Solar as an environmental product: Thin-film modules – production processes and their environmental assessment

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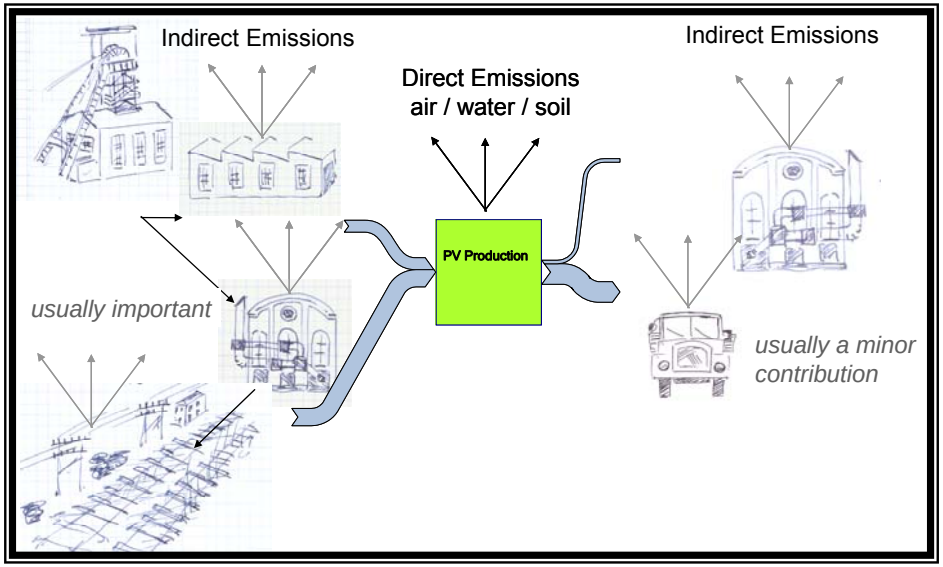
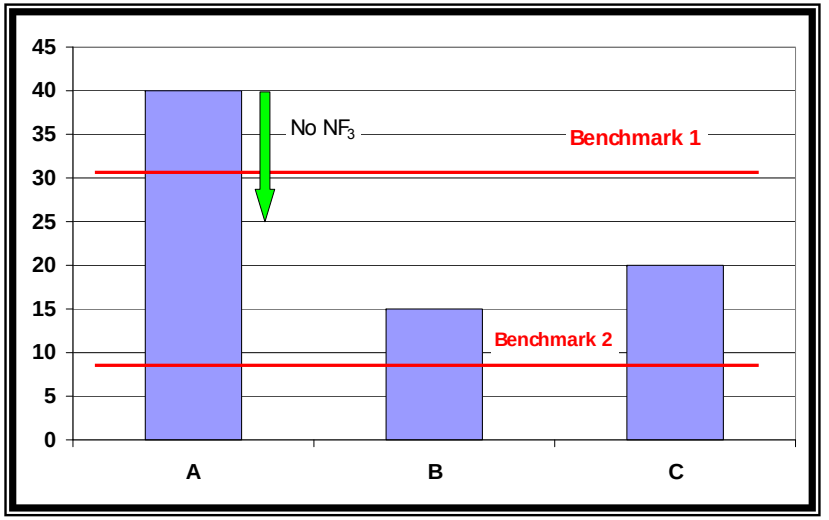
Outline

1) Life-cycle thinking
   1) Establish emissions from the production site.
   2) Include emissions from supply and disposal („Indirect Emissions“).
   3) Establish use of resources from nature
2) What are the life-cycle impacts and largest contributions?
   1) Energy payback time
   2) Greenhouse gas emissions
   3) Toxic impacts
   4) Others?
3) How to reduce life-cycle impacts?
   1) Near term objectives as a result of analysis from #2
   2) Long term objectives to reach an ecological optimum



