FEASIBILITY STUDY

UPDATE 2012

THIFITECH

APPLICATION OF THIN-FILM TECHNOLOGY IN DENMARK

a-Si/µc-Si modules mounted on private house in Gjern, Denmark.

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0.0 Introduction

This document contains an update regarding development in utilization and technology stage for the various kinds of thin film PV types commercially available, which has occurred since the original version of the feasibility study named ***"Feasibility Study – Thinfilm Photovoltaic"*** was published in 2009.

That document – as well as this one - was prepared in connection with the project "Application of thin-film technology in Denmark", shortly named **ThiFiTech**, carried out with Danish Technology Institute as project manager and by means of support from the ForskEl program.

The purpose of ThiFiTech is to uncover technical and architectonical aspects regarding thin-film photovoltaic (TFPV or thin-film) with special emphasis on utilisation under Danish and Northern European conditions.

The original study from 2009 was prepared as a general introduction to the subject with the purpose of collection and transmitting international experiences and development tendencies with respect to the prevailing TFPV technologies.

Despise the occurrence of a global economic recession the development in the PV deployment since 2009 has been considerably and in many cases surpassed even the most optimistic estimations, the thin-film technologies being no exception.

Giving this, the project consortium carrying out the ThiFiTech-project has found it relevant to prepare and public this supplementary document in order to describe the development during the last couple of years.

Since this document is intended as a supplementary to the original feasibility study, the basic description of the different TFPV technology is not repeated here, however a short introduction to the different technologies is given in part 2.0.

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1.0 Summary and conclusions

As part of the ThiFiTech project, a separate activity was launched with the purpose of preparing a Feasibility Study in which technical, architectural and market aspects regarding the thin film PV (TFPV) technologies were described.

The original study from 2009 was prepared as a general introduction to the subject with the purpose of collection and transmitting international experiences and development tendencies with respect to the prevailing TFPV technologies.

1.1 Production volume and previous expectations

When ThiFiTech was launched, TFPV have for several years gained marked shares over crystalline PV and at the same expanded production capacity on all the major TFPV technologies.

The general opinion at the time was that this tendency will steadily continue, since the production cost for TFPV modules potentially is very low and thus counterbalance that the efficiency is also lower compared to crystalline PV types.

The reality, however, turned out to be different, since the cost for traditional PV products soon took a very steep decrease, when large production capacities were established mainly in China while at the same time some incentive programme were terminated or reduced.

On account of this, TFPV in many respects lost their potential competitive benefit and thus from 2010 on have not been able to maintain the marked share gained, which is shown in the table below.

Development in PV-cell production by technology												
Technology	**2006**		**2007**		**2008**		**2009**		**2010**		**2011**	
	MWp	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**
- Mono-Si	1.098	43,3	1.806	42	3.030	38,3	4.711	37,8	9.091	33,2	11.490	30,9
- Poly-Si	1.179	47	1.934	45	3.774	47,7	5.384	43,2	14.485	52,9	21.196	57,0
- Ribbon c-Si	66	2,6	94	2,2	119	1,5	174	1,4	329	1,2	0	0,0
Crystalline	**2.343**	**92**	**3.834**	**90**	**6.922**	**87,5**	**10.270**	**82,4**	**23.904**	**87,3**	**32.686**	**87,9**
- a-Si and a-Si/μc-Si	119	4,7	223	5,2	403	5,1	760	6,1	1.369	5,0	1.264	3,4
- CIS/CIGS	5	0,2	21	0,5	79	1,0	212	1,7	438	1,6	892	2,4
- CdTe	68	2,7	201	4,7	506	6,4	1.122	9,0	1.451	5,3	2.045	5,5
Thin-film	**193**	**7,6**	**445**	**10**	**989**	**12,5**	**2.094**	**16,8**	**3.258**	**11,9**	**4.202**	**11,3**
Other	**0**	**0**	**4**	**0,1**	**0**	**0**	**112**	**0,9**	**219**	**0,8**	**297**	**0,8**
All	**2.536**	**100**	**4.279**	**100**	**7.911**	**100**	**12.464**	**100**	**27.382**	**100**	**37.185**	**100**

Development in PV cell production by technology

1.2 Technological developments

In the ThiFiTech project period some progress with respect to e.g. efficiency and usability were gained.

In the table below, the actual stage regarding efficiency for TFPV as well as crystalline modules is shown. Due to the lower efficiency for TFPV, more areas are needed to obtain a certain installed capacity. Thus in cases where area is a limited factor, crystalline PV has a benefit over TFPV

Module efficiency and area needed for thin film and crystalline base PV modules						
Technology	Thin film photovoltaic				Crystalline based	
	Amorphous silicon a-Si	a-Si/μc-Si	CIS - CIGS	Cadmium telluride CdTe	Mono crystalline	Poly crystalline
Module efficiency, %	5 – 8	9 - 10	11-13	8 - 11	14 - 20	12 – 15
Area needed pr. kWp, m^2	15	11	8	10	5	6

Another technical point, which has developed over the course of ThiFiTech, is that now several TFPV module manufactures allows there products to be used together with the more effective transformerless inverter types.

It is, however, very important to observe the requirement from the manufacture in this respect, since there is a risk that for some modules corrosion of the modules Transparent Conductive Oxides (TCO) layer can occur if there is no galvanic separation between the modules and the electrical installation of the building, which is the case when transformerless inverters are used.

In case the guidance from the module manufacture is not fully observed and complied with, the guarantee will almost evidently be voided, which will leave the owner or the supplier/installer with a serious problem.

1.3 Market aspects and future prospective

Although some benefits regarding architectural conditions are present, TFPV has not yet captured noteworthy marked shares in Denmark and it is difficult to imagine that the outlook for TFPV will improve significantly unless some radical change in marked conditions will occur.

