U.S. DEPARTMENT OF ENERGY

Energy Efficiency & Renewable Energy

Solar Energy Technologies Program

The Prospect for $1/Watt Electricity from Solar

$1/W Workshop
August 10, 2010

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Department of Energy

Office of Energy Efficiency and Renewable Energy

Disclaimer

“It’s tough making predictions, especially about the future.”

- Several sources

Reaching Cost Reduction Targets will require advances in all PV system components

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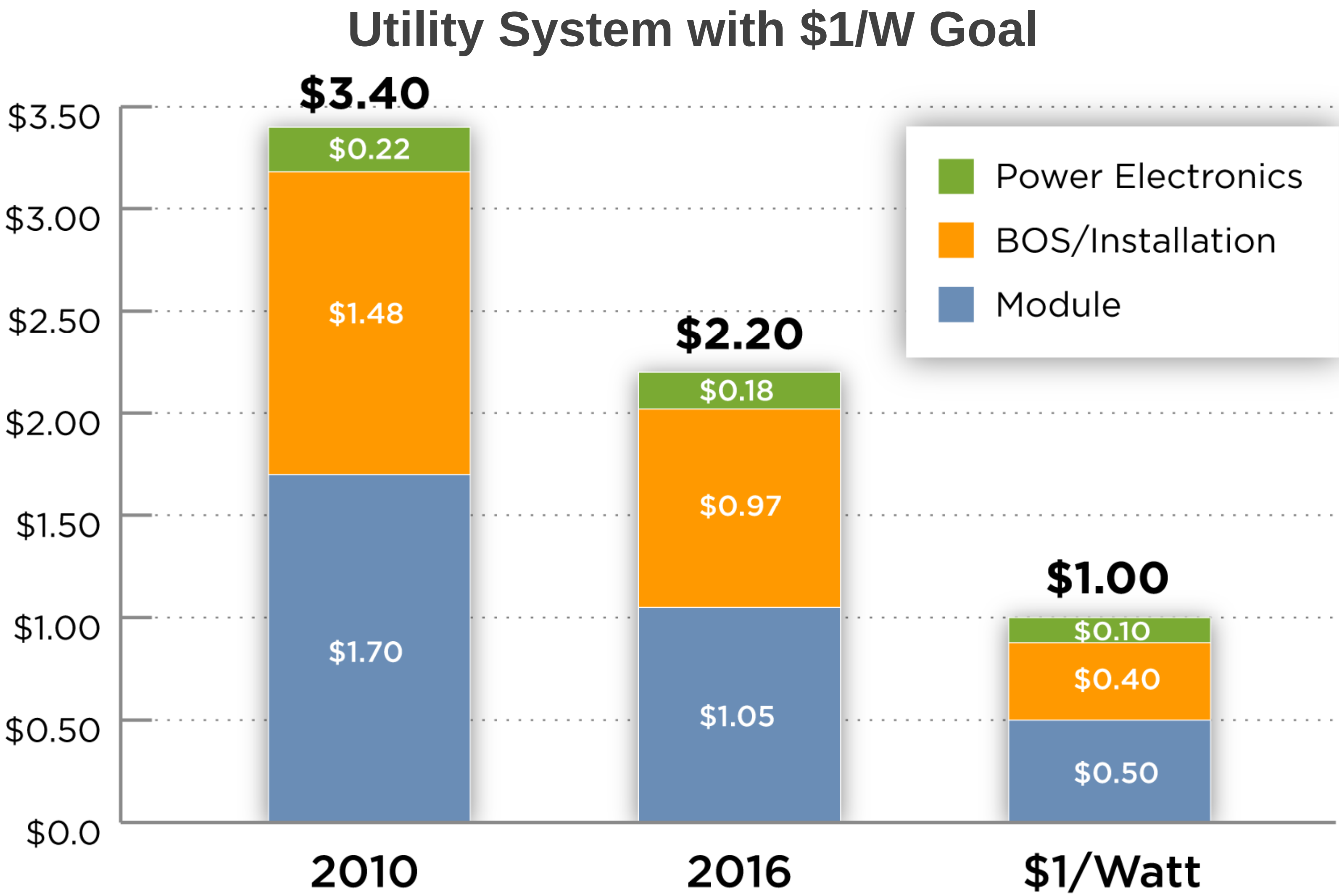

Utility PV: LCOE Targets

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<u>Financing Conditions</u>

- Low: 8.2% after-tax WACC
- High: 9.9% after-tax WACC

<u>Geographic Locations</u>

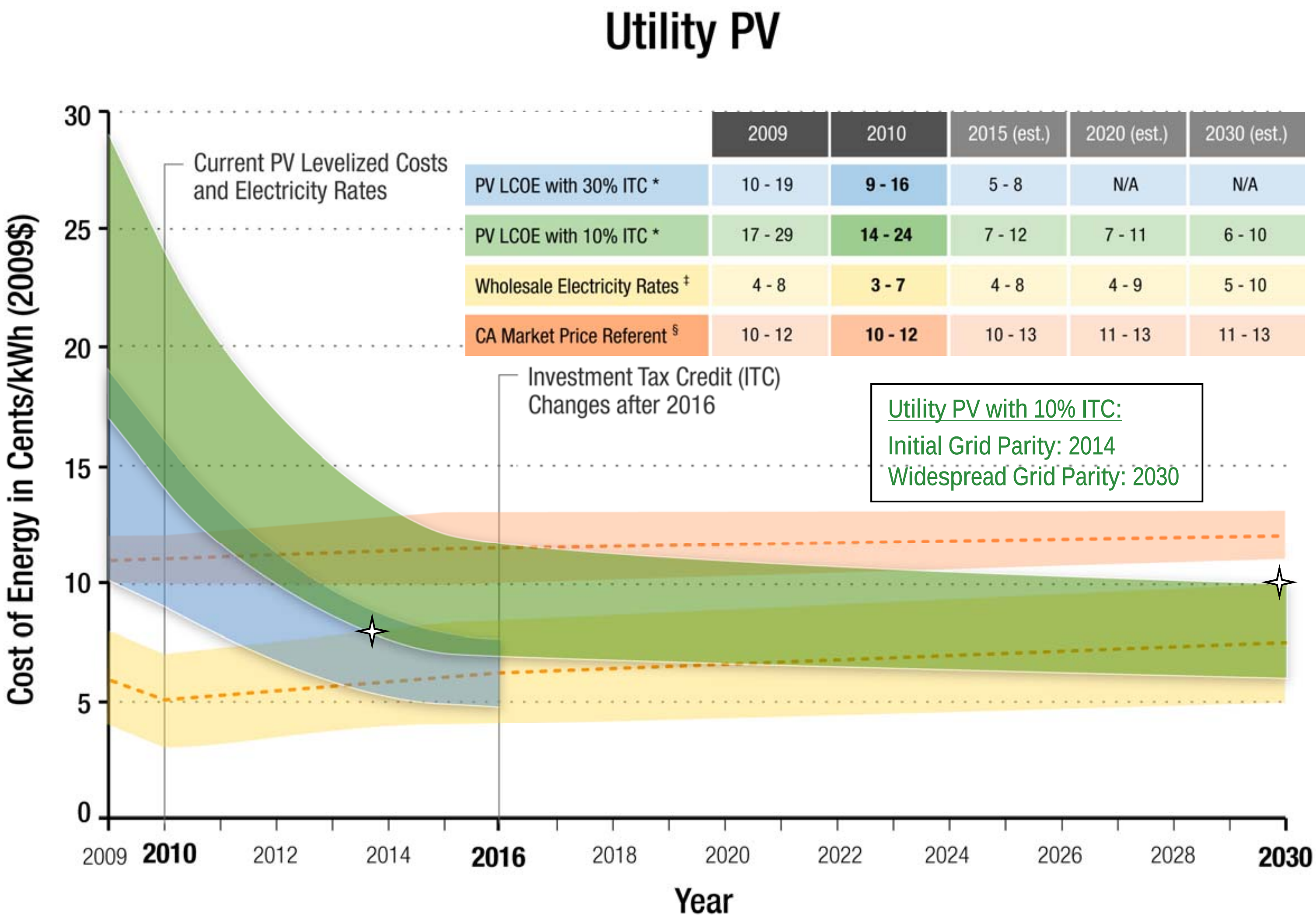
- Phoenix, AZ
- Kansas City, MO
- New York, NY

<u>2015</u>

- With the 30% ITC, PV is broadly competitive with wholesale electricity rates under all conditions
- With the 10% ITC, PV is equal to or below the CA MPR under most conditions and competitive with high wholesale electricity rates under the best insolation and financing conditions

<u>2030</u>

- With the 10% ITC, PV is broadly competitive with wholesale electricity rates under all financing and insolation conditions



	2009	2010	2015 (est.)	2020 (est.)	2030 (est.)
PV LCOE with 30% ITC *	10 - 19	9 - 16	5 - 8	N/A	N/A
PV LCOE with 10% ITC *	17 - 29	14 - 24	7 - 12	7 - 11	6 - 10
Wholesale Electricity Rates ‡	4 - 8	3 - 7	4 - 8	4 - 9	5 - 10
CA Market Price Referent §	10 - 12	10 - 12	10 - 13	11 - 13	11 - 13

* Assumes IOU or IPP ownership of PV, and thus the LCOE includes the taxes paid on electricity generated. Includes 5-year MACRS but not state or local incentives. The range in utility PV LCOE is due to different insolation and financing conditions. For a complete list of assumptions, see DOE Solar Cost Targets (2009 – 2030), in process.

‡ The electricity rate range represents one standard deviation below and above the mean U.S. wholesale electricity prices.

§ The 2009 CA MPR includes adjustments by utility for the time of delivery profile of solar (low case: SDG&E, mid case: PG&E, high case: SCE).

