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THIFITECH

APPLICATION OF THIN-FILM TECHNOLOGY IN DENMARK

MEDIUM AND LARGE SCALE DEMONSTRATION

a-Si thinfilm modules installed at Plejecenter Marinelyst in Skive.

September 2012

0.0 ThiFiTech – Medium and large scale demonstration

This report concerns the reporting of a part of the R&D project "*Application of thin-film technology in Denmark*" (ThiFiTech) which is carried out with Danish Technological Institute as project manager in the period from March 2008 to September 2012.

ThiFiTech has been realized through a funding of approx. 6.5 MDKr provided by the 2008 ForskEL program administrated by Energinet.dk. The project identification number is 2008-1-0030.

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

This report concerns one such activity, namely medium and large-scale demonstration. In the context of ThiFiTech, plants below 6 kW are defined as medium scale, whereas plants larger than 6 kW are denoted large-scale plants.

By this division, medium scale plants mainly are for single-family houses that are allowed to use the net metering scheme, whereas large-scale plants are for commercial and public buildings.

When ThiFiTech was launched, the knowledge to TFPV in Denmark was almost non-existing. Thus the purpose of the medium and large-scale demonstration part of ThiFiTech is to establish a number of plants, which can serve as examples on how TFPV can be realized.

Ideally the plants established through ThiFiTech shall demonstrate if - and how - unique features of TFPV can be exploited. In this way ThiFiTech will provide practice examples of utilization and thereby contribute to further dissemination of PV in general and TFPV in particularly.

This part of the ThiFiTech project has been carried out by Arkitema, EnergiMidt and En^{2}tech.

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1.0 Resume

Nærværende rapport omhandler rapportering af delelementet "Small- and medium size demonstration", som er udført i tilknytning til ForskEL projektet "*Application of thin-film technology in Denmark*" (forkortet til "ThiFiTech").

Projektet er udført med Teknologisk Institut som projektleder i perioden fra marts 2008 til september 2012 og er muliggjort gennem et tilskud på 6,5 MDKr bevilget fra ForskEL programmet administreret af Energinet.dk.

ThiFiTech har til formal at afdække tekniske og arkitektoniske forhold vedrørende tyndfilmsbaserede solceller (i rapporten forkortet til TFPV) med særligt focus på denne solcelletypes anvendelighed under danske og nordeuropæiske forhold.

Der er gennemført en række forskelligt-rettede aktiviteter under ThiFiTech-projektet, hvoraf nærværende rapport omhandler én sådan aktivitet, nemlig medium- og storskala demonstration, hvorved forstås anlæg hhv. over og under 6 kWp. Denne delaktivitet er gennemført af firmaerne Arkitema, EnergiMidt og En^{2}tech.

I praksis medfører denne opdeling at medium-skala (medium-scale) anlæg svare til typiske installationer på enfamilieshuse, mens stor-skala (large-scale) anlæg typisk vil være installeret på erhvervsmæssigt benyttede ejendomme eller offentlige bygninger.

Da ThiFiTech blev igangsat i 2008 var kendskabet til tyndfilmsolceller i Danmark beskedent grænsende til ikke eksisterende, hvilket var en vigtig medvirkende årsag til, at projektet blev bevilget tilskud fra ForskEL-programmet.

For at fremme kendskabet til tyndfilms-solceller og deres anvendelighed, blev det besluttet at der som en del af projektet skulle etableres et antal anlæg med forskellige tyndfilms-typer med henblik på at give praktiske eksempler på teknologianvendelsen.

Disse anlæg skulle så vidt muligt repræsentere såvel forskellige teknologier som størrelser samt - hvis muligt - demonstrere muligheden for at tilgodese arkitektoniske udfordringer.

