CIGS: Current status and future prospective

Sunday 2017, Hans Linden

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Status

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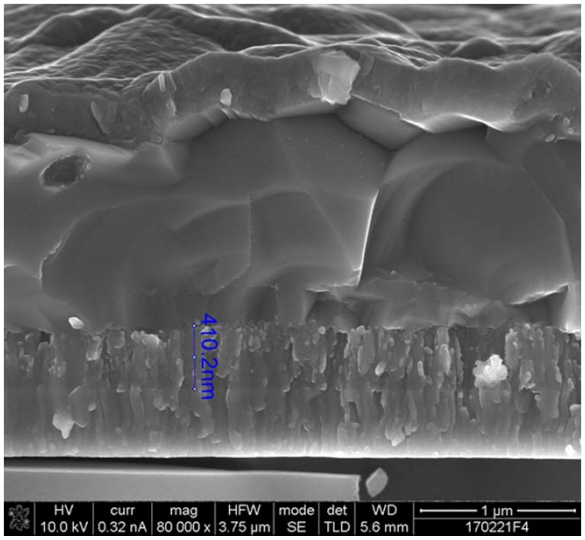
CIGS (thin film) PV

- **CIGS = Copper Indium Gallium Selenide/Sulfide**

- **Advantages, extra yield through:**
  - Light soaking effect
  - Temperature coefficient
  - Irradiance
- **Main challenges**
  - Cost (materials, processes and efficiency)
  - Process control / layer homogeneity
  - Closing efficiency gap: cell - module
  - Reliability



Total thickness 2 – 4 µm
(c-Si wafer thickness ≈ 150 µm)

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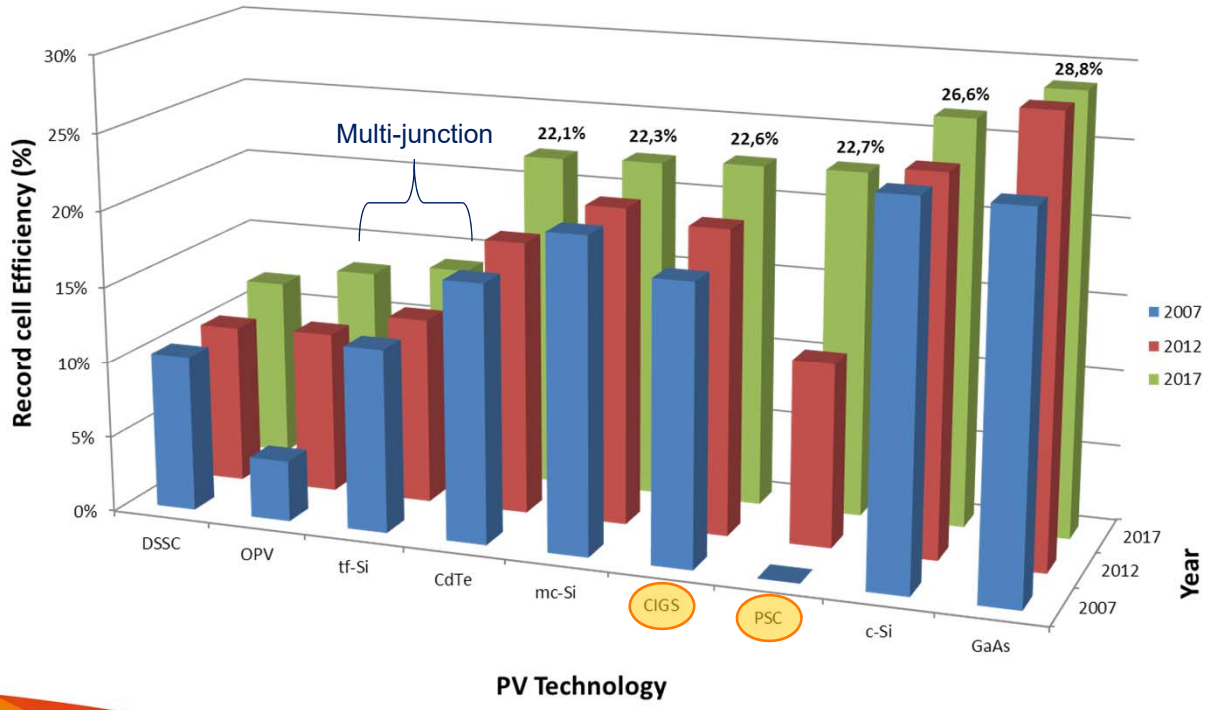
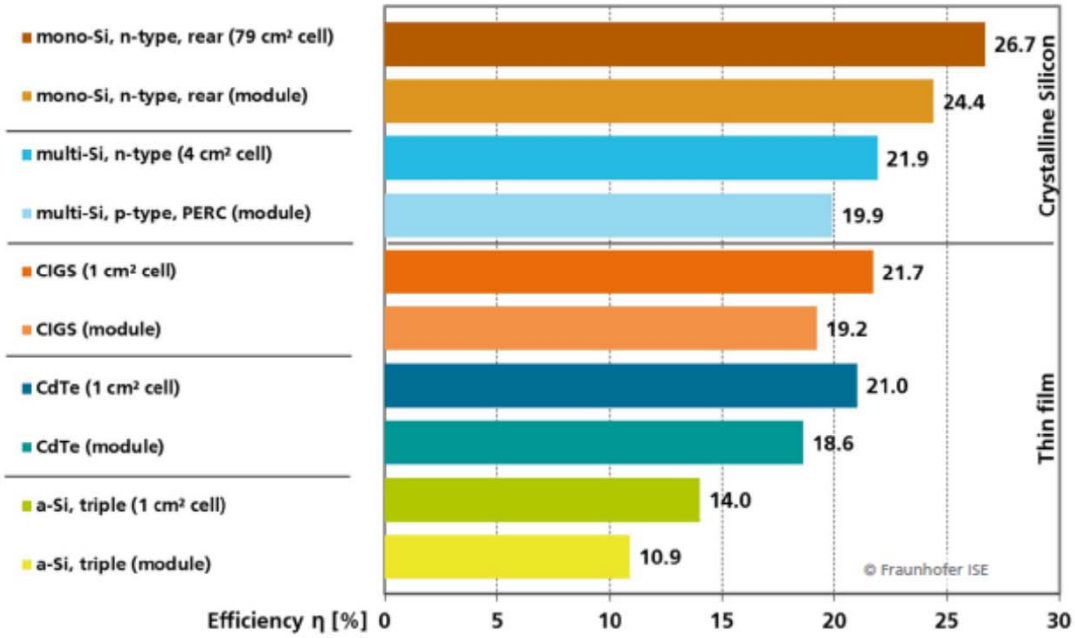
Hero Solar Cell efficiency evolution: 2007 - 2017