Residential PV: LCOE Targets

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Financing Mechanisms

- Home Mortgage (80% financing, 6.0% interest, 30-year term)
- Home Equity Loan (100% financing, 7.75% interest, 15-year term)

Geographic Locations

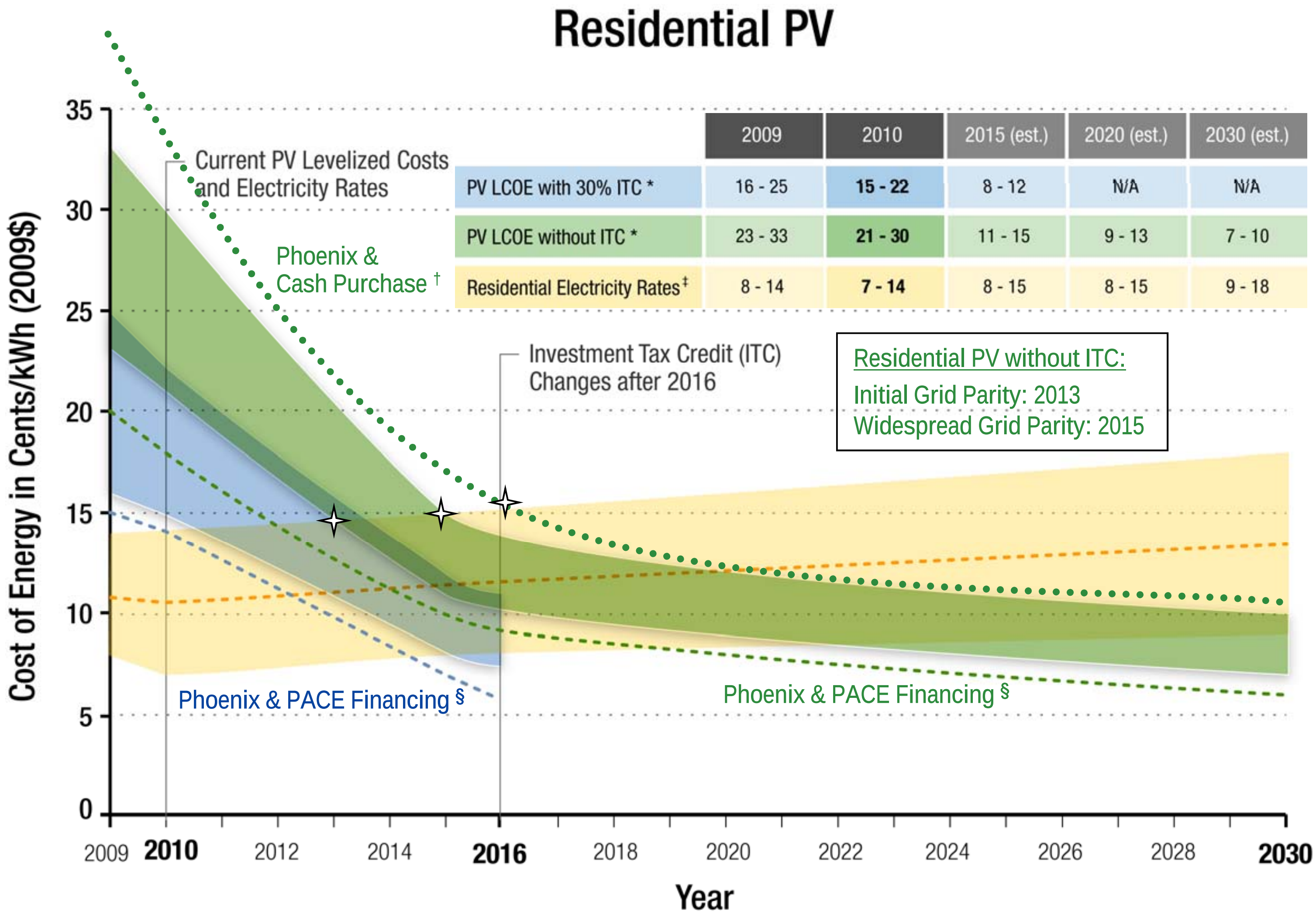
- Phoenix, AZ
- Kansas City, MO
- New York, NY

2015

- Without the ITC, PV is broadly competitive with residential electricity rates under all financing and insolation conditions

2030

- Without the ITC, PV has levelized costs that are lower than most residential electricity rates



	2009	2010	2015 (est.)	2020 (est.)	2030 (est.)
PV LCOE with 30% ITC *	16 - 25	15 - 22	8 - 12	N/A	N/A
PV LCOE without ITC *	23 - 33	21 - 30	11 - 15	9 - 13	7 - 10
Residential Electricity Rates ‡	8 - 14	7 - 14	8 - 15	8 - 15	9 - 18

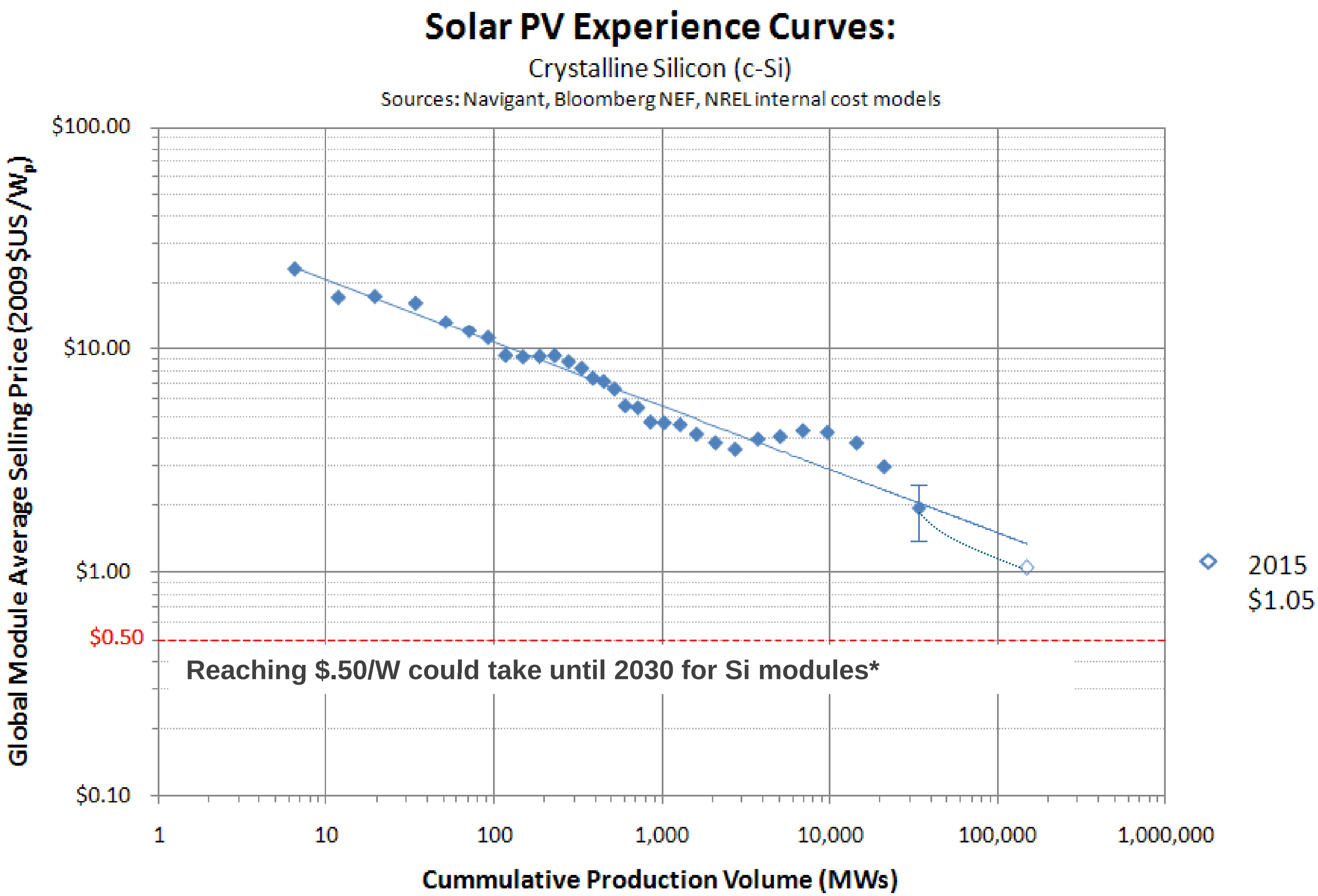
* No state, local or utility incentives are included. The range in residential PV LCOE is due to different insolation and financing conditions. For a complete list of assumptions, see DOE Solar Cost Targets (2009 – 2030), in process.

‡ The electricity rate range represents one standard deviation below and above the mean U.S. residential electricity prices.