Som incitament var det gennem ThiFiTech muligt for købere af demonstrationsanlæg at modtage en økonomisk kompensation på 40 % af de omkostninger, der var forbundet med etablering af anlægget. Dette blev skønnet nødvendigt, da tyndfilmsteknologien dels var ukendt i Danmark og dels var prisen på moduler relativ høj, da der var tale om specialindkøb i meget få styktal.

På trods af muligheden for at give et økonomisk tilskud viste det sig ganske problematisk at skabe kontakt til interesserede anlægskøbere. Den annoncering af projektet, der blev gennemført, genererede ganske vist en del henvendelser som førte til udarbejdelse af ca. 15 konkrete tilbud; men af disse valgte kun 3 husejere efterfølgende at købe tyndfilmsanlæg.

Hovedårsagen til den ringe interesse blandt private købere kan først og fremmest tilskrives det forhold, at det på trods af tilskuddet på 40 % af anlægsomkostningerne, kun vanskeligt prismæssigt kunne konkurrere med krystallinske moduler, på hvilke der opstod et markant prisfald som følge af dels en kraftig udbygning i produktionsvolumen og dels i kølvandet på den globale finansielle krise i kombination med ophør af lukrative incitamentsordninger i blandt andet Spanien.

For så vidt angår professionelle brugere havde Arkitema kontakt til en række bygherrer, som udviste interesse for inkludering af solceller på nye domicilbyggerier. For denne købergruppes vedkommende

strandede interessen for tyndfilmsolcellerne imidlertid på det forhold, at der af hensyn til opfyldelsen af kravene til bygningernes energiramme var ønsker om at opnå en så stor produktion som muligt pr. installeret solcelleareal. Dette diskvalificerede i alle de undersøgte byggeprojekter tyndfilmsceller grundet deres lavere virkningsgrad sammenlignet med krystallinske celler.

For at opfylde projektets formål omkring inkludering af såvel forskellige anlægsstørrelser som repræsentanter for hver af de fremherskende tyndfilms teknologier, blev der indgået et samarbejde med det ForskVE støttede udviklingsprojekt "Photo Skive", under hvilket Skive Kommune etablere solcelleanlæg på hovedparten af sine bygninger.

Gennem dette samarbede og aftalerne med de 3 private husejere, blev anlæggene nævnt i efterfølgende tabel etableret.

Anlæg etableret gennem ThiFiTech

Lokalitet	Teknologi	Producent	Antal moduler	Effekt
Stor-skala anlæg på kommunale bygninger				
1. Skive Rådhus	CdTe	Calyxo	377 stk. @ 60Wp	22,62 kWp
2. Skive Bibliotek	CIGS	Solyndra	176 stk. @ 182 Wp	32,03 kWp
3. Brårup Skole	CIGS	Solyndra	36 stk. @ 182 Wp	6,55 kWp
4. Plejecenter Marienlyst	a-Si	Schüco	642 stk. @ 90 Wp	57,78 kWp
Medium-skala anlæg på private ejendomme				
5. Sønderborg	CIGS	Schüco	58 stk. @ 75 Wp	4,35 kWp
6. Gjern	a-Si/µc-Si	Inventux	42 stk. @ 130 Wp	5,46 kWp
7. Ulstrup	a-Si/µc-Si	Inventux	32 stk. @ 130 Wp	4,16 kWp

Baseret på etablering og drift af anlæggene, er nogle generelle forhold og erfaringer oplistet herunder:

