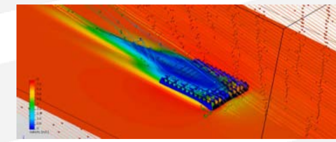
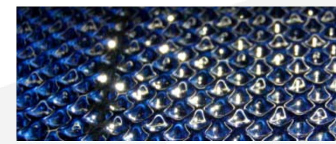
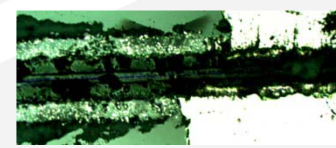
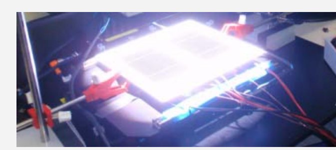
Fraunhofer Center for Sustainable Energy Systems

Emerging Technologies in the Solar Landscape: Can Thin Films Play a Role?

NOLAN BROWNE

Managing Director

PRESENTED AT

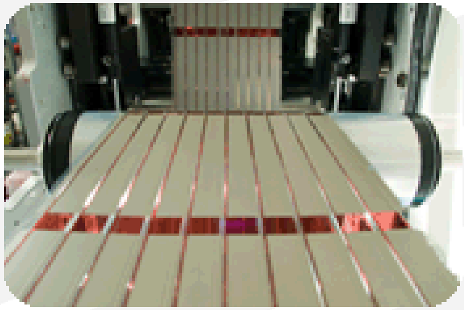
Thin Film Solar 2009
San Francisco, CA, USA
April 29th, 2009

Significant Advantages of Thin Film Solar vs. x-Si

- Potential for lower $/w than crystalline silicon (x-Si):
  - Less material required
  - Simplified fabrication process
  - Cheaper manufacturing equipment
- New products become possible:
  - Flexible modules
  - Lightweight modules
  - Awnings, clothing, roll-up PV blinds, portable devices
  - Partially transparent devices for BIPV
- Improved performance at lower light levels
- Less power lost at high temperatures

