National Renewable Energy Laboratory
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The Role of Polycrystalline Thin-Film PV Technologies in Competitive PV Markets

Bolko von Roedern and Harin S. Ullal

National Center for Photovoltaics
National Renewable Energy Laboratory
Golden, Colorado USA

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Presentation Outline

Update on comparing different PV technologies

Issues for Commercializing CdTe and CIGS PV technologies

Commercial PV developments

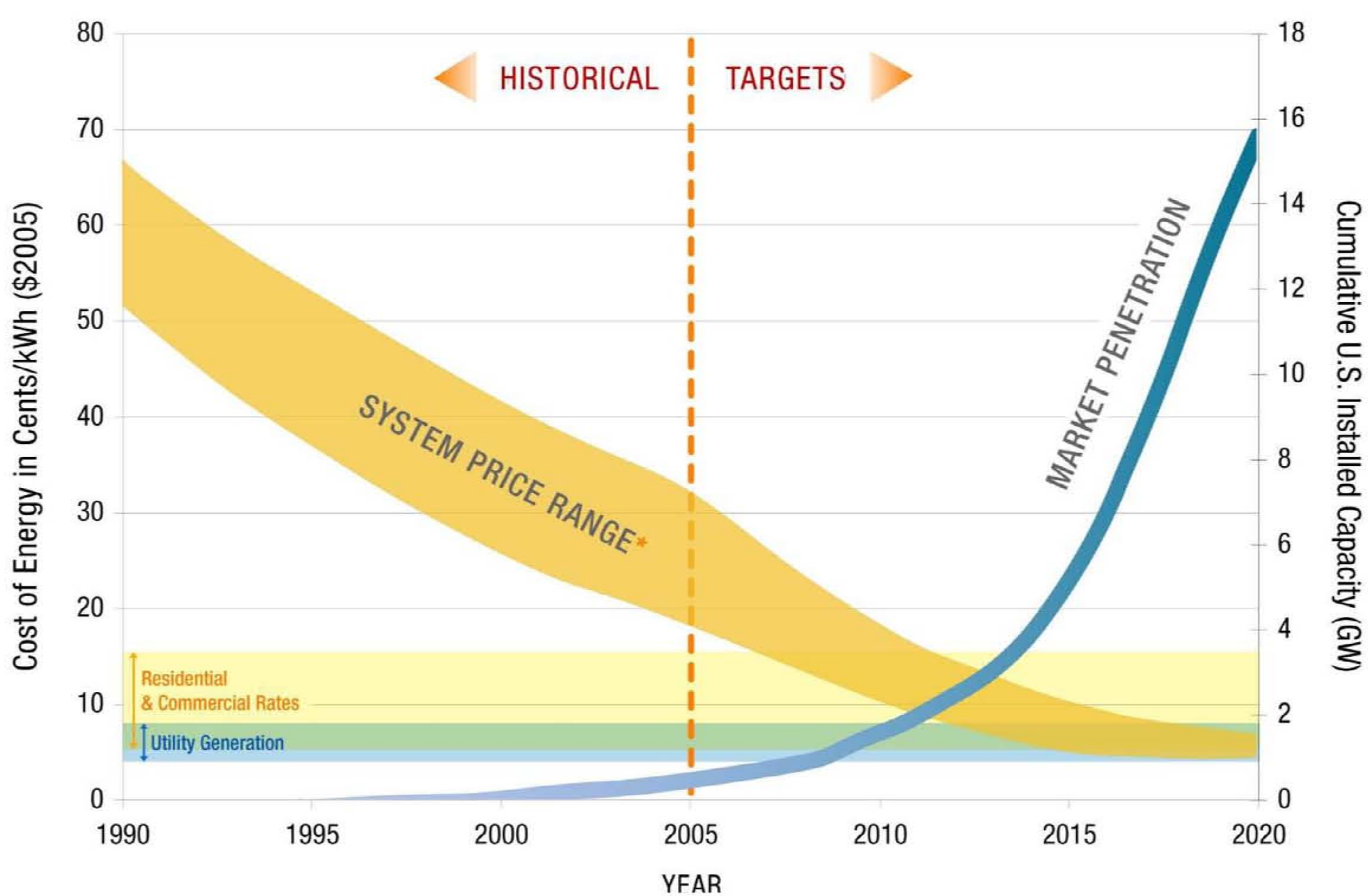
The US PV companies in 2007

- (1) First Solar: shipped: 120 MW, cap 08: 150 MW