- For nogle af de anvende modulers vedkommende er der tale om rammeløse laminater, der har den fordel at der ikke er tendens til ophobning af støv og snavs langs kanterne. Disse laminater skal dog håndteres meget forsigtigt under transport og montage, da der let opstår revnedannelser.
- Tyndfilmsmoduler har typisk højere udgangsspænding end krystallinske moduler med samme effekt. Dette betyder, der skal anvendes færre serieforbundne moduler til at matche inverterens spændingsvindue, hvilket igen indebærer at antallet af parallelle strenge stiger. Dermed stiger også antallet af samlingspunkter og kablingsarbejdet, hvilket gør, at montagetiden kan stige udover den forøgelse, der er betinget i det øgede modulareal-behov, der opstå som konsekvens af tyndfilmsmodulernes lavere effektivitet.
- De a-Si, a-Si/µc-Si og CdTe moduler, der er anvendt på demonstrationsanlæggene, har en relativ reflekterende overflade, som kan give anledning til generende blændinger. Hvorvidt der opstår problemer og i givet fald hvor store disse er, afhænger af den konkrete montagesituation. I den danske debat og blandt f.eks. kommunale myndigheder har der på det seneste været stor fokus på refleksionsproblematikker i relation til solcelleanlæg, og det må derfor stærkt anbefales at have

fokus på dette forhold tidligt i projekteringsfasen, eventuelt gennem egentlige refleksions-simuleringer, som tager hensyn til de store udsving i refleksionsmønstret, der forekommer over året.

- En del fabrikanter af tyndfilmsmoduler stiller som krav, at deres produkter skal tilsluttes invertere med transformere. Da garantien på produkterne bortfalder, hvis fabrikantens retningslinjer for brug af disse ikke er fuldt, skal et krav som dette naturligvis efterleves, og da invertere med transformere sædvanligvis opererer med lavere virkningsgrad end transformerløse typer, må en mindre reduktion i det årlige udbytte påregnes.
- I afsnit 6.1.1 er beskrevet, hvorledes der på taget af Skive Rådhus er anvendt tyndfilmsmoduler til visuel afdækning af ventilationsanlæg. Hvis det på denne måde er muligt at indbygge et flersidigt formål i anlægget, kan marginalomkostningen forbundet med at gøre installationen elproducerende vise sig at være lav.
  I det konkrete tilfælde, hvor en afdækning af 3 ventilationsanlæg under alle omstændigheder var påkrævet, er det vurderet at meromkostningen ved at erstatte facadeplader med aktive solceller samt at udføre kabling, installere invertere etc., udgjorde 35 – 40 % af de samlede etableringsomkostninger.

På baggrund af de erfaringer, der er indhentet i forbindelse med den generelle gennemførelse af demonstrationsprojekterne, er fremtidsmulighederne for anvendelse af tyndfilmsmoduler desuden søgt perspektiveret.

Det er her konkluderet, at det på trods af de arkitektoniske muligheder, tyndfilmsolceller giver anledning til grundet den meget ensartede overflade, disse typisk besidder, ikke er lykkedes at opnå en nævneværdig markedsandel.

Det er desuden projektets konklusion, at der ikke umiddelbart er udsigt til at denne situation ændre sig, med mindre der sker markante teknologiske- eller markedsmæssige ændringer.

Hovedårsagen hertil skal tilskrives økonomiske forhold: Med de stadigt faldende priser på traditionelle krystallinske moduler er det vanskeligt for tyndfilmsproducenterne at erobre markedsandele. På trods af, at prisen pr. Wp kan være lav for et tyndfilmsmodul, bliver den totale installationspris ofte højere end for et anlæg med samme installerede effekt udført med krystallinske moduler, idet der medgår mere montageudstyr, kabler og installationstid.

Projektet kan derfor ej heller pege på oplagte områder, hvor tyndfilmsolceller vil have åbenlyse fordele frem for krystallinske moduler. Mest relevante anvendelsesmuligheder synes at være i forbindelse med bygningsintegrerede anlæg, hvor modulernes meget ensartede overfladeudtryk og muligheden for at arbejde med forskellig transparens, kan udnyttes.

En andet - omend mindre oplagt - anvendelsesmulighed, kan være i forbindelse med etablering af jordbaserede storskala-anlæg, hvor der kan anvendes automatiseret udstyr til montagen. Når denne mulighed vurderes som mindre relevant, skyldes det først og fremmest at jord i Danmark er en begrænset ressource, som typisk prioriteres til landbrugsmæssige formål.