SOURCE: Xunlight

SOURCE: G24i



SOURCE: Konarka

SOURCE: Solarmer

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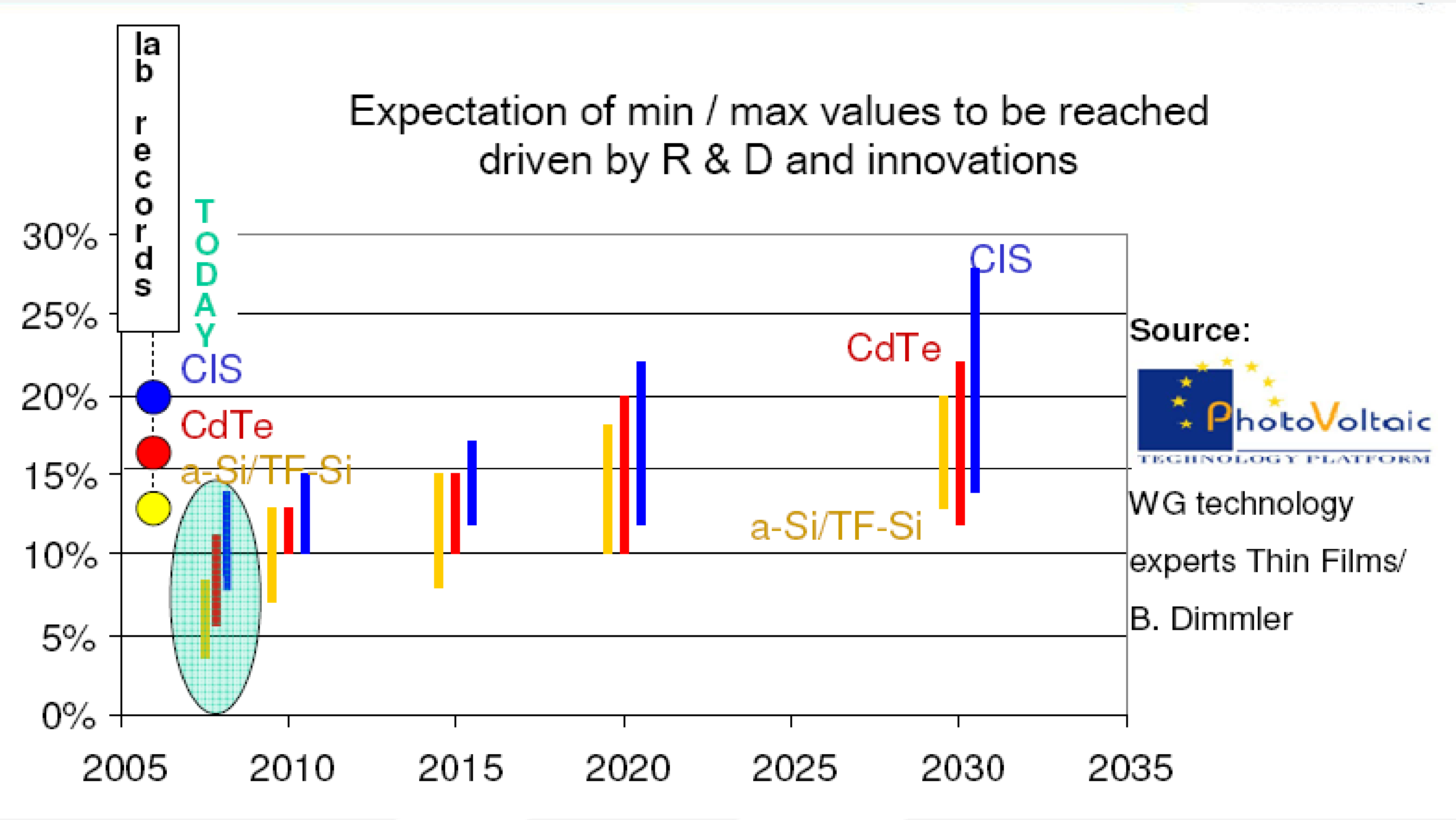
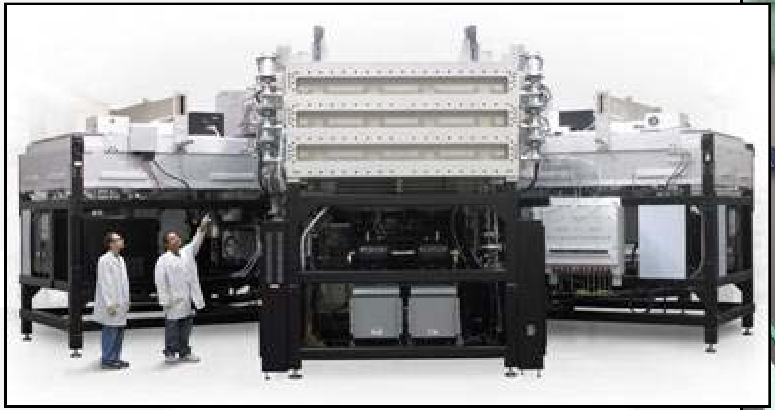
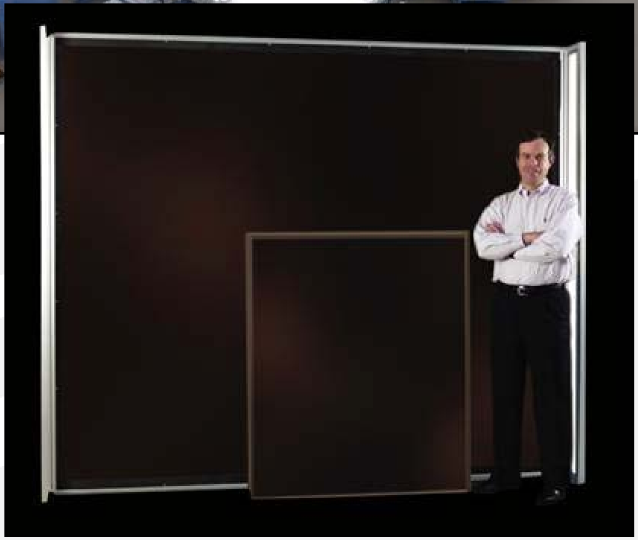
Thin Films May Surpass x-Si Efficiencies…



…but it will take time and resources.