The main reason for this is attributable to economical condition: At the present situation with steadily decreasing cost for traditional PV modules based on crystalline cells, TFPV has a hard time being competitive from a holistic point of view.

Although the crude module price per Wp is often lower, the total cost including BoS[1] will for the Danish situation very often be higher, due to the need for more cables, mounting equipment and manual labour for mounting.

It is thus difficult to pinpoint areas in which TFPV will have obvious benefits over crystalline PV in a Danish context; the most likely areas, however, could be large-scale PV power plants on marginal soils and for multiple purposes and/or special building integrating solutions, in which the uniform surface and especially the possibility to prepare the transparency of the module can be utilized.

The pictures inserted below gives two examples of TFPV utilized for multiple purposes, namely as solar shading device at a new office building respectively to visually covering of ventilation plants on a rooftop.

CdTe TFPV modules utilized to covered technical installation at the rooftop of Skive City Hall.

a-Si TFPV module used as solar shading device in a moving solar shutter. The picture is taking as the device is closing, whereby the transparency of the device is shown and can be compared with the view without the shutter (EnergiMidt, Silkeborg).

[1] BoS = Balance of System, e.g. inverter, mounting equipment, cables etc.

2.0 A short introduction to technology

Afterward a basic introduction to the TFPV technologies is presented. A more detailed description is given in the original Feasibility Study.

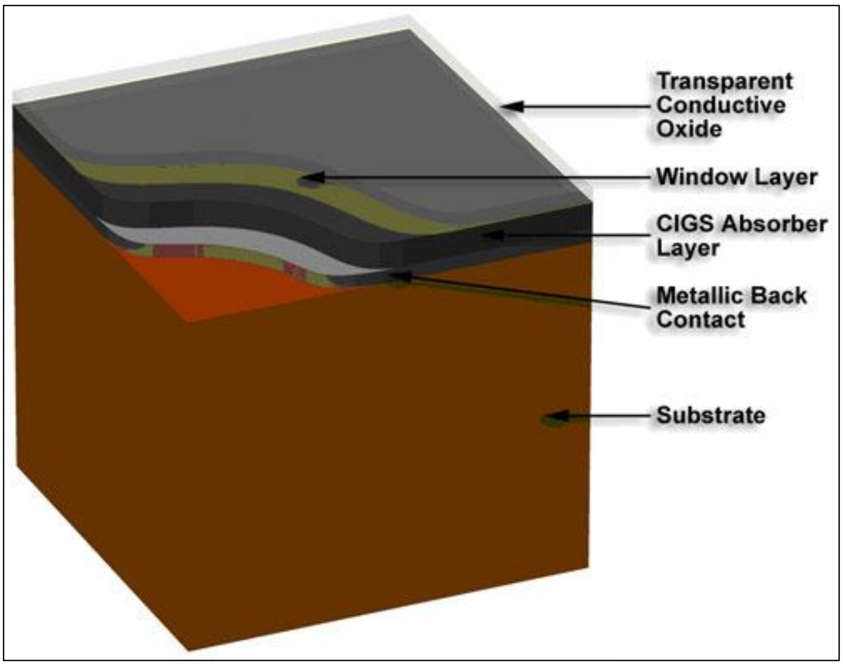
The basic principles of thin film photovoltaic are the same as for crystalline PV, namely taking advance of the fact that in certain materials a current is generated when exposed to light.

The production procedures, however, differ significantly. Where traditional crystalline cells are based on silicon in crystalline form, which is cut into thin slices of approximately 0.2-0.3 millimetres, TFPV modules are constructed by depositing extremely thin layers of photosensitive materials onto a low-cost backing such as glass, stainless steel or plastic.

This result in lower production costs compared to the more material-intensive crystalline technology, a price advantage, which, however, in most cases are counterbalanced by the lower efficiency rates.

During the production process, the module is divided into cells by means of a laser forming almost invisible lines in the active layers.

A module consists of different layers, each serving a specific function. The figure below shows the basic structure including the layers typically present.



Basic structure of a thin film module, illustrated by a CIGS module

Three types of thin film modules are commercially available at the moment. These are manufactured from amorphous silicon (a-Si and a-Si/µc-Si), copper indium (gallium) diselenide (CIS, CIGS) and cadmium telluride (CdTe).

Besides these, some new types as well as variations of the previously mentioned exist, which are not considered to have reached a commercial stage yet and thus not included in the ThiFiTech project.

TFPV typically have active layers in the thickness range of less than a few microns (one micron equals 1 x 10^{-6} meter = 0,001 mm). This allows higher automation once a certain production volume is reached, whilst a more integrated approach is possible in module construction.

The process is less labour intensive compared to the assembly of crystalline modules, where individual cells have to be interconnected. However, this also implies that to set up a TFPV production facility is very capital demanding, since the manufacture has to go “al in” whereas a producer in the crystalline sector can start by addressing a certain step in the manufacturing chain.

