Solar Cells and Light-Emitting Diodes: two optoelectronic devices for a greener planet

1. Solar cells and LEDs: how they fit into the world's generation- and lighting-mixes.
2. Solar cells and LEDs: their design and operation.
3. LEDs: their prospects for contributing significantly to general-purpose lighting.
4. Solar cells: their prospects for contributing significantly to sustainable electricity generation.

Photovoltaic Power Generation

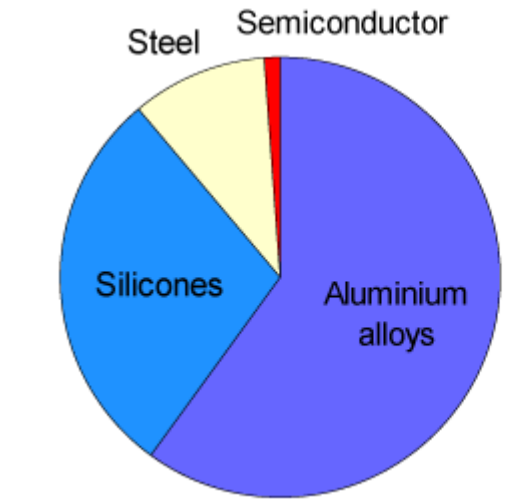
Issues:

- sustainability
- solar-cell cost and efficiency ($/W)
- variability of insolation
- energy storage and/or greening the generation mix

Silicon material

$$SiO_2 + 2C \longrightarrow Si + 2CO$$

Metallurgical grade Si



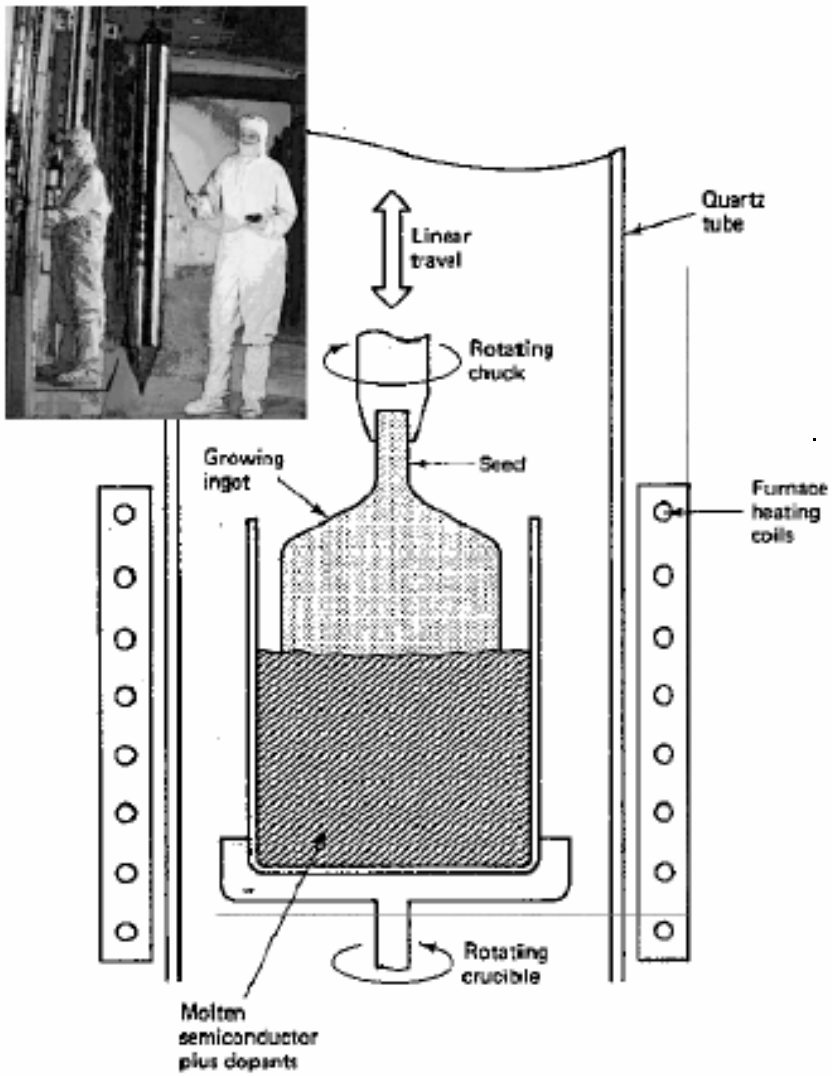
Total production ~ 900 000 tonnes/p.a.

