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Thin Film CIGS and CdTe Photovoltaic Technologies: Commercialization, Critical Issues, and Applications

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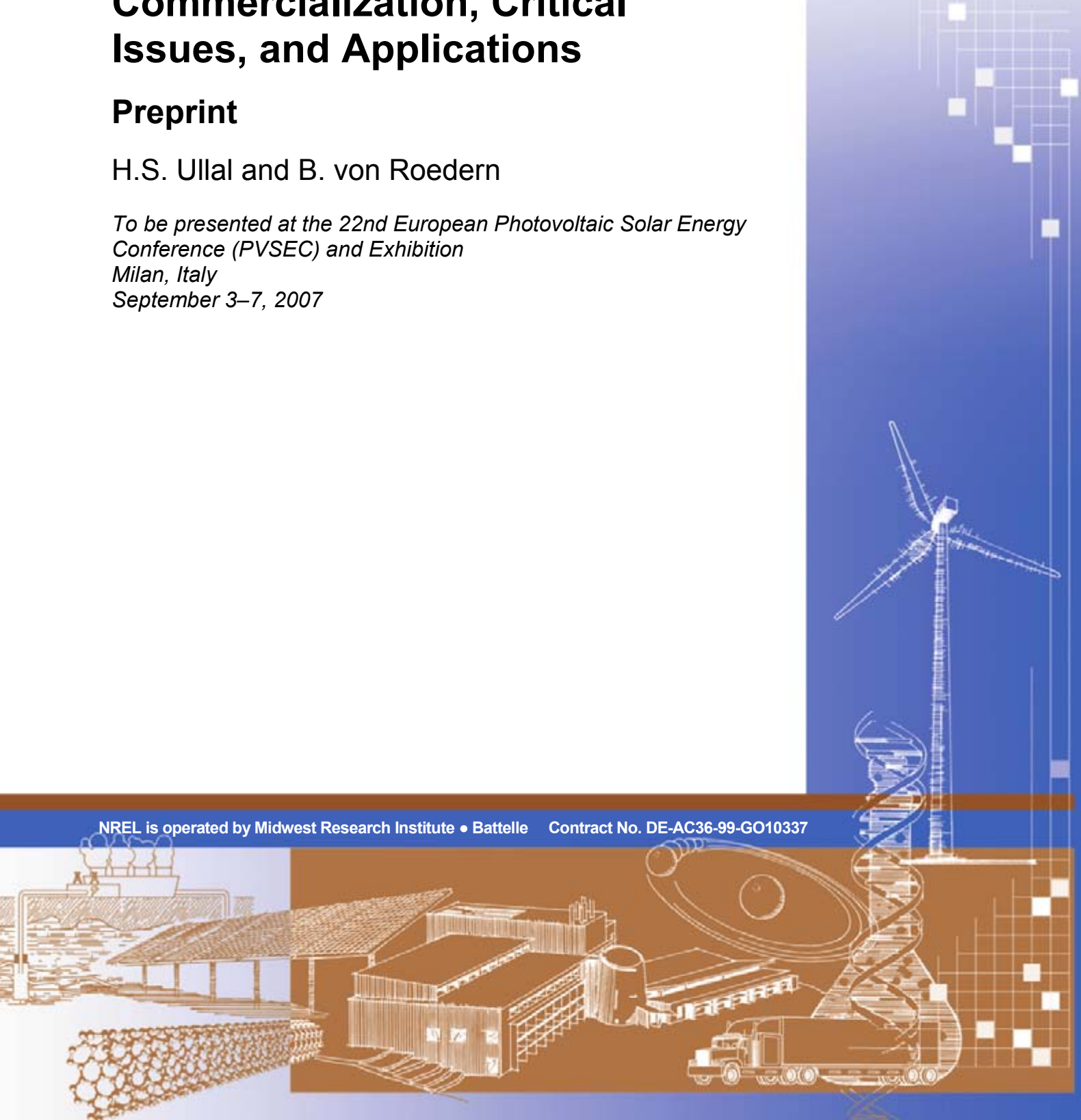