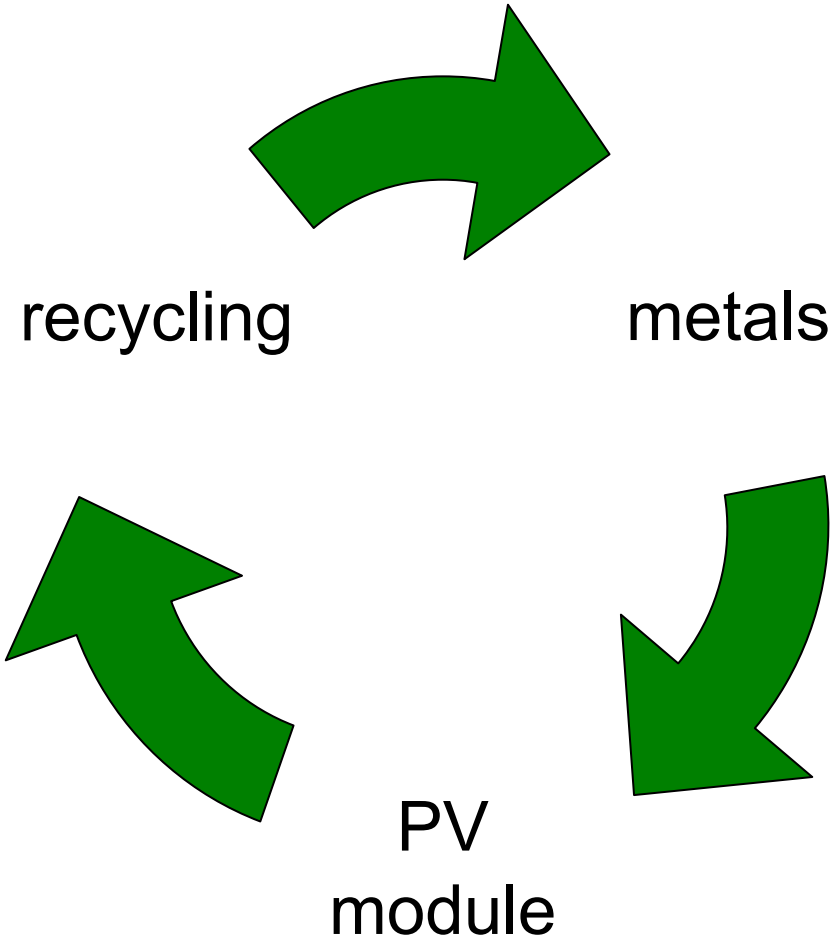


Photovoltaics as an environmental product

How sustainable is thin film photovoltaics?

We have to consider:

1) Impacts from “cradle-to-grave” per kWh produced
2) Moving target conditions due to rapid development
    1) Identify largest contributions only
    2) Identify objectives for improvement
3) Zero impact technology does not exist ➔ compare with other energy producing technologies as benchmarks, including crystalline Si PV modules.



Risk is not considered in environmental valuation

- Risk of production and usage is not valuated by environmental impact assessment / life cycle assessment.
- If regular emissions are created because „production risk“ leads to frequent spillage, soil contamination, etc. these impacts can be included provided the statistics are stable enough to calculate a steady-state effect.
- Rare events leading to toxic hazards are not included.
- These risk issues are covered by the permitting procedures of the respective authorities. These permitting procedures make sure that the risk is reduced to a level which is generally accepted by society in every day‘s life.
- Since this risk is at this level not different from a variety of social and technical activities then, it needs no extra valuation with respect to environment.

RISK ► Regulation, not valuation

Comparing CO_2 emissions to toxic emissions is.....

You are using toxic compounds!

Yes, but I'm more energy efficient!

Terrestrial ecotoxicity

Land use

Aquatic ecotoxicity

Ozone layer depletion

Chronic toxicity (carcinogens)