Element	Concentration (ppma)	
Al	1200-4000	X
B	37-45	X
P	27-30	X
Ca	590	
Cr	50-140	
Cu	24-90	X
Fe	1600-3000	X
Mn	70-80	
Mo	<10	
Ni	40-80	
Ti	150-200	
V	100-200	
Zr	30	

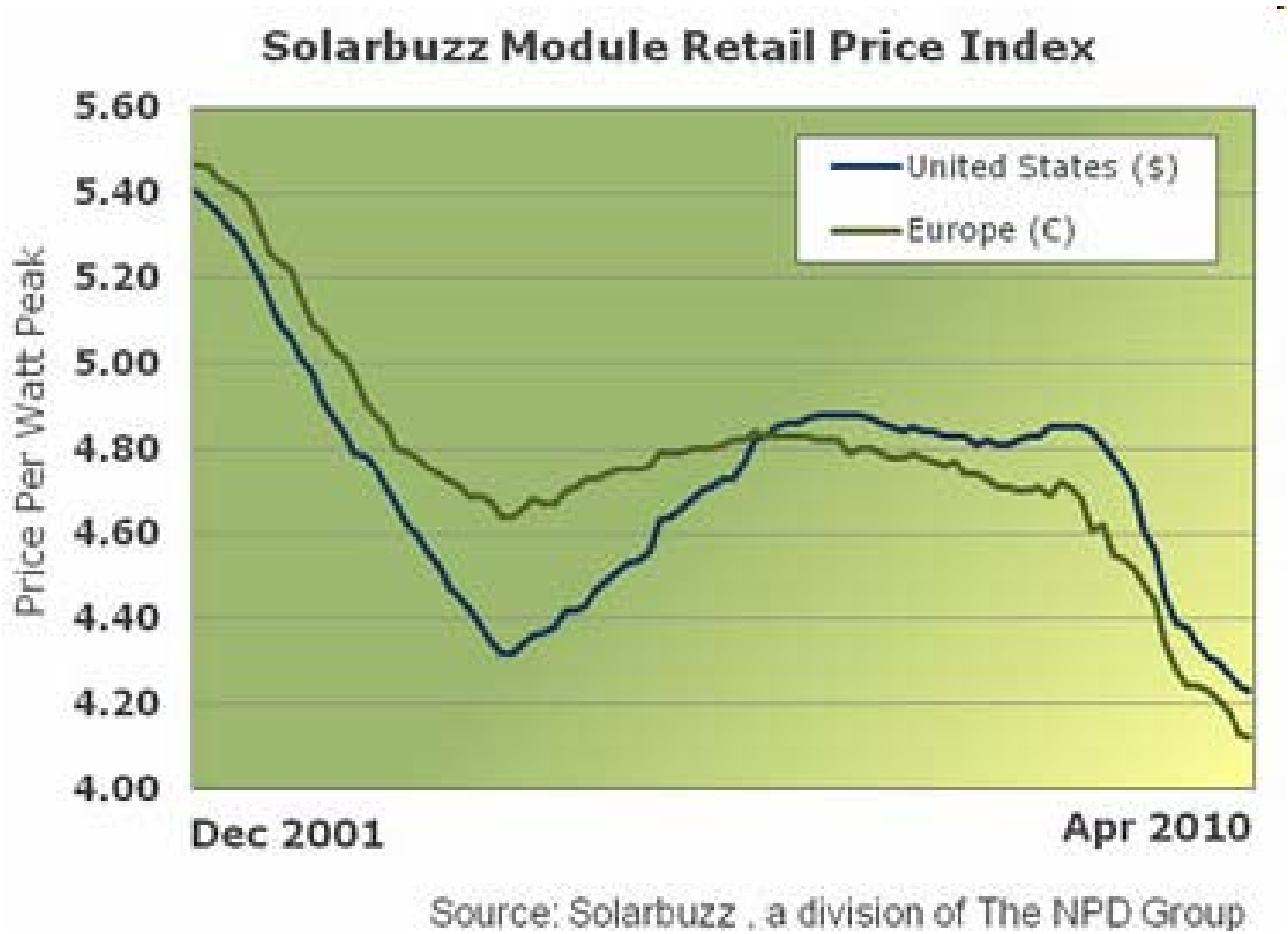
Semiconductor grade Si

$$Si + 3HCl \leftrightarrow SiHCl_3 + H_2$$

Single-crystal Si modules



Capital cost of PV