§ Property Assessed Clean Energy (PACE) Financing assumes 100% financing at 5.0% interest with a 20-year payback schedule

† Cash purchase assumes a discount rate of 9.2% (nominal), equal to the long term return on the S&P 500

Solar PV Cost Reduction Progress, Potential of Known Technology Pathways



Manufacturing Cost Model Scope: Crystalline Silicon PV

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Poly Si Feedstock → Wafers → Cells → Modules

- Detailed cost models developed for each step:
- Evaluate Technical (Cost) Improvement Opportunities
  - Simulate discrete manufacturing operations
- Sensitivity to independent process, material properties
- Margins at each step in the value chain
  - Intermediate product sales opportunity
  - pro forma income statement
  - Minimum sustainable: eliminate market noise from projections
- Collaborations with stakeholders from throughout the Industry critical to model development

Cost reduction of silicon feedstock to be led by introduction of FBR process

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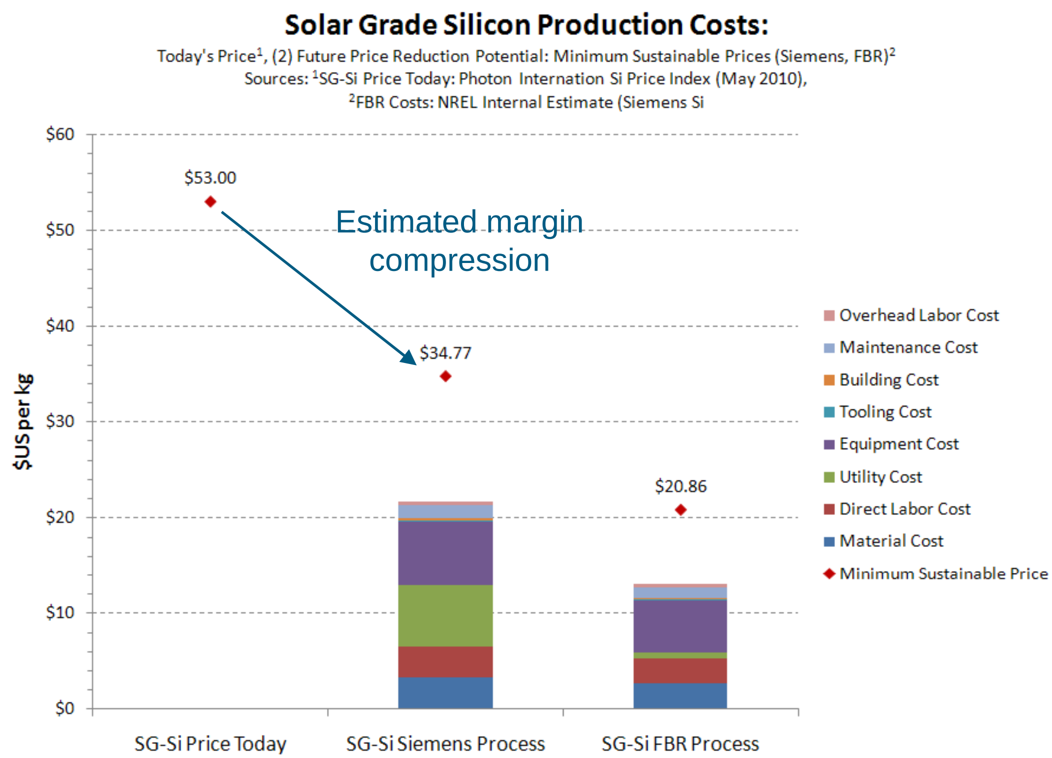


- By 2015, margin compression expected to drive SG-Si price to minimal sustainable.
- By 2030, 20% expected from FBR
- Additional driver for FBR will come from advanced cell architectures.

FBR process cost advantages:

- Better silane gas utilization
- Lower temperature (energy)
- Improved yield (rates)
  - Capital utilization
- Total cost benefit: ~40%

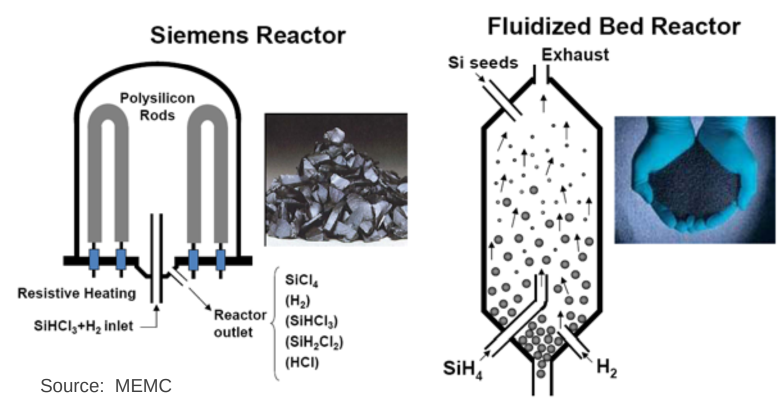
Material quality:

- Fewer metal, O_2 impurities

Crystal growth advantages:

- Multiple recharge (i.e. semi continuous Cz-growth)

Polysilicon Manufacturing Methods



Source: MEMC

Cost Reduction Opportunities: c-Si Wafers

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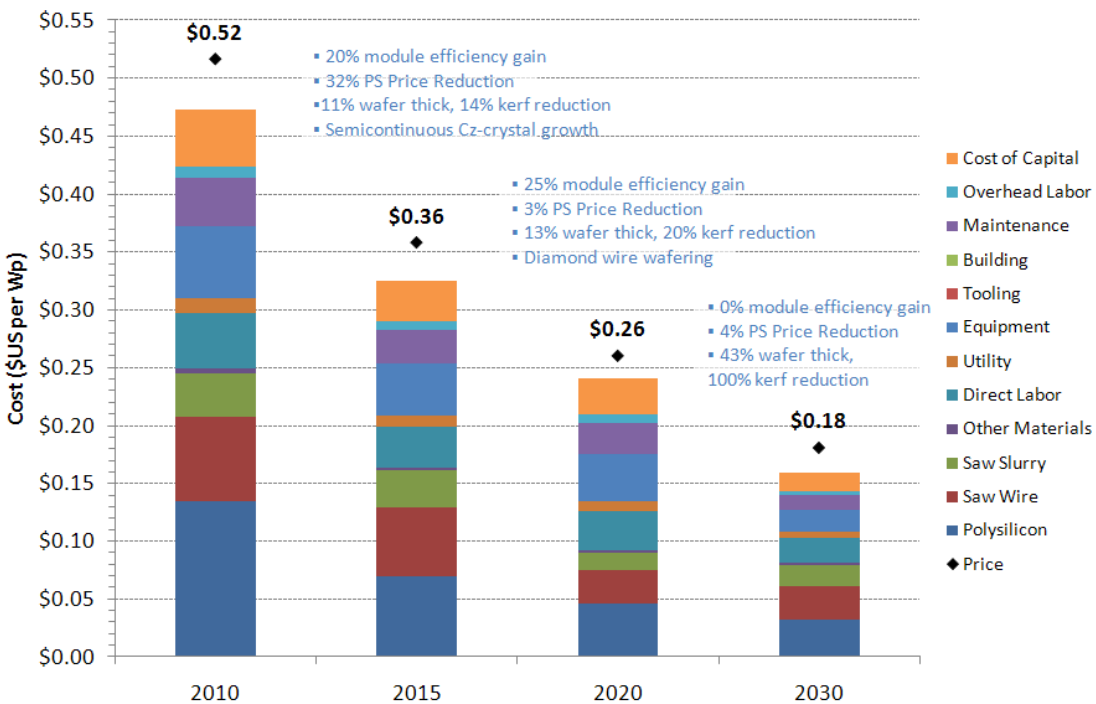
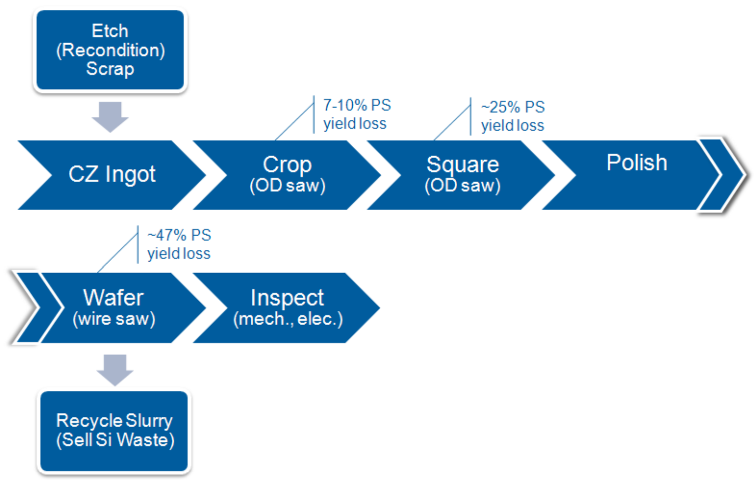
Mono Crystalline Silicon (c-Si) Crystallization and Wafering Costs:

Summary of Technical Improvement Strategies



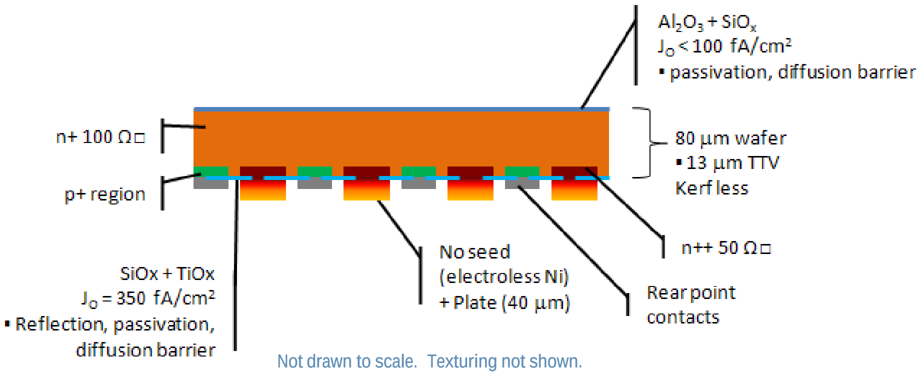


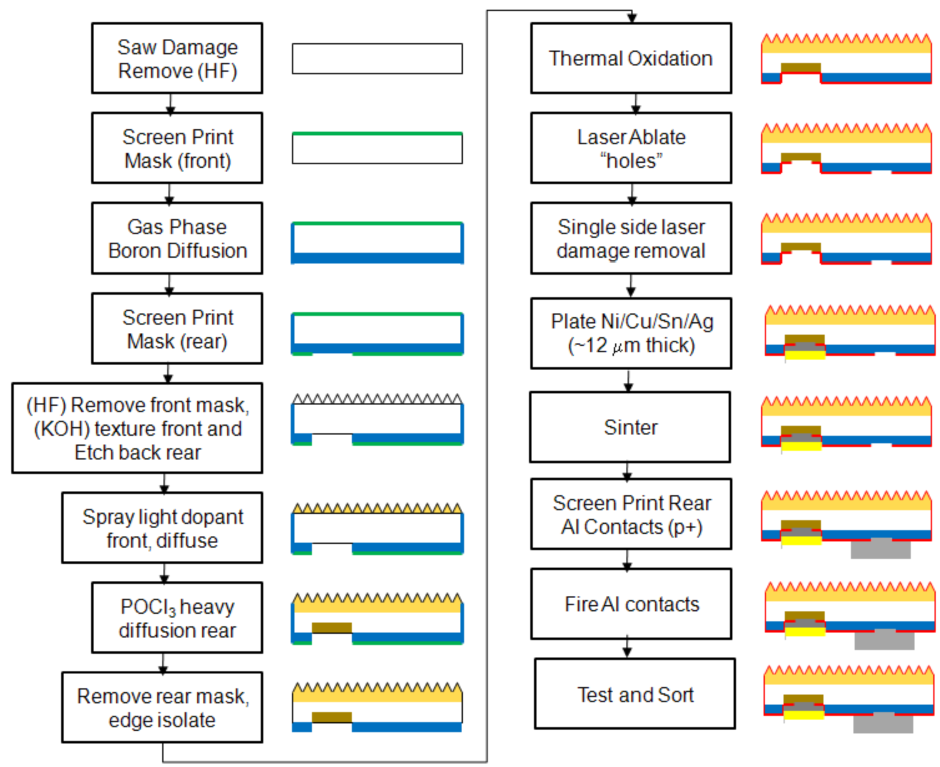
- Key innovations
  - Semi-continuous CZ-crystal growth
  - Diamond wire wafering
  - Kerfless wafer (80 microns)