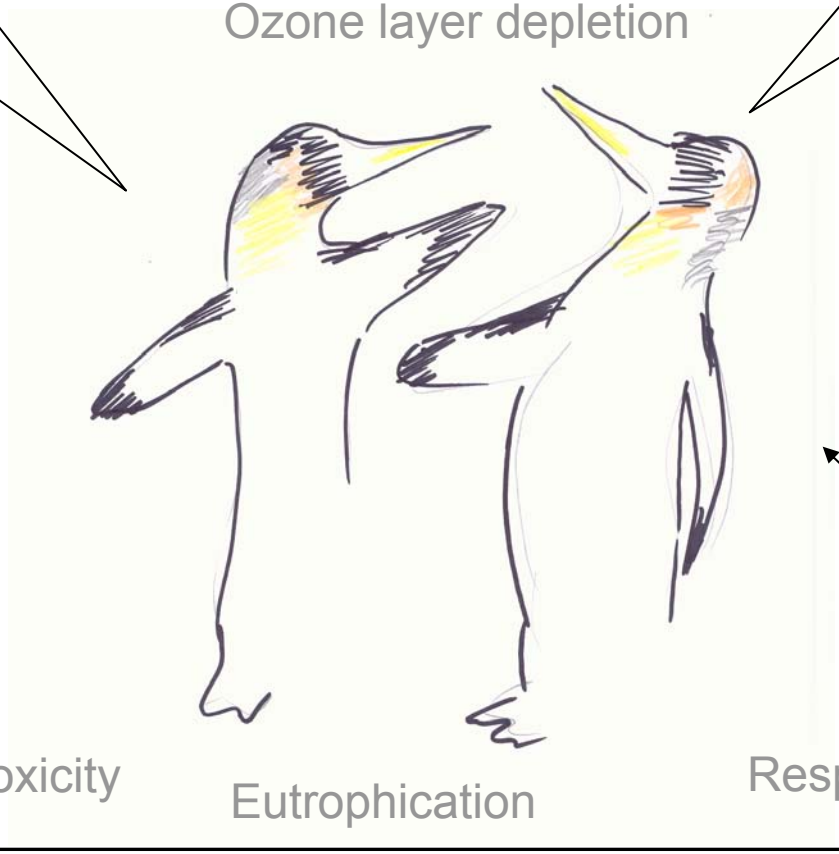
Resource depletion

Respiratory organics

Ionizing Radiation

Acidification

Global warming



less toxic

less CO_2

Acute Toxicity

Eutrophication

Respiratory Inorganics

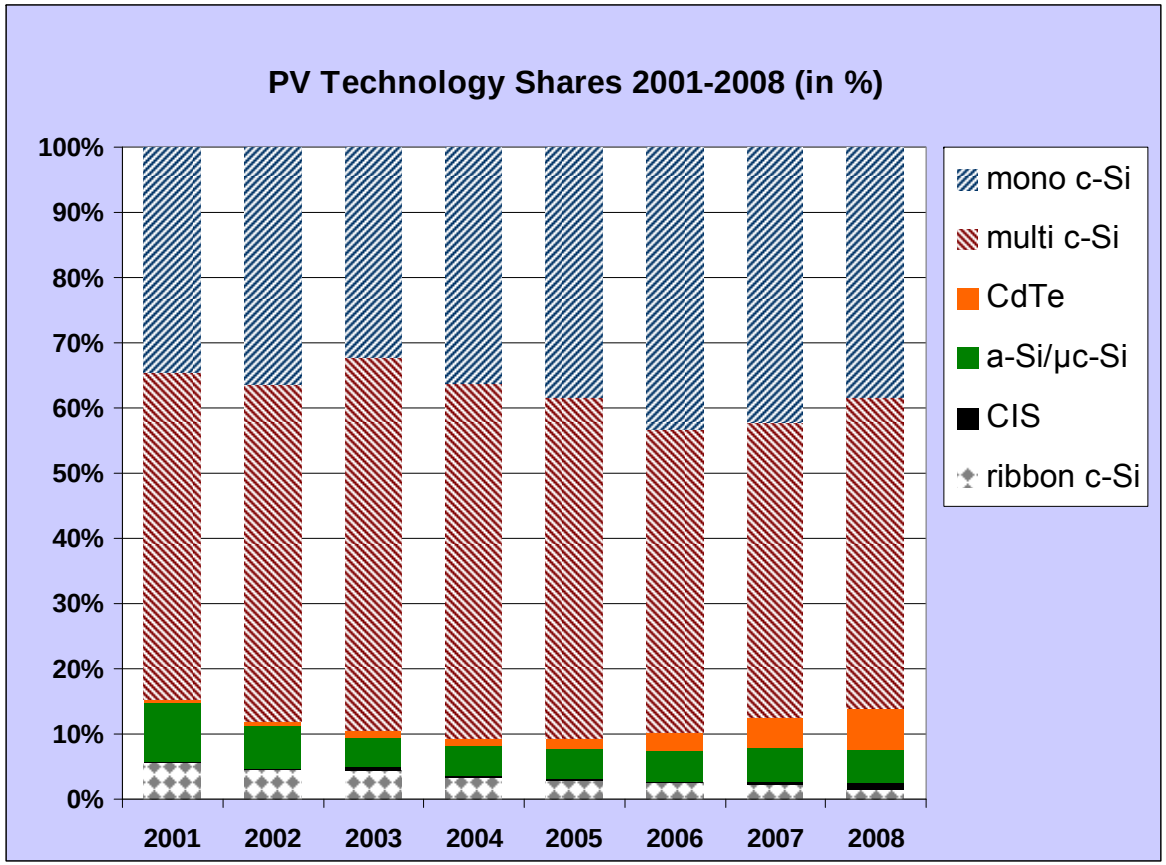
... comparing apples and pears?

- Environmental Assessment creates multiple „midpoint“ categories.
- Impact is most easily valuated within the same category.
- If important different categories are found, a valuation has to be undertaken.
- This procedure is pretty much the same in everyday‘s life when dealing with multiparameter decisions.

picture by courtesy of Prof. Maier
www.mpi-stuttgart.mpg.de/maier

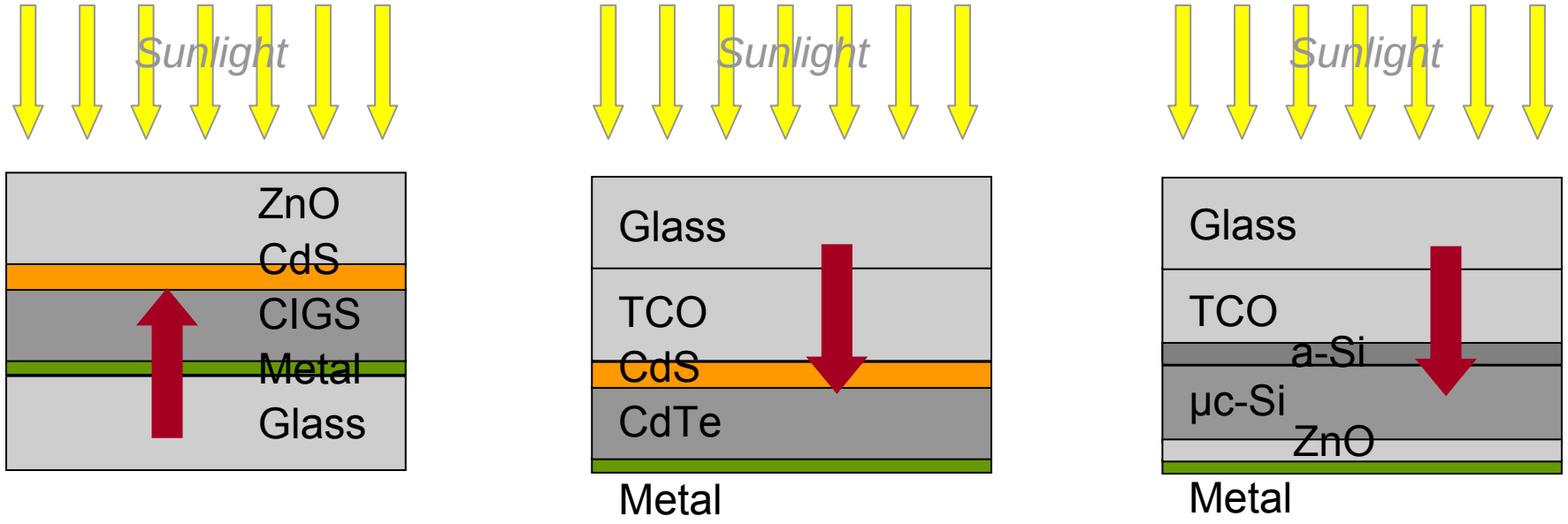
Thin film PV technologies and their market share