- (2) Uni-Solar Ovonics: 48 MW, cap 08: 120 MW
- (3) Solar World (Shell): 35 MW, cap 08: 100 MW
- (4) Evergreen Solar: 16.4 MW, cap 08: 86 MW
- US total: 266 MW, cap 08: 616 MW
- Slide considers MW produced in US only

DOE/NREL PV contract programs

- In the past: Thin Film Partnership and PVMatR&D
- Since 2006: Solar America Initiative

President's Goal for the Solar America Initiative (SAI)
Making Solar Cost-Competitive Nationwide by 2015



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7

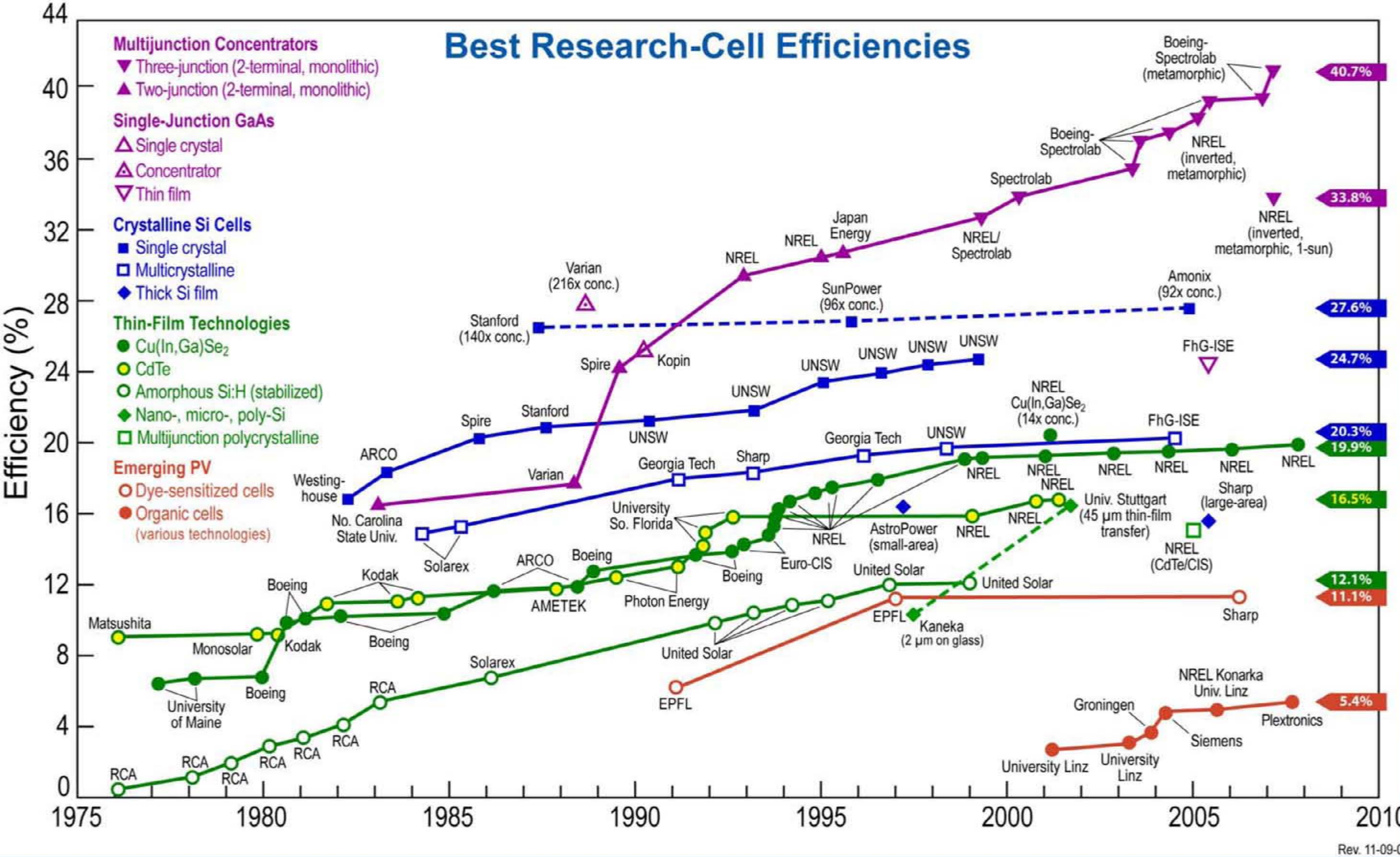
PV R&D pipeline will support technologies/companies, with funding opportunities calibrated to maturity

