Manufacturing challenges facing CdTe and CIGS

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Our Mission

To create enduring value by enabling a world powered by clean, affordable solar electricity.
Outline

• Brief market overview
• Current status
• Opportunities in TF PV manufacturing
  – Technological Improvements
  – Labor force characteristics
• Conclusions
Global Cumulative Installed Capacity of PV

Selected IEA countries

Cumulative Installed Capacity (GW)

Long-term View of the Solar PV Industry

A complex marketplace

PV Technologies

2008 Technology mix

- Mono: 38%
- Multi: 46%
- CdTe: 8%
- A-Si: 5%
- CIGS: 2%
- Other: 1%

Source: “Clean Technology Primer”, Jeffries Research, March 2
"Copy Smart" Production Capacity Growth

Driven by increasing efficiency, run rate, and yields

First Solar 2009 Market Share*

* - based on Analyst estimated 7.3 GW global installs in 2009

2005 & 2006 based on Q406 run rate; 2007 based on Q407 run rate; 2008 based on Q408 run rate; 2009 – 2012 based on Q409 run rate

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Products & Performance

Proven Record of Increasing Module Conversion Efficiencies

- Modules Produced
- Conversion Efficiency

- Q1'02
- Q2'02
- Q3'02
- Q4'02
- Q1'03
- Q2'03
- Q3'03
- Q4'03
- Q1'04
- Q2'04
- Q3'04
- Q4'04
- Q1'05
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- Q4'07
- Q1'08
- Q2'08
- Q3'08
- Q4'08
- Q1'09
- Q2'09
- Q3'09
- Q4'09
- Q1'10

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High-Confidence Roadmap to >12.5%

• **12.5% requires closing the gap between CdTe product and lab record performance**
  – NREL “hero” CdTe Cell is 16.5%
  – Best module is 80% of "hero" cell
  – Production average is 90% of best module
  – 16.5% hero-cell corresponds to ~13% production

• **Pathway is mostly improved light transmission into existing device**
  – NREL Jsc demonstrates upside of 1.3% absolute
  – Many opportunities for improvements in current
  – Technology challenge is to make these improvements manufacturable
    – Reducing thickness of CdS
    – Proprietary improvements to TCO
    – Proprietary improvements to glass transmission

• **FSLR Leveraging current leadership for sustained competitive differentiation**
1,000 Pathways to >16% and Beyond

- Multiple approaches to driving performance
- Renewed excitement in the technical field
- Fundamental device physics and materials science
- TF-CdTe still has enormous headroom

Optical Engineering
Contact Engineering
Grain-boundary Engineering
Band-Engineering
Dopant Engineering
Opportunities in TF PV Manufacturing

1. Technological Improvements
2. Labor Force Characteristics

Key Criteria

i. R&D needs to be compatible to HVM – i.e. takt times, CapEx, OpEx, environmental impact (toxicity, CO₂ footprint)

ii. No need to fix what isn’t broken/reinvent the wheel
Technological Improvements

- Increased fundamental understanding of semiconductor system and interfaces
- Novel in-situ, on-line, and off-line metrology
  - compositional control
  - key opto-electronic properties
  - module scale solar simulators and QE
- Equipment engineering
  - P1 through P3 laser scribing for CIGS
  - thermal processing
- Reliability
  - fundamental understanding of device & material degradation mechanisms
  - new packaging materials
  - energy rating standards, methods and algorithms
  - accelerated stress test protocols representative of multiple climatic regions
Technological Improvements cont.

- Novel materials for encapsulation and device stack
  - ohmic back contact
  - TCO
- Recycling methods for CIGS
- BOS optimization
  - inverters optimized for TF PV
  - NEC revision enabling > 600V system voltage
Labor Force Characteristics

- Solid state and theoretical physicists trained in polycrystalline compound semiconductor systems
- Analytical and physical chemists as well as process engineers understanding TF deposition technologies
- Materials Scientists skilled in materials characterization and failure analysis
- Electrical engineers and physicists trained in device characterization and instrumentation
- Mechanical engineers with focus on large area, HVM deposition and automation equipment
- Computer scientists
- Sound understanding of basic principles in physics, chemistry, and engineering
Conclusions

• PV historically too expensive; conventional electricity rising in price; PV reducing cost
• Grid parity leading to inflection in price elastic demand; exponential demand leading to continued growth of PV
• CdTe clear leader in LCOE from PV; c-Si will continue to play a major role; CIGS, if commercial scale will prove viable, can emerge as competitive on cost to c-Si
• Better understanding of fundamentals for CdTe and CIGS required
• Technology/engineering challenge is to make R&D improvements manufacturable
• Need for a wide array of experts – mechanical as well as electrical engineering, physics, chemistry, materials science, and computer science
Career Opportunities at First Solar

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