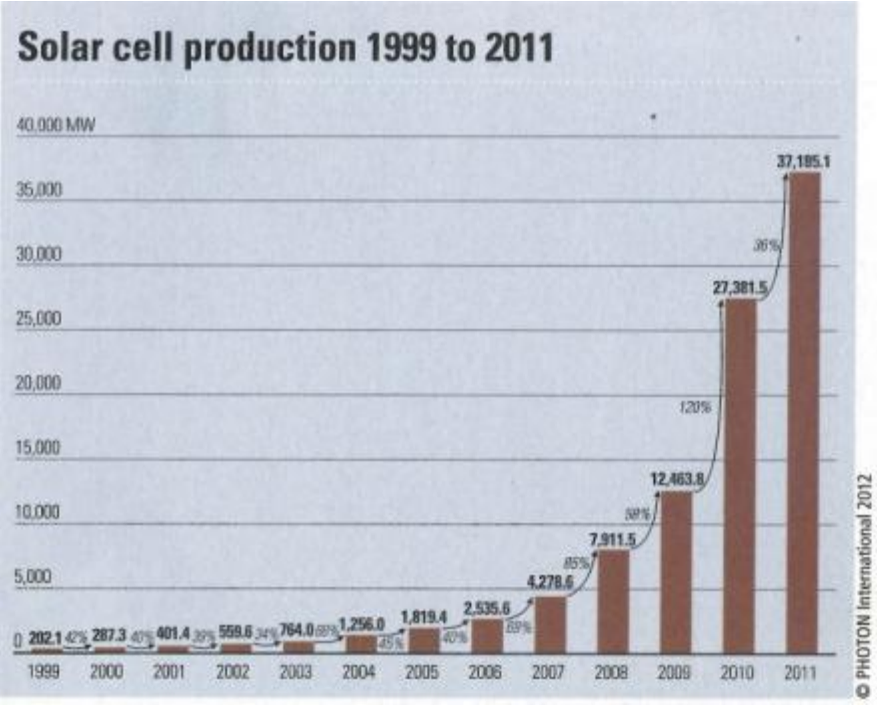
3.0 Production capacity

The PV production capacity has experienced a huge lap forward in the period since the first version of the feasibility study was published. In nearly all respects, this development has momentously exceeded all expectation and predictions carried out by experts and researchers.

To illustrate the extent to which experts and researchers have been taking by surprise, it is relevant to referee to one of the studies presented in the original feasibility study carried out in 2009: In this, carried out in 2008 by the Joint Research Centre, the combined production capacity in 2010 for all types of PV cells were estimated to be approx. 6 GW_p.

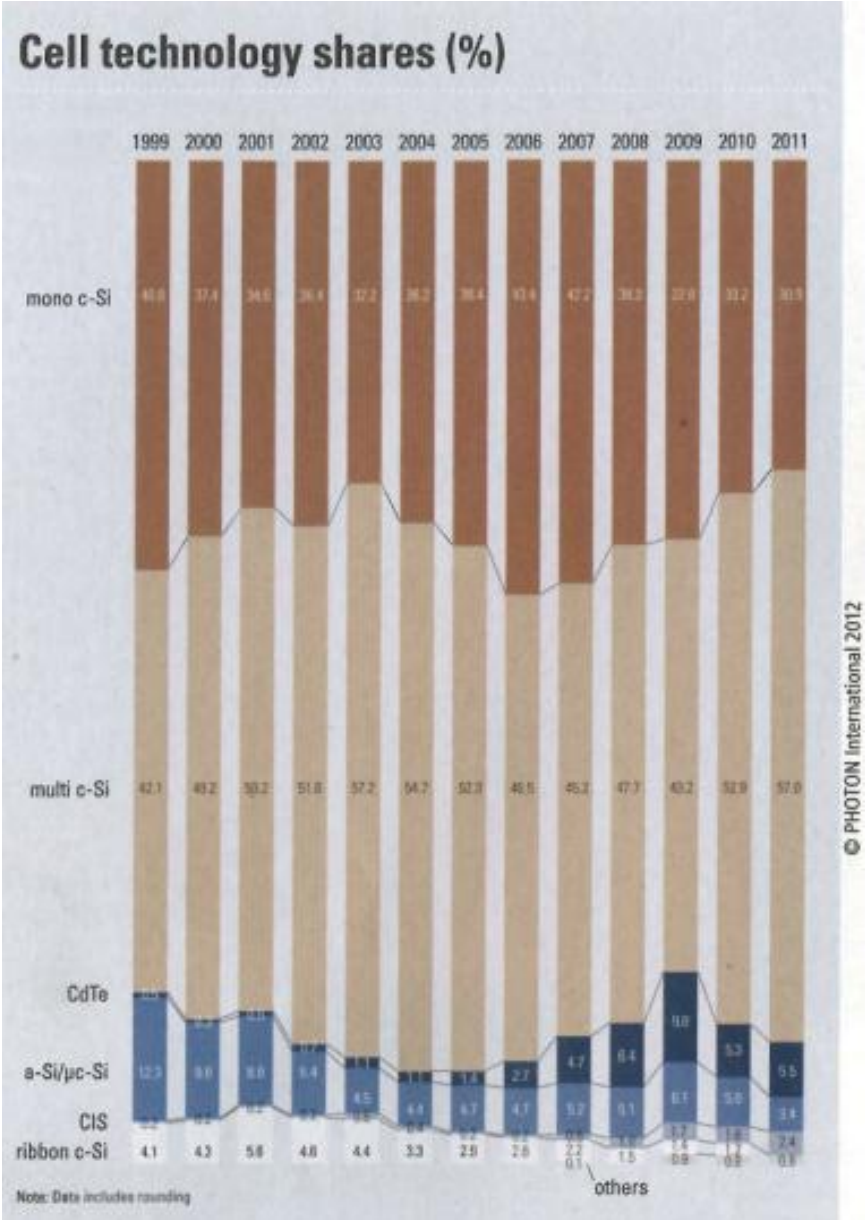
The actual figure, according to the 2010 cell production survey carried out by Photo International (PI), turned out to be more the 4 times this expectation, giving PI conclude that the actual production – not just the capacity as predicted above – amount to 27,2 GW_p /PI 3-2011 page 186/.

In the figure below taking from the 2011 cell production survey of PI /PI 3-2012 page 134/, it can be seen that although a slowdown in growth rate occurred, a further 10 GW were added in 2011, providing a total production of approx. 37 GW_p.



Development in PV cell production /PI 3-2012 page 134/

The production figure is further divided by technology in the figure shown on next page.



In the table inserted on next page, the calculated production volume from 2011 is shown together with the values for the previously five years. The values are divided by cell technology and stated in absolute values as well as in percentage of the total production for the year in question.

Taking all cell technologies into account it becomes clear that the PV sector is in a blooming stage. The production has increased almost 15 times in the 5-year period from 2006 to 2011.