Thin Films Have Come a Long Way In Reducing Costs



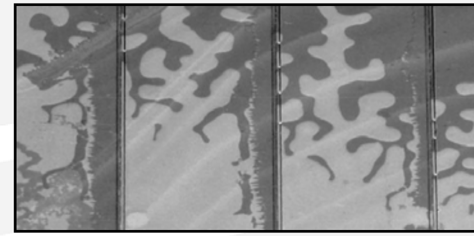


SOURCE: Applied Materials

- Applied Materials SunFab™
- Leveraging knowledge from flat panel display technology
- 5.7m² modules
- Tandem junction a-Si / mx-Si layers
- Targeting $0.71/W production
- Installation costs also reported lower

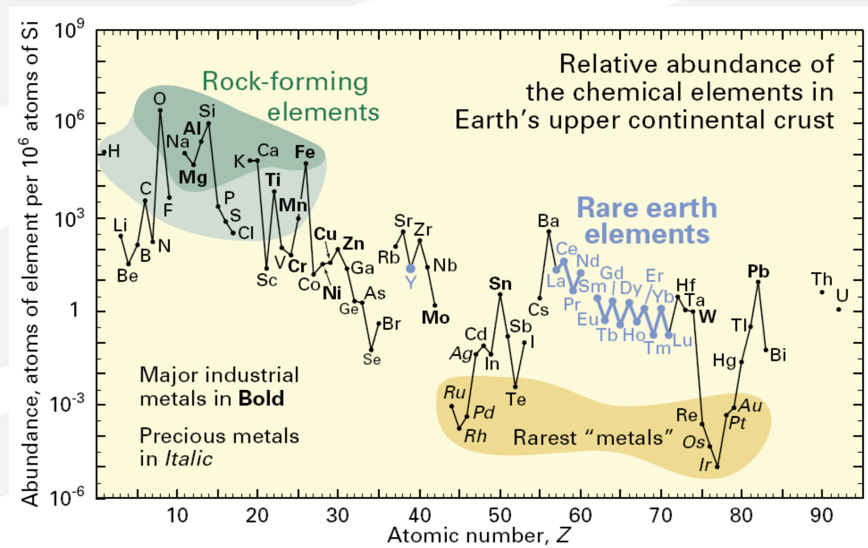
Need to Address Challenges to Wide-Scale Deployment

- Efficiencies still lag those of crystalline silicon
- Degradations of modules and material in the field
- Process yields
- Availability of materials
  - Concerns for CIGs and CdTe



Delamination of thin film cells.

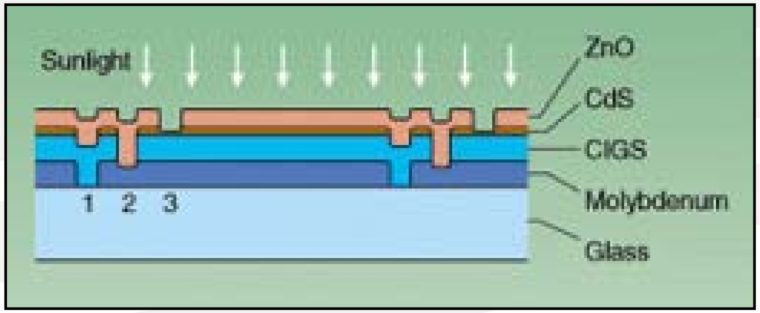
SOURCE: T.J. McMahon, Prog. Photovolt Res. Appl. 2004; 12: 235-248