2.0 Thin film PV – a short introduction to technology and exploitation

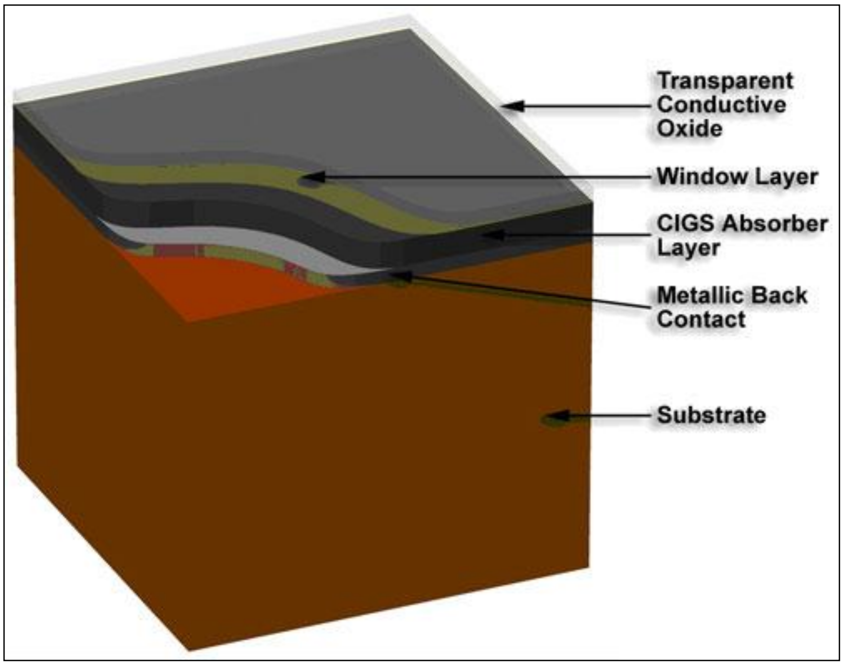
The basic principles of thin film photovoltaic are the same as for crystalline PV, taking advance of the fact that in certain materials a current is generated when exposed to light.

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 primary energy input and 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 demonstration programme.

TFPV typically have active layers in the thickness range of less than a few microns (one micron equals 1 x 10^{-6} meter). 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.

Among the three commercially available thin film technologies, a-Si was until 2007 the most important in terms of production with 223 MWp corresponding to 5.2% of the total production of 2,54 GWp that year.

Since 2008 this role has been taking over by CdTe, which is also the current leader with respect to low cost production in TFPV as well as in PV in general. In 2011, TFPV account for 11,3 % of the total PV cell production of approx. 37,2 GWp /1/. The share of the various PV technologies is listed below, starting with the TFPV types:

- CdTe: 2,0 GWp / 5,5 % of total PV production
- CIS/CIGS: 0,9 GWp / 2,4 % of total PV production
- a-Si and a-Si/μc-Si: 1,3 GWp / 3,4 % of total PV production
- Mono-crystalline: 11,5 GWp / 30,9 % of total PV production
- Poly-crystaline: 21,2 GWp / 57,0 % of total PV production
- Other PV technologies: 0,3 GWp / 0,8 % of total PV production

3.0 Feasibility Study

As part of ThiFiTech, a feasibility study was carried out in the starting phase of the project. In this the main characteristics for the different main technologies in thin film were described.

The feasibility study included technical, economical and architectural aspects, and the main benefits and drawbacks between the TFPV and the traditional crystalline modules as well as between the various kinds of TFPV technologies, was discussed.

At the end of the project period, an appendix to the feasibility study was prepared, in which the main development in TFPV in the project period were highlighted.

Part of the learning and knowledge published in this report, is collected through the tasks carried out with respect to the feasibility study,

The feasibility study is issued as a separate document as part of the reporting of ThiFiTech.