- **Efficiency:**
  - Thin film PV **PSC**, CdTe & **CIGS** between mc-Si and c-Si
- **Maturity:**
  - **PSC** << **CIGS** < CdTe
- **Cost targets** (€/W_p):
  - **PSC < CIGS** ≈ CdTe < cSi
  - **PSC** < 0,25 €/W_p)

Efficiency Comparison of Technologies:
Best Lab Cells vs. Best Lab Modules



Data: Green et al.: Solar Cell Efficiency Tables (Version 50), Progress in PV: Research and Applications 2017. Graph: PSE AG 2017

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CIGS

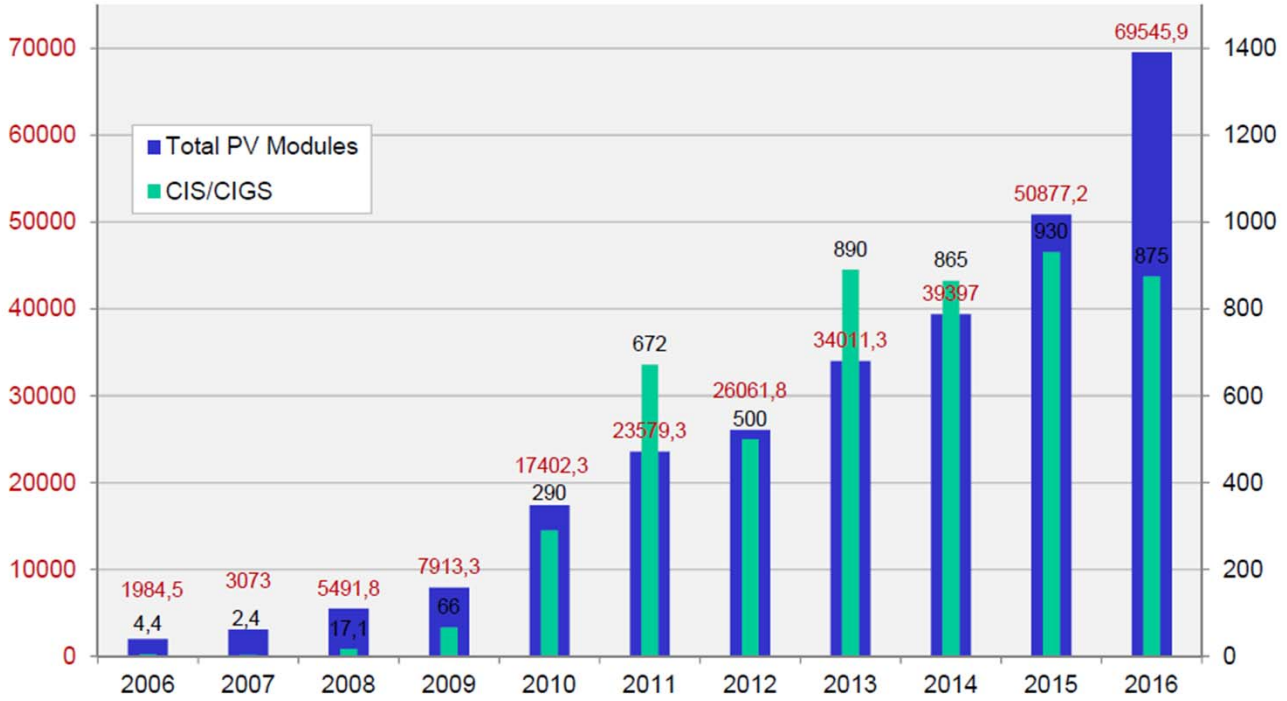
930 MW in 2015
875 MW in 2016

Cumulative: 5,3 GW
(= 1,8% of all PV)

CdTe: 14,7 GW
aSi: 2,9 GW

Total: 22,9 GW
thin film installed
(= 7,6% of all PV)

Total Photovoltaic Modules – CIS/CIGS



Source: Paula Mints, SPV Market Research / IDTechEx
http://www.pv-tech.org, May 2017