When giving a closer look at the object of this study – thin film modules – it can be seen that the production in absolute numbers is continuously increasing. This was also the case when looking at the percentage values until 2010, hereafter the thin films technologies were not able to keep up the pace of the crystalline types and as a result lost marked shares.

Development in PV-cell production by technology												
Technology	**2006**		**2007**		**2008**		**2009**		**2010**		**2011**	
	MWp	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**	**MWp**	**%**
- Mono-Si	1.098	43,3	1.806	42	3.030	38,3	4.711	37,8	9.091	33,2	11.490	30,9
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- Ribbon c-Si	66	2,6	94	2,2	119	1,5	174	1,4	329	1,2	0	0,0
Crystalline	**2.343**	**92**	**3.834**	**90**	**6.922**	**87,5**	**10.270**	**82,4**	**23.904**	**87,3**	**32.686**	**87,9**
- a-Si and a-Si/µc-Si	119	4,7	223	5,2	403	5,1	760	6,1	1.369	5,0	1.264	3,4
- CIS/CIGS	5	0,2	21	0,5	79	1,0	212	1,7	438	1,6	892	2,4
- CdTe	68	2,7	201	4,7	506	6,4	1.122	9,0	1.451	5,3	2.045	5,5
Thin-film	**193**	**7,6**	**445**	**10**	**989**	**12,5**	**2.094**	**16,8**	**3.258**	**11,9**	**4.202**	**11,3**
Other	**0**	**0**	**4**	**0,1**	**0**	**0**	**112**	**0,9**	**219**	**0,8**	**297**	**0,8**
All	**2.536**	**100**	**4.279**	**100**	**7.911**	**100**	**12.464**	**100**	**27.382**	**100**	**37.185**	**100**

To be able to take a more throughout examination of the development in growth rate, in the table below the year-to-year growth rate for each cell technology as well as the total growth in the period is shown.

Development in PV-cell production by technology						
Technology	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2006-11**
	%	**%**	**%**	**%**	**%**	**%**
- Mono-Si	64,4	67,8	55,5	93,0	26,4	**946,4**
- Poly-Si	64,0	95,1	42,7	169,0	46,3	**1.697,4**
- Ribbon c-Si	42,8	26,1	47,0	88,3	-100,0	**-100,0**
Crystalline types	**63,6**	**80,5**	**48,4**	**132,7**	**36,7**	**1.294,9**
- a-Si and a-Si/µc-Si	86,7	81,3	88,4	80,1	-7,7	**960,7**
- CIS/CIGS	321,8	269,8	167,8	106,8	103,7	**17.495,5**
- CdTe	193,7	151,8	121,6	29,4	40,9	**2.886,9**
Thinfilm types	**130,9**	**122,2**	**111,8**	**55,6**	**29,0**	**2.080,1**
Other types	**0,0**	**-100,0**	**0,0**	**95,3**	**35,8**	**6.852,1**
All	**68,7**	**84,9**	**57,6**	**119,7**	**35,8**	**1.366,3**

With respect to the crystalline types it is Poly-Si in particular that has taking the lead recently, and more than half of new cells produced in 2010 and 2011 were actually Poly-Si cells.

3.1 Tendencies for TFPV

When looking at the development for the thin-film types over the years from 2006 to 2011, the following points can be highlighted:

3.1.1 A-Si and a-Si/μc-Si

The traditional amorphous silicon (A-Si) is sometime denoted as "the working horse" of thin-film, referring to the fact that this was the first type that were widely utilize and reach a commercial stage.

The A-Si type together with the more efficient off-spring technologies with two or more cell layer each addressing a certain bandwidth of the light striking the cells, have until 2010 rather steadily accounted for approx. 5 % of cell production.

In 2011, however, a decrease in relative share as well as absolute production volume did occur, indicating that the manufactures involved in this technology is no longer able to attract new customers in competition with new TFPV technologies as well as with crystalline modules, that more or less constantly has been the subject of decreasing prices.

3.1.2 CIS/CIGS

Although CIS/CIGS is the technology with the highest growth rate in the period as well as in year to year basis – with the sole exception of Poly-Si in 2009-10 – it still account for a very small size of 2,4 % of the total PV marked.

There is, however, reason to believe that CIG/CIGS in a couple of years will reach production numbers comparable with CdTe, giving that the number of manufactures of CIG/CIGS modules recently have grown significantly – which is not the case for CdTe modules - and at the same time, some of these new manufactures, for instance Japanese base "Solar Frontier" has commenced construction of new production facilities in the GWp-scale /PI 4-2011 page 158/.