4.0 Environmental issues

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

4.1 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 utilisation.

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.

4.1.1 Recycling programme

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 IIc* (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.

4.2 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 organisation 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.

5.0 The future for TFPV in Denmark- barriers and potentials

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

5.1 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 plant – 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.

5.2 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 nieche 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.

5.3 High efficiency under low irradiation conditions

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 /7/ 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 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.

5.4 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 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 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.

6.0 Demonstration sites established through ThiFiTech

In ThiFiTech, two parallel demonstration activities were carried out:

- *Small-scale demonstration*, which has been carried out primarily at the daylight laboratory at *Statens Byggeforskningsinstitut* (Danish Building Research Institute, SBi). The purpose of this activity, which is reported in a separate document, is to establish how TFPV can be used in building integrated solutions for instance as an active solar shading device.
- *Medium and large-scale demonstration*, which is the activity reported in this document. The purpose is through practical installations to demonstrate, how TFPV can be utilized under the predominant conditions in Denmark.

Further purposes are to highlight special benefits of TFPV with respect to architectural conditions, flexibility etc., which might exist as well as to investigate the power yield from the plants established as a supplementary measure to the measuring programme carried out at *Dansk Teknologisk Institut* (Danish Technological Institute).

6.1 Identifying host for demonstration plants

When ThiFiTech was launched both the knowledge and availability of TFPV in Denmark were limited. To be able to attract hosts for demonstration plant a financial support of 40 % of installation expenditures were offered, but in spite of this, it has proven quite difficult to find relevant installation sites.

For the large plant part, the project partner Arkitema had some initial discussions with costumers whom were planning new commercial buildings and have expressed interest in including PV plants. Eventually, however, none of these contacts ended up with actual TFPV plants, either because the buildings were not constructed or crystalline PV were used in order to obtain as much production as possible with the purpose of meeting the energy frame requirements in the building directive.

In order to include some large scale plants, a cooperation with the ForskVE project *Photo Skive* was established. The purpose of Photo Skive is to implement PV on a significant part of the building owned by Skive municipal, and for some of these TFPV were then used. Since Photo Skive already received support from ForskVE, no grants for these plants were provided from ThiFiTech.

For the medium scale demonstration EnergiMidt used various information channels to reach potential hosts. For instance a number of people has previously expressed interest in receiving news and offers when available.

Based on this, approximately 15 people expressed initial interest in receiving a quotation for a plant, and as a result of this, 3 plants on private houses were eventually established. The predominant reason why the main part of offers were rejected, were due to the fact that the cost for a TFPV plant – in spite of the 40 % support – were not competitive with a comparable crystalline PV plant for reasons as described in part 5.1.

In the table below the basic data regarding the TFPV plants established through ThiFiTech is presented.

PFPV plants established through ThiFiTech				
ite	Technology	Producer	No. of modules	Plant size
Large scale plants at public buildings				
1. Skive Rådhus	CdTe	Calyxo	377 stk. @ 60Wp	22,62 kWp
2. Skive Bibliotek	CIGS	Solyndra	176 stk. @ 182 Wp	32,03 kWp
3. Bårup Skole	CIGS	Solyndra	36 stk. @ 182 Wp	6,55 kWp
4. Plejecenter Marienlyst	a-Si	Schüco	642 stk. @ 90 Wp	57,78 kWp
Medium scale plants on private households				
5. Sønderborg	CIGS	Schüco	58 stk. @ 75 Wp	4,35 kWp
6. Gjern	a-Si/μc-Si	Inventux	42 stk. @ 130 Wp	5,46 kWp
7. Ulstrup	a-Si/μc-Si	Inventux	32 stk. @ 130 Wp	4,16 kWp

As can be seen from the table, all the major TFPV technologies are represented in the demonstration plants. Afterwards some further information regarding the plants is given.