- Cadmium Telluride - (CdTe)
- Copper Indium (Gallium) Sulfide (Selenide) - (CIS/CIGS)
- Thin film Si (a-Si/µc-Si)



Thin film PV technologies

- Each type of product is built up (red arrow) using glass as a substrate (other materials exist, but are uncommon).
- The same layer may be formed using different production technologies (sputter, vaporisation, chemical reaction, vacuum process, wet process, etc.)
- With increasing production capacity, usually a scale effect leading to savings can be expected. This usually leads also to a better ecological valuation.



Early recognition of impact factors

- Comparatively low experience in steady-state high-volume production. Data for production models are incomplete, today.
- High diversity of production even for the same type of photovoltaic module. High speed of development in all sectors of thin film PV
- Today's results can serve as „early recognition" service to take strategic decisions.

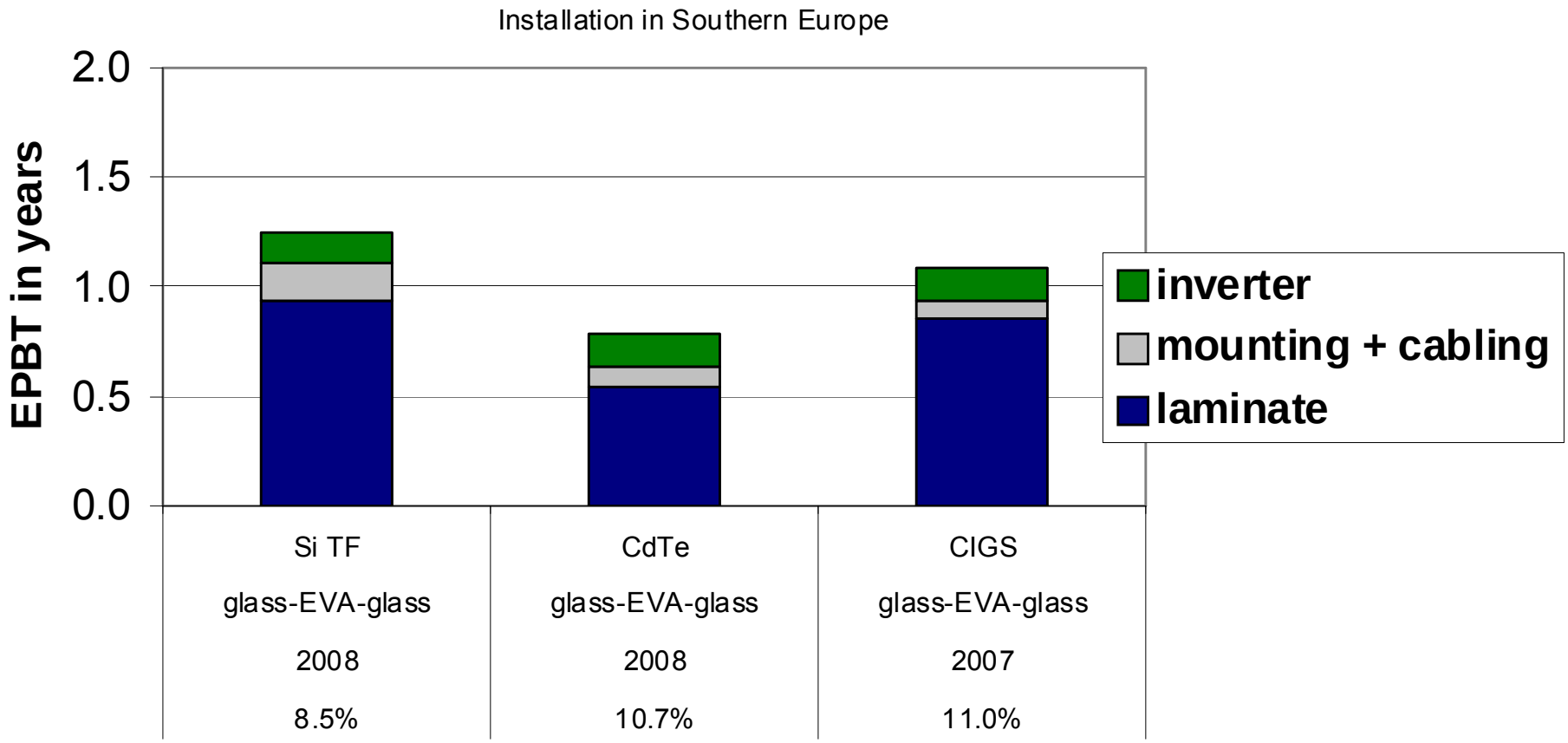
- Bad factors may soon decrease if efforts for improvement are addressed.

