How to Achieve the Sunshot Goal of $0.50/watt at the Module Level Using Compound Semiconductors?

Industrial Perspective

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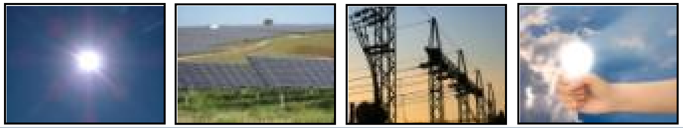
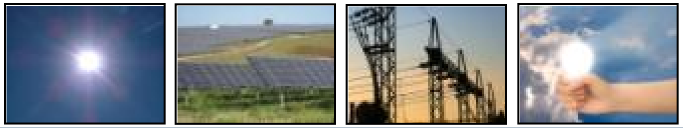


XSUNX™

Program Topics and Presentation Outline/Approach

- **Program Topic: How to Achieve the Sunshot Goal of $0.50/watt at the Module Level Using Compound Semiconductors?**
  - **What are the Major Costs in PV?**
  - **Is this an Achievable and Realistic Goal?**
  - **Identify Areas/Components of High Cost and Ideas to Lower those Costs. What Needs to Happen?**
  - **What can Material Scientists do to Reach the Goal?**

- **Presentation Outline/Approach**
  - **Assess Cost of the Module Finishing Materials**
    - ✓ Required For All Technologies and Module Manufacturers
    - ✓ Impact as a Function of Conversion Efficiency
  - **Determines Budget for Remainder of a Module Product**
    - ✓ Cells Materials, Interconnect Materials, Direct Overhead, Direct Labor
  - **Challenges and Possible Requirements to Meet Sunshot Goals**

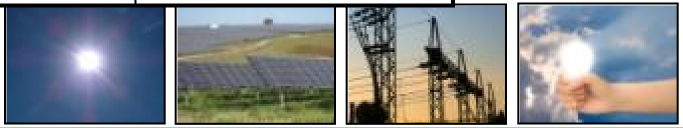


Definitions To Aid Discussion

❖ Efficiency

- **Active Area →** Area of the Active PV Only
  - ✓ Subtract Grid Area from Area
  - ✓ Don't Count Cell-to-Cell Spacing, Cell-to-Edge Spacing, Frame Area
- **Aperture Area or Cell Area →** Includes Grid Shadowing Losses
  - ✓ Don't Count Cell-to-Cell, Cell-to-Edge, Frame Areas
- **Total Area →** Efficiency Measured Using The Frame-to-Frame Area
  - ✓ Includes Grid Shadowing Losses
  - ✓ Includes Area Losses Associated with Cell-to-Cell Spacing, Cell-to-Edge Spacing and Frame
- **Example of Active Area-to-Module Losses**

Cell Configuration -->	Single Cell Module		MI Module
Losses	125 mm Pseudo Sq	125 mm Sq	0.5 cm wide cell
Cell Area and Resistance	8.99%	8.99%	12.84%
Cell Spacing	7.56%	2.81%	0.00%
Current Mismatch	0.00%	0.00%	10.00%
Periphery	6.40%	6.40%	6.40%
Last Cell (Covered with Buss)	0.00%	0.00%	4.88%
Total Loss	22.95%	18.20%	34.12%

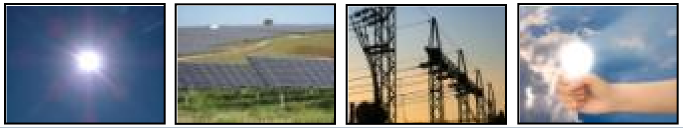


Definitions To Aid Discussion

❖ Cost Definitions for $/W Discussion

- **Product**
  - ✓ Cells
  - ✓ Strings
  - ✓ Module with All Components to Be Sold
    - o Laminated with Frame, J-Box, Label, and Instructions

- **Accounting**
  - ✓ Direct Material and Labor
  - ✓ Direct Material, Labor, and Overhead (OH)
    - o Includes Depreciation, Utilities, Factory Floor Space, Inbound Shipping
  - ✓ Total Factory Cost
    - o Bullet Above + Indirect OH, Sales/Marketing, G&A, Tax