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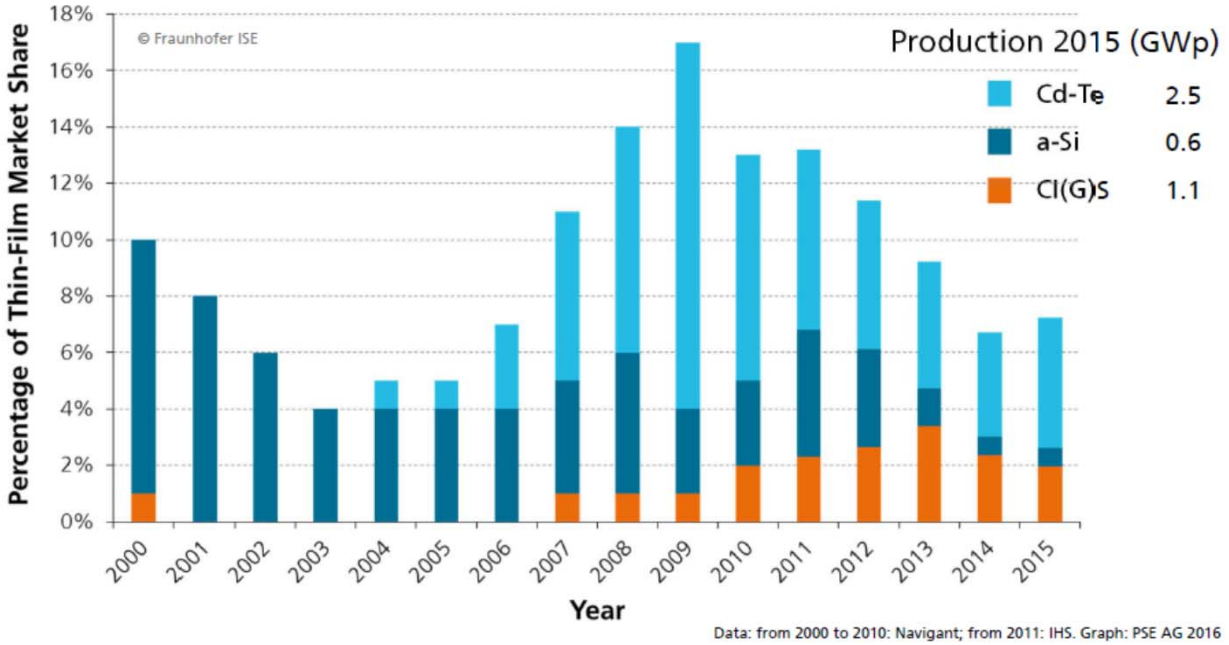
Market Share of Thin-Film Technologies
Percentage of Total Global PV Production



Data: from 2000 to 2010: Navigant; from 2011: IHS. Graph: PSE AG 2016

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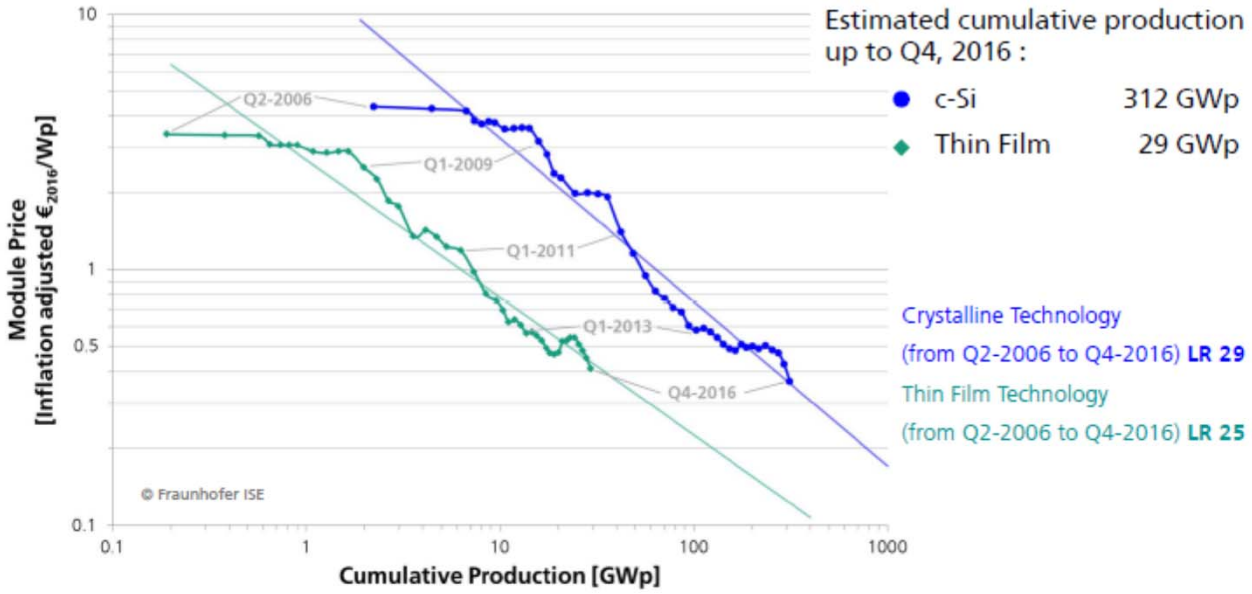
Price Learning Curve by Technology
Cumulative Production up to Q4. 2016



Data: from 2006 to 2010 estimation from different sources : Navigant Consulting, EUPD, pvXchange; from 2011 to 2016: IHS. Graph: PSE AG 2017

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Applications

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CIGS integration in built environment Flevopolder

The black color of the Solar Frontier thin-film modules fit in perfectly with the new black cladding of the barn rooftop. (Image: SolarClarity)

SOLAR FRONTIER

solarclarity importeur & groothandel

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MiaSolé Flexible CIGS Utrecht Hojel2 by Sunprojects

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Large CIGS rooftop installation at Plantion, Ede

22 Jun, 2017 | News Items | 0 comments

On the longest day of the year, Wednesday 21th of June, a 2.4 Megawatt peak thin film rooftop solar installation was taken into service at Plantion, Ede, The Netherlands. The 18.500 installed CIGS-modules are manufactured by Solibro, in Germany. The installation consist out of East, South and West oriented modules to enable maximum productivity during the whole day. It will cover 25% of the yearly electricity consumption of Plantion. The

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Bergen 1.2 MW Solibro groundmounted

Bergen, Netherlands, june 2017

Together with Sunprojects, Hanergy has realised a 1.2 MW groundmounted project for Bergen Energie, a local civic solar energy cooperation. For this project Hanergy's Solibro thin film modules were used.