"The lowest retail price for a mono-crystalline silicon module is also $2.23 per watt (€1.65 per watt), from a German retailer."

http://www.solarbuzz.com/Moduleprices.htm

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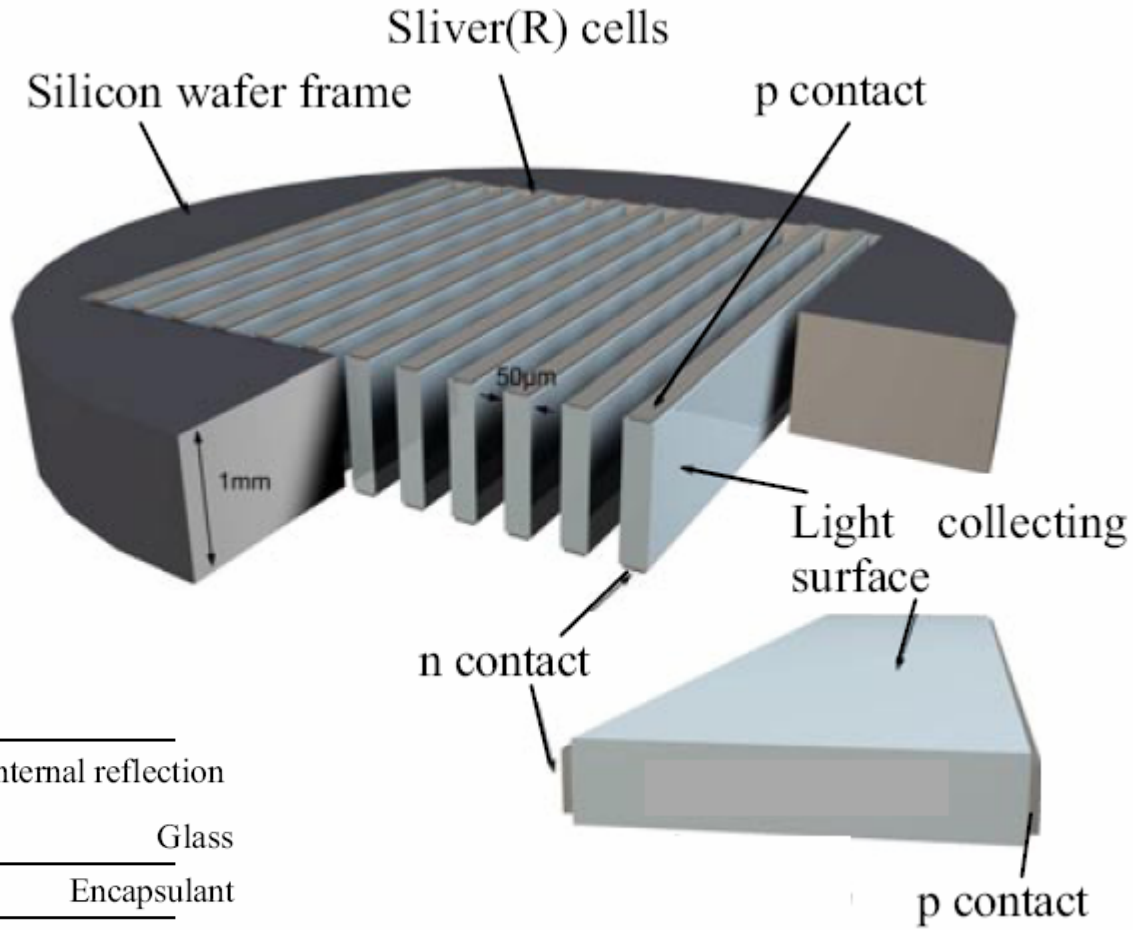
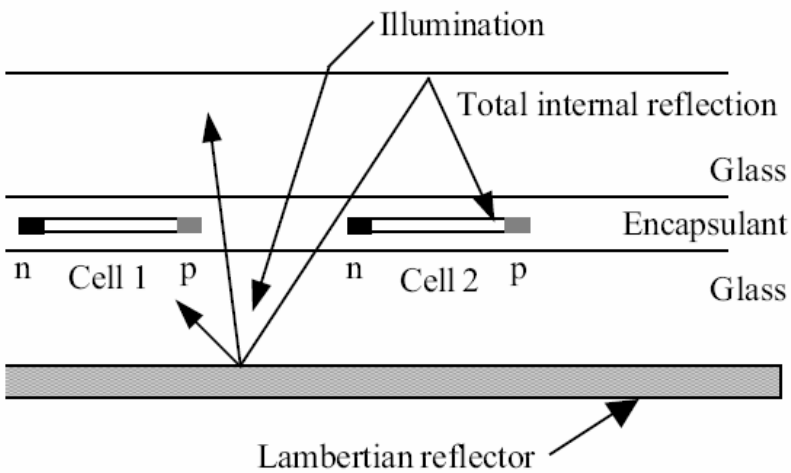
Thin sc-Si solar cells





