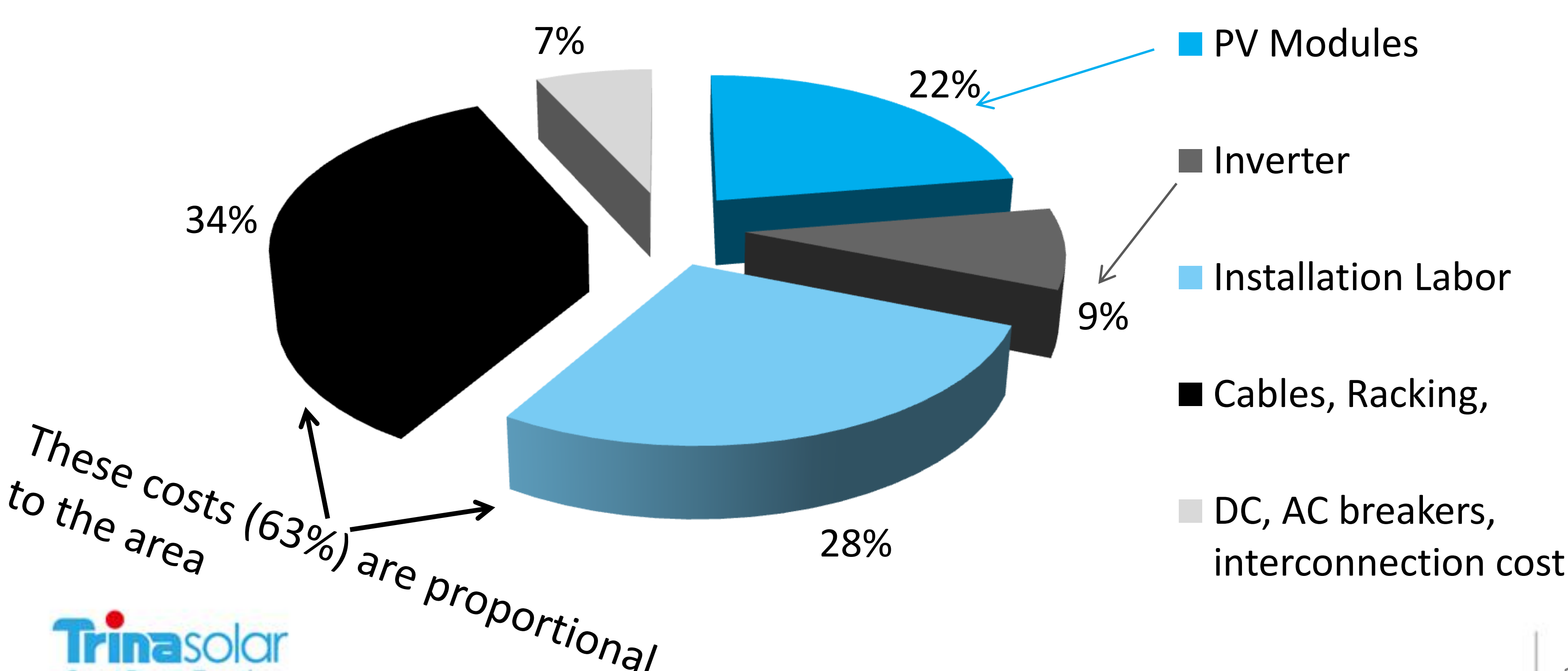
Cost of overall PV System

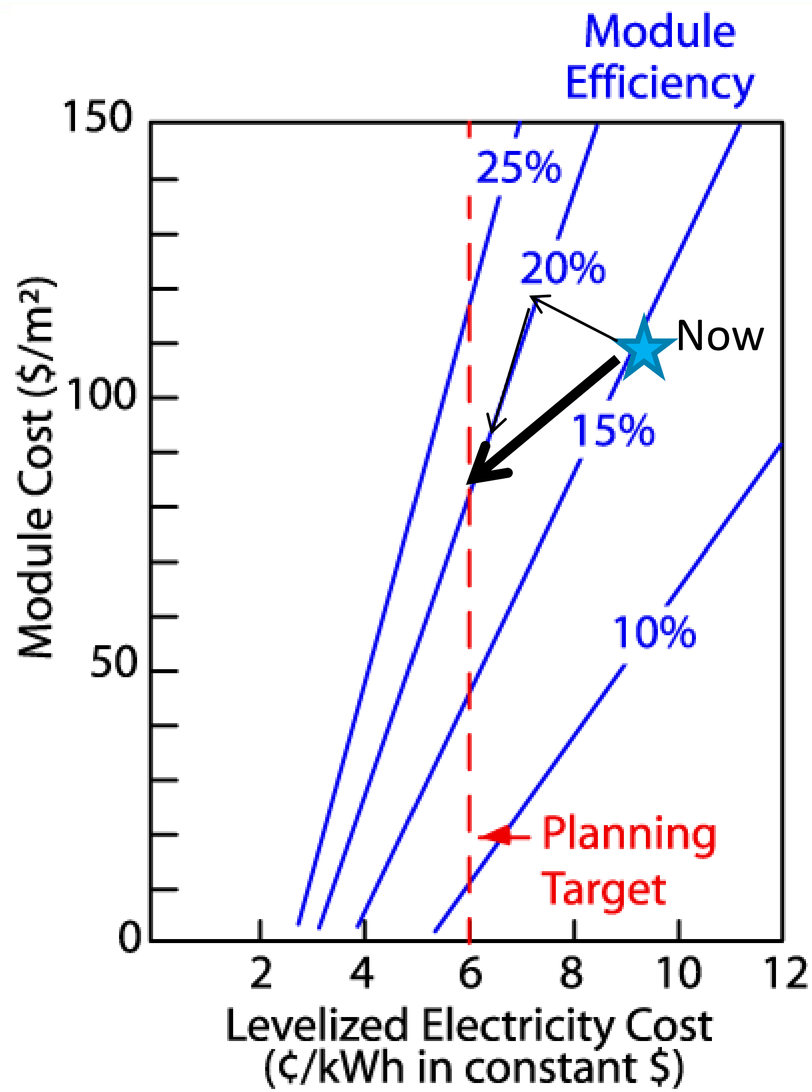
- PV Modules + Inverter ~ 1/3 of total cost
- Except for DC, AC breakers and interconnection cost, the rest of BOS cost is proportional to area, and is highly dependent on efficiency.

PV System Cost (US$/W)

