Life Cycle Assessment of Present and Future Photovoltaic Systems

M. Raugei[1], P. Frankl[2], E. Alsema[3], M. de Wild-Scholten[4], V. Fthenakis[5], H.C. Kim[5]

[1] Ambiente Italia, Italy
[2] IEA, France
[3] Utrecht University, The Netherlands
[4] ECN, The Netherlands
[5] BNL and Columbia University, NY, USA

AIST Symposium "Expectations and Advanced Technologies in Renewable Energy"

Chiba, Japan, 11 October 2007

LCA

Methodology: environmental life cycle assessment

Load	Impact
Resource use (use of minerals, fossil fuel)	Resource depletion
Emission to air	Global warming
Emission to water	Ozone layer depletion
Emission to soil	Toxicity
	Acidification
	Eutrophication

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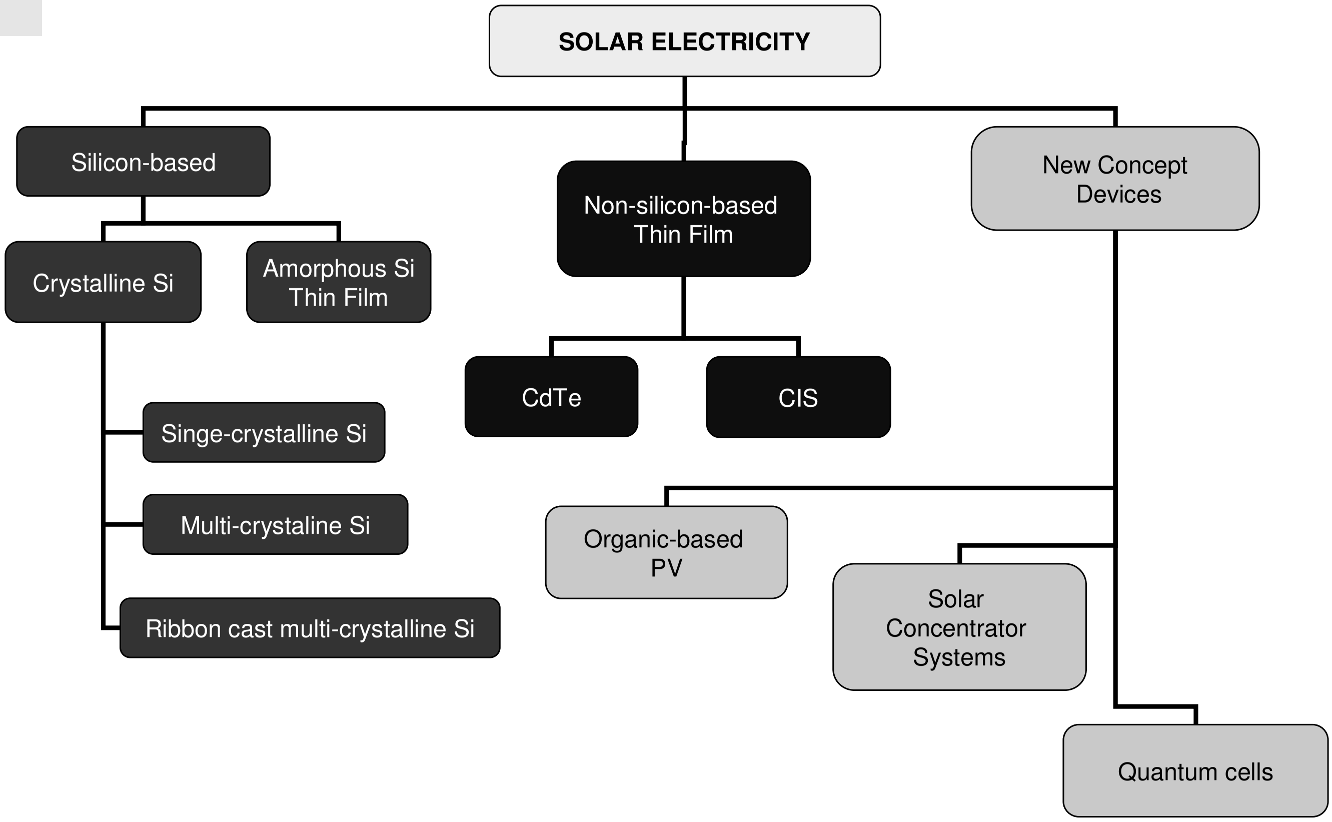
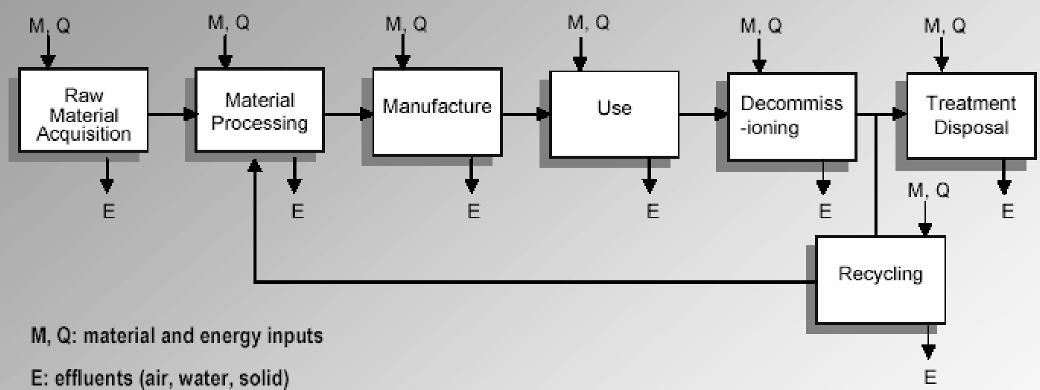
PV Technologies