SOURCE: P.H. Stauffer et al, *Rare Earth Elements - Critical Resources for High Technology*, USGS (2002)

Challenges in the Field vs. x-Si

- It is more challenging to make thin film modules that can survive 30 years outdoors compared to x-Si:
  - Cells are not surrounded by encapsulant
  - Laser scribes can provide a route for water to wick into devices
  - Delamination between glass and TCO
  - Many thin film materials tolerate less moisture than x-Si before problems become apparent
  - More distinct layers over which delamination problems can occur

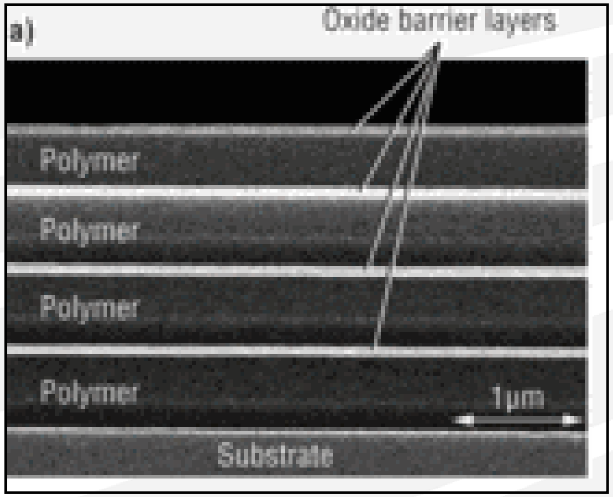


SOURCE: DayStar Technologies

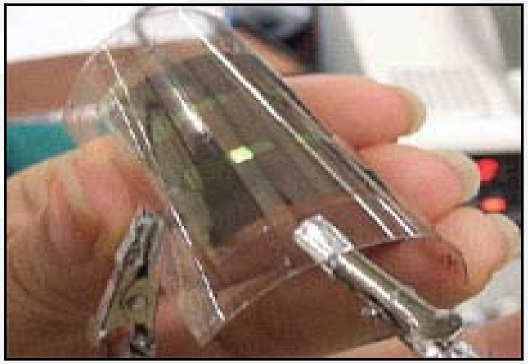
Addressing Moisture Absorption in Thin Film Modules

- Edge sealing for glass modules
- Improved encapsulation for flexible modules
  - Use of organic/inorganic materials developed for OLED
  - Nano-particle pore sealing technology

MATERIAL	Moisture permeation rate (g/m2/day)
Typical barriers	1E-02 to 1E-03
Multilayer	1E-05
Nano-particle pore sealing	As low as 1E-08



SOURCE: Chu et al, *Solid State Technology*, March 08



SOURCE: *Semiconductor International*, 5/1/08

More Suitable Module Testing Standards Are Needed

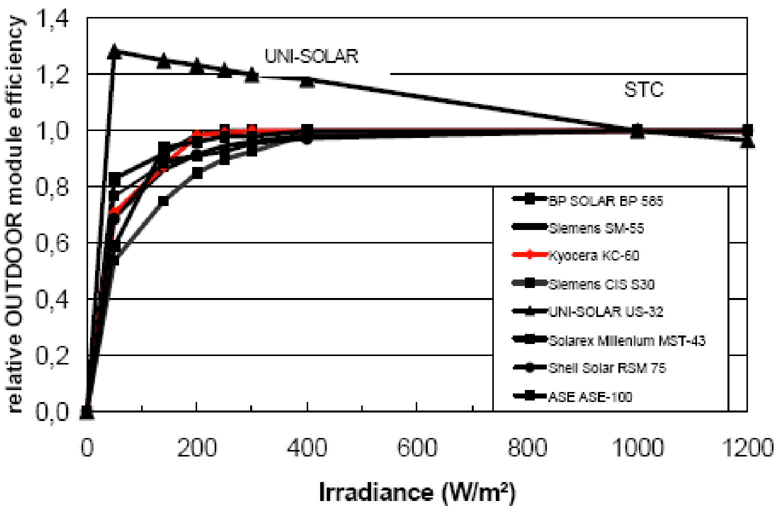
- Standard "Peak Power" Conditions:
  - 1000 W/m^2
  - Irradiation normal to module plane
  - am 1.5 spectrum
  - 25 ^{0}C
- Real-Life Conditions:
  - Light intensity changes with time of day and seasons
  - Diffuse light (cloudy, early or late in day)
  - Angle of irradiation changes
  - Efficiency of modules decreases as they heat up under high irradiation
- **Most Important Economic Metric: Total kWh Generated by System**