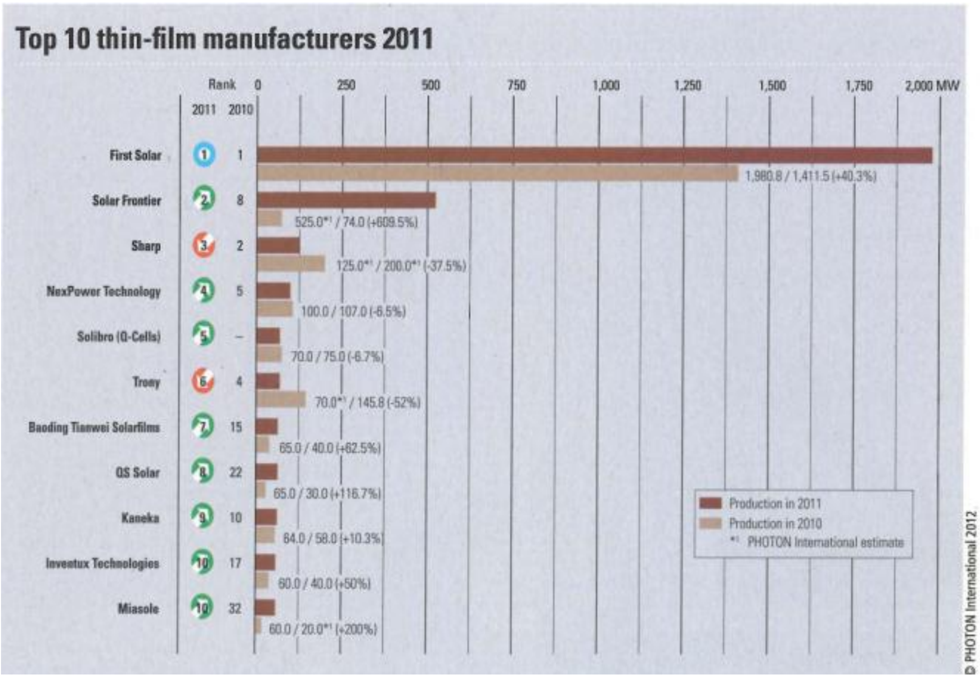
3.1.3 CdTe

The marked for CdTe modules has until now been dominated by US based manufacture First Solar, which in 2009 hold the position as the most productive manufacture – not only in TFPV but in PV as a whole - with a total volume of 1,1 GW.

According to PI this number increased in 2010 to approx. 1,4 GW, which, however, in light of the boost occurring in the crystalline sector, only provide a 3rd place among PV cell manufactures – outnumbered by Suntech Power and JA Solar.

In 2011 a further increase to approx. 1,98 GW occur, whereby First Solar gained one place in the overall statistic to become the 2nd larges PV manufacture and First Solar is still by far the most productive thin-film producer.

This is clearly demonstrated in the diagram below, showing that the production from First Solar in 2010 and 2011 were higher than the combined production of the companies ranking 2 to 10 in the top 10 thin-film manufactures.



Top 10 TFPV manufactures in 2011 / PI 3-2012 page 145/

Although First Solar most likely will continue to be the leading company in the CdTe-technology, new enterers - like for instance German based Calyxo –, has announced ambitious plans for production facilities and cost saving manufacturing technologies, which might change marked conditions in the years to come.

4.0 Technological aspects

Over the course of the ThiFiTech project, developments regarding technological mattes have occurred. In this part of the reporting, the most significant trends are highlighted.

4.1 Development in efficiency

As previously mentioned, TFPV modules have a lover efficiency as there crystalline counterparts. Consequently, more space and module area are needed in order to obtain a certain installed capacity, which in some case exclude TFPV utilization, if for instance the available area is limited.

Since the first feasibility study was made in 2009, the efficiency of all the various kinds of TFPV have increased – as well as the case is for crystalline PV modules.

Below a table presented in the 2009 edition regarding efficiency is shown together with an updated version. Thereby the progress becomes apparent.

Table 1.1: Module and cell efficiencies for thin film and crystalline base PV modules

Technology	Thin film photovoltaic				Crystalline based	
	Amorphous silicon a-Si	a-Si/μc-Si	CIS - CIGS	Cadmium telluride CdTe	Mono crystalline	Multi crystalline
Cell efficiency, %	5 - 7	8	7 -11	8 - 11	16 - 19	14 – 15
Module efficiency, %					13 - 15	12 – 14
Area needed pr. kW_p, m^2	15	12	10	11	App. 7	App. 8

Table regarding module and cell efficiency taking from the 2009 feasibility study

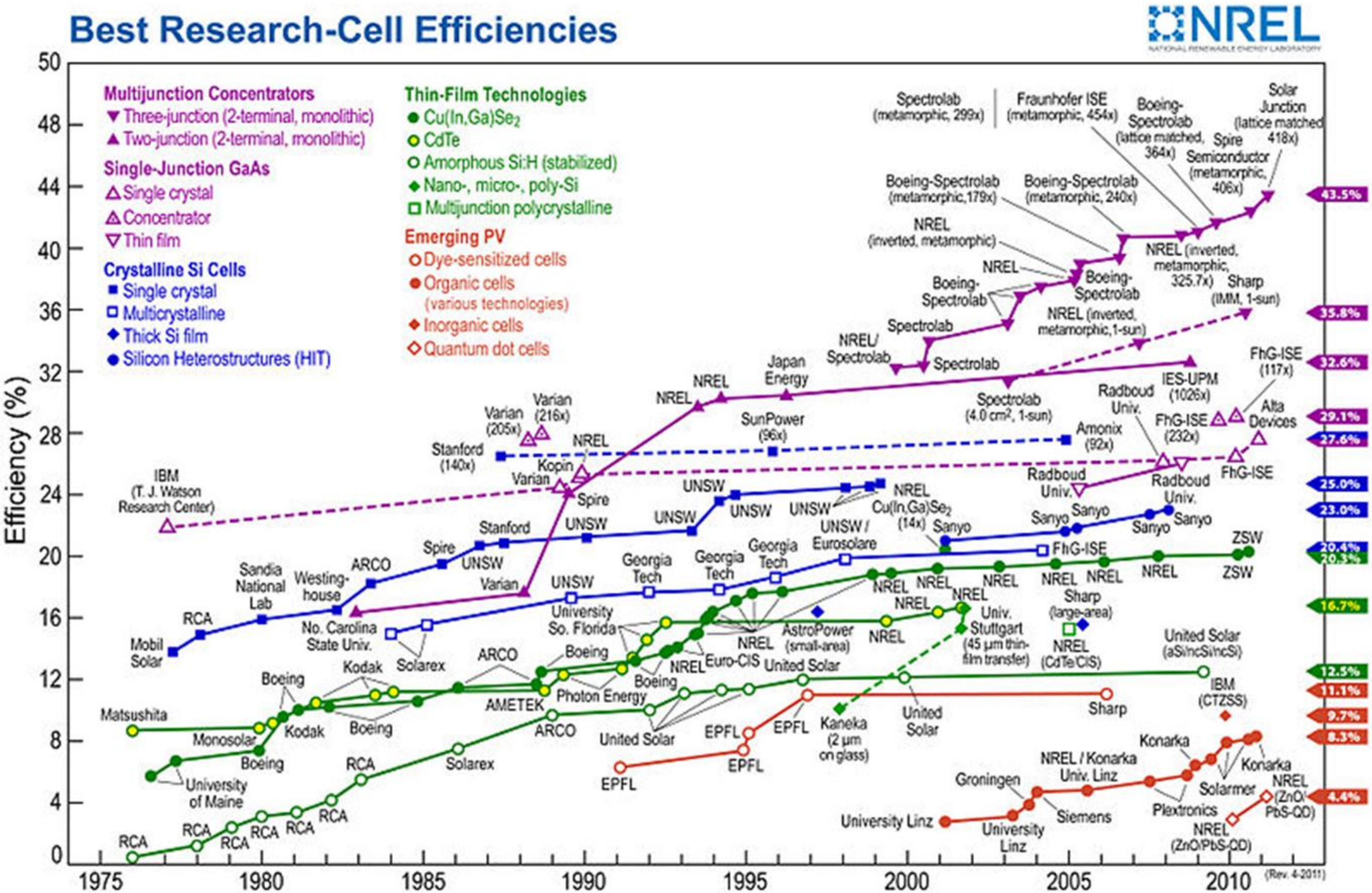
Module efficiency and area needed for thin film and crystalline base PV modules