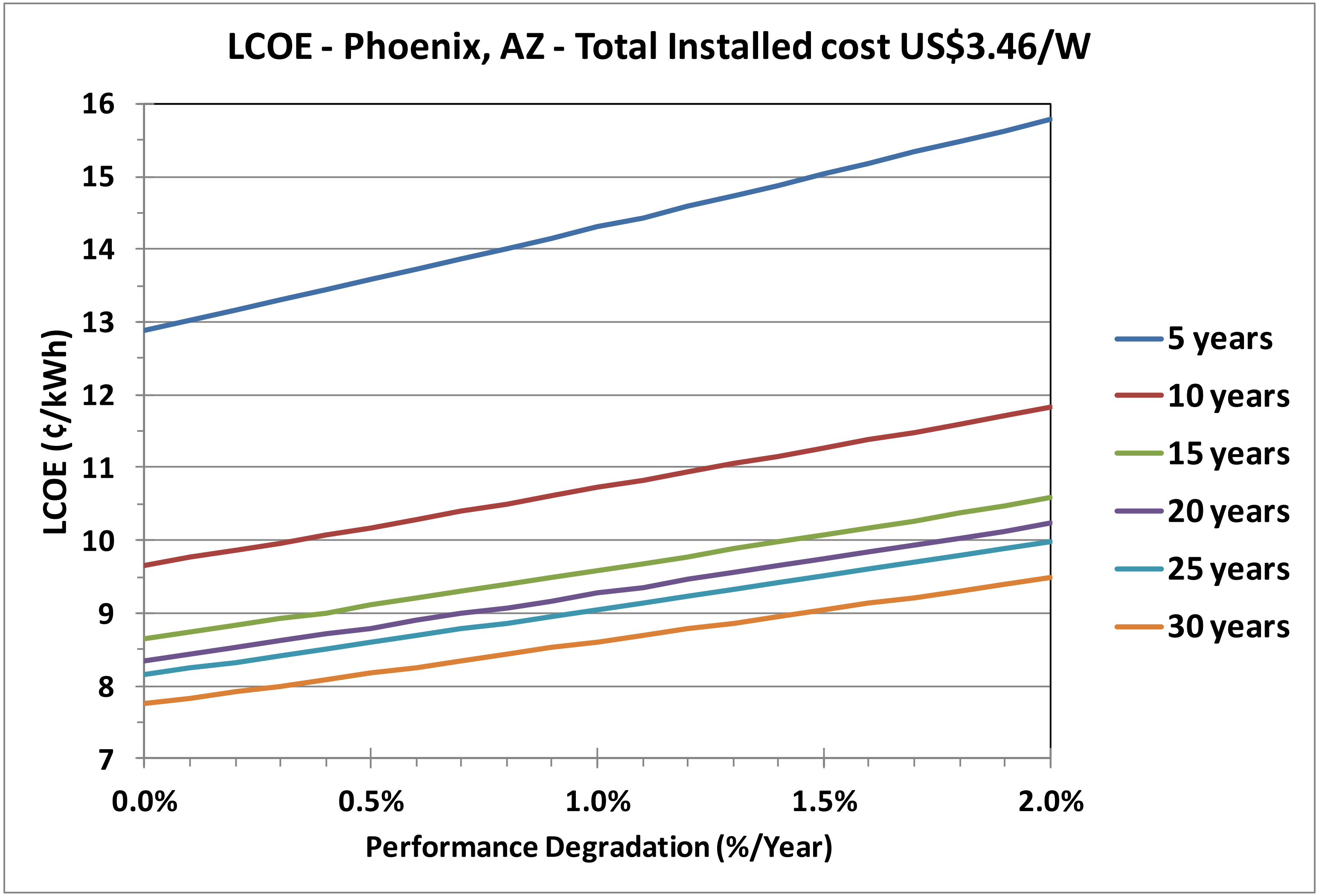


Levelized Cost Of Electricity (LCOE)

- Target of US$0.06/kWh places PV in the same league as bulk electricity production by gas-fired power plants
- The easiest way to reach this target is by improving the efficiency while we keep reducing manufacturing cost
- Even temporary cost increase combined with efficiency improvement reduces LCOE



Levelized Cost of Electricity - What is the cost of reliability?



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How to combine High-Reliability and Low LCOE?

- Reliability is expensive. PV companies cannot offer the highest quality module at the lowest cost for every part of the world.
- Cost reduction may have an impact on reliability or quality.
- But the PV industry can:
  - Offer a highly reliable product that is adapted to a particular climate,
  - Design a cell that has a better energy efficiency at a typical irradiance,
  - Optimize reliability and the energy production rate for each typical climate,
  - Focus on reduction of LCOE instead of $/Watt
  - Educate