6.1.1 Skive Rådhus

Location: Skive Rådhus / Skive City Hall, Torvegade 10, 7800 Skive, Denmark

At Skive Rådhus, CdTe modules from German manufacturer *Calyxo* have been installed with a multiple purpose, since they are used both as energy producing devices and as a visual cover for the technical installations placed on the roof.

On the photo below, one of the 3 ventilation plants placed on the roof is shown. Although the building is 4-storey high, due to the landscape these technical installations are visible from other buildings in the town, which also is shown in the picture.

One of the ventilation plants which needed to be covered for the sake of aesthetics.

A total of 377 CdTe - and 150 crystalline modules are used to cover the 3 ventilation units placed on the roof. In 2 cases, the ventilation units are fully covered on all 4 sides as well as on the upper part. The horizontally mounted modules are slightly tilted in order to facilitate cleaning when raining.

The motivation to cover the ventilation units also on the upper side is mainly to raise energy production, since the horizontal mounting position is more productive compared to the various vertical positions utilized.

One of the ventilation plants being covered. Picture taken during installation.

In order to be able to compare production from TFPV modules with their crystalline counterparts, one of the horizontal covers is made with mono-crystalline modules delivered by Danish manufacture *Gaia Solar*. These modules have the same physical size of 600 x 1.200 mm but a nominal effect of 76 Wp whereas the nominal effect of the Calyxo CdTe module is 60 Wp.

When observing the photos it becomes obvious, that the module utilized is very reflective. In the case in question this is not causing problems, however, it is important to be very attentive to the fact that reflections of the sunlight can be extremely annoying to people in traffic and neighbouring buildings when using a module as reflective as this.

The covered technical installation after completion of the TFPV plant. The ventilation plant visible to the left does not belong to the city hall.

The cost for this plant has been rather high, but given the fact that some measures were bound to be taking in order to cover the ventilation plants, another perspective is to examine the additional cost for the PV module, inverters and cabling compared to a solution utilizing standard façade covering plate. Taking this approach, the marginal cost for creating a power producing shelter is estimated to be in the range from 35 – 40 % of the total expenditures held and as such affordable.

6.1.2 Skive Bibliotek

Location: Skive Bibliotek / Skive Library, Østergade 25, 7800 Skive, Denmark

At the flat roof of Skive Bibliotek 176 CIGS modules from US based manufacture *Solyndra* are placed. When lifted to the roof, these modules have been very easy to mount, since no fixing to the roof or penetration is needed. This plant is not visible from the ground; it is however visible from the neighbouring building hosting the city hall since this building is both higher and placed on higher ground.

Since Solyndra went bankrupt in 2011 and the company has not been reorganised or the production continued by other companies, it will not be possible to establish other plants using this very unique module, in which the CIGS thin film cells are placed on the inside of tubular pipes.

One unique benefit obtained when using the tubular shaped modules is that irradiation from multiple directions can be utilized. This is the reason why a bright layer of bitumen has been applied on the hitherto black roof, since this will increase the reflection from the roof and thereby also the yield obtained from the TFPV plant.

Solyndra CIGS modules on the roof of Skive Bibliotek.

Closer look at the modules shoving the tubular shaped cells.

6.1.3 Bårup Skole

Location: Bårup Skole / Bårup School, Bårupvej 94, 7800 Skive, Denmark

In the previously mentioned Photo Skive project, Bårup Skole is used as a case study for various crystalline module types and in line with that it was decided also to make a small plant using TFPV modules on a side building with flat roof.

For this purpose also the Solyndra module were chosen, since this has been especially developed for retrofitting on flat roofs without the need for fixing to – or penetration of – the roof surface.

Solyndra CIGS plant on Bårup Skole.

Looking retrospective, it could have been valuable if modules from another supplier were chosen, especially given that fact, that the Solyndra modules are no longer available; at the time when this decision were made, however, there were no imminent signs of an approaching bankruptcy.