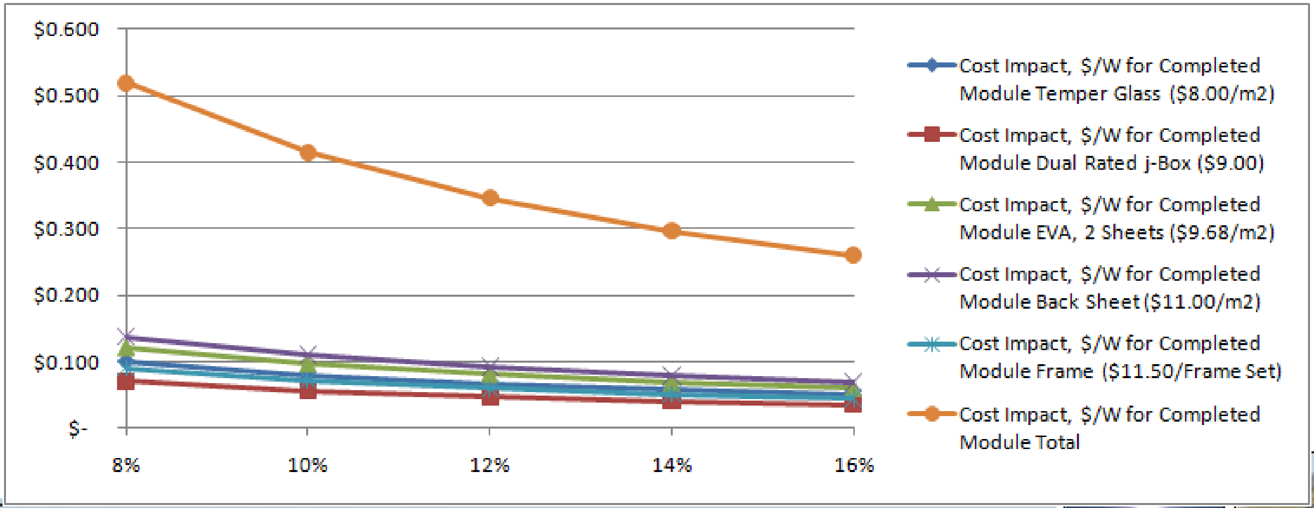


Module Material Cost as a Function of Efficiency ("Back End Cost")

❖ Module Packing Materials

- **Quotes from Recognized UL/IEC Qualified Suppliers for 1.0 x 1.6-m Module, >20MW/yr Volume**

Module Efficiency	Typical 1.0 x 1.6-m Module, Watts	Cost Impact, $/W for Completed Module					
		Temper Glass ($8.00/m2)	**Dual Rated j-Box ($9.00)**	**EVA, 2 Sheets ($9.68/m2)**	**Back Sheet ($11.00/m2)**	**($11.50/Frame Set)**	**Total**
8%	128	$ 0.100	$ 0.070	$ 0.121	$ 0.138	$ 0.09	$ 0.519
10%	160	$ 0.080	$ 0.056	$ 0.097	$ 0.110	$ 0.07	$ 0.415
12%	192	$ 0.067	$ 0.047	$ 0.081	$ 0.092	$ 0.06	$ 0.346
14%	224	$ 0.057	$ 0.040	$ 0.069	$ 0.079	$ 0.05	$ 0.296
16%	256	$ 0.050	$ 0.035	$ 0.061	$ 0.069	$ 0.04	$ 0.259



Module Material Cost Drivers

- **Material**
  - **Glass → Energy….Glass Plants are Virtually Fully Automated**
  - **J-Box → Petroleum Products for Box Resin, Copper**
  - **EVA → Polymers (Vinyl Acetate and Ethylene)**
  - **Back Sheet → Polymers (Polyvinyl Fluoride, PET, EVA Bond Layer)**
  - **Frame → Aluminum, Energy**

- ***All Module Finishing Materials are Already Commoditized and Further Cost Reductions Are Unlikely → Likely a Rising Fixed Commodity Cost For Module Packaging Materials***