Global Solar
Prorail Utrecht

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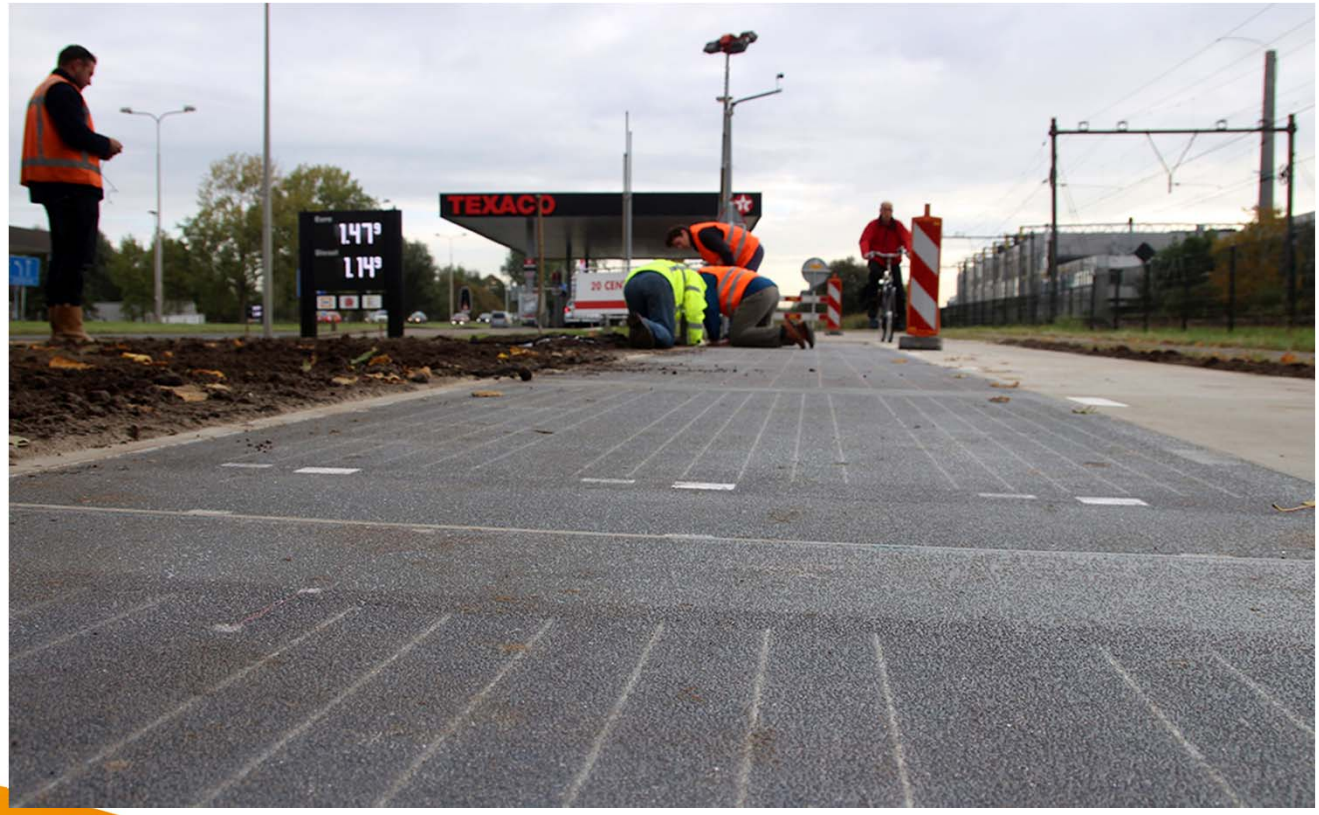
Hanergy/Global Solar fietspad Krommenie



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Symbolica Efteling: 800 panels

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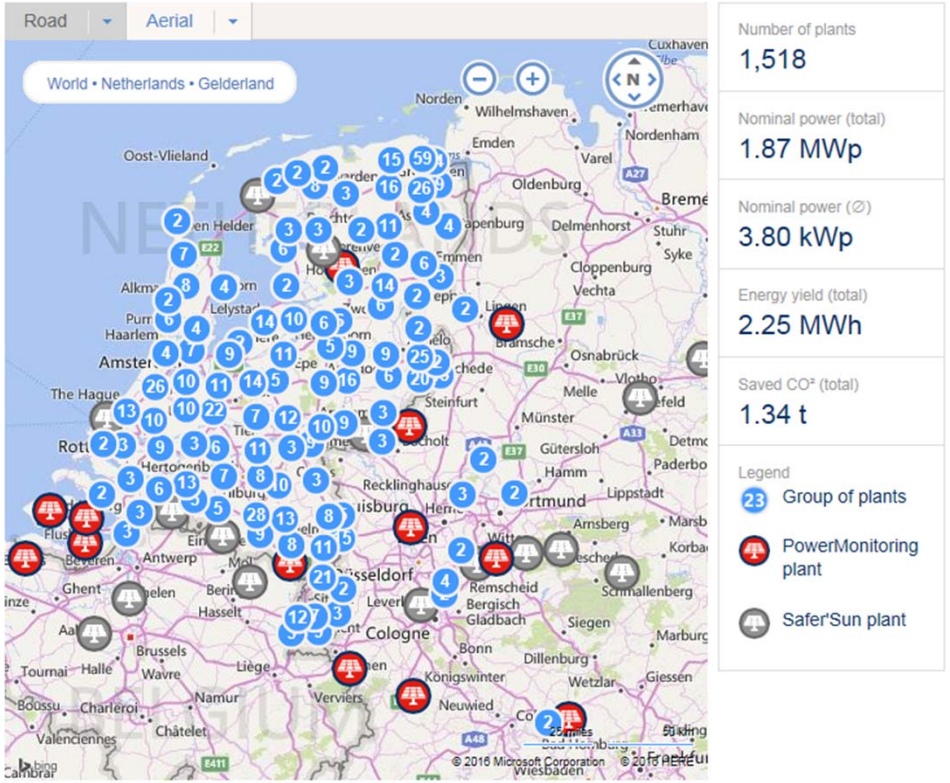
Solar Frontier