PHASES	Material & Device Concepts	Device & Process Proof of Concept	Component Prototype & Pilot Scale Production		System Development & Manufacturing	
SOLICITATION	Solar Energy Utilization	Future Generation PV Devices & Processes	PV Component / System Incubator	Advanced Inverters & Energy Management Systems	University Product & Process Development Support	Technology Pathway Partnerships
FUNDING SOURCE	DOE/O/S, BES	DOE / SETP	DOE / SETP	DOE / SETP	DOE / SETP	DOE / SETP
DESCRIPTION	New materials and pathways for solar to electric conversion	Novel devices or processes with potentially significant performance or cost advantages	Prototype PV components or systems produced at pilot-scale with demon-strated cost, reliability, or performance advantages	Design, test, and produce advanced inverters and energy management systems with improved reliability, enhanced value, and reduced costs	Universities perform targeted materials science and process engineering research in support of industry-led teams developing new PV systems for commercialization in 2010-2015	PV systems and components ready for mass production delivering energy at target costs
PROJECT LIFECYCLE	3 years	3 years	1.5 years w/ 9 mo. On/Off Ramp	3 years	3 Years	3 years
ANNUAL FUNDING LEVEL	$0.3 - 1.5 Million	≤ $300K	$1 - 2 Million	$1 - 2 Million	Up to $300,000/year	$2 - 7 Million
TEAM LEADS	Universities or Laboratories*	Businesses or Universities*	U.S. Commercial Entity	U.S. Commercial Entity	Universities	U.S. Commercial Entity
ELIGIBLE PARTICIPANTS	All	All	Universities / Laboratories*	All	Universities	Universities / Laboratories*
ENTRANCE CRITERION	Basic science properties conceived/simulated	Materials synthesized; properties observed	Coupon-scale PV cell; process demonstrated in lab; proof of concept demo	Power electronics and control system manufacturing capability	Identification of manufacturing process or component improvements possible through targeted research investigations.	Prototype components; pilot production demo; business case established
EXIT CRITERION	Materials synthesized; properties observed	Coupon-scale PV cell; process demonstrated in lab; proof of concept demo	Prototype components; pilot production demo; business case established	Pre-commercial inverters / energy management systems submitted for product certification	Incorporation of research results into commercial manufacturing operations or product designs.	Commercial PV systems and subsystems; scaled production demonstrated >25MW
TOPICS	• Single-crystal, poly-crystalline, amorphous, and nanostructured inorganic and organic materials • Electronic structure • Single or multiple junction solar cells	• New devices and structures using materials such as thin-film silicon, microcrystal-line/amorphous silicon, poly-crystalline metal chalcogenides and oxides, nanocrystal-line materials, biomimetic concepts, organic materials, photoelectrochemical cells, dye-sensitized materials, materials with low-dimensional quantum structures • Very-high efficiency epitaxial solar cells or other concepts	• Modules: multiple technologies (including CPV) seeking efficient material use, better performance, or improved manufacturing • BOS Components: higher reliability inverters, CPV trackers, rapid installation features, storage systems • Systems: controls and smart monitoring, integration of components, factory diagnostics	Lower cost, higher value systems resulting from: • integrated circuitries, • advanced thermal management, • advanced transient overvoltage protection, • micro-grid-ready controls, • replacement of unreliable components, • integration with storage or UPS, • compatibility with buildings applications, • communications options, • customer-friendly energy monitoring, • reduction in parts and installation steps, • standards compliance, • innovative packaging, • self diagnostics, and • incorporation of other new enabling technologies	Identifying and developing: • Fabrication processes to improve material properties during manufacture • Improved solar cell materials • Innovative device designs to improve solar cell efficiency • Simpler, lower cost manufacturing processes • New electrical contacting techniques for improved efficiency and reliability • Diagnostic techniques to identify properties and quality of solar cells materials during manufacturing • Improved materials utilization processes • Understanding of chemistry between encapsulants and solar cell materials • Providing careful long-term field testing of modules and systems in support of product improvement	• Partnerships with U.S. industry for projects that focus on development, testing, demonstration, validation, and interconnection of new PV components, systems, and manufacturing equipment • Technology improvements in PV system and component design, integration, and installation will be a focus • Cost reductions, performance enhancements, and reliability improvements are sought for all aspects of PV systems