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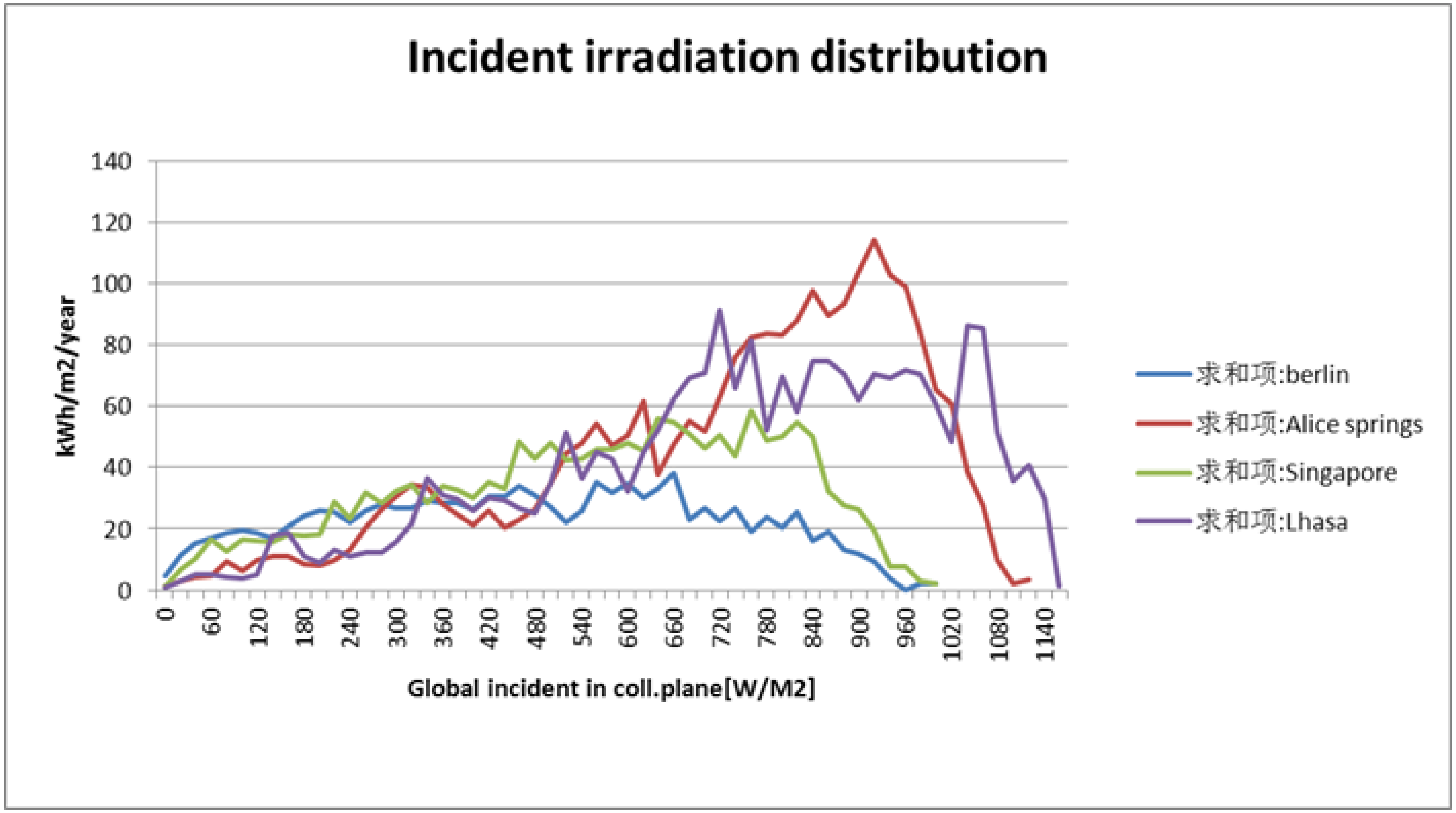
Irradiance profile for 4 different climates



- Total Irradiation
  - Temperate (Berlin) 1130 kWh/m^2
  - Desert (Alice Springs) 2420 kWh/m^2
  - Tropical (Singapore) 1625 kWh/m^2
  - Mountain (Lhasa) 2370 kWh/m^2