Source: Sigen

c-Si Cell Description: 2030

*Based on publicly disclosed (literature) cell designs, not intended to depict proprietary architectures





- All Rear (Interdigitated) Contacts
- High lifetime (n- type) wafer
- Ultra thin (80 microns) kerfless wafers
- High quality surface passivation
- Plated emitter contacts
  - Electroless nickel barrier, Cu plating
- Base point contact absorbers
  - Printed Al contacts

c-Si Cell Costs

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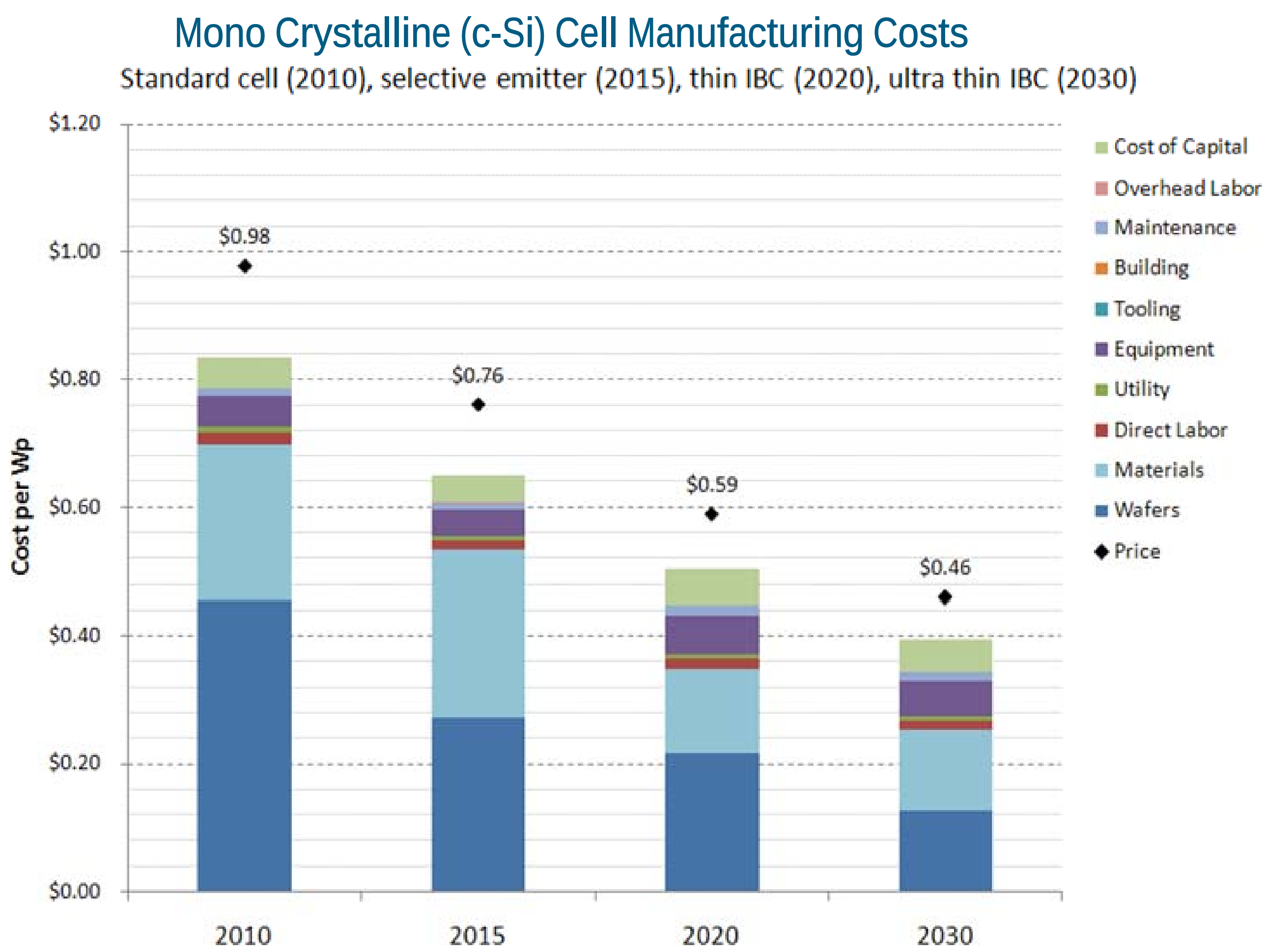

- Silicon PV approaching practical performance limit
    - 2030 case: 24% production average cell, 21.5% module

c-Si Module Costs

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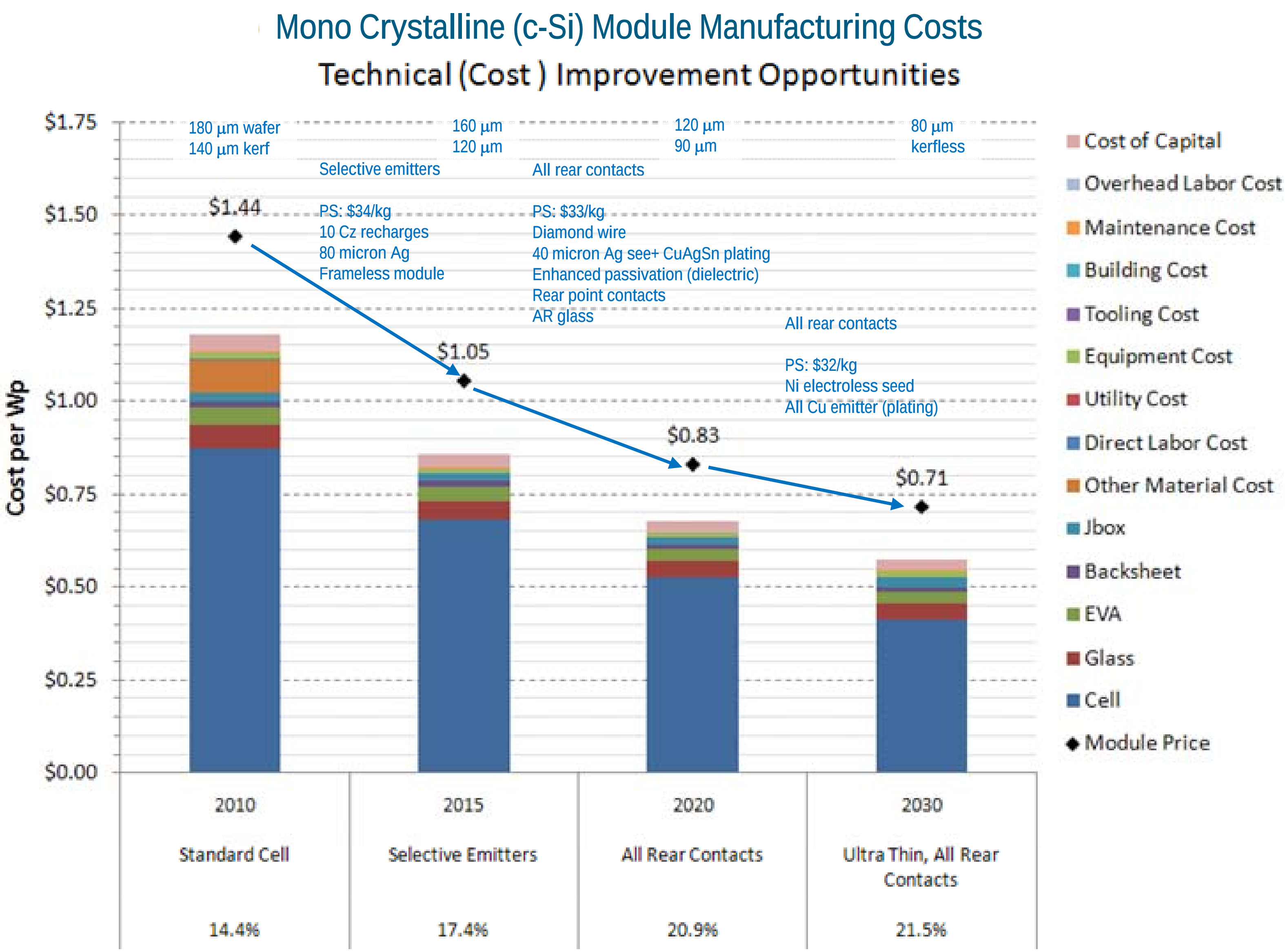
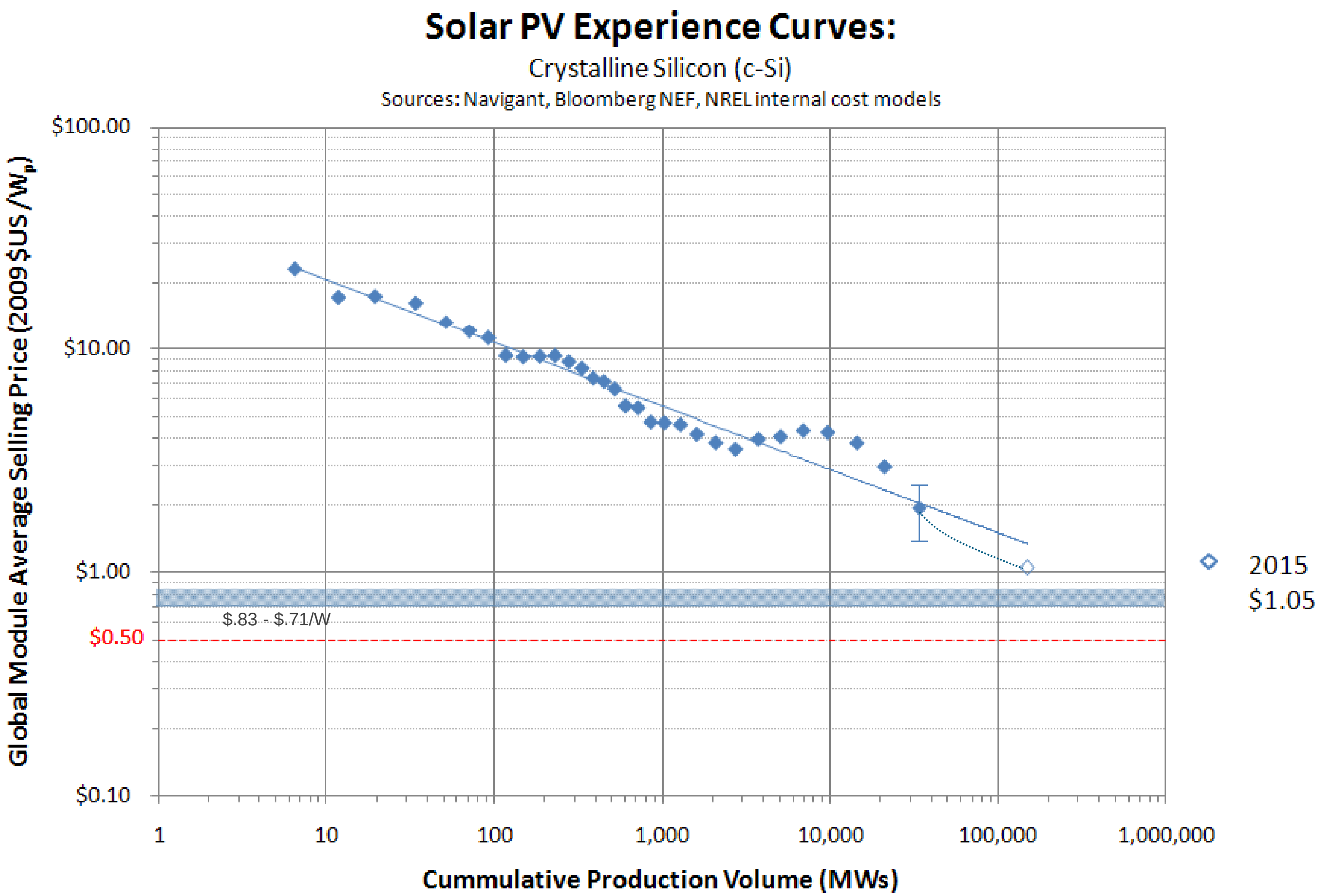