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Thin-Film CIGS and CdTe Photovoltaic Technologies: Commercialization, Critical Issues, and Applications

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ABSTRACT: We report here on the major commercialization aspects of thin-film photovoltaic (PV) technologies based on CIGS and CdTe (a-Si and thin-Si are also reported for completeness on the status of thin-film PV). Worldwide silicon (Si) based PV technologies continues to dominate at more than 94% of the market share, with the share of thin-film PV at less than 6%. However, the market share for thin-film PV in the United States continues to grow rapidly over the past several years and in CY 2006, they had a substantial contribution of about 44%, compared to less than 10% in CY 2003. In CY 2007, thin-film PV market share is expected to surpass that of Si technology in the United States. Worldwide estimated projections for CY 2010 are that thin-film PV production capacity will be more than 3700 MW. A 40-MW thin-film CdTe solar field is currently being installed in Saxony, Germany, and will be completed in early CY 2009. The total project cost is Euro 130 million, which equates to an installed PV system price of Euro 3.25/-watt averaged over the entire solar project. This is the lowest price for any installed PV system in the world today. Critical research, development, and technology issues for thin-film CIGS and CdTe are also elucidated in this paper.
Keywords: thin film, photovoltaics, amorphous silicon, cadmium telluride, copper indium diselenide, solar cell, module

1.0 INTRODUCTION

Major advances have occurred in the past several years as thin-film photovoltaic (PV) technologies based on copper indium gallium deselenide (CIGS) and cadmium telluride (CdTe) continue to enter the market for various applications . (Amorphous silicon [a-Si] and thin-Si are included in this paper to give completeness on the status of thin-film PV.) The market share worldwide for thin-film PV in CY 2006 was less than 6%. However, the market share for thin-film PV in the United States continues to grow rapidly and was reported at more than 44% in CY 2006 (see Fig. 1; [1]). This number is mainly due to the aggressive growth in the manufacturing capacity of First Solar in Perrysburg, Ohio. In the case of a-Si, Uni-Solar in Auburn Hill, Michigan continues to play a leading role in the United States. Both companies report strong growth in CY 2006, and CY 2007 estimates should be even better.

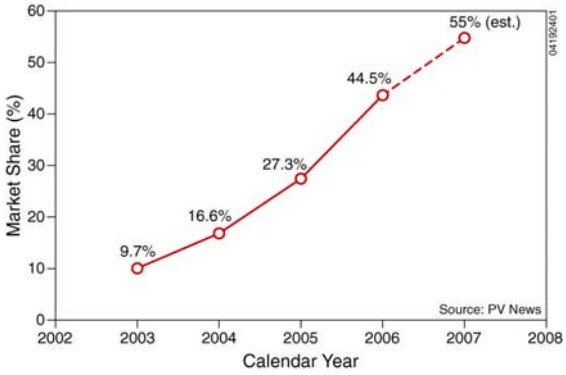

Figure 1: Thin-film PV market share versus calendar year

Several research, development, and, technology issues, both in thin-film CIGS and CdTe, are identified as the technology scales up to multi-megawatt production. In the case of thin-film CIGS absorber layers, about ten deposition processes are currently being developed worldwide. Issues such as standardization of the absorber-layer deposition needs to be addressed to help in large-scale thin-film PV manufacturing to lower the unit cost of module production. For thin-film CdTe, back-contact stability offers an opportunity for researchers to make more reliable thin-film CdTe PV products.

A number of applications are being pursued using thin-film PV technologies, including building-integrated photovoltaics (BIPV), roof-top applications and utility-scale applications.

2.0 COMMERCIALIZATION – THIN-FILM PV

Several thin-film PV companies in the United States and worldwide are actively involved in commercializing thin-film PV technologies using a-Si, CIGS, and CdTe. Table I summarizes the numerous groups in the various technology areas of a-Si, CIGS and CdTe that are actively involved in the scale-up and commercialization of thin-film PV technologies in the United States.