NOTE: The NREL and SNL teams that are part of the SETP program will continue to provide technical support for these activities through the SETP but will not be direct participants

PV Technologies

- Following slide shows all of them
- Will come back to ordinate (not abscissa) values
- Need to see where technologies are and compare relative value


Best Research-Cell Efficiencies
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
Efficiency (%)
40.7%
33.8%
27.6%
24.7%
20.3%
19.9%
16.5%
12.1%
11.1%
5.4%
Rev. 11-09-07

Near-term PV technologies

"standard" wafer/ribbon Si
amorphous silicon

"Non-standard" wafer Si
a-Si (nc-Si) spectrum splitting multijunctions
CdTeCIGS

Next generation OPV and DSC

Concentrators at all of the above levels

A Rigorous Scheme for Comparing the Near-Term Potential of Different PV Module Technologies

- We needed to asses real efficiency numbers, knowing that champion cell results and commercial product are well documented.
- Define the c/c ratio as the ratio between verified (stabilized) champion cell efficiency and commercial product efficiency
- Assume that at some point in the future, c/c values of 0.8 will be achieved for all technologies
- Project cost effectiveness ($\$/W_p$) assuming that a thin-film module will avoid Si wafer cost, otherwise cost the same as Si modules.

Web Survey of (“best”) Flat Plate Commercial Modules (04/08)

Eff. (%)	Module	T.coeff (%P/^{o}C)	Technology	c/c-ratio
19.3	SunPower 315	-0.38	FZ-Si, ‘point contact’	78%
17.4	Sanyo HIP-205BAE	-0.30	CZ-Si, ‘HIT’	70%
15.1	BP7190	-0.5	CZ-Si, ‘PERL’	61%
14.2	Kyocera KC200GT	Only for Voc	MC-Si	70%
14.2	SolarWorld SW 185	Only for Voc	CZ-Si	70%
13.4	SolarWorld SW 225	Only for Voc	MC-Si,	70%
13.4	Suntech STP 260S-24V/b		MC-Si,	66%
13.3	Sharp ND-216-U1	not given	MC-Si	66%
11.0	WürthSol. 11007/80	-0.36	CIGS	55%
10.4	First Solar FS-275	-0.25	CdTe	63%
8.5	Sharp NA-901-WP	-0.24%/C	a-Si/nc-Si	70%
6.3	Mitsubishi H. MA100 T2	-0.2	a-Si (1-j)	66%
6.3	Uni Solar PVL-136	(-0.21)	a-Si (3-j)	52%
6.3	Kaneka T-SC	Not given	a-Si (1-j)	66%

Future commercial module performance based on today's champion cell results and a c/c-ratio of 80%