Electrical Characteristics[2]	SX 3200	SX 3195
Maximum power (P_{max})[3]	200W	195W
Voltage at P_{max} (V_{mp})	24.5V	24.4
Current at P_{max} (I_{mp})	8.16A	7.96A
Warranted minimum P_{max}	182.0W	177.5W
Short-circuit current (I_{SC})	8.7A	8.6A
Open-circuit voltage (V_{OC})	30.8V	30.7V
Temperature coefficient of I_{SC}	(0.065±0.015)%/°C	
Temperature coefficient of V_{OC}	-(111±10)mV/°C	
Temperature coefficient of power	-(0.5±0.05)%/°C	
NOCT (Air 20°C; Sun 0.8kW/m²; wind 1m/s)	47±2°C	
Maximum series fuse rating	15A	
Maximum system voltage	600V (U.S. NEC rating)	

SOURCE: BP Solar SX3200 200W module data sheet

Thin Film Modules Can Perform More Favorably Than x-Si

- Low/Diffuse Light:
  - Some thin film modules become more efficient
  - x-Si becomes less efficient
- Increased Temperature:
  - Power output of x-Si modules typically decreases by 0.5% / °C above nominal operating temperature



Product	Temp Coefficient / °C	Source
mc-Si	-0.47%	Schott litterature
a-Si (Triple Junct)	-0.31%	NREL
CIGS	-0.60%	Shell litterature
CdTe	-0.20%	First Solar litterature
X-Si	-0.47%	Schott litterature
a- Si (Tandem Junct)	0.00%	Sanyo brochure (a-Si)

SOURCE: IBIS report for XsunX: *Levelized Cost of Electricity*

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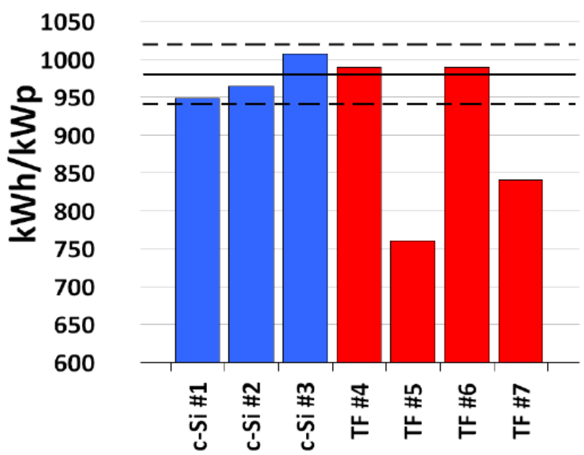
Performance of Thin Film Modules

- Performance difficult to compare
- Rating kWh/kWp relates generated power to nameplate power
- Developing better metrics to compare thin films with x-Si on "energy harvesting" capabilities

Test facilities at ISET, Kassel



SOURCE: S. Ransome, 23rd EUPV Solar Energy Conference, 2008, Valencia, Spain

Summary

- Thin films represent a promising opportunity:
  - Possibility of lower costs
  - Opportunity to significantly improve efficiencies
- Technical challenges exist and need to be worked out:
  - Moisture protection is badly needed
  - New testing standards and methodologies must be developed and utilized