Table 1: Thin Film PV Companies — USA

Thin-Si	CdTe	CIS
Uni-Solar – MI	First Solar – OH	Global Solar – AZ
Applied Materials – CA	Primestar Solar – CO	Miasole – CA
Power Films – IA	AVA Solar – CO	Energy PV – NJ
Energy PV – NJ	Solar Fields – OH	Ascent Solar – CO
MV Systems – CO	Canrom – NY	ISET – CA
XsunX – CA	Ascentool – CA	ITN/ES – CO
OptiSolar – CA	Nuvo Solar Energy – CO	Daystar – NY
Signet Solar – CA	Zia Watt Solar – TX	Nanosolar – CA
Nano PV – NJ		Heliovolt – TX
MWOE Solar – OH		Solo Power – CA
Solexant – CA		Solyndra – CA
Proto Flex – CO		RESI – NJ
New Solar Ventures – NM		Light Solar – NV
Innovalight – CA		Dow Chemicals – MI
Nanogram – CA		Stion – CA
Soltaix – CA		

Some 16 companies in the United States are pursuing the development and commercialization of a-Si and thin-Si PV products. Clearly, the U.S. leader is Uni-Solar (US), Michigan, with an installed capacity of 60 MW in CY 2006. An additional 60 MW with come online in CY 2007, resulting in a cumulative capacity of 120 MW. US was supported by the National Renewable Energy Laboratory (NREL) in the technology development of the multi-junction solar cells. Applied Material (AM) supplies turn-key projects for the manufacture of single-junction and tandem a-Si/nano Si also known as micromorph solar modules. Thus far AM has completed sales of more than 200 MW worldwide in countries such as China, India, Germany, Spain and Taiwan. There are 15 CIGS companies using several deposition methods for the growth of the thin-film CIGS absorber layer. This offers both a challenge and opportunity for these emerging companies. Finally eight companies are scaling up the thin-film CdTe PV technology. All these groups are U.S.—based thin-film PV companies.

First Solar (FS) is clearly the world leader in all thin-film PV technology development and global sales. They have an installed capacity of 90 MW in Perrysburg, Ohio for the manufacture of thin-film CdTe power modules, shown in Figure 2. FS has also recently started a new facility in Germany with an installed manufacturing capacity of 120 MW.

Figure 2: First Solar's 90-MW thin-film manufacturing plant in the USA

They are also installing an additional 240 MW manufacturing capacity in Malaysia to be completed in CY 2009. Thus, the total global target for FS is about 450 MW by 2009 making it one of the leading PV companies in the world. Incidentally, NREL awarded the first subcontract to the predecessor company — Solar Cells, Inc, Ohio for the technology development of thin-film CdTe solar cells and modules in 1991and has since supported SCI and FS in the technology development for commercializing thin-film PV products. Figure 3 shows FS's manufacturing cost for thin-film CdTe PV modules. As economies-of-scale have been realized, the manufacturing cost has dropped substantially from $-2.94/W (6-MW) in CY 2004 to $-1.25/W (90 MW) at present (2), shown in Fig. 3. The target manufacturing cost is expected to be $-0.70/W due to improvements in productivity, module efficiency, and yield by CY 2012, thus making it potentially price competitive with grid-parity electricity.

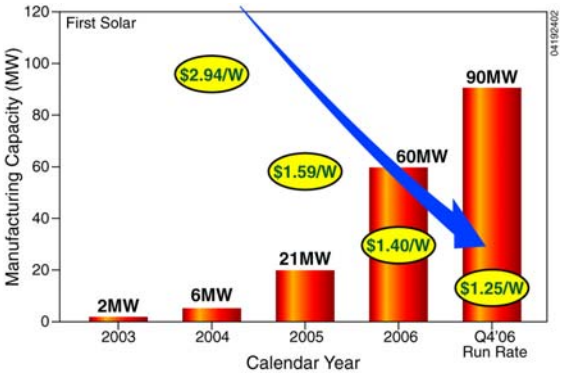

Figure 3: Thin-Film CdTe manufacturing capacity and cost reduction versus calendar year