Technology choices & data quality

- **UCTE (European) electricity mix**
- **No framing, slanted roof-top installations**
- **Si TF**
  - is best best best case
  - manual chamber cleaning
  - 2 x 3.2 = 6.4 mm glass ; 5% glass loss
  - 600 micron EVA encapsulation + 1 cm cutting loss
  - mounting: fiX
- **CdTe**
  - ecoinvent 2.0 data US + modified energy/glass consumption/Cd emission
  - mounting: Schletter roof-top, same as xSi
- **CIS**
  - ecoinvent 2.0 data + modified energy consumption/Se emission
  - glass technology
  - mounting: Schletter roof-top, same as xSi

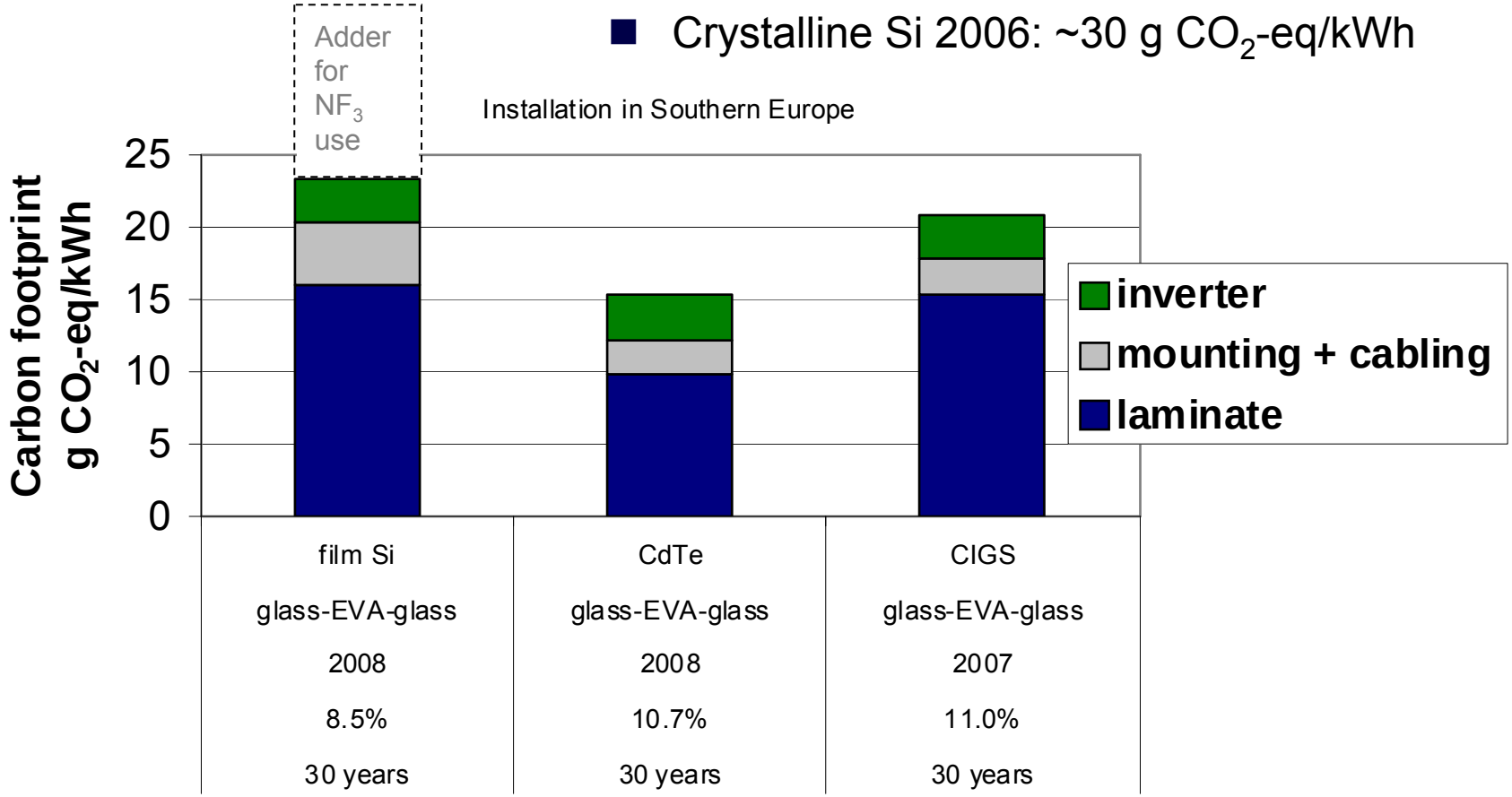
Energy payback time

- Higher weight/m^2 & lower module efficiency increases mounting + cabling



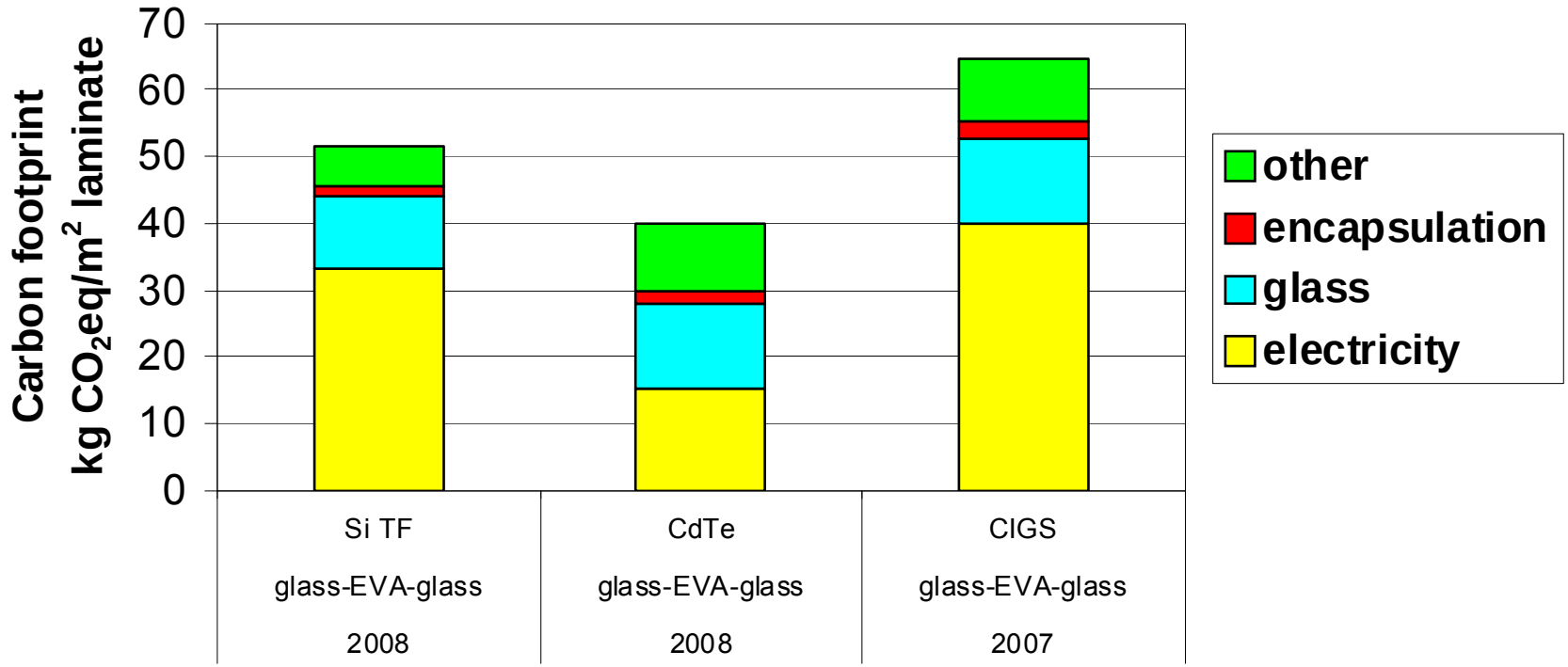
Carbon footprint of thin film PV roof-top system

- Coal ~1070 g CO_2-eq/kWh
- Nuclear ~8 g CO_2-eq/kWh
- Wind ~12 g CO_2-eq/kWh
- Crystalline Si 2006: ~30 g CO_2-eq/kWh



Carbon footprint of laminate

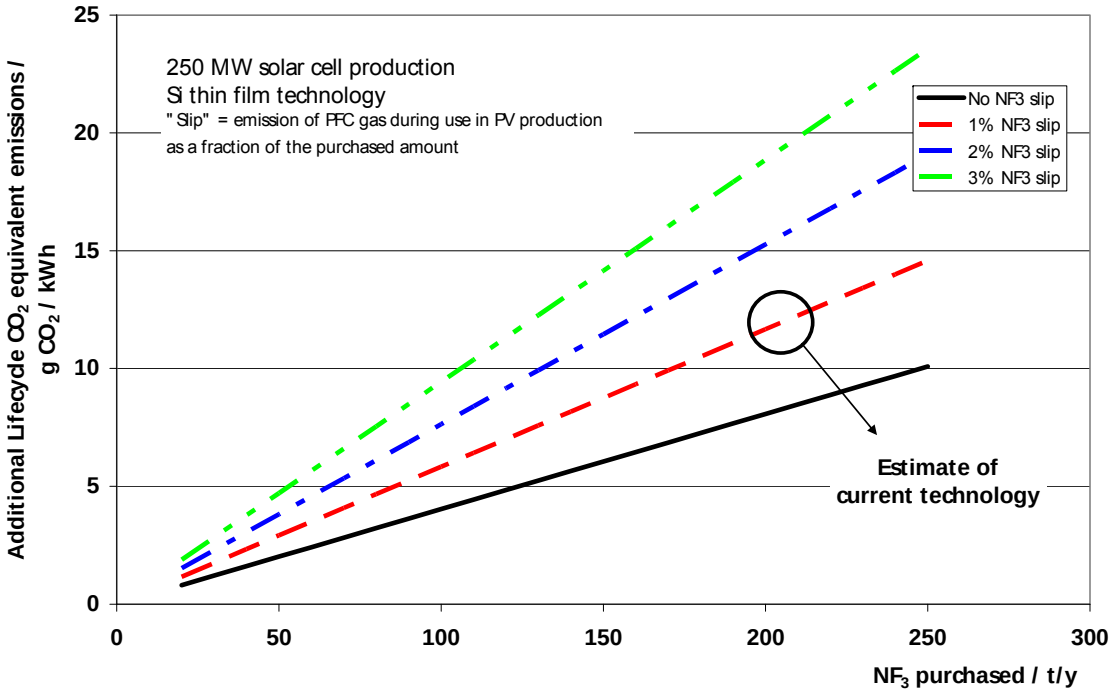
- Major impact from energy consumption and glass



