Appendix B
Characteristics of Solar Photovoltaic Technologies

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Solar Photovoltaic (PV) technology coverts sunlight to electricity directly. Historically, PV devices used silicon, but in recent years other materials are gaining prominence in the market. These newer PV technologies can broadly be classified as thin film, essentially because a much thinner layer of light-absorbing material is needed. Table B1 below compares the technology, physical and market characteristics of silicon and thin film PV technologies. Other niche or less mature PV technologies do exist, but they are not discussed below.

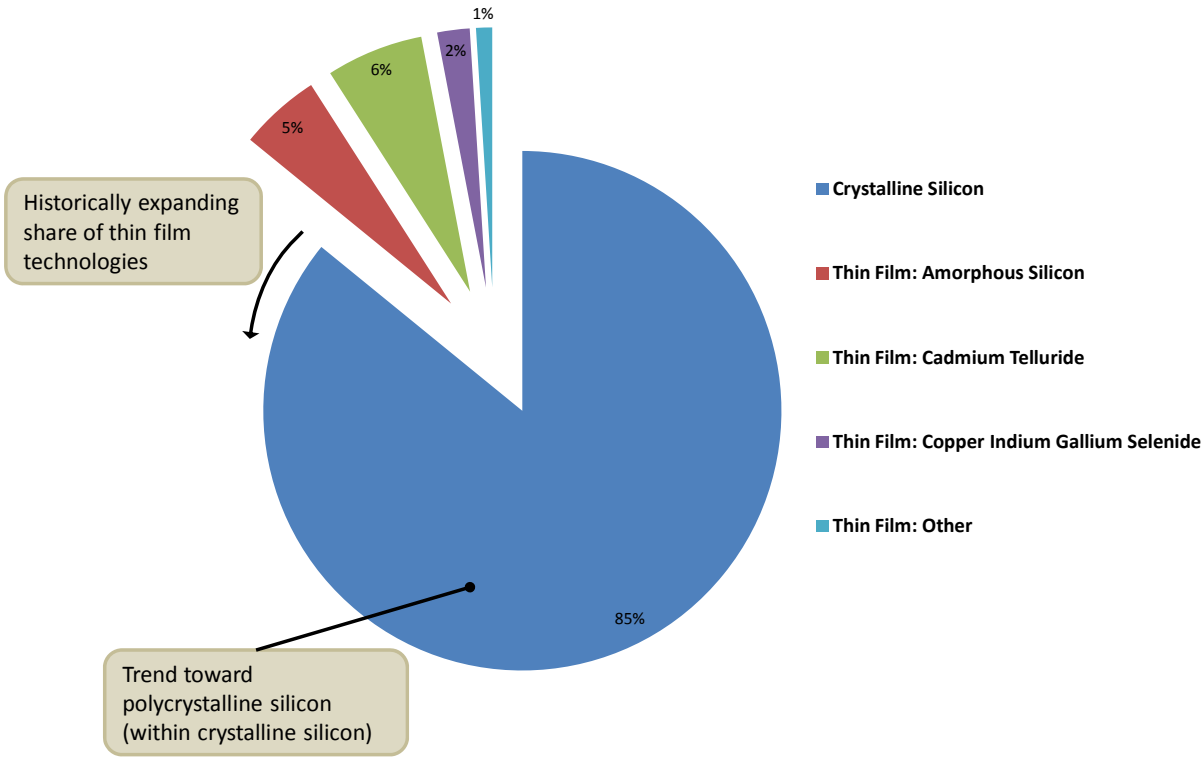
Table B1: Technology, physical and market characteristics of silicon and thin film PV technologies