Technology	Future commercial performance	Relative Performance (s.p. Si =1)	Relative-cost/relative-performance (*50%* thin film cost advantage)
Silicon (non-stand)	19.8%	1.18	0.85 (competitive)
Silicon (standard)	17.0%	1.00	1.00 (reference)
CIS	15.9%	0.94	0.53 (highly competitive)
CdTe	13.2%	0.78	0.64 (highly competitive)
a-Si (1-j)	8.0%	0.47	1.06 (about the same)
a-Si (3-j) (or a-Si/nc-Si)	9.7%	0.57	0.88 (competitive)

Summary:

- Champion cell results can predict commercial product performance
- Without a 15% efficient total-area stabilized cell, there will be no commercial 10% low-cost module product.
- a-Si/nc-Si will need greater laboratory efficiency to be competitive with competing technologies in the long run
- Near term, all technologies are competitive, thin film modules with efficiencies >9% will lead the way towards lower module prices.
- Concentrator systems, technically ready, would be promoted if a PV growth rate >~40%/per year was mandated.

Technical Issues (general)

- Efficiency value to be understood in context (R&D efficiency, pilot, commercial)
- Better knowledge when to further optimize and when to substitute or add new processes
- Better knowledge as to what creates a stable or instable module

Technical issues (CIGS)

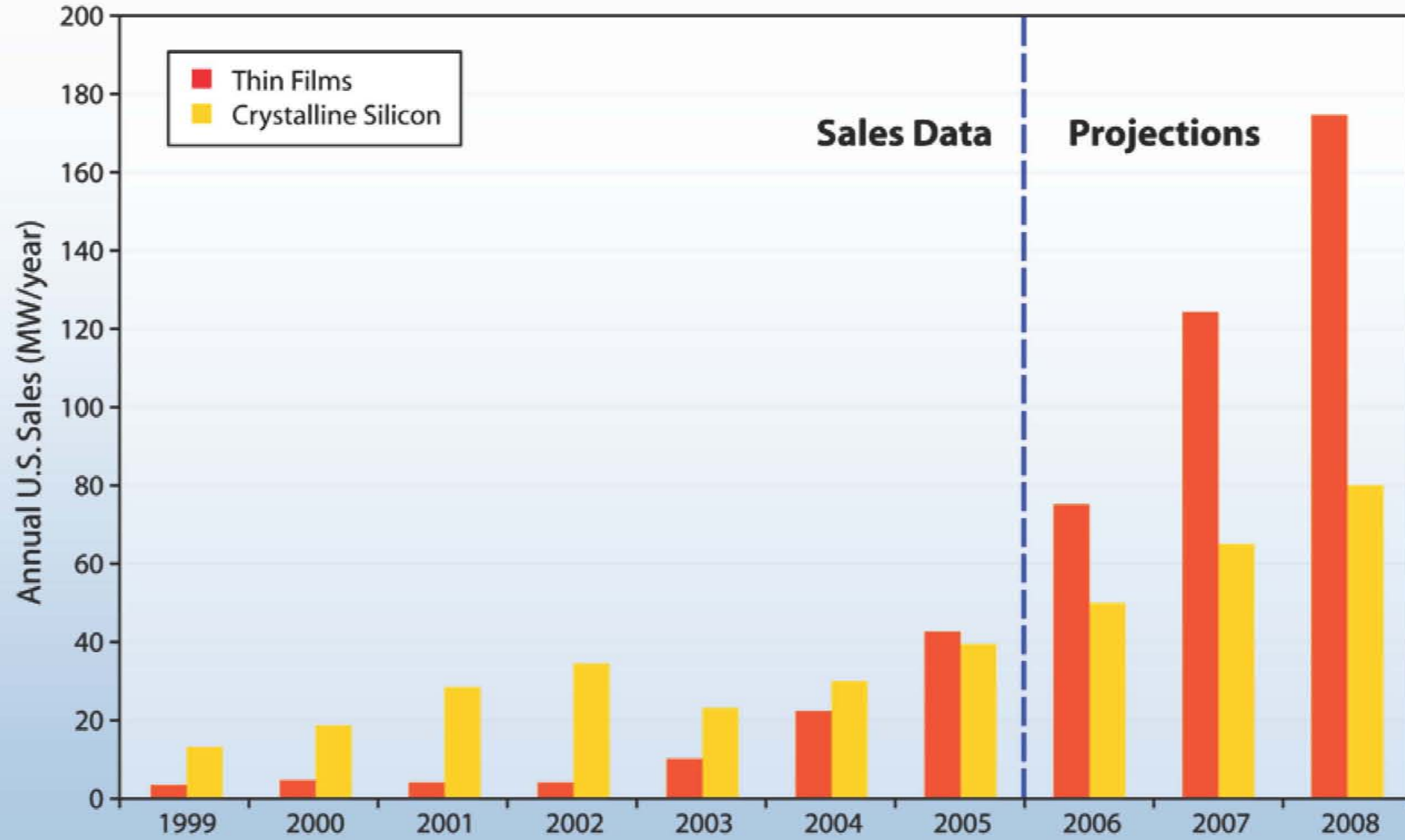
- How can very high efficiencies be achieved on large areas under manufacturing conditions?
- What deposition processes are most promising?
- What factors afflict module stability?
- How can we reduce In usage?