- ***At 16% Module Eff. Cost of the Module Packaging is ~$0.25/Watt***
- ***Leaves ~$0.25/Watt for:***
  - **Factory, Direct Labor, Cell Direct Material, Interconnect Direct Material, Direct OH (Depreciation, Utilities, Consumables)**




❖ CIGS Provides the Highest Thin Film Efficiency and the Most Head Room For Improvement

Solar Cell Technologies	Module Efficiency*	Record Lab Efficiency**	Efficiency Difference
Crystalline Silicon (Si)			
Mono or Single Crystalline Si	15 – 18%	25%	39%
Poly Crystalline Si	13 – 16%	20%	25%
Thin Films			
Amorphous Silicon (a-Si)	5 – 8%	9.5%	10%
Nano or Micro Crystalline Si	8 – 9%	10.1%	12%
Cadmium Telluride (CdTe)	8 – 10%	16.7%	67%
Copper Indium Gallium Diselenide	**8 – 10%**	**19.9%**	**100%**
Organic and Chemical			
Dye Sensitized	N/A	10.4	N/A
Organic/Polymer	N/A	5.1	N/A

XsunX Approach → Rapid Single Cell Processing to Capture the CIGS Headroom Potential By Reducing Processing Variation

*** Acquired from Published Data/Sell Sheets**

**** Green MA, Emery K, Hishikawa Y, and Warta W. Solar Cell Efficiency Tables (Version 33). *Progress in Photovoltaics: Research and Applications* 2008; 17: 85-94.**




Challenges to Achieve the Sunshot Objective: $0.50/Watt Module

- **Efficiency Improvement is a Must**
  - **At Less Than 10% Module Area Eff Entire Budget Required for Module Materials**
  - **Requires High Cell Ef, Low Loss Interconnect, Low Loss Grids (Minimize Area)**
    - ✓ a-Si, CdTe, CIGS, x-Si

- **Factory Cost Requirements Must Be Minimized**
  - **Must Be Low Cost (No H-Occupancy, B or F Occupancy) and Minimize Foot Print**
    - ✓ a-Si, CdTe, CIGS, x-Si

- **Long-Term Module Stability Is Required**
  - **> 20 Year Warranty….Is 50 Year Possible? Decelerate the Gradual Degradation**
  - **Field Performance Guarantee are Becoming the Norm**
    - ✓ a-Si, CdTe, CIGS, x-Si

- **Final Product Must No Have Toxic Materials Requiring Special Disposal**
  - **Avoid Expensive Product Disposal Requirement (And Reserves on Revenue)**
    - ✓ a-Si, CdTe, CIGS, x-Si

- **Cell Materials Must be Low Cost and have Cost Stability**
  - **Thin Films Are Much Less Susceptible to Cell Material Commodity Pricing Fluctuations**
    - ✓ a-Si, CdTe, CIGS, x-Si

- **Legend**
  - **Red: Possible Major Impediment to Meeting theSunshot Goal**
  - **Blue: May Be a Challenge to Meeting the Sunshot Goal**
  - **Green: Compatible with Meeting the Sunshot Goal**




All Roads Lead to CIGS

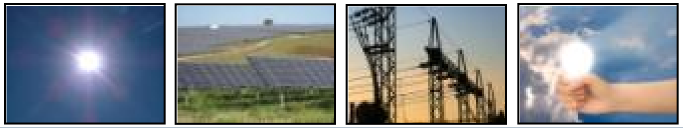
- ***High Efficiency*** **→** Highest of the Thin Films and Equivalent to Poly Crystalline Si (Laboratory Scale)

- ***Tolerant Chemistry*** **→** Good Performance Achieved with a Wide Range of Cu/(In+Ga) and Ga/(In +Ga) Composition Ratios

- ***Thin-Film Nature*** **→** CIGS absorber is ~2.5 um compared to ~170 to 250 um for Si
  - CIGS Less Susceptible to Commodity Pricing of Raw Materials or to Material Shortages

- ***Stability*** **→** CIGS Does ***NOT*** Exhibit Light-Induced Instability Found with Some Thin-Film Solar Devices

- ***Non-Toxic*** **→** *CIGS Does Not have Reportable Quantities of Hazardous Substances* → *Ref:* Vasilis Fthenakis, Brookhaven National Lab



Thank You!!

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