Popularity of CIGS in the Netherlands:

Distribution of Solar Frontier installations on public website of German SF office



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Developments

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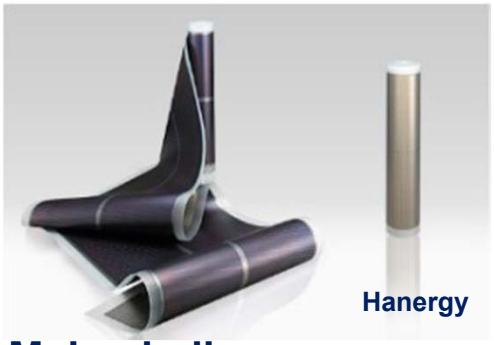
CIGS (thin film) PV

- **CIGS = Copper Indium Gallium Selenide/Sulfide**

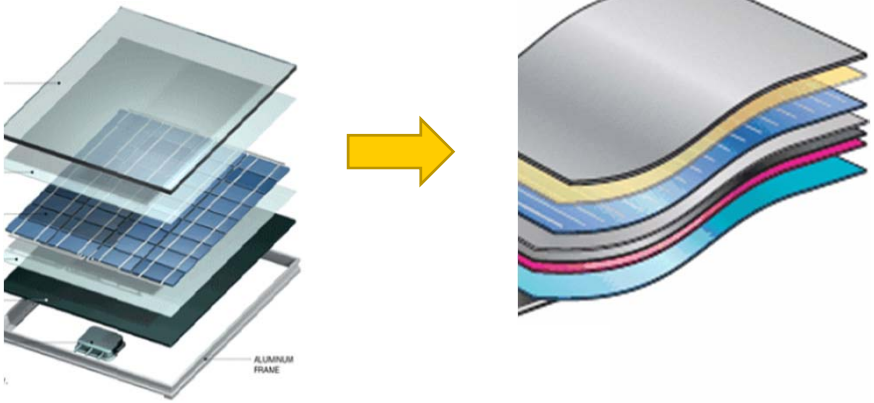


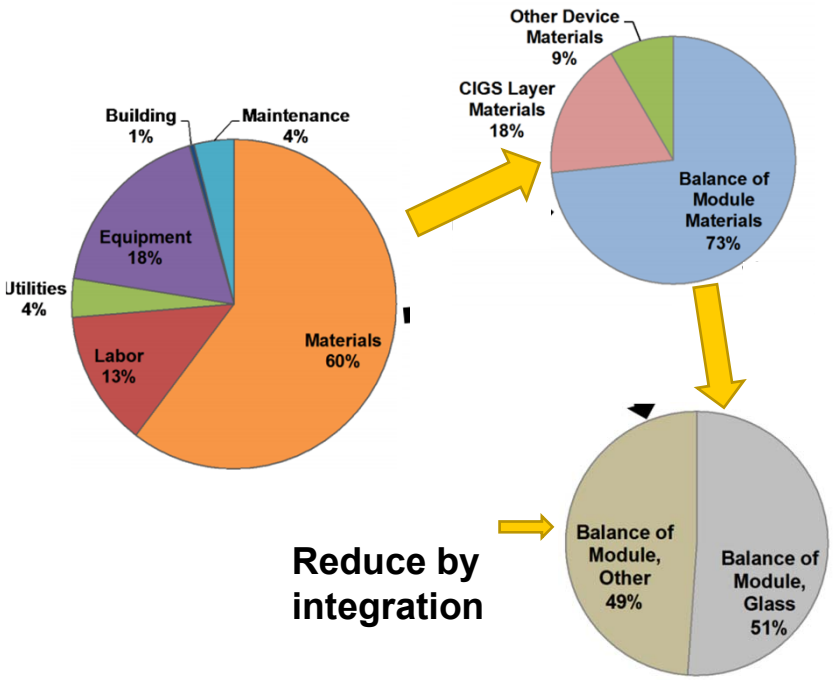
- **Main challenges**
  - Cost (materials, processes and efficiency)
  - Process control / layer homogeneity
  - Closing efficiency gap: cell - module
  - Reliability