Worldwide, five companies are presently offering commercial thin-film PV CIGS products: Wurth Solar, (Germany), Global Solar, (USA), Honda, (Japan), Showa Shell, (Japan), and Sulfurcell, (Germany). The production capacity ranges between 5 and 27 MW per year. Also, worldwide, about 34 companies are actively developing thin-film CIGS PV technologies. These companies are using about ten different deposition methods for growing the thin CIGS absorber layers, as is shown in Table II. The absorber layer for commercial products uses either co-evaporation or the two-stage process such as the deposition of the precursors by sputtering followed by selenization. All companies use Mo as the back contact deposited by sputtering, and the majority use ZnO as the front contact deposited either by sputtering or chemical vapor deposition.

Table 2: Thin Film CIGS Technology

Company	Substrate	Back Contact	Process	Front Contact
Shell Solar	Glass	Mo	Sputter/ Selenization	ZnO
Global Solar	Steel	Mo	Coevaporation	ITO
Miasole	Glass	Mo	Sputter	ZnO
Würth Solar	Glass	Mo	Coevaporation	ZnO
Avancis	Glass	Mo	Sputter / RTP	ZnO
Daystar Tech	Glass	Mo	Sputter	ZnO
EPV	Glass	Mo	Sputter/ Evaporation	ZnO
Ascent Solar	Polymer	Mo	Coevaporation	ZnO
ISET	Glass/Flex	Mo	Ink/Selenization	ZnO
Nanosolar	Flexible	Mo	Print / RTP	ZnO
Heliovolt	Glass/Flex	Mo	FASST	ZnO
SoloPower	Steel	Mo	ED / RTP	ZnO

3.0 CRITICAL RESEARCH, DEVELOPMENT, AND TECHNOLOGY ISSUES

Several critical issues still need to be addressed as emerging and new groups develop thin-film PV technologies. For thin-film CIGS PV technologies, the following six issues are critical for developing low-cost and reliable products: (1) standardization of equipment for the growth of the CIGS absorber films, (2) higher module efficiencies, (3) prevention of moisture ingress for flexible CIGS modules, (4) columnar structure for CIGS deposited by alternative process for high efficiency cells and modules, (5) thinner absorber layers of less than 1 micrometer or less and (6) CIGS absorber film stoichiometry and uniformity over large areas. For thin

film CdTe technology, five key issues include: (1) standardization of equipment for deposition of the absorber layer, (2) higher module efficiency, (3) back-contact stability, (4) reduced absorber layer thickness to less than 1 micrometer and (5) control of uniformity over large area.

4.0 APPLICATIONS AND PRODUCTION CAPACITY

As thin film PV technologies matures, applications get larger in size for installed solar arrays. First Solar, along with Juwi Solar, Germany, is installing a 40-MW thin-film CdTe solar field in Saxony, Germany. The project, shown in Fig. 4, is currently under construction and will be completed by early CY 2009. Thus far, 6-MW of the solar field has been installed. When completed, this will be one of the largest solar fields in the world. The total price of this project is Euro 130 million. Thus, the installed PV system price is Euro-3.25 per watt, also the lowest installed price for any PV system in the world. Figure 5 shows a thin-film CIGS facade installed on a building by Honda in Japan. The system size is estimated around 22-kW.

First Solar / Juwi Solar

Figure 4: A 40-MW thin-film CdTe solar field being built in Saxony, Germany to be completed in early CY 2009

Honda

Figure 5: Building-integrated thin-film CIGS façade on a Honda building in Japan

It is estimated that by 2010, the production capacity for thin-film PV technologies worldwide will be more than 3700 MW, as depicted in Table III. The table in divided into various regions of the world. The United States — is estimated at 1127 MW, Japan at 1312 MW, Europe at 793 MW and Asia at 472 MW for thin-film PV production capacity.

In breaking new, Sharp recently announced a 1000-MW thin-film factory to be built in Japan by CY 2010. The technology, -presumably micromorph multijunction solar modules, will significantly reduce the manufacturing cost of PV, making it potentially more price-competitive with conventional energy sources.