Technology	Thin film photovoltaic				Crystalline based	
	Amorphous silicon a-Si	a-Si/μc-Si	CIS - CIGS	Cadmium telluride CdTe	Mono crystalline	Poly crystalline
Module efficiency, %	5 – 8	9 - 10	11-13	8 - 11	14 - 20	12 – 15
Area needed pr. kWp, m^2	15	11	8	10	5	6

Table with latest figures inserted

On next page, a diagram from US National Renewable Energy Laboratory (NREL) is presented, which shows the development in efficiency for various PV cell types.

The efficiencies shown on this diagram are for small research cells and as such not directly comparable with commercially available products, however, the development over time and variation between the different technologies is clearly visible.



Best Research-Cell Efficiencies
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Efficiency (%)
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
Silicon Heterostructures (HIT)
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)
Inorganic cells
Quantum dot cells
Spectrolab (metamorphic, 299x)
Fraunhofer ISE (metamorphic, 454x)
Boeing-Spectrolab (lattice matched, 364x)
Spire Semiconductor (metamorphic, 406x)
Solar Junction (lattice matched 418x)
Boeing-Spectrolab (metamorphic,179x)
Boeing-Spectrolab (metamorphic, 240x)
NREL (inverted, metamorphic)
NREL (inverted, metamorphic, 325.7x)
Sharp (IMM, 1-sun)
NREL (inverted, metamorphic,1-sun)
Spectrolab (4.0 cm², 1-sun)
IES-UPM (1026x)
FhG-ISE (117x)
FhG-ISE (232x)
Alta Devices
Radboud Univ.
Amonix (92x)
SunPower (96x)
Stanford (140x)
Varian (205x)
Varian (216x)
IBM (T. J. Watson Research Center)
Japan Energy
NREL/ Spectrolab
UNSW
Sanyo
ZSW
Georgia Tech
UNSW / Eurosolare
Cu(In,Ga)Se2 (14x)
FhG-ISE
Sandia National Lab
Westing-house
ARCO
Spire
Stanford
Mobil Solar
RCA
No. Carolina State Univ.
Solarex
University So. Florida
AstroPower (small-area)
Univ. Stuttgart (45 µm thin-film transfer)
Sharp (large-area)
NREL (CdTe/CIS)
United Solar (aSi/ncSi/ncSi)
Euro-CIS
United Solar
Kodak
Boeing
Matsushita
Monosolar
University of Maine
AMETEK
Photon Energy
IBM (CTZSS)
EPFL
Kaneka (2 µm on glass)
Sharp
Konarka
NREL / Konarka Univ. Linz
Groningen
University Linz
Siemens
Plextronics
Solarmer
NREL (ZnO/PbS-QD)
43.5%
35.8%
32.6%
29.1%
27.6%
25.0%
23.0%
20.4%
20.3%
16.7%
12.5%
11.1%
9.7%
8.3%
4.4%
(Rev. 4-2011)

4.2 Thin-film and inverters

One aspect of particular important when TFPV is concerned is whether or not transformerless inverters can be utilized or the less efficient types with transformers must be used.

The reason inverters with transformers in many cased are mandatory, is that galvanic separation between the module area and the building installations has to be provided in order to avoid corrosion of the modules Transparent Conductive Oxides (TCO) layer.

Since publication of the 2009 Feasibility Study, progresses in this field have also occurred on different areas. With respect to the module side, several manufactures have now allowed utilization of transformerless inverters since development of new TCO layers with improved characteristics has now stabilized the TCO layers making this less vulnerable for corrosion.

At present, for instance Unisolar and Solar Frontiers – major producers of a-Si respectively CIGS modules – both allow utilization of transformerless inverters together with their modules.

Also from the inverter manufactures side, steps have been taking to obviate the requirement for inverters with transformers. For instance Danish inverter manufacture Danfoss Solar Inverters has developed a unit, which provide the galvanic separation without significant loss in efficiency.

This unit, however, is intended solely for large-scale PV plants and is not economically feasible for residential size plants.

4.3 High efficiency under low irradiation

Manufacturers usually highlight that TFPV have higher production under low irradiation conditions compared to crystalline PV modules.

Some international studies seems to confirm this effect, for instance one[2] which based on outdoor test with high accuracy measuring devices have analysed obtainable yields dependant on various figures such as temperature coefficient, low irradiance behaviour, seasonal change in solar spectrum etc. The analysis were carried out in the period from 1st May 2010 to 30th April 2011 and concluded, that the observed yield from TFPV in general were in line with traditional crystalline PV in respect to yield pr. Wp.