Solar PV Cost Reduction Progress, Potential of Known Technology Pathways



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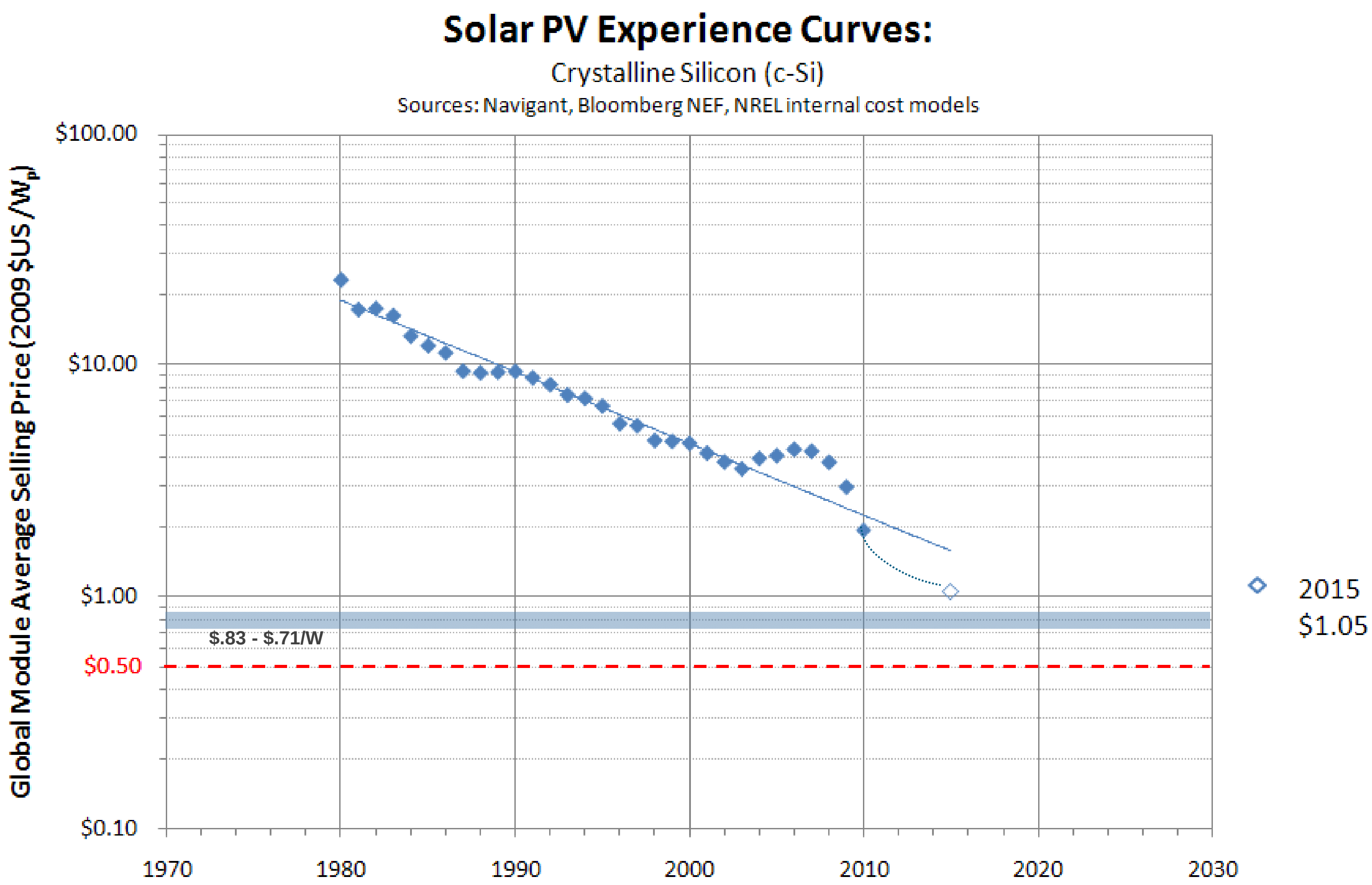