Si thin film PECVD chamber cleaning with SF_6 & NF_3

Global Warming Potential (100 years) and life time:

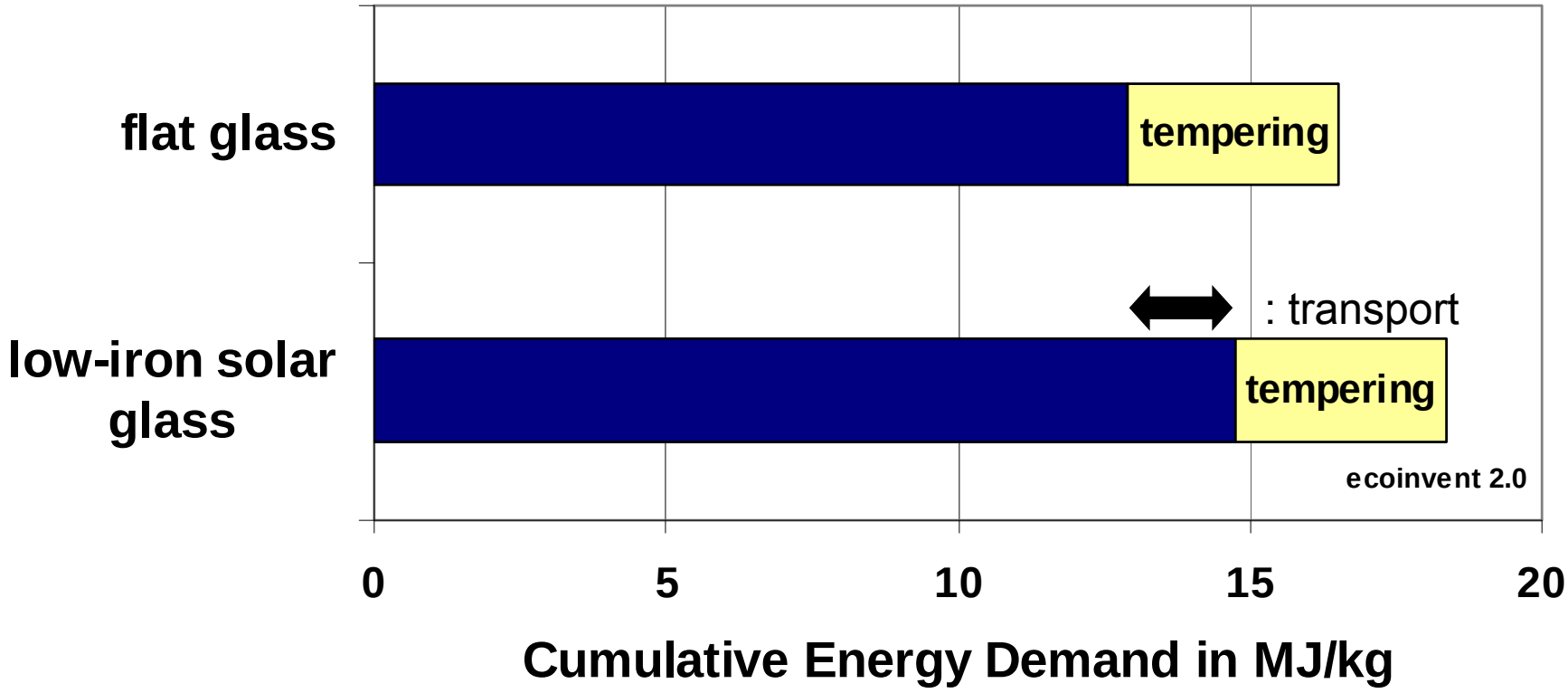
- 1 kg SF_6 = 22,800 kg CO_2-equivalent & 3200 years
- 1 kg NF_3 = 17,200 kg CO_2-equivalent & 740 years



Source: *Photovoltaics International 2nd Ed. Q42008., Schottler et al., p. 64-69.*