	Technology	Substrate	Capacity MWp/yr (+expansion)	Nationality	Remarks
Solar Frontier	Sputtering	Glass	>1GW (+150MW)	Japan	>90% of global CIGS production; expanded 2015
Solibro	Coevaporation	Glass	>50 MW	Germany	Owned by Hanergy
MiaSolé	Sputtering	Polymer foil	>40 MW	United States	Owned by Hanergy
Global Solar	Coevaporation	Steel foil	>40 MW	United States	Owned by Hanergy
Avancis	Sputtering	Glass	>100 MW (+1 GW)	Germany	Owned by CNBM
Solopower	Electrochemical	Steel foil	>10 MW	United States	
Manz/Wurth	Coevaporation	Glass	>10 MW	Germany	Specials production; turn key offer for factory
Ascent Solar	Coevaporation	Polyimide foil	>10 MW	United States	
Flisom	Coevaporation	Polyimide foil	>1 MW	Switzerland	Demo line; Link with Tata
Midsummer	Sputtering	Steel	>1 MW	Sweden	Demo line; equipment builder
Arcelor Mittal	Sputtering	Steel	< 1MW	France/Belgium	Demo line
Crystalsol	Monograins	Foil	< 1MW	Austria	Start up
SIVA	Coevaporation	Steel foil	<10MW	United States	Start up
Sunplugged	Sputtering	Steel foil	< 1MW	Austria	Start up
Sunshine PV	Sputtering	Glass	>10 MW	Taiwan	
Hulk Energy	Sputtering	Glass and flex	>50 MW (+200MW)	Taiwan	200 MW Expansion announced June 2015
AdPV	Sputtering	Glass	< 1MW (+100MW)	China	100 MW announced 2016
Nanoco	Printing	Glass	< 1MW	Great Britain	Start up

Integration of CIGS film

Thin Film enables new module concepts





Reduce by integration

Source: http://www.nrel.gov/docs/fy16osti/64507.pdf

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Customizing and integration of thin film PV

- **PV customizing technologies**
  1. Technology to make modules flexible → R2R
  2. Technology to make modules in any size/shape
  3. Technology to make modules with any color
  4. Technology to make modules transparent

- **PV integration**
  - Public infrastructure integration (**IIPV**)
  - Building integration (**BIPV**)
  - Vehicle integration (**VIPV**)

Seamless PV integration

Het gebruik van flexibele CIGS-halffabricaten in BIPV
Peter Toonssen, Solliance
Jack Smit, Flexipol

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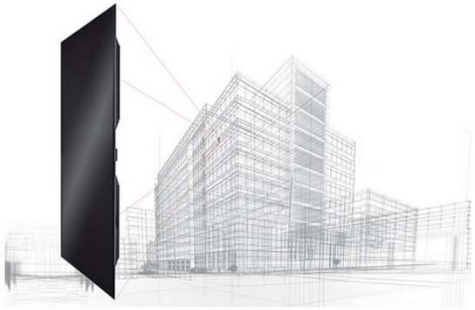
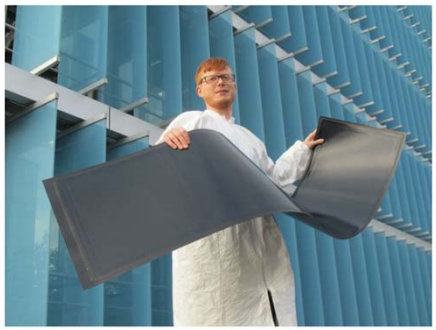
Application development

POWERMAX® **SKALA**
THE AVANCIS ARCHITECTS PANELS



ques semi-transparents WYSIPS® Design-Glass de Sunpartner ©Sunpartner

The Flisom modules are super thin (under 2mm), have a uniform, jet black appearance and by nature are ultra-light (in some versions under 500g/m2). The company said it was gearing up for full-commercialisation of its product range this year.



Floating solar cover for water reservoirs

BENECKE-KALIKO

MiaSolé
A Hanergy Company

Post date: 27/06/2016 - 14:38

The Germany based polymeric specialist Benecke-Kaliko AG produced a special UV light and tear resistant foil which can be laminated with flexible thin film photovoltaic panels in a roll-to-roll mode to install small PV power plants ranging from 500 kW up to 5.0 MW. The company is discussing first

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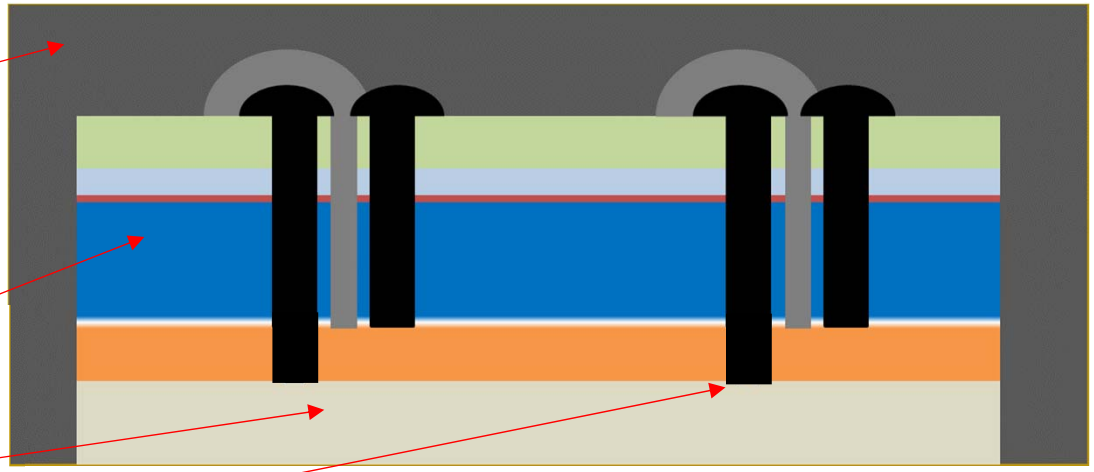
Developments at Solliance: CIGS device 2.0

- **Low cost packaging:**
- **Thin absorber (<500 nm)**
- **Metal foil substrate (isolating barier)**
- **Back end interconnect**