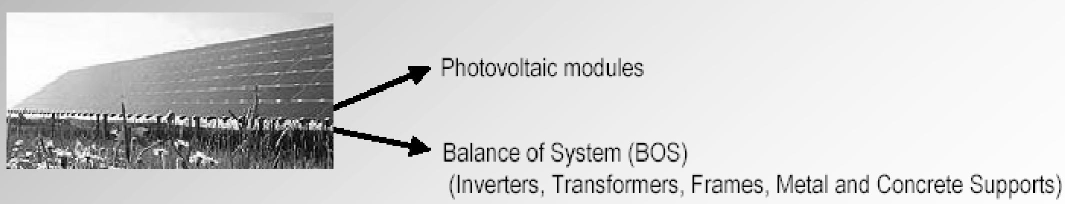


The Life Cycle of PV



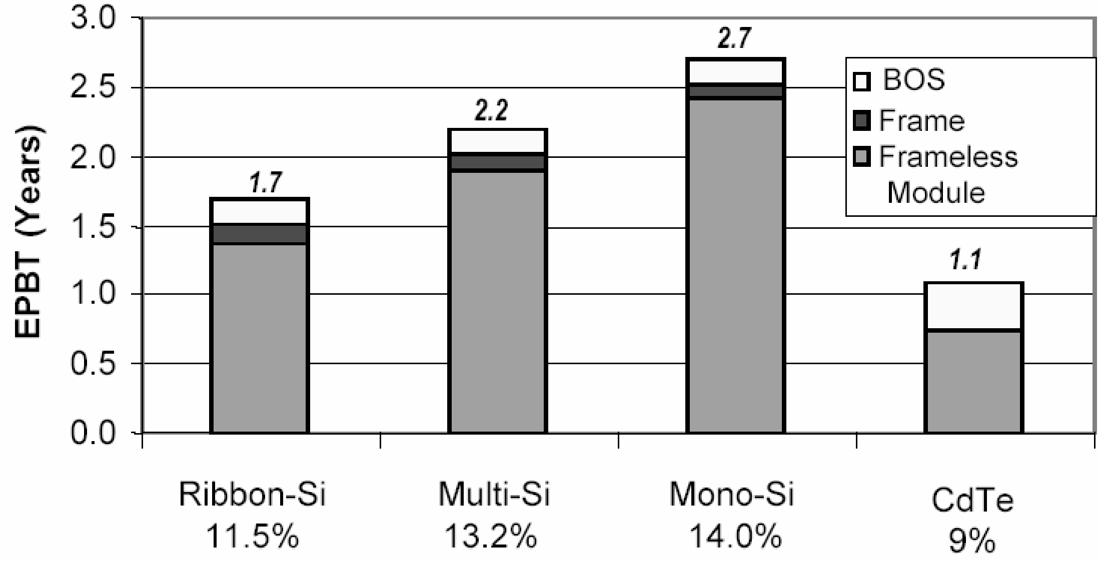
M, Q: material and energy inputs

E: effluents (air, water, solid)



Energy Pay-Back Time

Insolation: 1700 kwh/m2-yr



-**Alsema & de Wild,** *Material Research Society, Symposium vol. 895, 73, 2006*
-**deWild & Alsema,** *Material Research Society, Symposium vol. 895, 59, 2006*
-**Fthenakis & Kim,** *Material Research Society, Symposium vol. 895, 83, 2006*
-**Fthenakis & Alsema,** *Progress in Photovoltaics, 14, 275, 2006*

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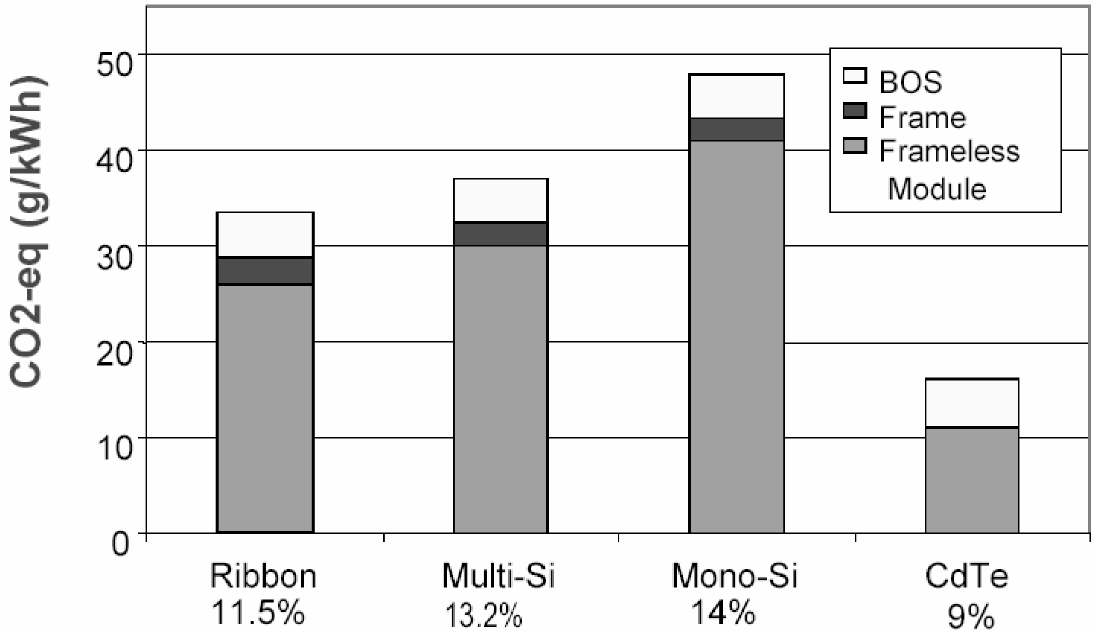
Global Warming Potential