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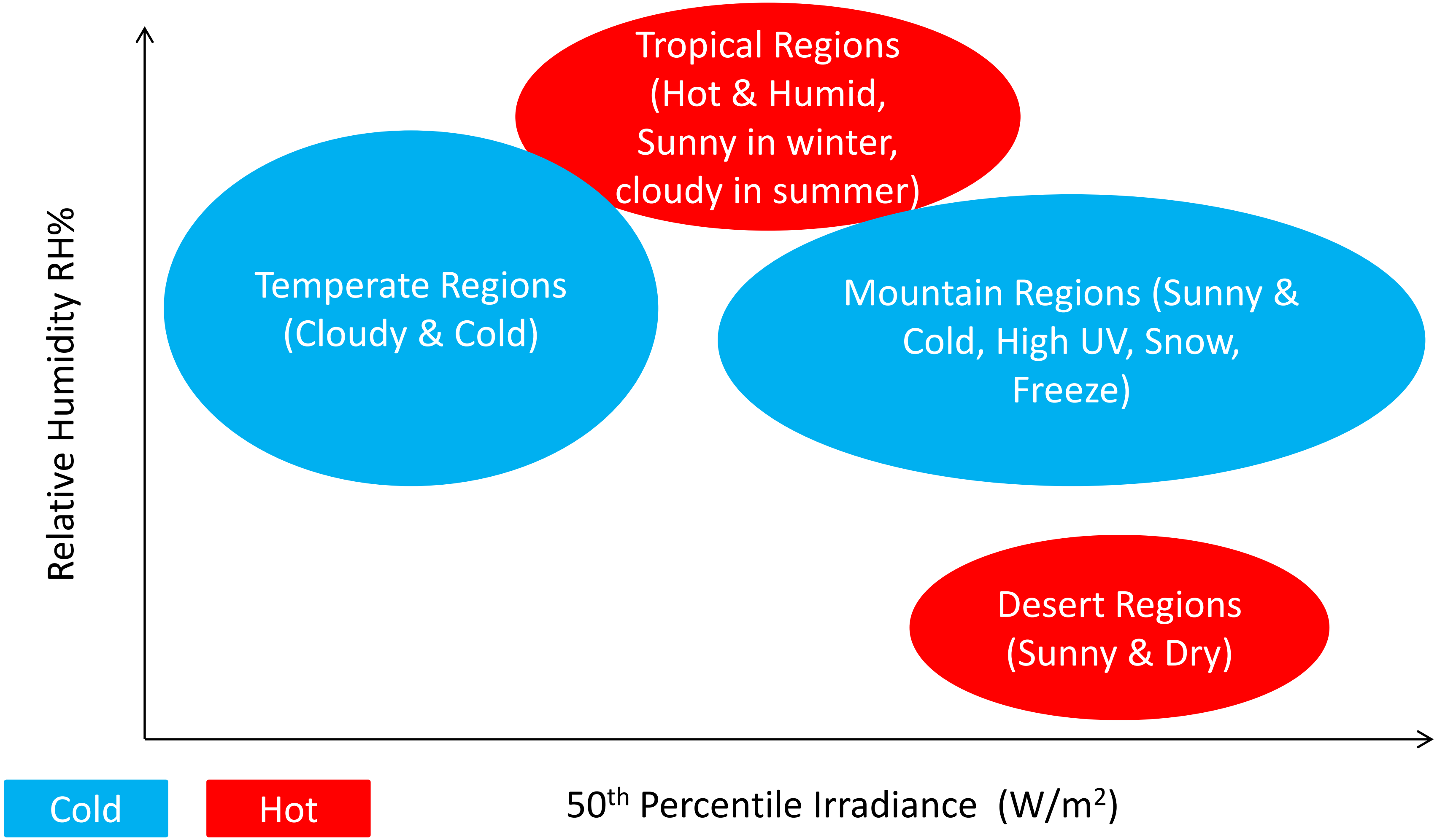
Definition of Particular Climates



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Smart PV: a way to reduce LCOE with Power Optimizer

Trinasmart DC

⬇TOTAL COST

⬆PRODUCED ENERGY

Active Energy Management

- Enhanced Commissioning
- Predictive Failure Analysis
- Panel-Level Monitoring

Power Optimization

- MPPT per Panel
- 3.2% more energy on day 1
- Mitigate system aging
- Improved Roof Utilization