10X reduction in Si use claimed

K.J. Weber *et al.*, *IEEE Photovoltaic Specialists Conf.*, 991-994, 2005.

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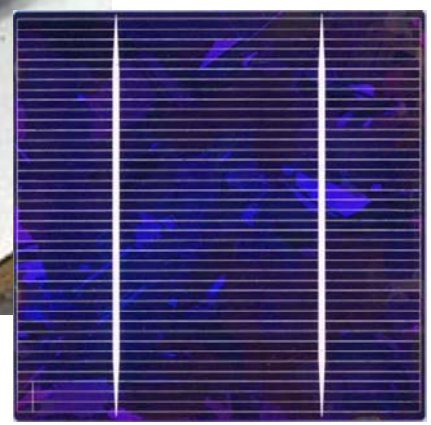
mc-Si solar cells



http://www.udel.edu/igert/pvcdrom/index.html

"The lowest retail price for a multi-crystalline silicon solar module is $1.74 per watt (€1.29 per watt) from a US retailer."

http://www.solarbuzz.com/Moduleprices.htm

Electricity price comparison

Conventional:

Country/Territory	US cents/1kWh	As of
Australia	7.11	2006-2007
Belgium	11.43	2006-2007
Canada	6.18	2006-2007
Croatia	17.55	2008-07-01
Denmark	42.89	2006-2007
Finland	6.95	2006-2007
France	19.25	2009
Germany	30.66	2009
Hong Kong (Kowloon/ NT)	10.90	2008-05-07
Hong Kong (HK Is.)	12.30	2008-05-07
Iceland	11.61	2008-07-07
Ireland	23.89	2006-2007
Italy	37.23	2009
Malaysia	7.42	Dec 2007
Netherlands	34.70	2009
Perú	10.44	2006-2007
Portugal	16.39	2009
Singapore	15.31	2009-2009
Spain	19.50	2009
South Africa	10.15	2008-2009
Sweden	27.34	2009
UK	18.59	2009
USA	9.28	2006-2007

http://en.wikipedia.org/wiki/Electricity_tariff

PV (April 2010):