Insolation: 1700 kwh/m2-yr



Alsema & de Wild, *Material Research Society, Symposium vol. 895, 73, 2006*
deWild & Alsema, *Material Research Society, Symposium vol. 895, 59, 2006*
Fthenakis & Kim, *Material Research Society, Symposium vol. 895, 83, 2006*
Fthenakis & Alsema, *Progress in Photovoltaics, Accelerated Publication, 14, 275, 2006*

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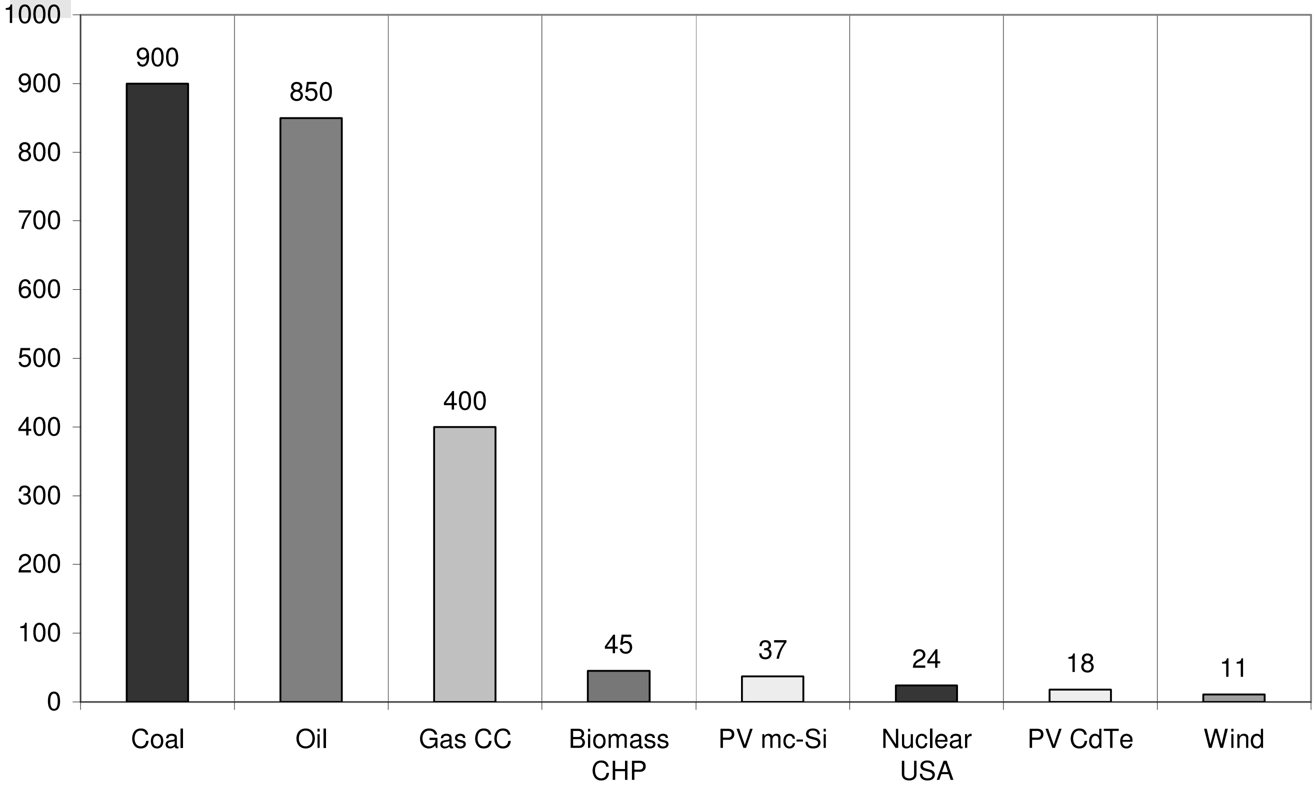
GWP Benchmark (present)



Sources: ExternE project, 2003; Kim and Dale, 2005; Fthenakis and Kim, 2006; Fthenakis and Alsema, 2006; Fthenakis and Kim, in press.