6.1.4 Plejecenter Marienlyst

Location: Plejecenter Marienlyst / Nursery Centre Marienlyst, Marienlystvej 11, 7800 Skive, Denmark

Plejecenter Marienlyst is a nursery centre situated in the northern part of Skive. In 2010 an extension of the centre with 3 building sections with low sloop roofs were carried out and in order obtain a certain degree of self production of power it was decided to establish a PV plant at the site.

To avoid penetrating the roof material, a system from German manufacturer *Schüco International* was chosen which contains of self-balancing a-Si TFPV modules facing east respectively west. A total of 642 modules have been installed on two of the building sections providing an installed PV capacity of 57.8 kWp.

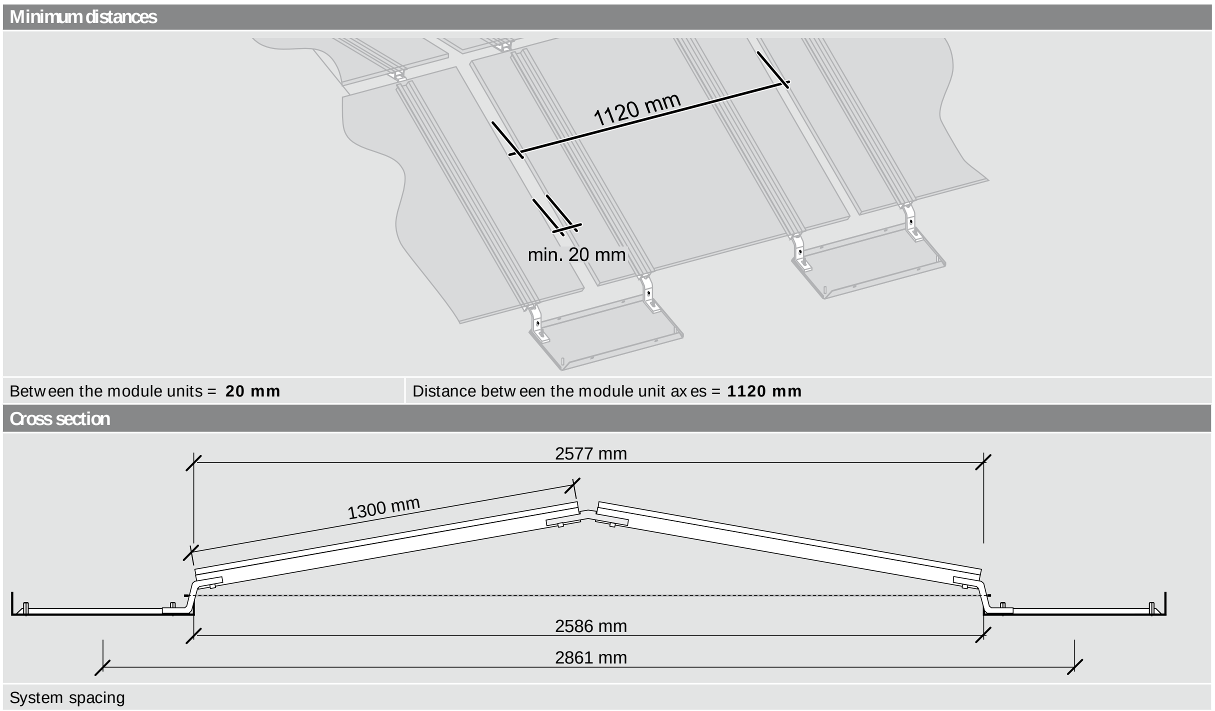
As can be seen from the pictures, the modules obtain their self-balancing capability by leaning against each other using the same principle as when building a house of cards. Brackets at the top and button as well as wires at the button provide the necessary support for the modules to remain stable.

At the plant, however, some damage occurred during a storm in November 2011, which caused the manufacture to make additional supporting features to the system.