Residential	Commercial	Industrial
34.84	24.81	19.33

http://www.solarbuzz.com/solarprices.htm

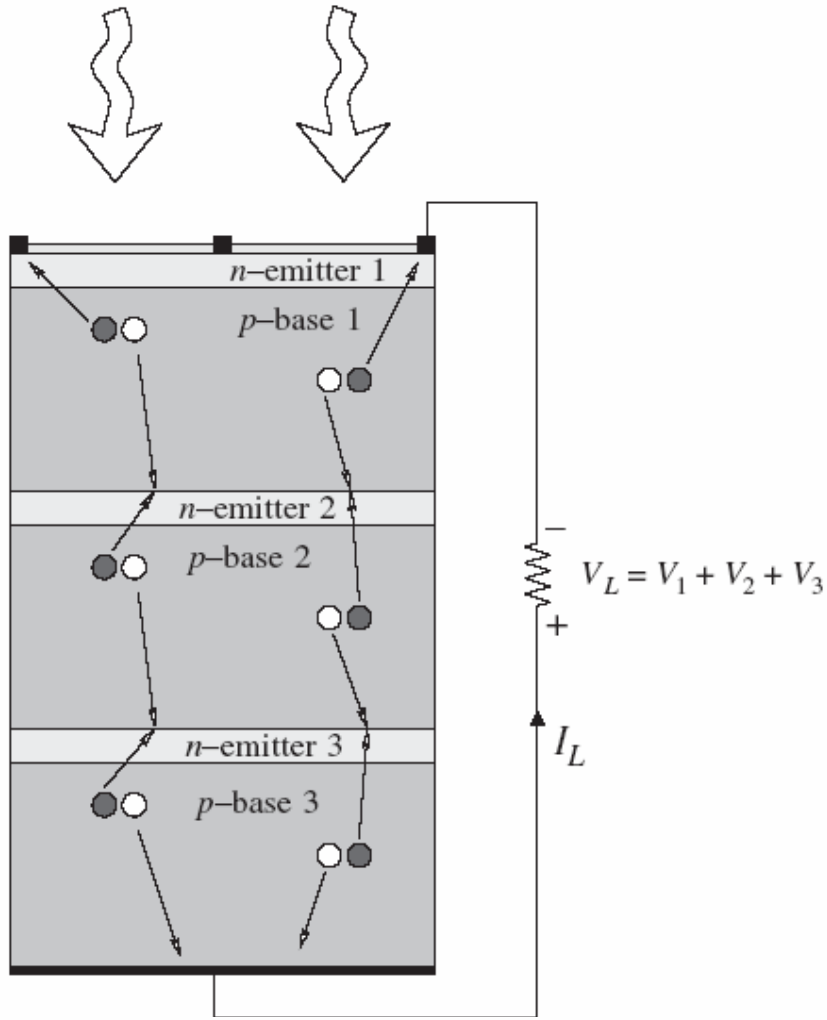
Levelized energy costs in AUD (2006)

Technology	Cost (AUD/MWh)
Nuclear (to COTS plan)[13]	40–70
Nuclear (to suit site; typical)[13]	75–105
Coal	28–38
Coal: IGCC + CCS	53–98
Coal: supercritical pulverised + CCS	64–106
Open-cycle Gas Turbine	101
Hot fractured rocks	89
Gas: combined cycle	37–54
Gas: combined cycle + CCS	53–93
Small Hydro power	55
Wind power: high capacity factor	75
Solar thermal	85
Biomass	88
Photovoltaics	120

http://en.wikipedia.org/wiki/Relative_cost_of_electricity_generated_by_different_sources

Alternatives to limited-area Si: tandem cells

Small-area, very-high efficiency cells, vertically stacked.



- What are the limitations and difficulties?
- How can a low-cost PV plant be made with this concept?