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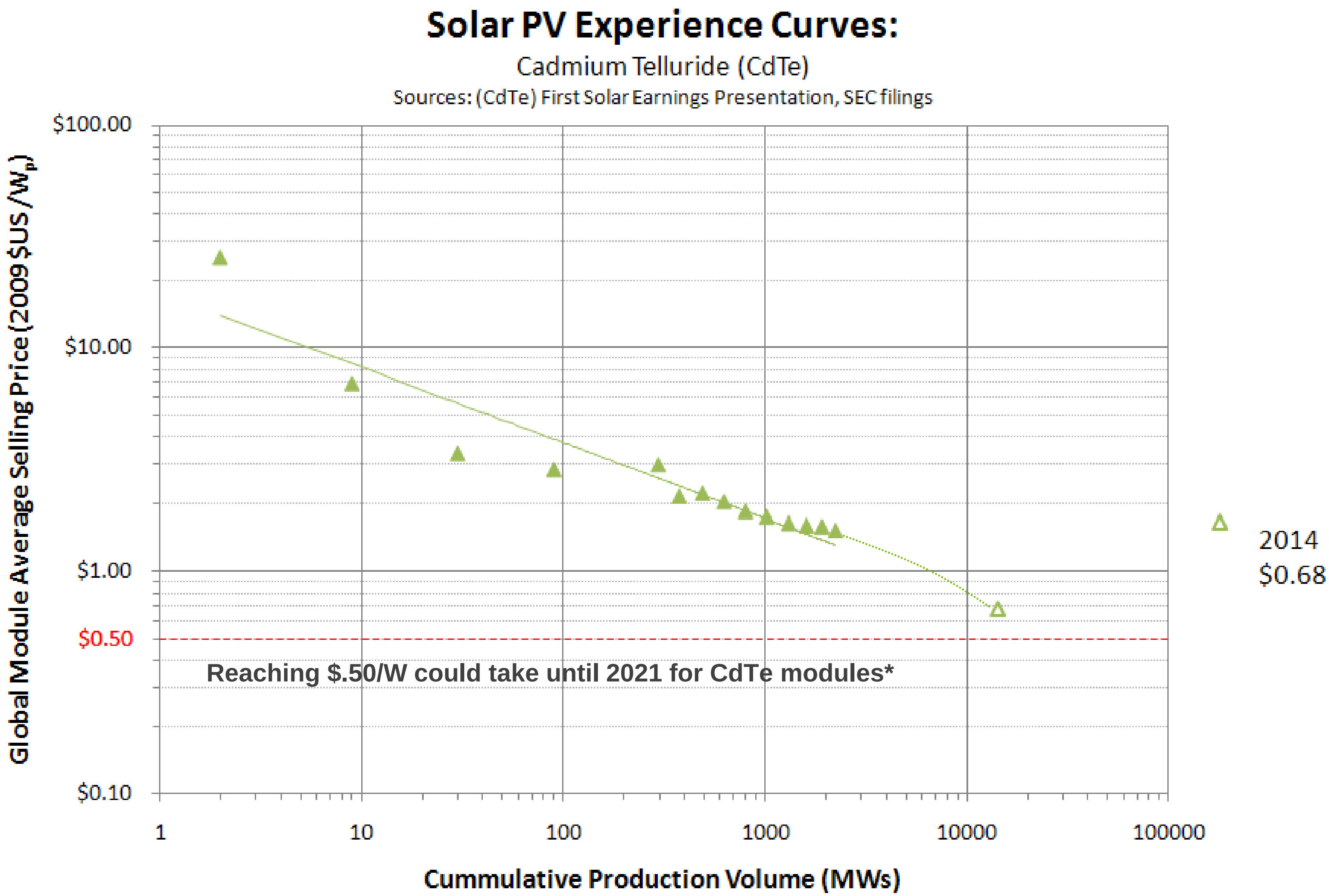
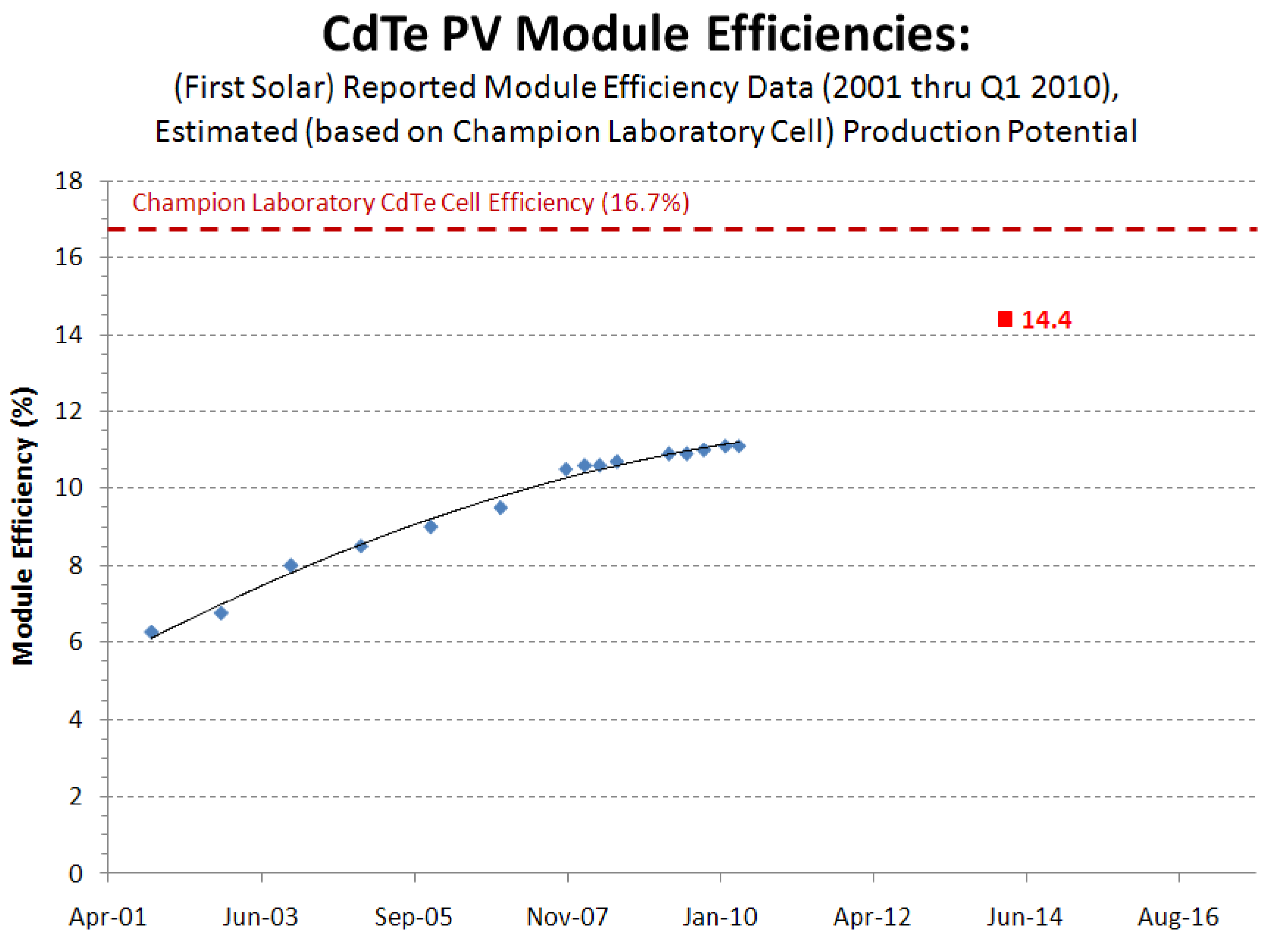
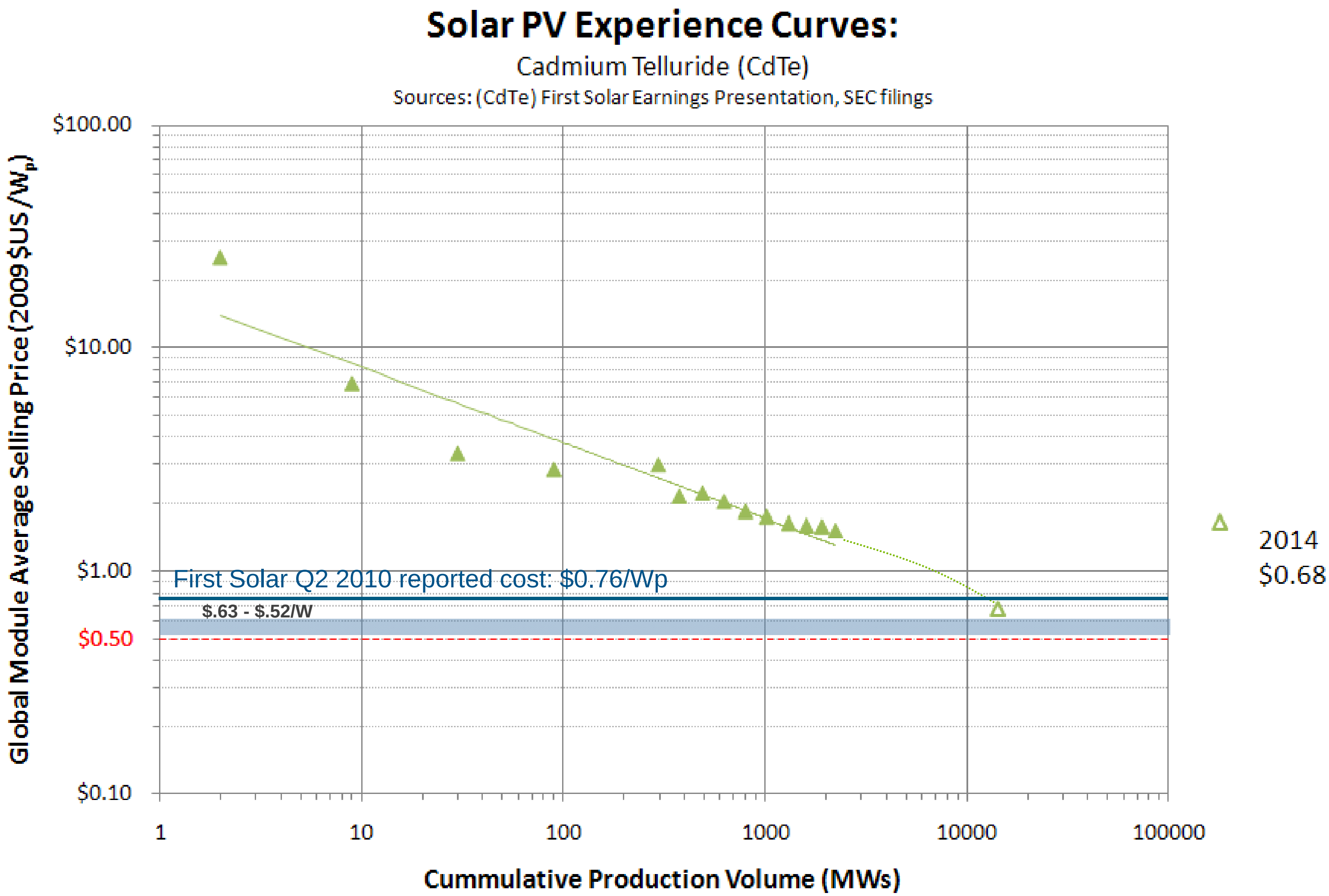


CdTe Efficiency Road Map: Innovation Remains an Important Factor



- First Solar stated (June 2009) goal for $.52/W cost ($.63/W price)
  - 14.4% implies a significant advancement in module technology (86% of current, or new ‘champion cell’)
  - Best in class c-Si module: ~79% of champion lab cell, many more years to close the gap