Boundary condition:
On demand lifetime to realize a bankable product

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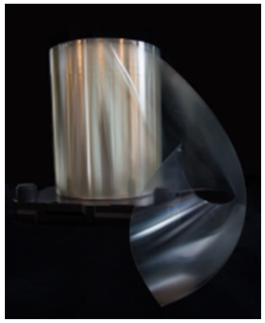
Developments at Solliance: CIGS device 2.0

- **Flexible water barrier**
  - Unique tool developed by Solliance and its partners
  - R2R produced barrier stack
  - WVTR tune-able between 10^{-3} and < 10^{-6} g/m^2.day



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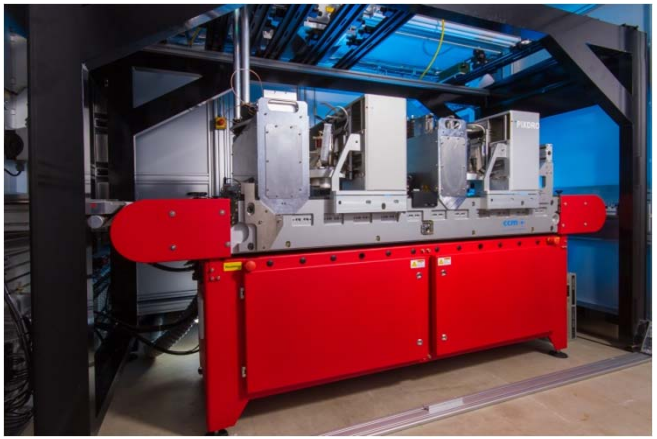
Developments at Solliance: CIGS device 2.0

- ***Back end interconnection process for dimensional and electrical freedom in Thin Film PV concepts***
  - fully digital which enables free-form modules
  - reduced dead zone without cost increase
  - no alignment and cleaning steps needed
  - specifically CIGS: reduces P1 shunt losses
- **Connects mass volume front end manufacturing with high mix back end products**
- **Increase design and (or) dimensional flexibility**



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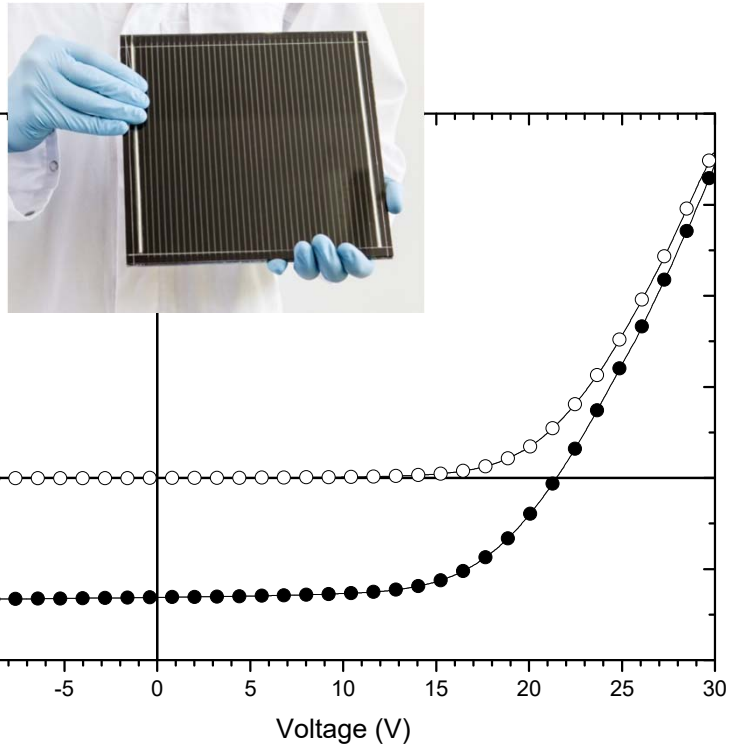
CIGS mini module ECD with back end interconnect

- **Large scale modules**
  - Sample size: 220 x 220 mm
  - Module size: 200 x 185 mm
  - Cell size: 200 x 5 mm
  - Number of cells: 37
- **Characteristics**
  - Laser scribing: shunt-free
  - Conductive path: TCO
  - Interconnection width: ~ 1mm (80% GFF)
- **Best working module (170612G)**
  - J_{sc} = 26.2 mA/cm^2
  - V_{oc} = 21.5 V
  - FF = 61 %
  - **Efficiency = 9.3 %** (average reference cells 11.9%)



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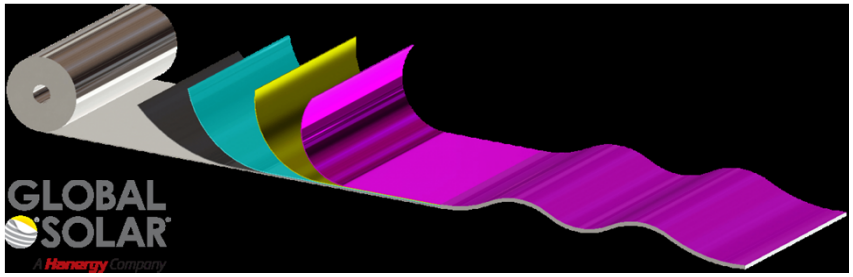
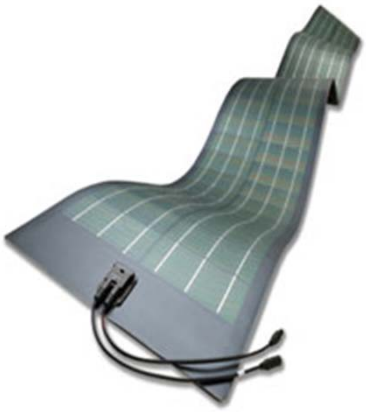
Developments at Solliance: CIGS device 2.0