Afterwards pictures showing the plant are inserted as well as a sketch showing the "house of cards" principle used to stabilise the modules.

East-west facing a-Si modules placed on Plejecenter Marienlyst.

Same plant from another perspective.



The basic principle of the east-west system. Source: Schüco International KG.

6.1.5 Private house in Sønderborg

Sønderborg is located in the southern part of Jylland near the border to Germany. The owner of this house needed to renovate the roof of the building since the existing roofing tiles were crumbling, and in this context he wanted to utilize a PV module that harmonize with the new black bitumen roofing material.

To fulfil this purpose, CIGS modules from German manufacture Schüco International with a black/dark blue uniform surface were utilized. The modules in question were actually produced as an OEM product by Japanese company Solar Frontiers, which is now the major producer of CIGS TFPV modules.

A total of 58 modules are placed on roof surfaces facing east and south. On the pictures below, the completed plant is shown.

CIGS modules placed on south facing roof surface.

CIGS modules on east facing roof surface. Vacuum solar collectors for hot water production is placed to the right.

6.1.6 Private house in Gjern

On this building located in Gjern in the central Jylland, 130 Wp a-Si/μc-Si modules from the German manufacture *Inventux* have been utilized. In this particularly case, the owner of the house for architectural reasons wanted to have a PV plant that could cover the whole surface of the south side of the roof.

a-Si/μc-Si modules mounted on south facing roof surface.

The same a-Si/μc-Si TFPV plant from another perspective.

In this situation, the lower efficiency of TFPV compared to crystalline modules actually becomes a benefit, given it was possible to cover the roof almost entirely with modules and still not extend the limit of 6 kWp installed capacity that exist in Denmark for utilizing net metering.

If crystalline module were used, either the surface could not be covered completely or the plant would not qualify for net metering and hence the economic conditions would not be beneficial.

It is notable that as well as the case was regarding Skive Rådhus described in part 6.1.1, also these modules are relatively reflective. In this situation, this is not causing any inconvenient for the neighbouring buildings, but as already mentioned it is important to take this aspect into consideration when projection the plant.

6.1.7 Private house in Ulstrup

At another house located in the central Jylland, also 130 Wp a-Si/μc-Si modules from Inventux have been used. Since the solution chosen on this house is very similar to the one describe for the case in Gjern, no further description of this installation will be presented.

6.2 General and conclusive remarks to the demonstration plants

When looking at the installed plant in a general perspective, some aspects can be drawn forward.

- Some of the modules utilized were frameless laminates that benefit from the fact, that dust etc. will not built up near the edges on account of the frame. These modules, however, have to be handled with great caution during transportation and installation since the glass easily brakes when no supporting frame is present.
- Another point worth mentioned, is that TFPV typically have higher output voltage compared to crystalline modules which means that the number of modules needed to match the input voltage range of the inverter is lower, which again means that significantly more string is needed for a certain installed capacity. As consequents the number of connection points and length of DC cables increase and thus the mounting time needed usually also rise beyond the time explainable due to the increased module area needed on account on lower efficiency.
- The a-Si, a-Si/μc-Si and CdTe modules utilized in the demonstration plants established, has a relatively reflective surface, which can give rise to annoying reflection from the sunlight striking the modules. Since this aspect has recently become the subject of interest for e.g. planning departments of certain municipalities, it is highly recommendable to address separate consideration hereto, for instance by making simulations and/or calculations of the reflection pattern during the course of the year.
- Module manufactures always circumscribe under which condition there product may be used and still benefit from the warranty giving. With respect to TFPV, very often it is stated, that only inverters with transformers may be utilized. These devices usually not have as high efficiency as the case is for inverters without transformers and therefore a lower specific annual yield often has to be expected.
- As described for the TFPV plant established on Skive Rådhus, a PV plant can in some cases serve multiple purposes. If the value of these additional purposes is taking into account, the marginal expenditures for adding power production may not be very high.

7.0 References

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