Interestingly the study also concluded, that the gain in yield obtained at low radiations conditions from modules with optimal low irradiation behaviour, to a certain extent were counterbalanced at high irradiation levels, resulting in

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[2] Factors affecting the performance of different thin-film PV technologies and their impact on the energy yield. Markus Schwiger, Ulrike Jahn, Werner Herrmann, TÛV Rheinland Group, Köln, Germany

comparable yields taking over the course of a whole year between modules with different low irradiation behaviours.

In the study referred to above, especially the CdTe and a-Si modules turned up beneficially with respect to efficiency under low irradiation conditions – as well as they did with respect to temperature dependency – but it has to be taking into consideration, that only a small number of modules were included in the test, and thus the result may not be representative.

As a separate activity in ThiFiTech a measuring programme has been carried out at *Dansk Teknologisk Institut* in *Taastrup*. The results from this study are reported in a separate document, the main conclusion, however, seems to be that no significant higher specific annual yield from TFPV compared to crystalline PV can be verified under Danish conditions.

5.0 Environmental aspects

Considering environmental factors, the issues drawn forward generally concern utilisation of resources and risk of pollution.

5.1 Availability of resources

With respect to resources the question very often concern, whether it is prospective to lean on TFPV given the fact, that some of the materials needed – especially tellurium, the basic material for telluride used in CdTe modules and indium needed in the manufacturing of CIS/CIGS modules – according to some analysts limit the continuing expansion of these technologies.

Tellurium is an element not currently used for many applications. Only a small amount, estimated to be about 800 tons per year, is available. Most of it comes as a by-product of copper, with smaller by-product amounts from lead and gold. At current efficiencies and thicknesses 1 GW of CdTe modules require approximately 90 tons of tellurium.

The counter argument from the CdTe industry is, that due to the fact that tellurium has had very few uses, it has not been the focus of geologic exploration and that new supplies of tellurium-rich ores have been located, e.g., in China, which will be more than sufficient to cover the demand even for a major rise in utilization.

Similar disputes exist for indium with respect to the CIS/CIGS technology, and also here the opinions strongly depend on the interest of the author.

A more balanced and realistic view might be found in a study made by the Centre for Energy Policy and Technology at the London Imperial College /2/. In this study, researchers conclude that it is unlikely, that the availability of tellurium and indium will necessarily constrain CdTe and CIGS technologies respectively in their ability to supply expected future PV market growth. However, future escalation in indium and tellurium price resulting from extended demand could have a negative impact on CdTe and CIGS cost reduction ambitions and thus indirectly affect the growth potential.

5.1.1 Recycling program

One of the reason material constrains might be avoided, is that various recycling programmes have been launched for all kind of PV technologies.

In Europa, an attempt was made to make a common recycling platform for all manufacturers via the organization *PV Cycle* (www.pvcycle.org). Although supported by a number of organisations and significant manufacturers, this effort has only partially been successfully, since consensus between the members regarding the position and strategy of the organisation prove to be hard to reach.

In some analyst's opinion this lack of achievement is due to the fact that the launching of PV Cycle to a large extend has been made as a try to avoid PV modules being included in the *Waste Electrical and Electronic Equipment Directive* issued by the European Commission, known as the WEEE /3/.

PV modules are now included in the revised edition of the WEEE, and thus European manufacture now has to provide a recycling solution for the products delivered at the time of deliverance, giving rise to commercial companies pursuing the business potential in recycling PV modules, for instance the US based *PV Recycling llc* (www.pvrecycling.com) and German *take-e-way* (www.take-e-way.com)

In some case, manufactures have launched individual recycling programmes covering their own modules. For instance anyone in possession of modules from US CdTe manufacture First Solar can request collection of these free of charge via the website of the company. According to information given from First Solar /4/ and /5/, 90 % of glass and 95 % of the semiconductor material is recycled from a scraped module.

5.2 TFPV - a source for pollution?

Given the fact that some of the elements utilized in CIS/GIGS and CdTe modules are based on toxic, heavy metals, some claims there is a risk that TFPV module can pollute air and earth if for instance they are exposed to fire or handled irresponsibly somewhere in the production-, mounting-, utilization-, decommissioning- or disposal stage.

The main disputes has so far concentrated on CdTe modules, probably due to a combination of the facts that this is the most successfully TFPV technology in respect to gaining marked shares and that the highly toxic material cadmium is one of the ingredients used when producing the CdTe-material, of which approx. 14 gram are used for a standard 60 x 120 cm CdTe modules.

Cadmium is usually produced as a by-product of zinc smelting and is very similar to zinc in terms of chemical characteristics. Cadmium is cumulative toxin, giving it is building up in the body over a lifetime and its effect become more noticeable over time.

It is, however, important to note, that CdTe as it appears in a TFPV-module is a unified material, which has fundamentally different characteristics as the two different materials - cadmium and telluride - taking separately.

Unlike cadmium, which is well described in scientific literature, very little is known regarding the toxicological qualities of CdTe. To compensate for this lack of knowledge, a number of studies carried out by internationally recognised experts and sciences have been made to establish the potential hazard that CdTe modules can affect.

The main finding from these conclude, that the only way CdTe can escape to the environment, is if modules are exposed to temperatures above 1.041°C. In a typical fire in a building, the temperature will be in an interval of 800 – 1.000 °C.

Further on, the studies conclude that pollution will not occur from modules – whole or broken - dumped in landfills or elsewhere, which is partly due to the fact that CdTe – unlike elemental cadmium - does not dissolve in water. For a comprehensive description of these, please refer to /5/.

Some sciences disagree with the conclusions from the studies mentioned above – which also is the case for a number of (crystalline) module manufactures, arguing that it is unnecessary to use potentially dangerous materials, when non-hazardous solutions are available.