5.0 SUMMARY AND OUTLOOK

Rapid progress is being made by both a-Si- and CdTe-based thin-film PV technologies in entering the commercial market. Several thin-film CIGS companies are also entering the market with power modules. In the United States, market share for thin-film was about 44% in CY 2006 and is expected to surpass Si sales in CY 2007. Several critical research, development, and technology issues need to be addressed by emerging thin-film PV companies as they plan to enter the market. The

Table 3: Thin Film PV Capacity (2007-2010)

	Group	Material	Present (MW)	Additional (MW)	Total (MW)	Group	Material	Present (MW)	Additional (MW)	Total (MW)	Totals	Grand Total
USA	First Solar	CdTe	90	–	90	Nanosolar	CIS	–	430	430	1127	3704
	Uni-Solar	a-Si	60	240	300	AVA Solar	CdTe	3	20	3		
	MiaSole	CIS	5	50	55	Nano PV	a-Si	–	4	4		
	Global Solar	CIS	3	60	63	OptiSolar	a-Si	–	40	40		
	EPV	a-Si	2	25	27	Primestar Solar	CdTe	–	20	20		
	Daystar Technologies	CIS	1	10	11	SoloPower	CIS	–	20	20		
	Power Film	a-Si	1	10	11	ISET	CIS	–	3	3		
	Ascent Solar	CIS	2	25	27	MWOE Solar	a-Si	–	3	3		
						Heliovolt	CIS	–	20	20		
JAPAN	Kaneka	a-Si	20	50	70	MH1	a-Si	14	56	70	1312	
	Showa Shell	CIS	20	60	80	Kanto Sanyo	a-Si	7	–	7		
	Sharp	a-Si	15	1000	15	Honda	CIS	3	27	30		
	Fuji	a-Si	15	25	40							
EUROPE	First Solar	CdTe	120	100	120	AMI	a-Si	–	160	160	793	
	CSG Solar	Thin-Si	10	15	25	Johanna Solar Tech	CIS	–	30	30		
	Wurth Solar	CIS	3	15	18	Brilliant	a-Si	–	25	25		
	Antec Solar	CdTe	10	–	10	Solisbro	CIS	–	30	30		
	Schott Solar	a-Si	3	27	30	Global Solar	CIS	–	30	30		
	ICP Solar Tech	a-Si	3	–	3	Helio Grid	a-Si	–	50	50		
	Solar Cells	a-Si	1	–	1	SunFilm	a-Si	–	60	60		
	Free Energy	a-Si	1	–	1	T. J. Solar	a-Si	–	40	40		
	Solar Plus	a-Si	–	5	5	Signet Solar	a-Si	–	20	20		
	Sulfur Cells	CIS	5	–	5	Clyxco	CdTe	–	25	25		
	Aleo Solar	CIS	–	30	30	Avancis	CIS	–	20	20		
	Ersol	a-Si	–	40	40	Odersun	CIS	–	5	5		
						Scheuten Solar	CIS	–	10	10		
ASIA	First Solar	CdTe	–	220	220	GET	a-Si	–	40	40	472	
	Bangkok Solar	a-Si	7	–	7	Nanowin Tech	a-Si	–	35	35		
	Sinonar	a-Si	3	–	3	Mosen Baer	a-Si	–	20	20		
	T. J. Solar Cell	a-Si	2	–	2	Solar Morph	a-Si	–	20	20		
	Soltech	a-Si	15	–	15	Topray Solar	a-Si	20	–	20		
	Suntech Power	a-Si	–	50	50	CMC	a-Si	–	40	40		

projections for worldwide production capacity for all thin-film PV are estimated as more than 3700 MW in 2010, with First Solar's global target at 450 MW by 2009 and Sharp's target of 1000 MW by 2010. This economies-of-scale production capacity should substantially reduce the manufacturing price of the thin-film PV products and potentially make solar electricity price-competitive with grid-parity electricity in the not-too-distant future.

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7.0 REFERENCES

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