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Energy research Centre of the Netherlands

Environmental assessment of future photovoltaics

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Environmental impact of future PV?

- What are the future technologies shares?
  - driver 1: economics: €/kWh
  - driver 2: environmental impacts/kWh
  - driver 3: social aspects
- What are the future parameters/technology?
  - LCA data of today often outdated and incomplete
  - scaling: lab ➔ pilot ➔ industrial

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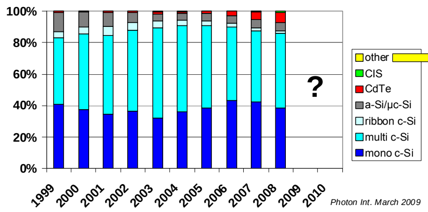
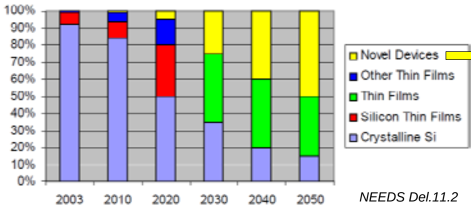
Technology shares





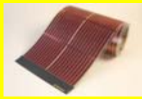
Concentrator Photovoltaics

Concentrix Solar
27.2% module efficiency

Dye Sensitized Photovoltaics

Fraunhofer ISE
5% module efficiency

Organic Photovoltaics



Konarka
1.7% module efficiency

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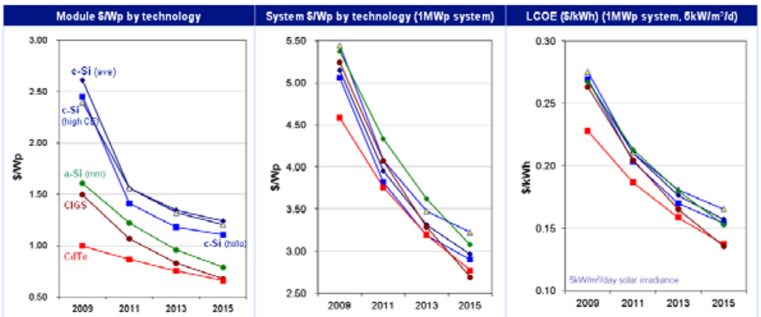
Driver 1: cost



- CdTe is a disruptive technology and will maintain a large module $/Wp advantage over c-Si at the module level. CIGS has the potential to challenge over the long term.
- c-Si's apparently large learning curve is more a result of substantial polysilicon cost reduction.

- Fully installed system price ($/Wp) for fixed tilt systems.
- There is substantial sensitivity to numerous variables (e.g. BOS costs (ex. inverter), margin structures, business models). The greatest variance error in any analyses resides here.

- At the LCoE CdTe has a distinct advantage over c-Si; CIGS has the potential to challenge over the long term.
- Margin structures are critical to assess the true competitiveness of technologies (and companies)

Source: Deutsche Bank estimates

Stephen O'Rourke (212) 250-8670

Deutsche Bank

24 April 2009

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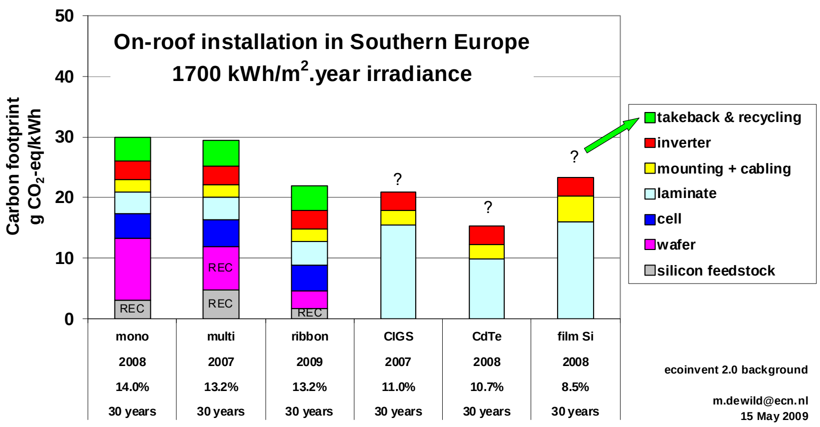
Driver 2: Environmental impacts



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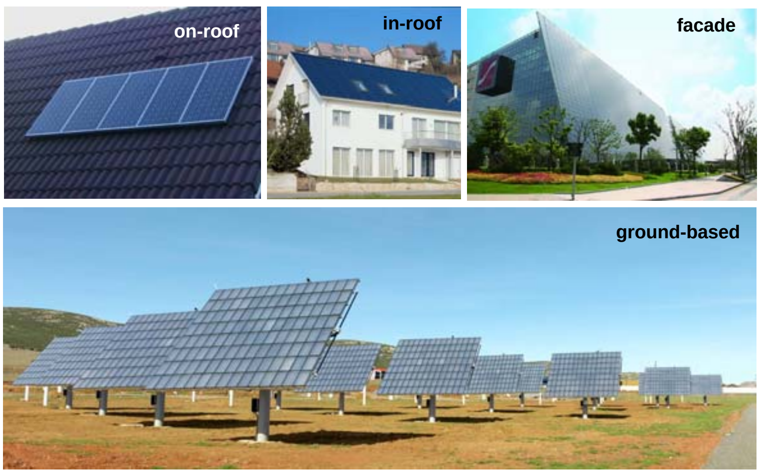
Driver 3: Social acceptance - aesthetics