	(Crystalline) Silicon	Thin Film
Technologies (in order of decreasing maturity)[1]	• Mono-crystalline silicon (c-Si) • Poly-crystalline silicon (pc-Si/ mc-Si) • String Ribbon	• Amorphous silicon (a-Si) • Cadmium Telluride (CdTe) • Copper Indium Gallium Selenide (CIGS) • Organic (Organic Pholovoltaic, OPV; Dye Sensitized Solar Cell, DSSC)
Technology		
Module efficiency[2,3]	13 – 20%, typically • Mono-crystalline: up to 23% • Poly-crystalline: up to 15% (mono-crystalline silicon has generally been more efficient than poly-crystalline, but the gap is reducing) *Advantage: typically higher efficiencies (but not necessarily lower cost per watt)*	4 – 12%, typically • Amorphous silicon: up to 10% • Cadmium Telluride: up to 11% • Copper Indium Gallium Selenide: up to 14%
Power extraction efficiency[4]	73 – 82% (I-V fill factor)	60 – 68% (I-V fill factor)
Temperature coefficient (power drop/deg.)[4]	Higher	Lower *Advantage: better suited to high temperature operation*
Physical		
Module construction[4]	With metal frame, typically anodized Aluminium	Frameless, sandwiched between (tempered) glass *Advantage: Lower weight and potentially more durable, leading to lower installation and maintenance costs.*
Mounting systems[4]	Industry standard	Special clips and structures may be needed; in some cases labor cost is significantly saved
Wiring (DC)[4]	Industry standard	May require more number of circuit combiners and fuses
Required area[4]	Industry standard	Requires more land area, up to 50% more, for a given MW-project size (e.g., due to lower efficiency)
Miscellaneous[5]	*Advantage: Higher structural resistance to heat*	*Advantage: Ease of washing / cleaning dust and sand (Indian or desert conditions)*

	(Crystalline) Silicon	Thin Film
Market		
Market penetration[6,7] (Figure B2)	All crystalline Silicon: 86% • Trend towards polycrystalline silicon (cheaper to produce, while efficiencies are increasing)	All thin film: 14% • Amorphous Silicon: 5% • Cadmium Telluride: 6% • Copper Indium Gallium Selenide: 2% • Other: 1%
Price per watt[8]	$2.29 (average across all solar modules) • Lowest mono-crystalline price: $1.10 • Lowest poly-crystalline price: $1.06	$2.29 (average across all solar modules) • Lowest thin film price: $0.84
Companies (regions, technologies, 2010 production in MW) [9,10,11]	Company (region): cell ; module production in MW • Suntech (China/Taiwan): 1,600 ; 1600 • JA Solar (China/Taiwan): 1,500 ; - • Yingli (China/Taiwan): 1,100 ; 1,100 • Trina Solar (China/Taiwan): 1,100 ; 1,100 • Q-cells (EU/US/Japan): 900 ; - • Gintech (China/Taiwan): 800 ; - • Sharp (EU/US/Japan): <700 ; <1,000 • Motech (China/Taiwan):700 ; - • Kyocera (EU/US/Japan):650 ; 650 • Hanwha (China/Taiwan): 500 ; 800 • Neo Solar (China/Taiwan): 500 ; - • Canadian Solar (China/Taiwan): 500 ; 800 • Sunpower (US): 500 ; - • REC (EU/US/Japan): <500 ; <500 • Sanyo (EU/US/Japan): - ; 400 • Schott Solar (EU/US/Japan): - ; 400 • SolarWorld (EU/US/Japan): - ; 400 • LDK Solar (China/Taiwan): - ; 400 • Jaiwei Solar (China/Taiwan): - ; 300 • Renesola (China/Taiwan); - ; 300 Others: Evergreen, Schuco, ET Solar, Solon, Conergy.	Company (region, tech): module production in MW • First Solar (US, CdTe): 1,400 • Sharp (Japan, a-Si): 200 • Trony (China, a-Si): 150 • United Solar (US, a-Si): 125 • NexPower (Taiwan, a-Si based): 100 • Solibro GmbH (EU, CIGS): 75 • Solar Frontier (Japan; CIGS): 75 • Solyndra (US; CIGS): 75 • Kaneka Solartech (Japan, a-Si): 50 • Auria Solar (Taiwan, a-Si based): 50 Others: UniSolar, Konarka, Dye Solar, Bosch Solar, Abound Solar
Value chain distribution	See Figure B3 below	See Figure B3 below