Decrease manufacturing costs by:

Monolithic CIGS stack on low cost flexible (metallic) substrates

- Insulating barrier necessary
- Na and K dosing (PDT)





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CIGS process development

Electrodeposition and reactive thermal annealing in elemental Se:

- Lower Capex and high Cu/In/Ga material utilization through electrodeposition
- Processes suitable for full Roll2Roll processing

IV parameter (10x10 cm^2)	$Cu(In,Ga)(Se,S)_2$
Efficiency (avg)	13.3%
Max eff (0.5 cm^2)	15.6% (A.A.)
Open circuit voltage (avg)	617 mV
Short circuit current Jsc (avg)	33.7 mA/cm^2
Fill Factor(avg)	64 %

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Market acceptance of CIGS based products

Bankability of CIGS products:

- **Reduction of the risks associated with investments in CIGS based solar energy**
- **Realize an on demand lifetime**

Roll of Solliance:

- **Understand loss mechanism: three main routes**
  - Loss mechanism at a cell level
  - Loss mechanism in packaged devices
  - Post mortem analyses
- **Quality management process to realize new products and semi fabricates**

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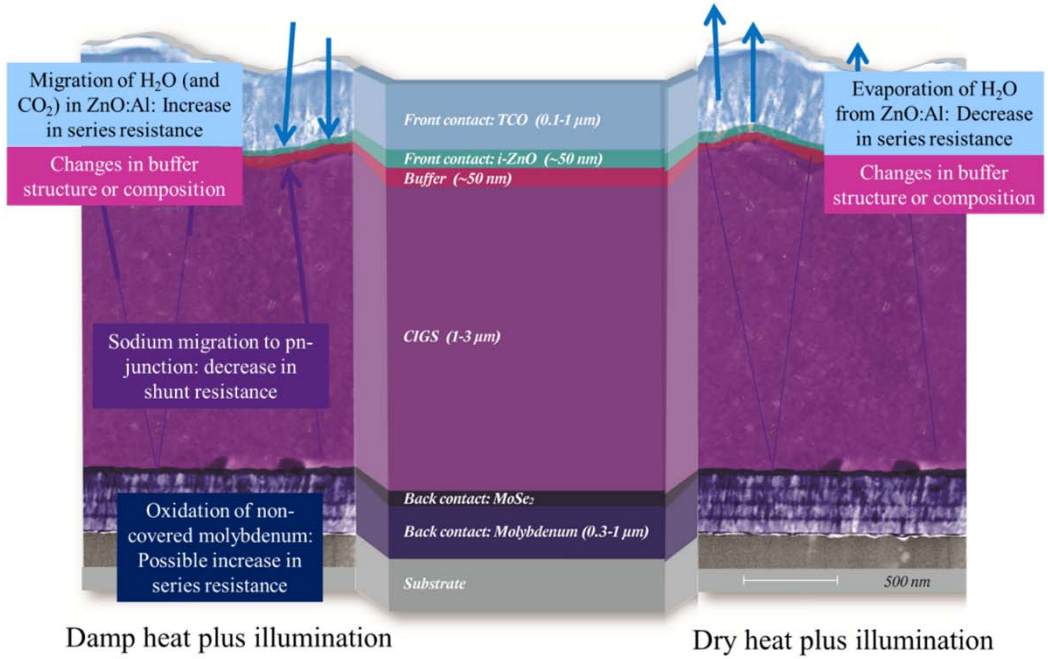
Low cost modules with high lifetime

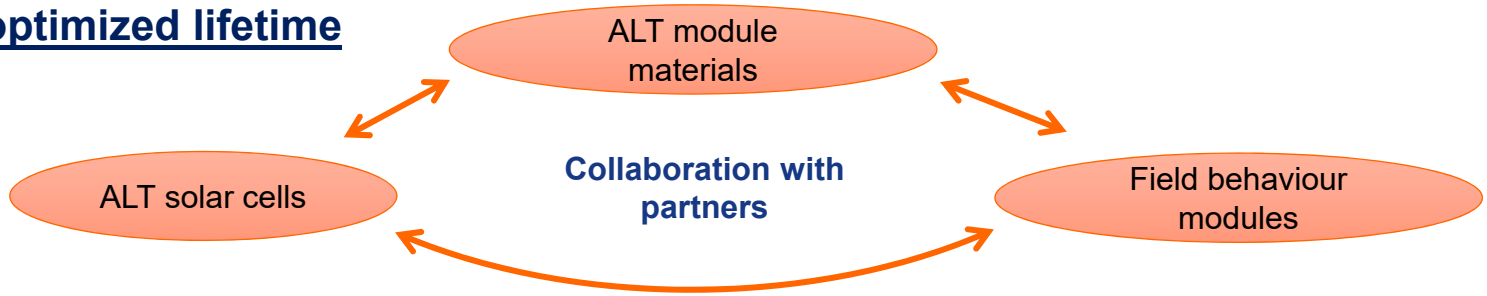
- **Identify the failure mechanisms**
- **Identify the degradation conditions**
- **Make modules more intrinsically stable**



M. Theelen, K. Beyeler, H. Steijvers, N. Barreau, Stability of CIGS Solar Cells under Illumination with Damp Heat and Dry Heat: A Comparison, Solar Energy Materials and Solar Cells 166 (2017) 262-268

CIGS reliability at Solliance

- **(Flexible) PV for product or building integration with <u>application dependent optimized lifetime</u>**



- **Unique equipment for lifetime studies**

In-house prototype test for cells Solliance (2011)

Commercial product for modules - Eternal Sun, Hielkema, ReRa (2017)

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CIGS: revival of an existing technology?

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