Solar PV Cost Reduction Progress, Potential of Known Technology Pathways



Solar PV Cost Reduction Progress, Potential of Known Technology Pathways

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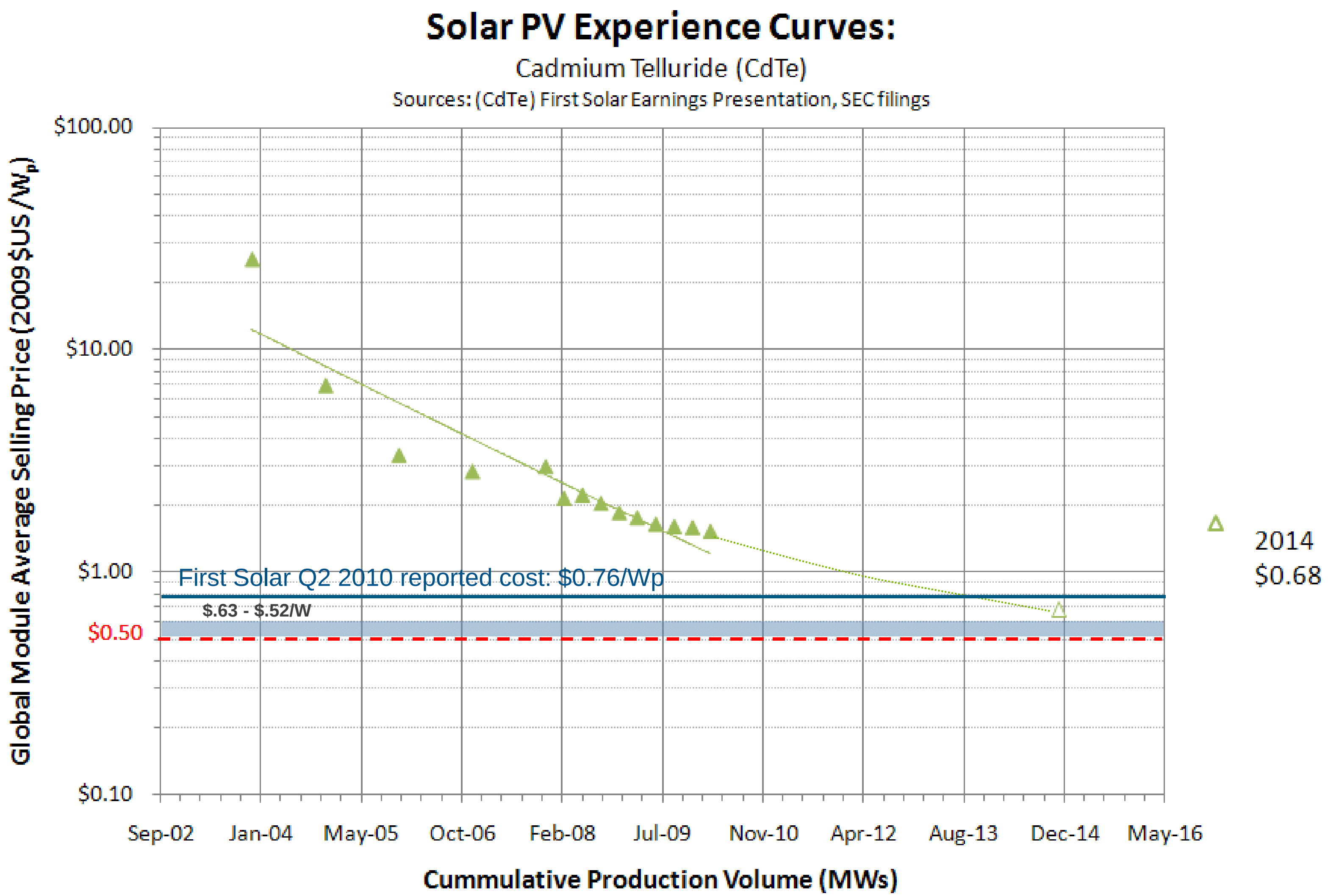

$0.50/W Module Challenge: Potential Breakdown of Module Costs

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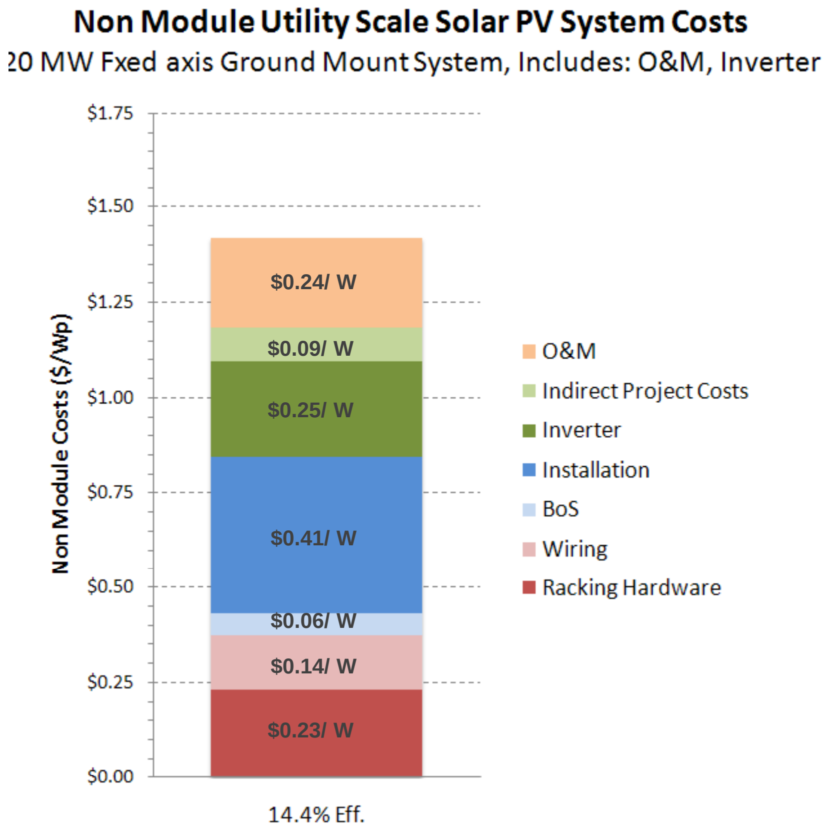
	2010	2015	$1/W Target	
	Cost	Cost	Cost ($/W)	Cost ($/m2)
Capital	$0.24	$0.20	$0.10	$28
Materials	$1.11	$0.49	$0.23	$68
Labor	$0.27	$0.12	$0.06	$17
Margin	$0.79	$0.24	$0.11	
Total Module	**$1.70**	**$1.05**	**$0.50**	

- In order to achieve $0.50/W module selling price
  - Capex of $0.70/W may be required.
  - Materials costs must be about $68/m^{2*}
    - Glass, EVA, and backsheet today costs about $18/m^2, about 25% of the budget for materials. Metallization next significant opportunity.
  - Manufacturing labor must account for less than $0.06/W
    - For 100 MW factory, equivalent to 120 FTEs at $50k/yr fully loaded

*$/m2 assumes 25% efficiency

Non-Module Solar PV Installation (BoS) Costs



- Glass module installation costs burdened by disaggregate systems (number of components)
    - Integrate components at factory?

'Installation' labor:

- Nearly 75% of labor hours skilled
    - Electrician wage premium
    - Grid connect, wiring, power, other electronics

'O&M' costs: reliability

- Inverter reliability, repair costs
- System monitoring and preventative maintenance

'Indirect Project Costs' vary:

- Environmental review: $100K, up to $1 MM and 2 years
- Land prep.: <$0.10/Wp, depending on site selection
- Transmission interconnect: $1.0-$1.5 MM, up to $80 MM (prohibitive)

Utility Scale Solar PV: Non Module Costs

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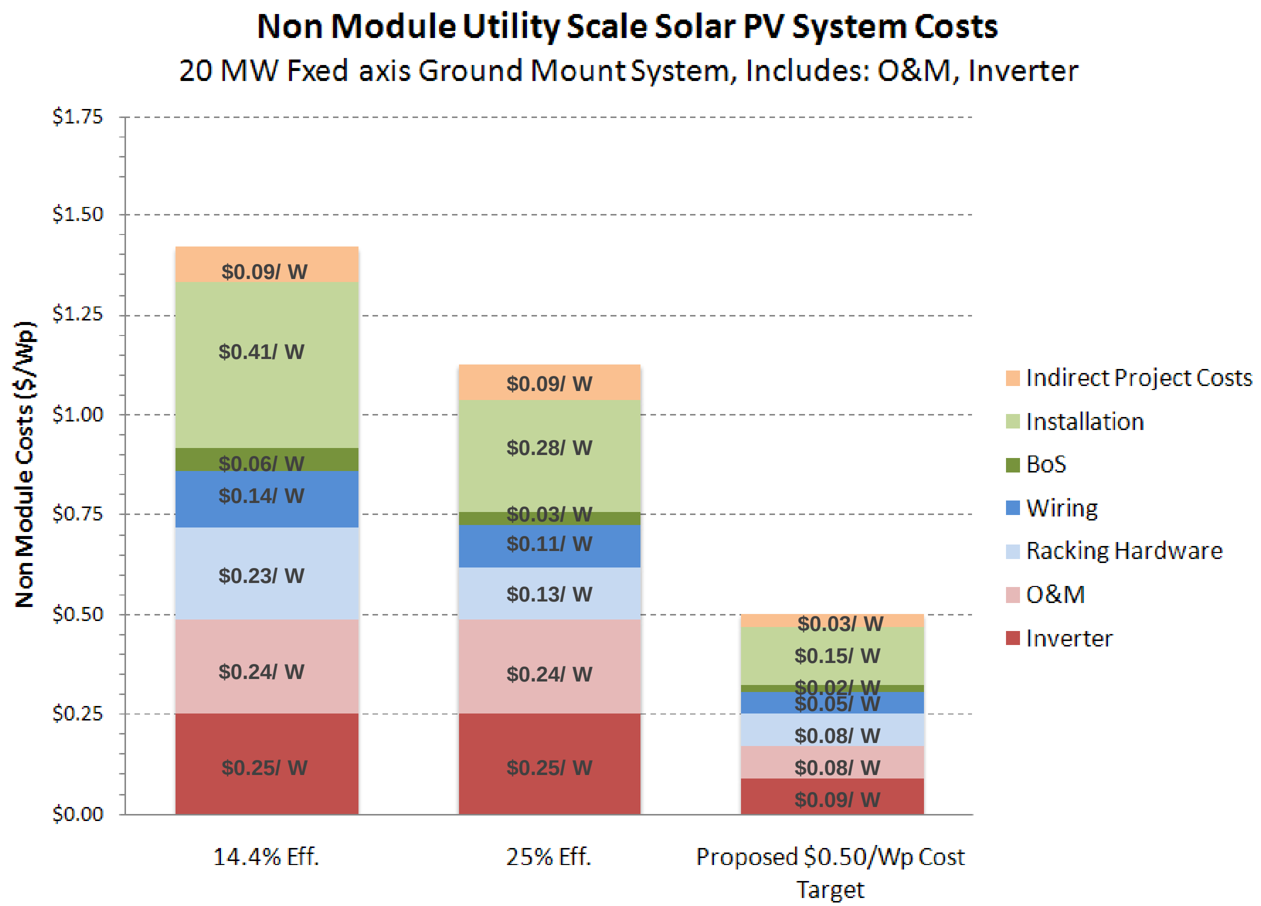