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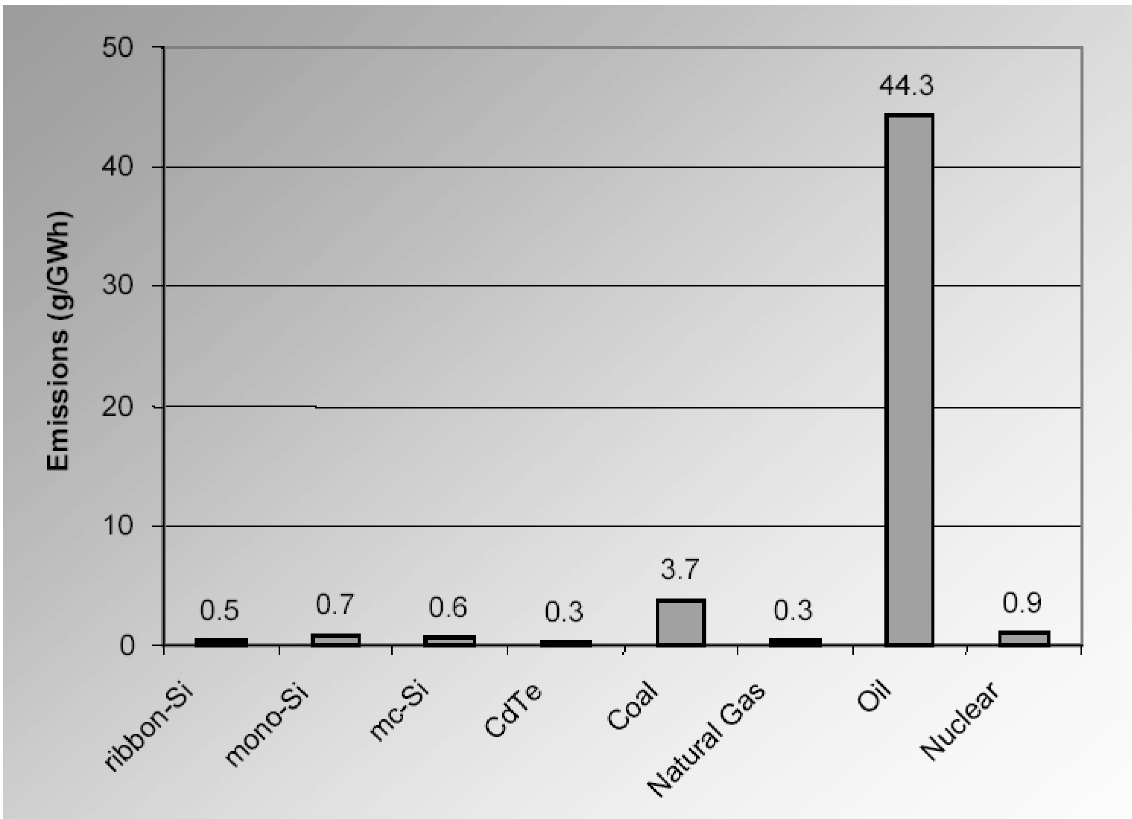
Life-Cycle Cd emissions



Source: Fthenakis, 2006

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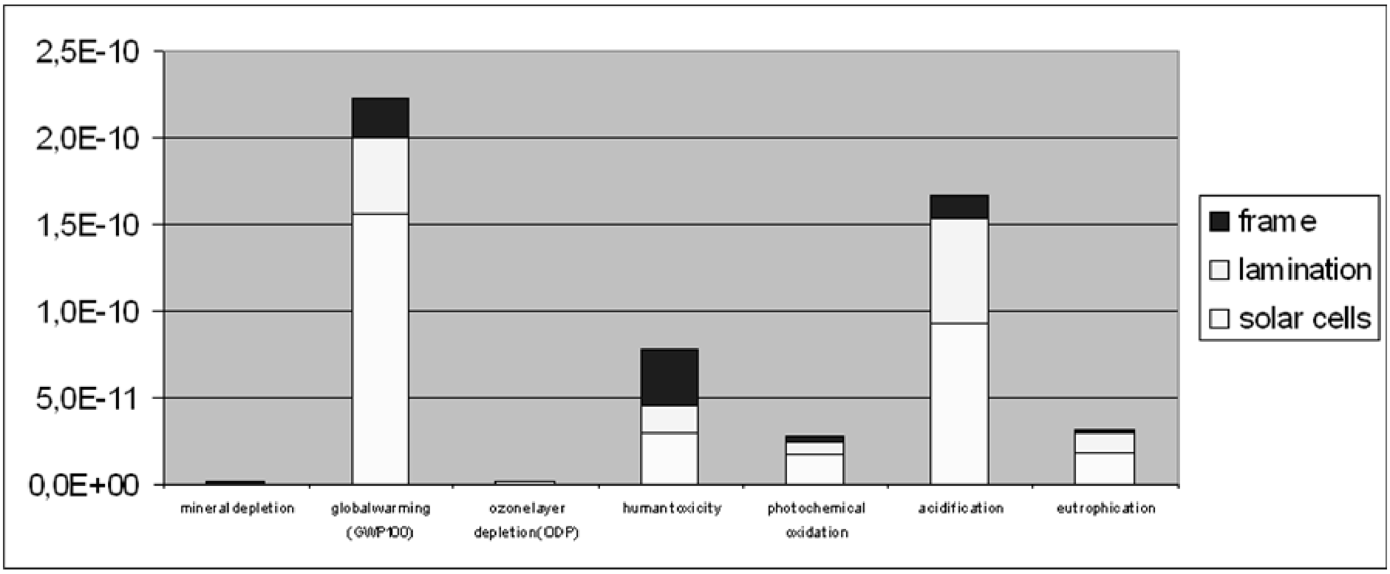
Normalized impact scores (CML 2) mc-Si