Technical issues (CdTe)

- What deposition processes are most promising?
- What factors afflict module stability?
- Do we require improved back-contacting schemes?
- How can we reduce Te usage?
- (Will there be customer acceptance of a CdTe PV module?)

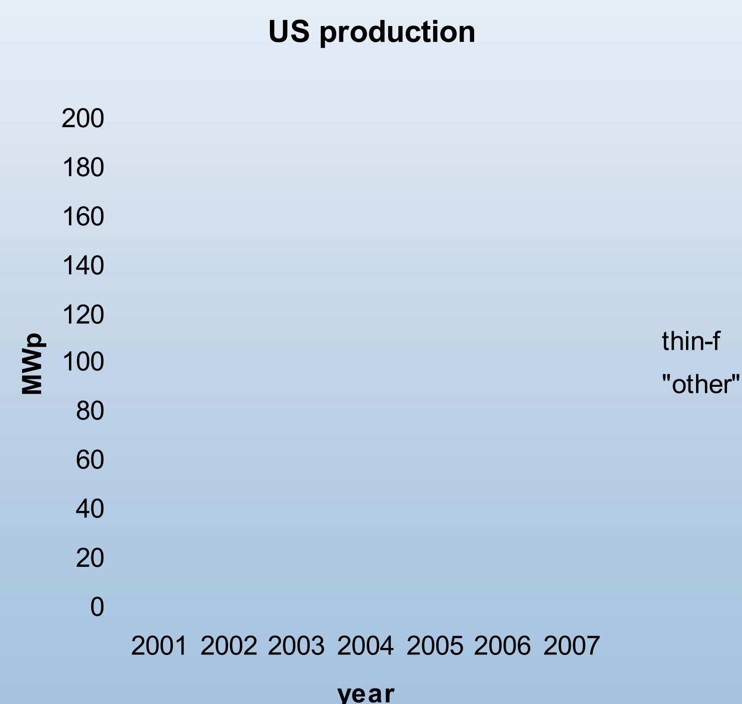
40 MW – Thin Film CdTe Solar Field

First Solar / Juwi Solar



US-owned, US manufactured modules by technology, crystalline Si and Thin Films (incl. a-Si) 1999-2008

PVNews reported US production thru 2007



Conclusions

- Who will win the PV race, non-standard Si, standard Si, or thin-films?
- U.S.-based commercial thin-film PV module production reached a share of 29% in 2005, 45% in 2006 in the U.S., 65% in 2007, indicating much more rapid growth than crystalline Si PV
- Commercial module performance is increasing based on current knowledge. Today's R&D will lead to future product improvement
- A sustained growth of PV technology >~40%/year will require more resources than are currently available world-wide.