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Key parameters for LCA & LCC

NEEDS RS 1a – WP11 Technology specification: photovoltaic systems

		Year 2025				Year 2050		
	Technology	sc-Si	ribbon-Si	CdTe	UHE (conc./III-V cells)	Crystalline-Si	CdTe	UHE (conc./III-V cells)
VERY OPTIMISTIC	Layer thickness (µm)	100	150			100		
	% Avg. module efficiency	22	20	10	35	25	22	50
	Module lifetime (yrs)	35		30	30	50	40	45
	Avg. system efficiency	90				95		
	Material and energy flows source	Crystalclear 2005		Data from Industry	Fthenakis et al 2006, Mohr et al. 2006	Crystalclear 2005	Data from Industry	Fthenakis et al 2006, Mohr et al. 2006
	Estimation	Process materials and energy: -20% of current data		Process materials and energy: -20% of current data	Process materials and energy: -25% of current data	Process materials and energy: -20% of current data	Process materials and energy: -30% of current data	Process materials and energy: -35% of current data
REALISTIC OPTIMISTIC	Layer thickness (µm)	100	150	-	-	100	-	-
	% Avg. module efficiency	22	20	10	35	22	22	40
	Module lifetime (yrs)	35	30	30	30	40	35	35
	Avg. system efficiency (%)	90				95		
	Material and energy flows source	Crystalclear 2005		Data from Industry	Fthenakis et al 2006, Mohr et al. 2006	Crystalclear 2005	Data from Industry	Fthenakis et al 2006, Mohr et al. 2006
	Estimation	Process materials and energy: -20% of current data		Process materials and energy: -20% of current data	Process materials and energy: -25% of current data	Process materials and energy: -20% of current data	Process materials and energy: -30% of current data	Process materials and energy: -35% of current data
PESSIMISTIC	Layer thickness (µm)	150	200			150		
	% Avg. module efficiency	17	14	12	NA	18	16	35
	Module lifetime (yrs)	30		25	NA	35	30	30
	Avg. system efficiency (%)	90				95		
	Material and energy flows source	Crystalclear 2005		Data from Industry	NA	Crystalclear 2005	Data from Industry	Fthenakis et al 2006, Mohr et al. 2006
	Estimation	Process materials and energy: -20% of current data		Process materials and energy: -20% of current data	Process materials and energy: -25% of current data	Process materials and energy: -20% of current data	Process materials and energy: -30% of current data	Process materials and energy: -35% of current data

Table 18 Key parameters and data sources

- energy/material flows
  - layer thickness
- ➔ impacts

- module efficiency
- system efficiency
- lifetime
- ➔ kWh produced

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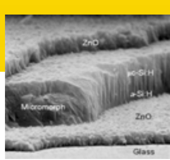


Scaling of production

	lab	pilot	industrial
optimization	efficiencies		cost
product	components		final product
product size			
production			automation & integration
equipment	batch	inline	inline
throughput			
yield			
consumption			
emission control	limited	central	central + dedicated
waste	no recycling	no recycling	recycling: heat, water, HF, etc..

From solar cell to total area module efficiency

ECN module A288	area	efficiency
160 µm cell (average)		17.2%
encapsulated cell: glass | EVA | cell | EVA | back foil		16.9%
module (aperture area)	0.8867 m^2	16.7% (16.4% TüV)
module (total area)	0.9425 m^2	15.7%

world record

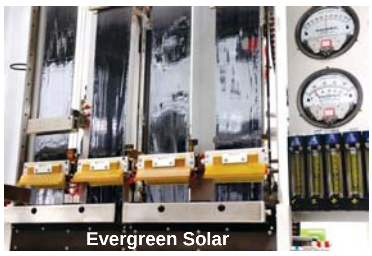
- Highly automated module manufacturing for rear-contacting cells
- Suitable for very thin solar cells
- 1 module per minute (~8 times faster than H-pattern)

Fast reduction in wafer/ribbon thickness

... because not enough solar grade Si factories

- 180 µm wafer thickness 2009
  Comparison with NEEDS study:
  150 µm pessimistic 2025,
  100 µm realistic/optimistic & very optimistic 2025.

- 190 µm ribbon Si thickness 2009 (Evergreen Solar),
  Comparison with NEEDS study:
  200 µm pessimistic 2025,
  150 µm realistic/optimistic & very optimistic 2025.



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Conclusions

- Analyzing the future starts with good knowledge of today
- Estimations of environmental impacts of future PV technologies must be based on analysis of:
  - €/kWh
  - social acceptance (example visual impacts)
  - environmental impacts of today