Module Integrated

- Smart-Curve Technology
- Located within J-box

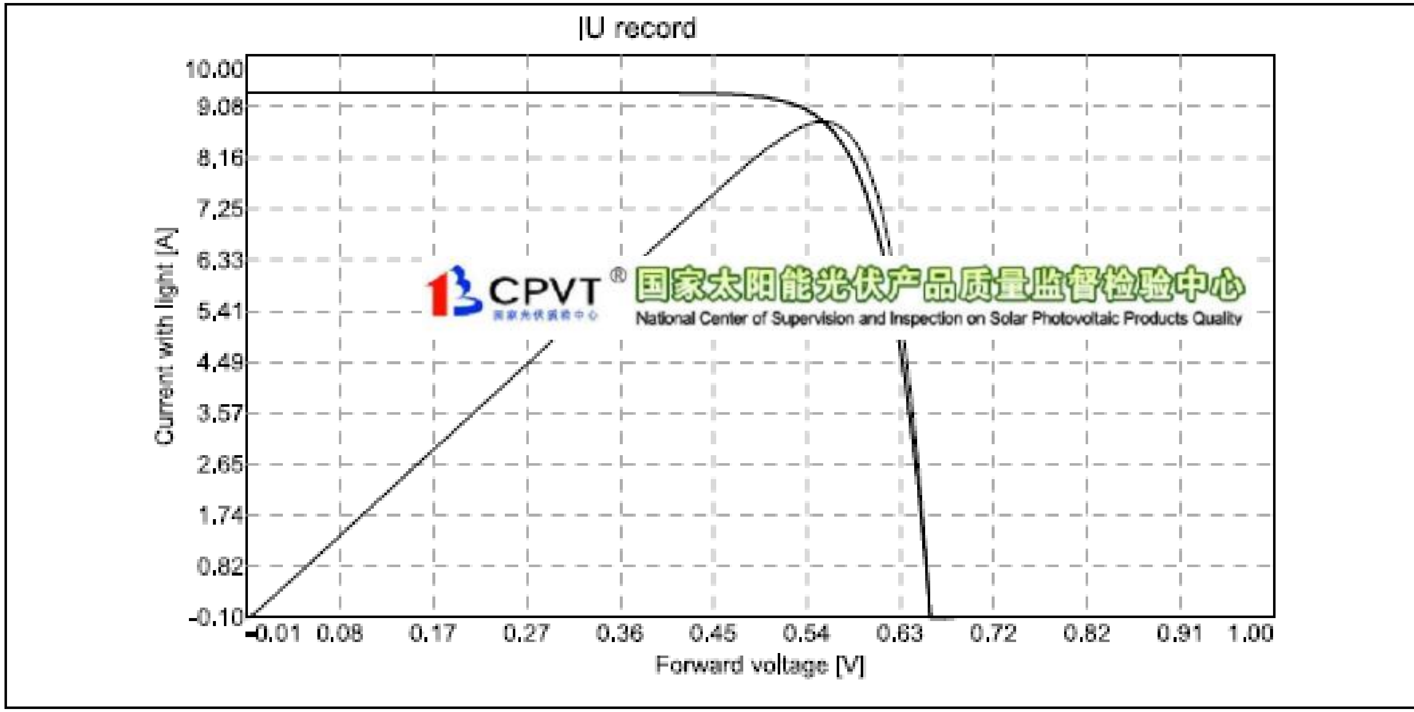
Safety

- Module level off-switch
- Fire safety
- Arc-fault detection
- Theft prevention

Up to 20% Additional Energy

20.54% Mono-Si Solar cell in Pilot Production

- ✓ Higher Efficiency
- ✓ Less Area
- ✓ Less installation cost
- ✓ Less O&M cost
- ✓ Lower Temperature coefficient
- ➢ Lower LCOE



Cell data

9.3460 [A] Isc	8.816 [A] Impp	998.9 [W/m²] Irradiance (Isc)
0.6618 [V] Uoc	0.5570 [V] Umpp	24.60 [°C] T Monitor Cell
20.543 [%] Eta	4.911 [W] Pmpp	25.0000 [°C] T Cell
79.39 [%] FF		
9.346 [A] Ivld1		
0.0100 [V] Uvld1	0.093 [W] Pvld1	

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Double Glass : The Most Durable Module

More Reliable Performance

• No PID

• Less degradation after Thermal Cycling, Humidity Freeze, Damp Heat

More Durable

• No “snail tracks”

• No delamination or degradation of backsheet

• No yellowing

Faster, Lower-cost of Installation

• Frameless modules do not require grounding, leading to faster installation and lower component and labor costs