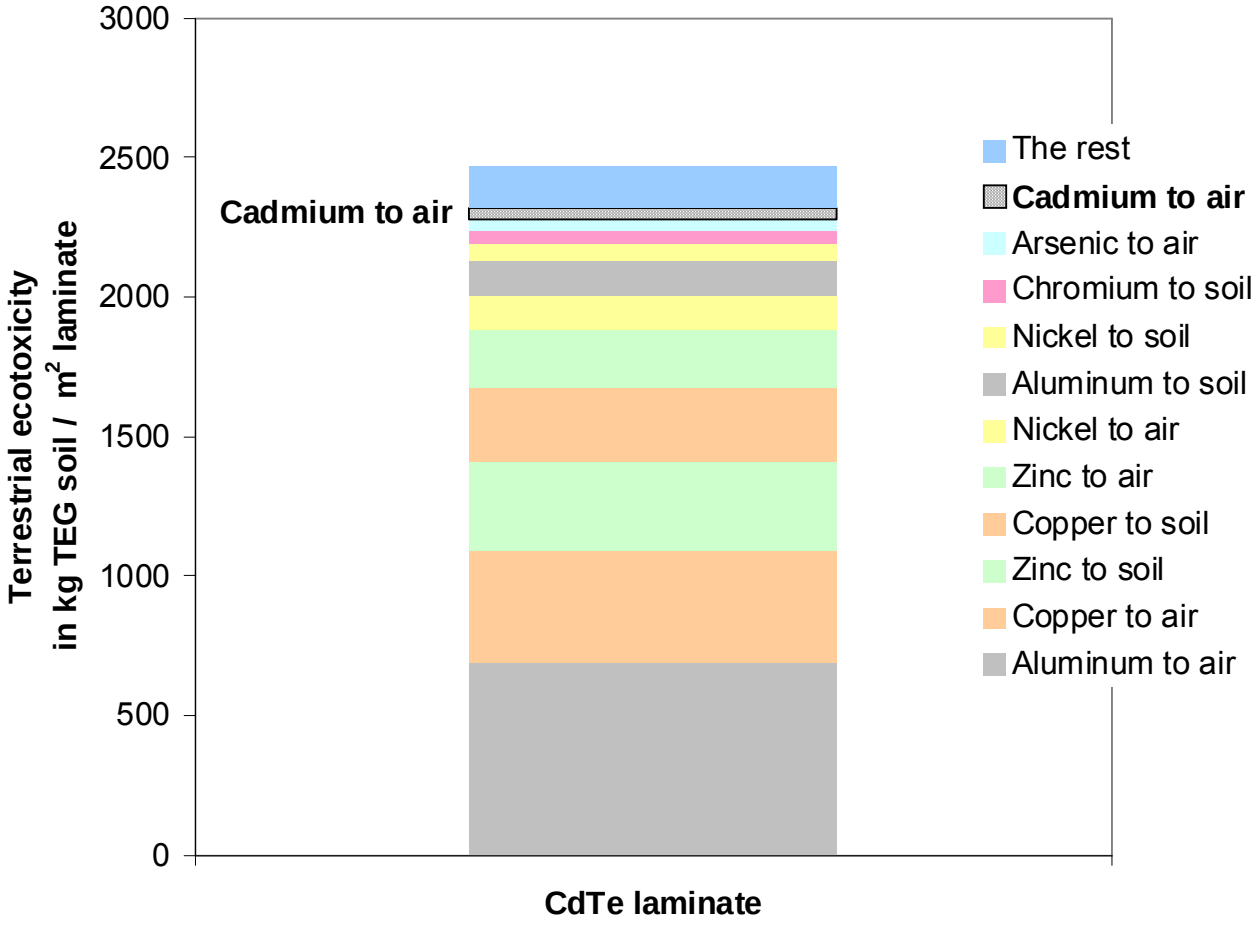
Glass

- **Type:** flat glass (soda lime glass) or low-iron solar glass ; tempering?
- **Thickness:** 2 x 3.2 mm --- 2 x 4.0 mm
- **Yield:** <95% ; breakage and off-spec



Cadmium emissions – worst case estimation

- Direct cadmium emissions are 13% of total life-cycle cadmium emissions
- Life-cycle cadmium emissions have minor impact to total terrestrial ecotoxicity



Conclusions

- Yes, thin film PV is sustainable.
- The environmental impact of all the technologies is highly affected by the **electrical energy** used in production, and by the **glass** which is a part of the product.
- **Si TF** has a potential to outperform crystalline Si PV modules. However, all influence factors have to be turned to the “best of all possible” solutions, then. This is especially true for NF_3 or SF_6, which both cannot be used for the best scenario. Improving input data certainty with future experience from mass production could help to confirm these findings, and to spot further opportunities for improvement, too.
- **CdTe** is today the ecologically leading technology, and the impact calculation is the most certain one of those presented. The toxic impact to environment by the usage of Cadmium is not a concern in case emission limits are met.
- **CIS and CIGS** present the broadest variety of production technologies among the investigated. Thus, depending on the installed processes for production, better results are possible. For improvement, especially the reduction of electrical energy consumption is necessary. Again, toxic impacts are not a concern.

How to reduce the environmental impacts

- Reduce energy consumption, use renewable energy in production
- Reduce material consumption (less glass, no framing)
- Reduce emissions (SF_6/NF_3, toxic materials)
- Increase module efficiency
- Increase lifetime
- Recycle materials

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