Doubts regarding the seriousness of these counter-arguments were rapidly put forward by the CdTe industry, claiming they to a large extent were a mere expression of anxieties for the business potential of traditional silicon-PV manufactures rather than environmental concerns.

In December 2009 a new player joined the game, when a number of companies and organisations clustered together in "The Non-Toxic Solar Alliance", a group which - according to its foundational statement - the purpose of ….*"work with the industry, policymakers and NGOs to make PV production in Europe compliant with highest environmental standards and to abandon the use of toxic materials in solar modules"* /6/.

The formal responsible entity behind this organization is a consultancy company – Bohnen Kallmorgen & Partners -, who declared it has paid expenses needed to establishing and operation of the initiative pro bono. It was, however, soon implied that in fact a few employees of solar companies from their private funds have provided the necessary means.

Although this rumour remains unconfirmed, the very fact it is put in circulation highlight that in a harsh and highly competitive business atmosphere as the PV sector, statements – official as well as unofficial - can be put forward with diverse motives and hidden agendas.

6.0 Thin-film utilization – future prospects

Afterwards some of the main barriers and potentials for future deployment of TFPV in Denmark are discussed.

The section is concluded in part 6.3 with a perspectivation and discussion regarding further utilization and potential for dissemination of TFPV-technologies in Denmark.

6.1 Economy

In many respect, economic conditions will likely have to be considered a barrier rather than a possibility when utilization of TFPV in Denmark is concerned. When ThiFiTech started in 2008 it was generally expected, that TFPV – although more modules and mounting equipment were needed due to lower efficiency – would in a short time gain an economic benefit over crystalline PV giving a significantly lower production cost.

The reality, however, turned out to be different, since the cost for traditional PV products soon took a very steep decrease, when large production capacities were established mainly in China while at the same time some incentive programme were terminated or reduced.

The global financial recession manifesting itself in 2008-2009 which also hit the PV branches hard causing many bankruptcies were particularly hard on TFPV manufactures, of which many were start up companies not having established a stable marked position.

One particularity dividing TFPV manufacturing from crystalline PV, is that the module is produced in one fully integrated process. This means that a TFPV manufacture has to go “all in” at once, which require high CAPEX.

Thus a TFPV manufacturer is forced to maintain a high price in order to provide the income necessary to remunerate the investment; this, however, makes the products unattractive. For many TFPV manufactures this situation has resulted in a self-reinforcing downward spiral, which eventually has caused the cease of their business.

Examples of TFPV companies that either went bankrupt or into serious financial challenges in the project period of ThiFiTech are quite numerous, the most noteworthy being the US manufacture of cylindrical CIGS modules *Solyndra*. The downfall of the latter caused political debate in the US, since the company received a 535 M$ loan guarantee from the Obama administration.

One particularly area in which TFPV at one time achieved a high marked share is large scale PV power plant established in high irradiation countries like Spain. The reasons for this being that the temperature coefficient of certain TFPV technologies are low – meaning that the decrease in production with raising temperature is minimal. Especially the CdTe manufacture First Solar has been able to gain marked shares in this segment.

For these large-scale plants – sometime extending 50 MW – it is possible to gain a benefit of scale; meaning for instance that highly automatic equipment for ramping poles in the ground can be utilized in order to speed up and minimize cost for installation.

If at the same time the plant is erected on marginal soils with few or no alternative possibility for utilization, like for instance mountainous or dessert areas, the cost for purchasing or renting of land can be minimized as well.

In a Danish context, however, these kinds of soils are next to non-existing, and thus cost of land is usually high, which in general results in deprived conditions for TFPV, unless the maximum installed PV capacity for some reason is limited and at the same time plenty of space is available, e.g. in the form of a large roof on an industrial or commercial building.

6.2 Architectural conditions

TFPV's benefits in respect to architectural matters over traditional crystalline modules are sometime highlighted to be more uniform surface and design flexibility regarding colour and size.

It is apparent that the surface of a TFPV module in most cases will have a more uniform visual appearance over a crystalline module due to the fact that the latter traditionally have visual division between cells, cell interconnectors and bus bars.

Recently, however, new designs in crystalline PV with back side contacts or hidden interconnectors and bus bars to some extend catch up with these shortcomings, although this has until now been features reserved mainly for premium products like for instance modules from *Sunpower*.

With respect to design flexibilities, however, it has to be taking into account, that the lion share of TFPV productions comes in the shape of mass produced modules, where cost reductions are pursued through high volume production of standard products.

A few TFPV producers have tried to establish a sound business case through customising design possibilities, for instance the Swiss manufacture *Flexcell*, but these products must still be considered a niche in the present market like the case is also for customising production of crystalline PV modules.

A very important aspect to consider is that some of the TFPV modules, especially the CdTe and a-Si types, have a highly reflective surface. Since reflections have become an important issue in the Danish municipalities, this could sometime put boundaries for products from certain manufactures.

6.3 Conclusion regarding barriers and potentials

Although some benefits regarding architectural conditions are present, TFPV has not yet captured noteworthy marked shares in Denmark and it is difficult to imagine that the outlook for TFPV will improve significantly unless some radical change in market conditions will occur.

The main reason for this is attributable to economic condition: At the present situation with steadily decreasing cost for traditional PV modules based on crystalline cells, TFPV has a hard time being competitive from a holistic point of view.

Although the crude module price per Wp is often lower, the total cost including BoS will for the Danish situation very often be higher, due to the need for more cables, mounting equipment and manual labour for mounting.

It is thus difficult to pinpoint areas in which TFPV will have obvious benefits over crystalline PV in a Danish context; the most likely areas, however, could be large-scale PV power plants on marginal soils and for special building integrating purposes, in which the uniform surface and especially the possibility to prepare the transparency of the module can be utilized.