• Less soiling

Sleek, Clean Appearance

- Frameless design for more seamless array appearance

Greater Inventory Flexibility

- Certified to 1000V for both UL and IEC

Enhanced Safety

- UL and IEC Fire Class A certified

Electrical and Mechanical Characteristics

•PMAX 240-255W

•15.1% efficiency

•60 cells

•IEC1000V, UL1000V Dual Rated

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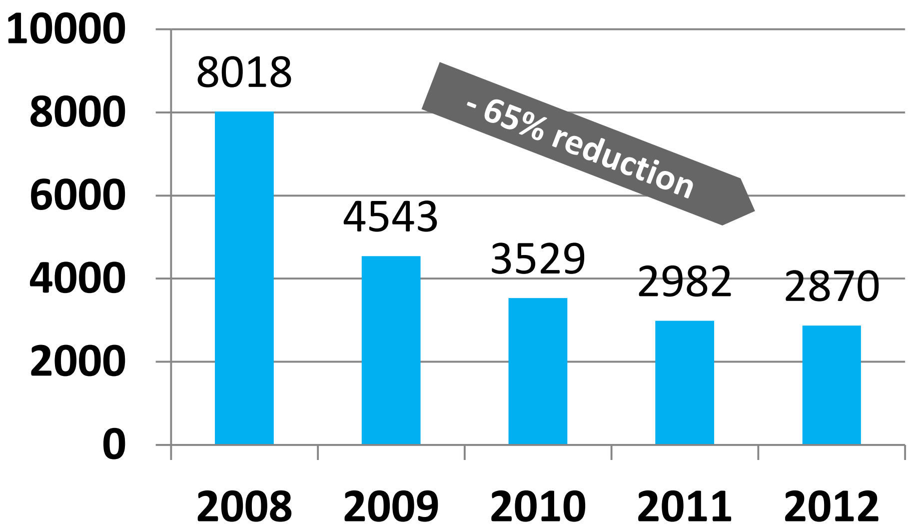
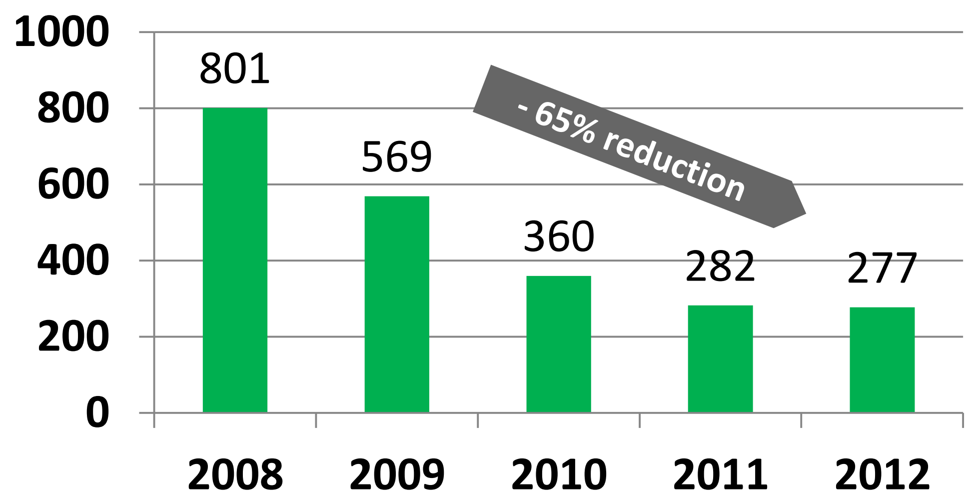
Energy Sustainability

Water consumption (m^3/MW)



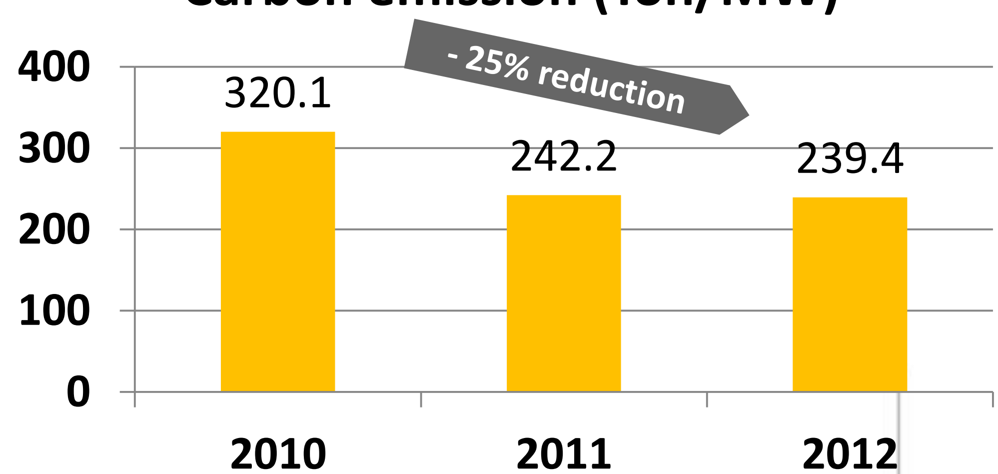
Electricity Consumption (MWh/MW)



SVTC SOLAR SCORECARD 2012
A PROJECT OF THE SILICON VALLEY TOXICS COALITION

#1 in SVTC Solar Scorecard in 2012 and 2013 for Responsible Manufacturing

Carbon emission (Ton/MW)