Most significant impacts:

- **global warming**
- **acidification**
- **human toxicity**

} **mostly caused by energy consumption**

Source: CRYSTALCLEAR project

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CONCLUSIONS (I):
Strong points of PV technology

- Large installation potential
- GHG emissions reasonably low
- Zero or near-zero emissions of toxic substances (direct emissions)
- Potential for further improvement in GHG/EPBT

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CONCLUSIONS (I):
Issues which need attention

- Reduce energy consumption (and GHG emission) in solar cell production
- Reduce dependency on scarce metals (In, Te, Ag)
- Close the material cycles (recycling)
- Zero-emission production facilities

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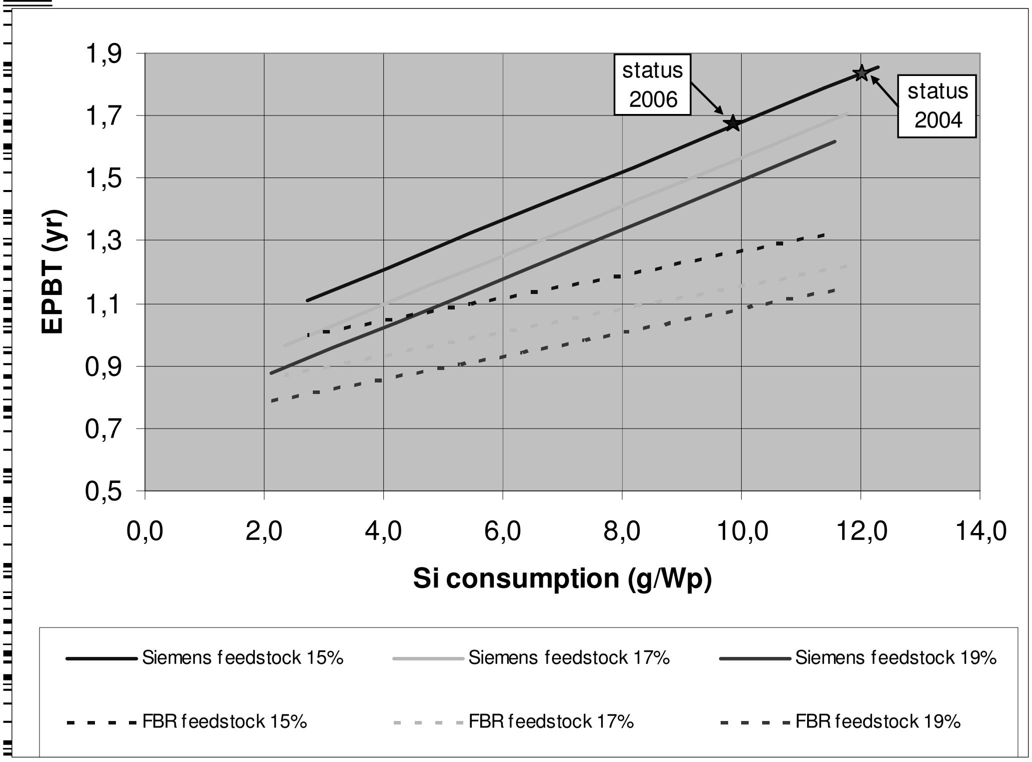
FUTURE OUTLOOK – CRYSTALCLEAR Project[1] (c-Si PV)



Standard techn. 2006:
- Siemens SoG feedstock
- Si cons. <10 g/Wp
- cell eff. 15%