Relative to the 25% module efficiency scenario, the $0.50/Wp system must:

- Reduce fixed power costs (Inverter, O&M) by 66%
- Trim (short, long) wiring costs (content) and installation by 50%
- Decrease racking hardware, BoS components by 33%

Non Module Cost-Sensitivity to Efficiency

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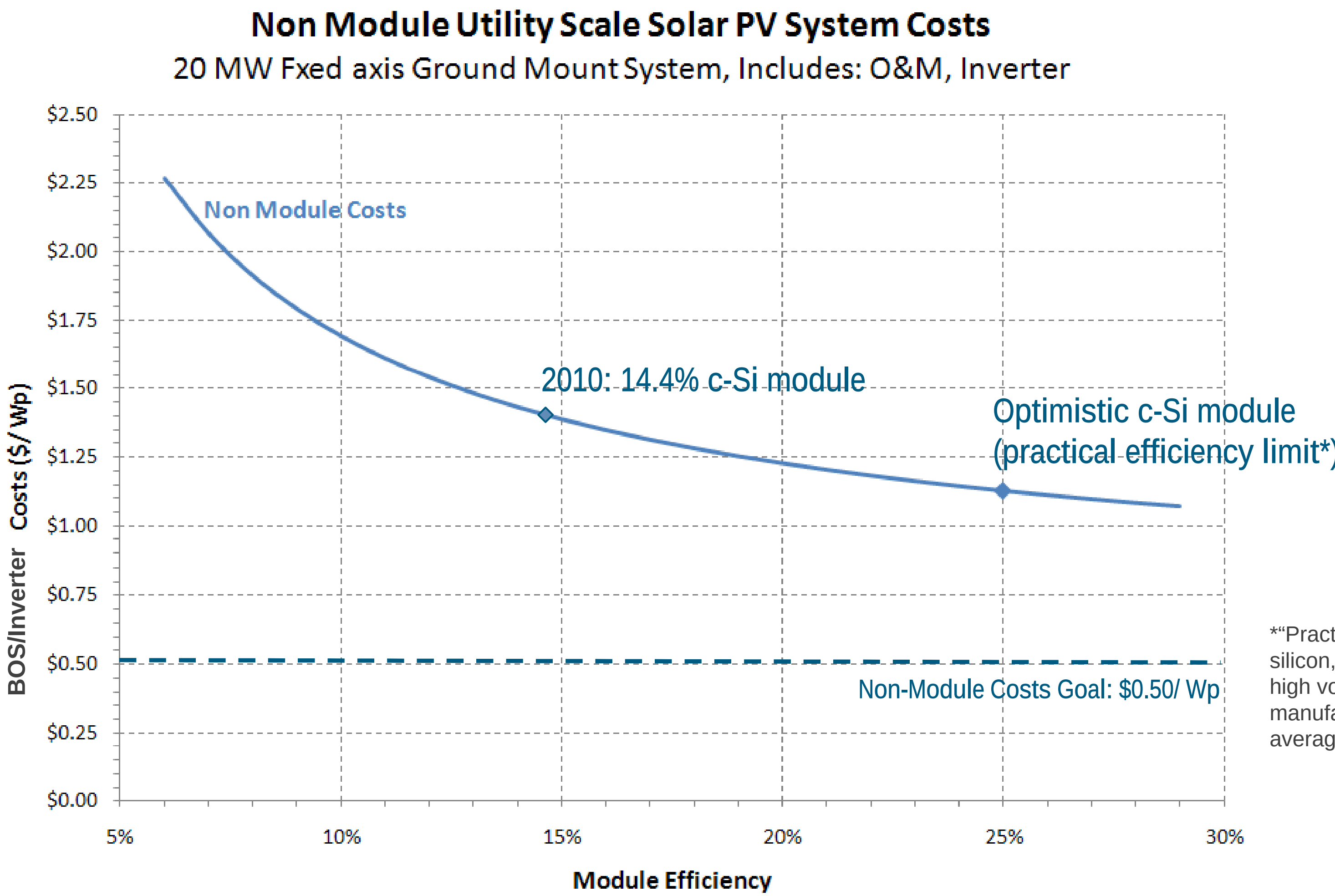

*"Practical limit"; silicon, one sun, high volume manufacturing average.

- Module efficiency alone is not adequate to achieve grid parity (non-module costs exceed $/W at practical limit; 25%)

Solar PV Energy Costs:
Current and Projected, Leading Technologies

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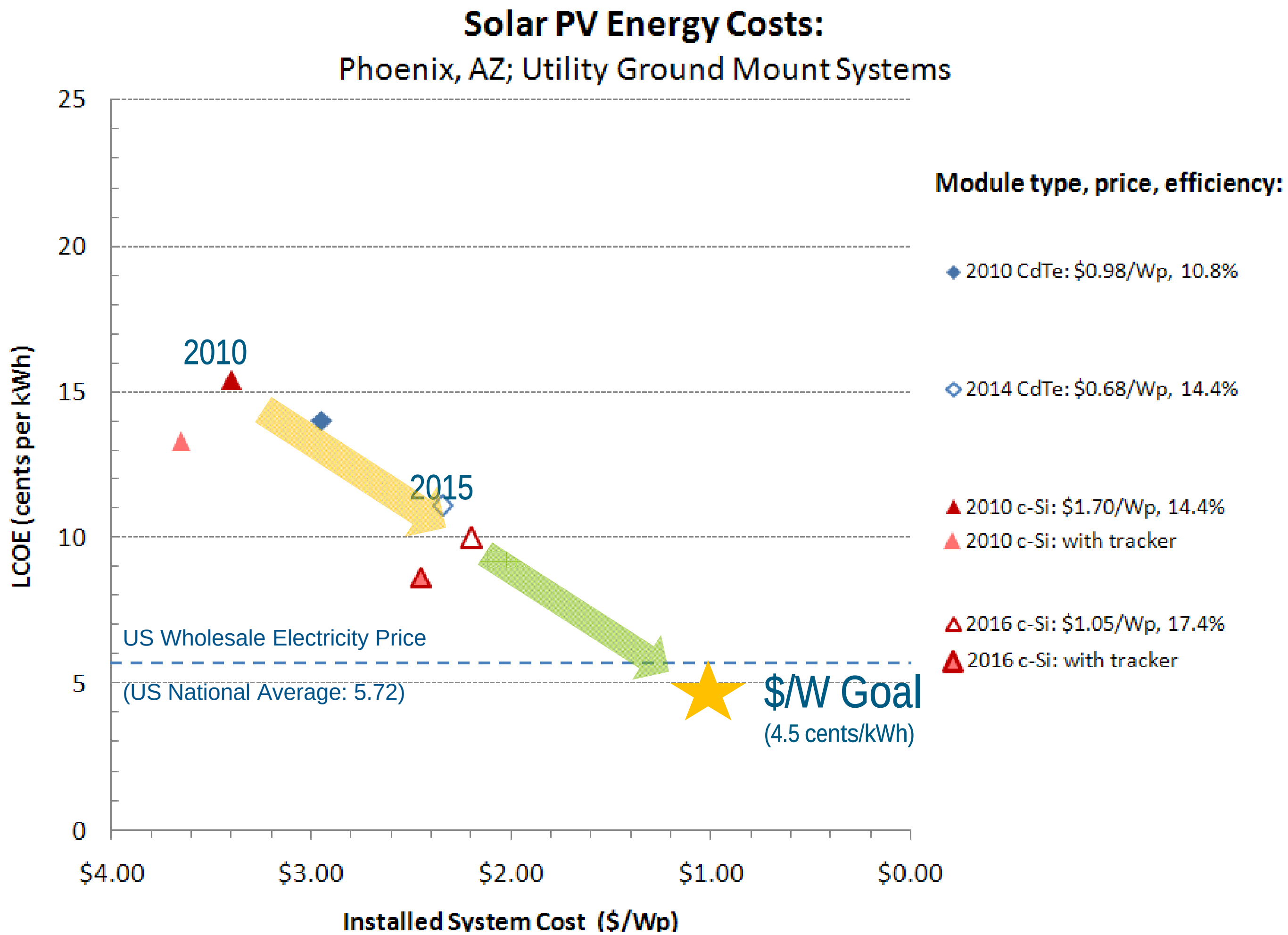

- Unsubsidized Solar PV energy costs will remain >50% higher than US wholesale average (optimal solar resources)

Summary

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- History of module cost reduction may not continue to be extrapolated
- Cost target for broad (unsubsidized) US adoption likely requires revolutionary technical innovations
  - Module cost and performance
  - Power electronics efficiency and reliability
  - BoS, installation costs
- Focus on high cost electricity markets may reduce the incentive for such industrial investments
- Success in the US market at $1/W will enable US companies to lead in other regions of the world

Thank You

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