Semiconductor	E_g (eV)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	η_{pv} %
GaInP/GaInAs/Ge	1.8/1.3/0.7	16.0	2.392	0.819	31.3

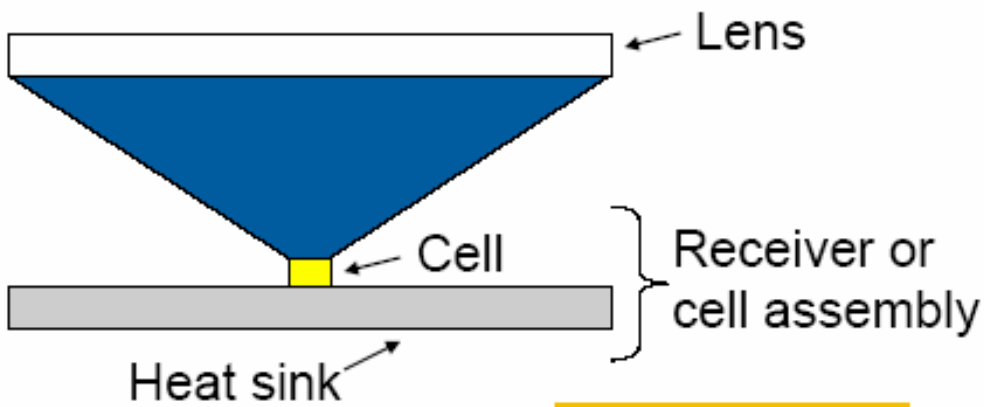
UMTD [Fig. 7.15]