Improvements:
- reduce Si consumption

- cell eff -> 17%
- cell eff -> 19%

--- **switch to FBR feedstock**

[1]http://www.ipcrystalclear.info

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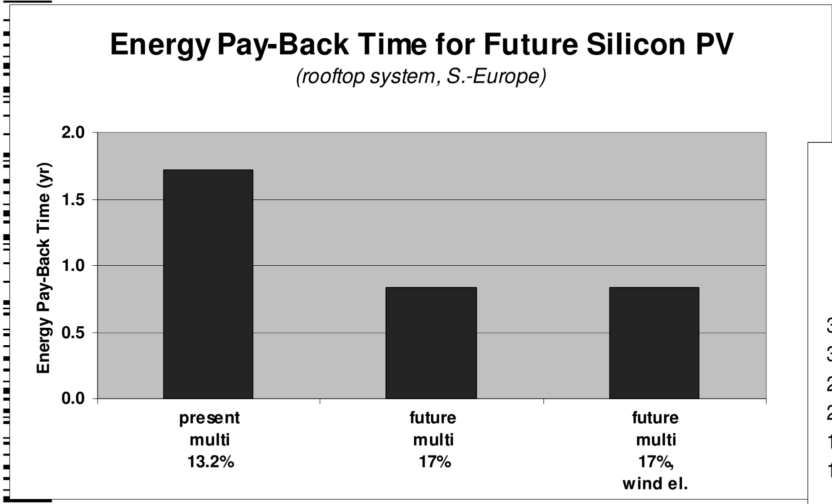
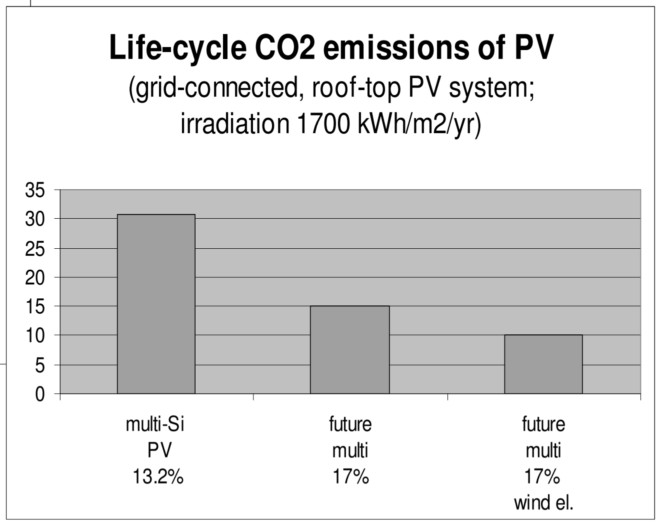
c-Si PV Outlook





- Energy Pay Back Time can be halved, to < 1 year;
- $CO_{2\text{-eq}}$ emission can be reduced to 15 g/kWh, with use of "green" electricity to 10 g/kWh.

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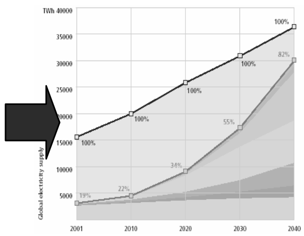
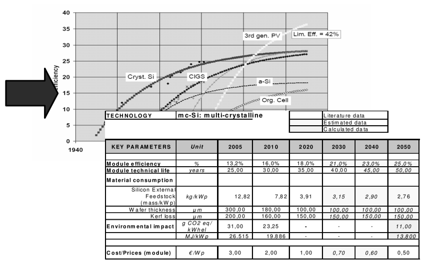
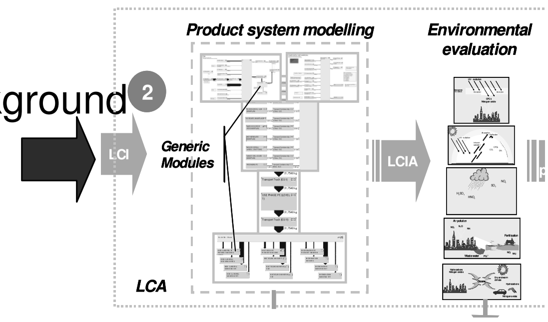
FUTURE OUTLOOK - NEEDS Project[2]

1. Technology diffusion scenario analysis
   - *3 different scenarios*
2. Technology development path
   - Factors affecting technological development
   - Technology shift
3. Parametric LCA for each scenario
   - With and without change of background system
4. Estimate of External Costs







[2]http://www.needs-project.org

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Three Development Scenarios

- **‘Pessimistic’**
  - Current incentives not supported long enough for PV technology to ever become competitive. Growth of world PV market severely stunted by 2025.
- **‘Optimistic / Realistic’**
  - c-Si, thin films and new concept devices likely to co-exist. Initial growth according to industry (EPIA) predictions; after 2025 reduced growth rates (GP/EREC).
- **‘Very optimistic / Technological Breakthrough’**
  - Bold (quadratic) annual growth rates as early as 2010. By mid 2030’s large scale energy storage infrastructure available; very rapid expansion of new concept devices after 2025.