Figure B2

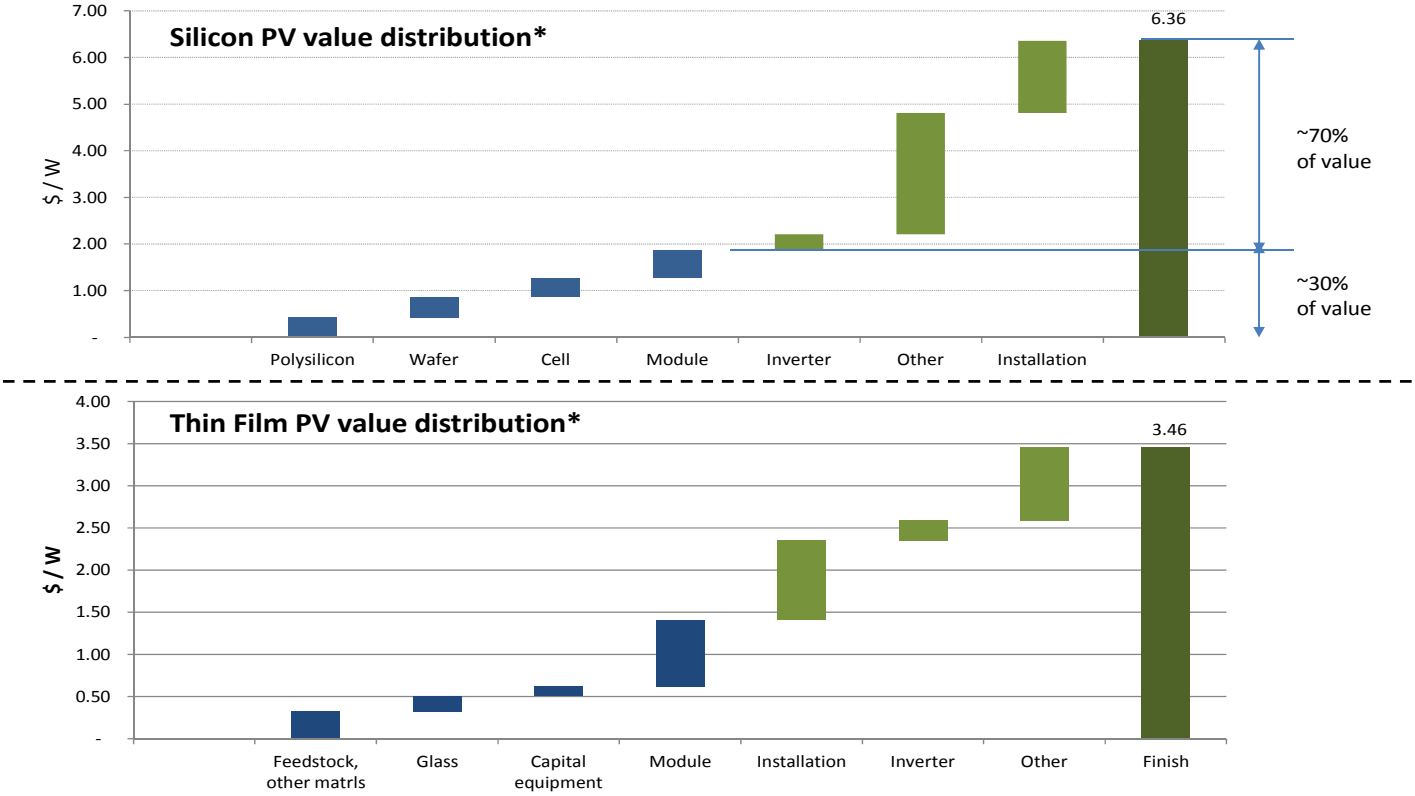
Market share of various PV technologies



Source: PV News May 2011 Issue, greentechmedia.com/articles/read/pv-news-annual-data-collection-results-cell-and-moduleproduction-explode-p/ (accessed April 2, 2012); GBI Research, "Thin Film Photovoltaic (PV) Cells Market Analysis to 2020," altenergymag.com/emagazine.php?art_id=1557 (accessed April 2, 2012); European Photovoltaic Industry Association, "Market Report 2011".

Figure B3

Value distribution for silicon and thin film PV technologies



*Based on unsubsidized value chain analysis of U.S. silicon PV market. Roughly similar value distribution for thin film technologies.
Source: GTM Research prepared for Solar Energy Industries Association (U.S.A), "U.S. Solar Energy Trade Assessment 2011: Trade Flows and Domestic Content for Solar Energy-Related Goods and Services in the United States."August 2011;

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[4] "Thin Film vs. Crystalline Silicon PV Modules", *CivicSolar*, November 2010, http://www.civicsolar.com/resource/thin-film-vs-crystalline-silicon-pv-modules (accessed April 27, 2012).
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[7] Shyam Mehta, "PV News Annual Data Collection Results: 2010 Cell, Module Production Explodes Past 20 GW", excerpted from *PV News* May 2011 Issue, May 9, 2011, www.greentechmedia.com/articles/read/pv-news-annual-data-collection-results-cell-and-module-production-explode-p/ (accessed April 2, 2012).
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[10] "Thin Film Photovoltaic (PV) Cells Market Analysis to 2020", *GBI Research*, altenergymag.com/emagazine.php?art_id=1557 (accessed April 2, 2012).
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