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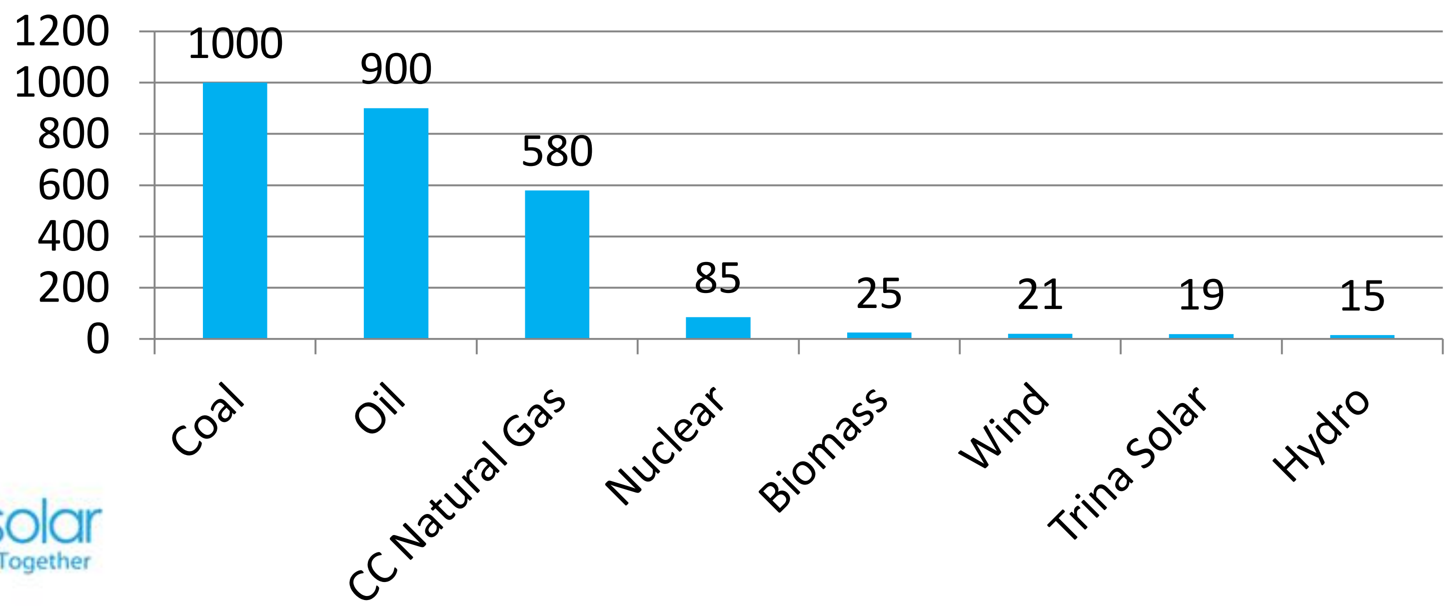
Low Carbon Footprint and Short Energy Pay-back Time

- The British Standards Institution (BSI) verified Trina's low carbon footprint of 781.8kg per KW produced for the entire module manufacturing process from raw material acquisition to packaging as environmentally friendly according to PAS 2050 and ISO 14067 standards
- Over 25 years of operation, that is less than 19g of CO_2 per kWh (Assuming 1600 kWh/kW/year in sunny area)



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Conclusions

1. The “Great Price Decline” of PV is over. Recovery will take time.
2. Between 2008 and 2012, ASP has dropped by 81.75%, while manufacturing cost has dropped by 70.1%, mostly driven by Si price. Non-Si Cost has dropped by 48.4% only. Learning Curve Model predicted a Cost reduction by 53.3%.
3. Major Cost reductions have been achieved in some areas: Silicon feedstock, casting, wafering, Back-side electrode (Al and Ag)
4. Minor Cost reductions have been achieved in: Cell Processing and Module Assembly
5. Cost increases have been observed in: Labour and Front Ag

Conclusions (2)

6. Challenges for the PV Industry:
   - Regain Profitability and Increase Gross Margin
   - Sustainable Growth
     - Enough Gross Margin to grow
     - Low EPBT
   - Develop Ag-free cell process to avoid the next Supply Constrained Market
7. Opportunities
   - Focus on Reliability and LCOE
   - Develop highly <u>reliable</u> products with high <u>Energy</u> performance for particular climates and particular regions
8. Reducing the Energy Payback Time and Carbon footprint are key to a sustainable PV industry

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GERMANY
FRANCE
ITALY
SPAIN
SWITZERLAND
AUSTRALIA

THANK YOU

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