[2]http://www.needs-project.org

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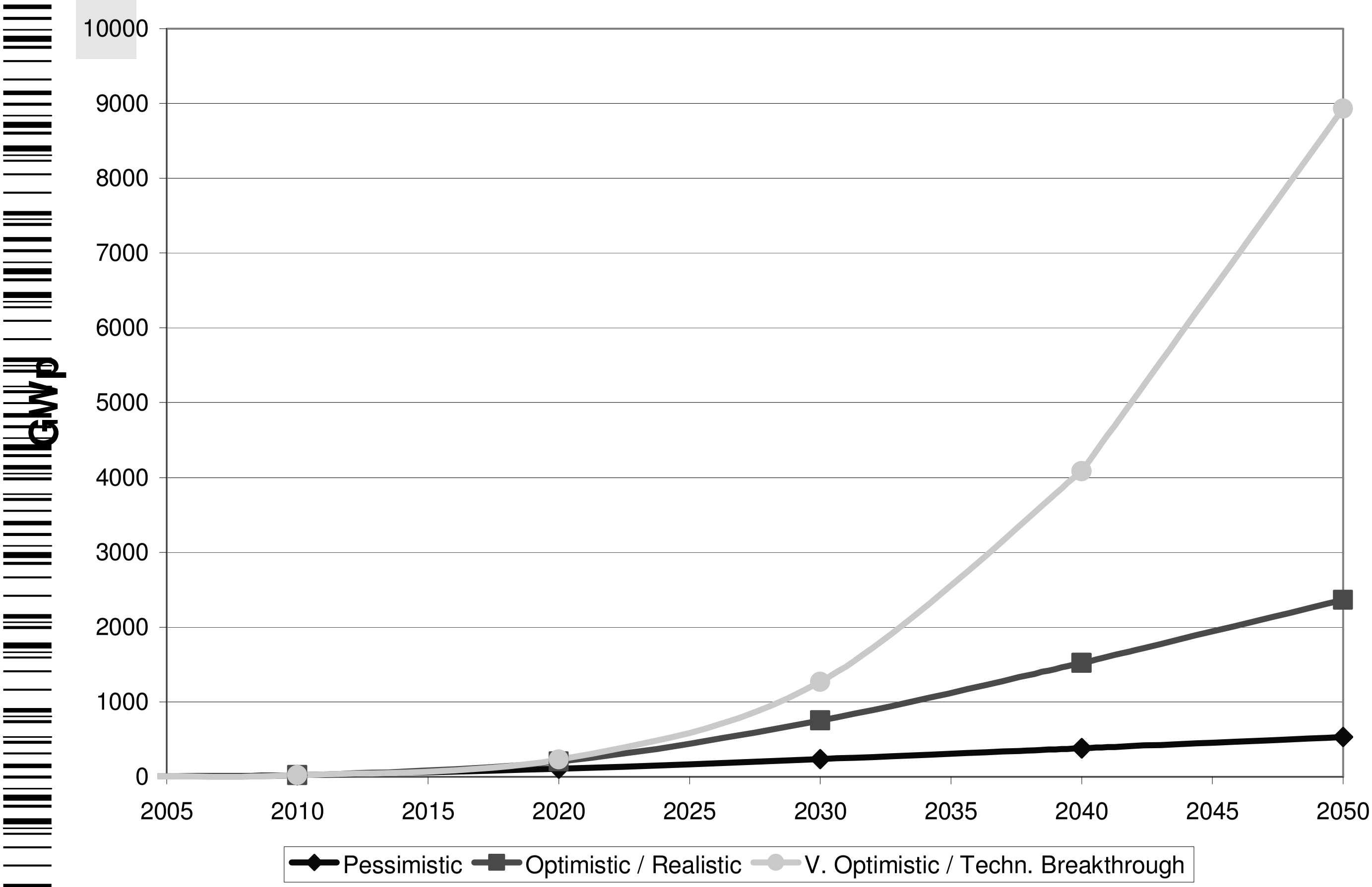
Cumulative Installed Capacity (World)



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Technology Specification (3 scenarios)

V.Optimistic		2025										2050									
Cum. Capacity	GWp	570										8,900									
Technology		crystalline-Si				thin films			novel devices			crystalline-Si				thin films			novel devices		
		sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell	sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell
c-Si layer thickness	um	100	100	150	100	N/A			N/A			100	100	100	50	N/A			N/A		
Module efficiency		22%	20%	20%	12%	15%	20%	18%	10%	35%	35%	28%	25%	25%	16%	20%	25%	22%	17%	50%	50%
Module lifetime	years	35				30			10	30	30	50				40			15	45	45
Installed capacity	GWp	290				260			20			1300				3100			4500		
Market share	%	50%				45%			5%			15%				35%			50%		

Opt. / Realistic		2025										2050									
Cum. Capacity	GWp	430										2,400									
Technology		crystalline-Si				thin films			novel devices			crystalline-Si				thin films			novel devices		
		sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell	sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell
c-Si layer thickness	um	100	100	150	100	N/A			N/A			100	100	100	50	N/A			N/A		
Module efficiency		22%	20%	20%	12%	15%	20%	18%	10%	35%	35%	25%	22%	22%	14%	18%	25%	22%	15%	40%	40%
Module lifetime	years	35				30			10	30	30	40				35			10	35	35
Installed capacity	GWp	220				190			20			720				840			840		
Market share	%	50%				45%			5%			35%				35%			30%		

Pessimistic		2025										2050									
Cum. Capacity	GWp	170										530									
Technology		crystalline-Si				thin films			novel devices			crystalline-Si				thin films			novel devices		
		sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell	sc-Si	mc-Si	ribbon (thick)	ribbon (thin)	a-Si	CIS	CdTe	DSC	Conc	Q-cell
c-Si layer thickness	um	150	150	200	150	N/A			N/A			100	100	150	100	N/A			N/A		
Module efficiency		17%	14%	14%	12%	10%	14%	12%	N/A			22%	18%	18%	12%	15%	18%	16%	10%	35%	35%
Module lifetime	years	30				25			N/A			35				30			10	30	30
Installed capacity	GWp	140				30			0			270				240			0		
Market share	%	85%				15%			0%			50%				45%			5%		

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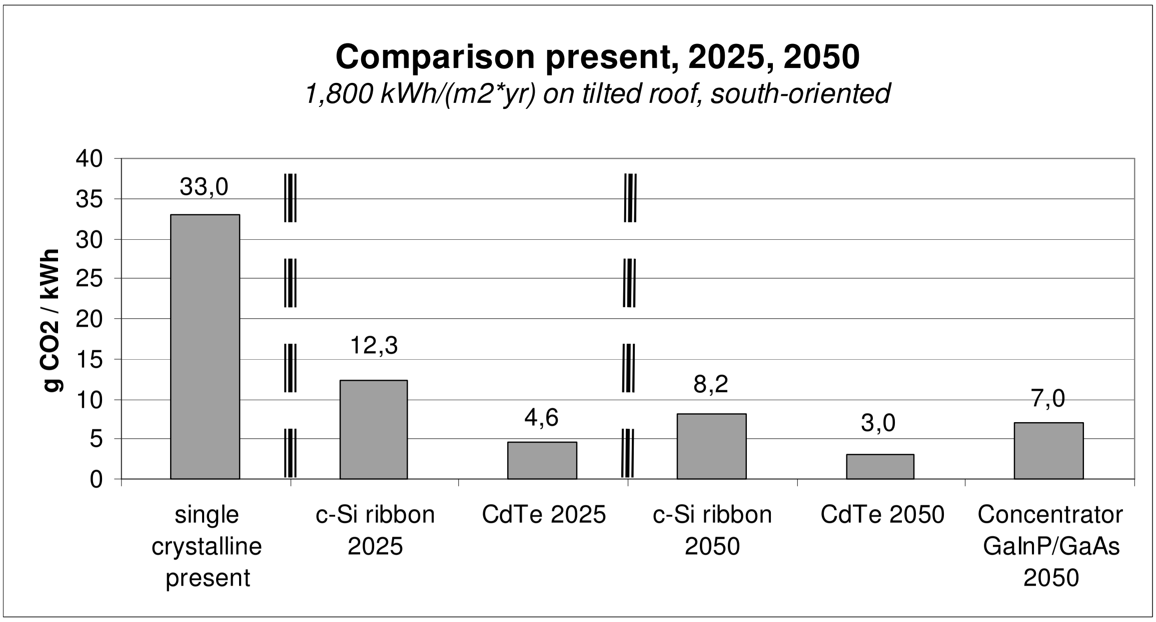
Preliminary Results

- LCI results (‘Optimistic / Realistic’ scenario) with adjusted background data



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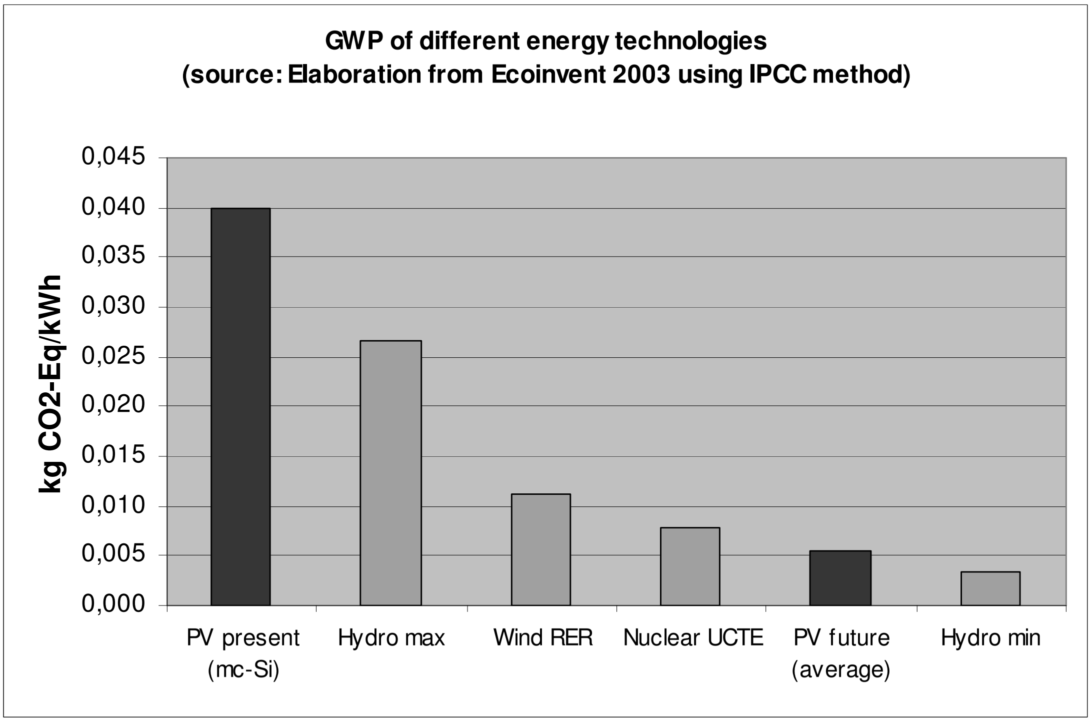
Benchmark – Future PV Systems



For comparison (present):

Coal= **750** - **900** g CO_2/kWh; Gas CC = **400** g CO_2/kWh

UCTE mix = **454** g CO_2/kWh

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CONCLUSIONS (II)
SUSTAINABILITY OF PV

- Low PV life cycle emissions already today
- Expected to further decrease by an order of magnitude by 2050
  - 2 orders of magnitude lower than fossils
  - Lower than nuclear

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