Concentrating Photovoltaic Systems: CPV

Dish: requires active cooling

Microdishes can be passively cooled

Fresnel lenses focus light on small cells: Passive cooling



Many designs

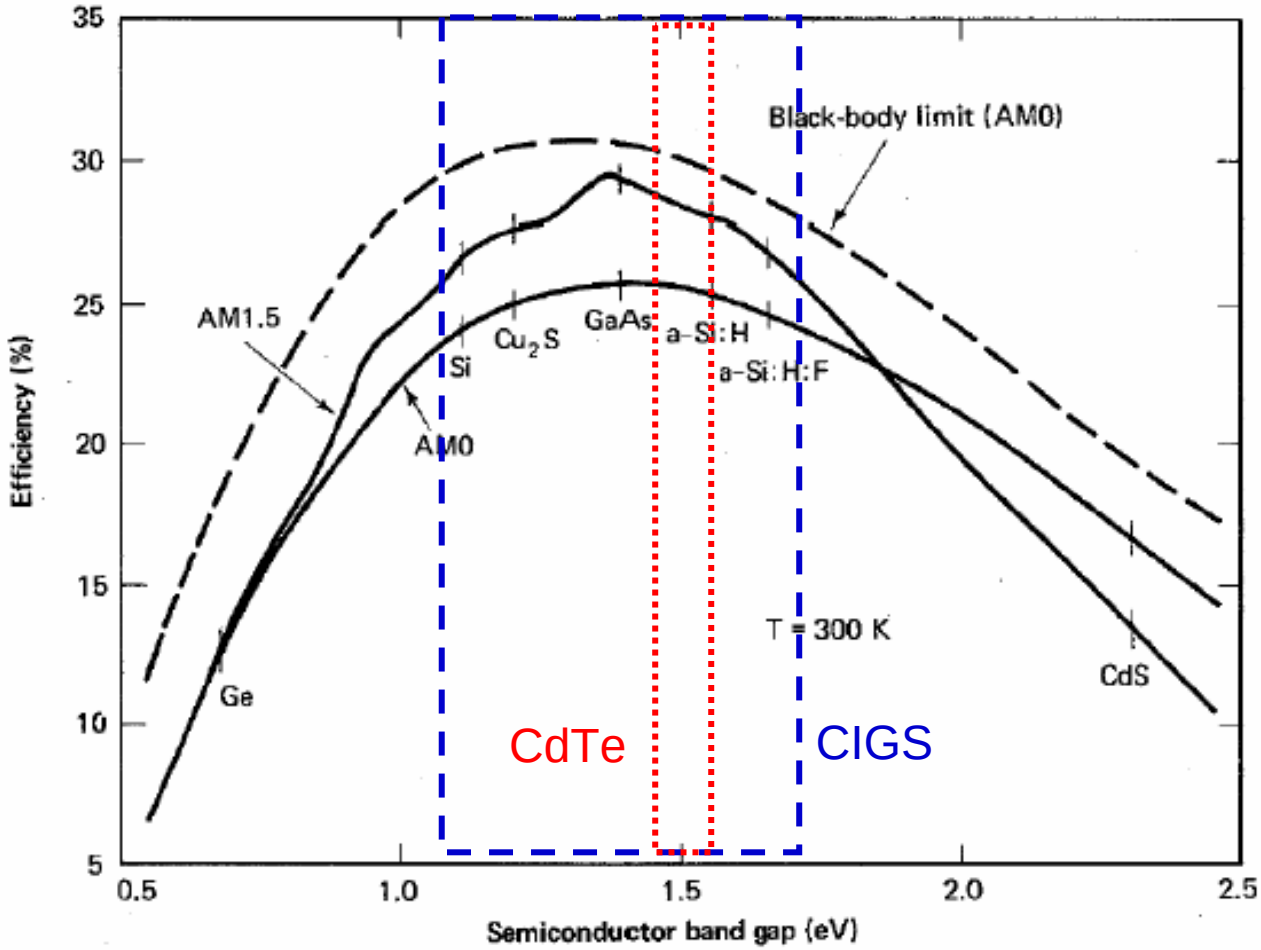
S. Kurtz, NREL/PR-520-46924, Oct. 2009

Alternatives to limited-area Si: thin-film cells

Requirements:

- near optimum bandgap
- direct bandgap
- long minority carrier lifetime
- abundant material
- large-area-deposition capability

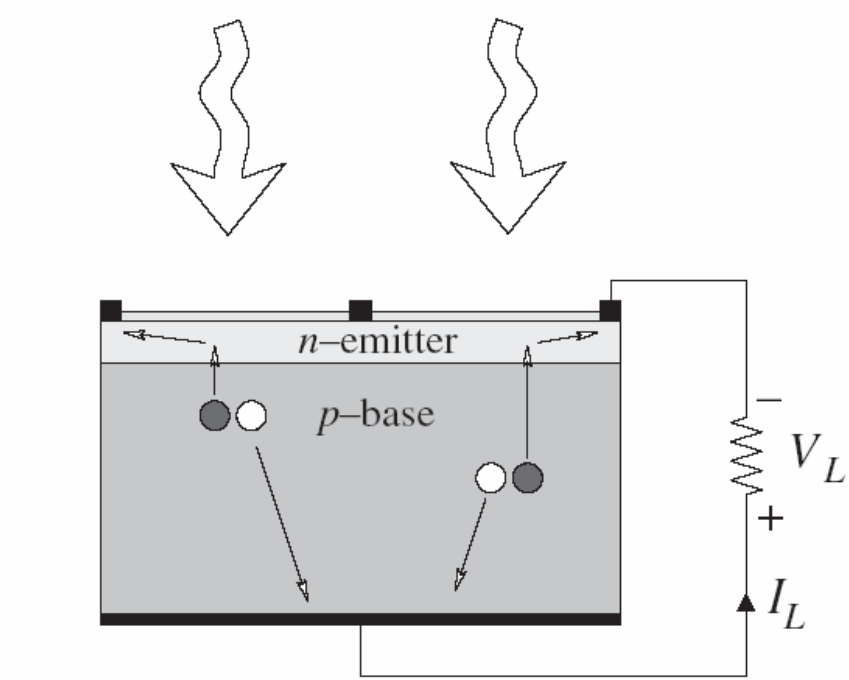
Efficiency and bandgap

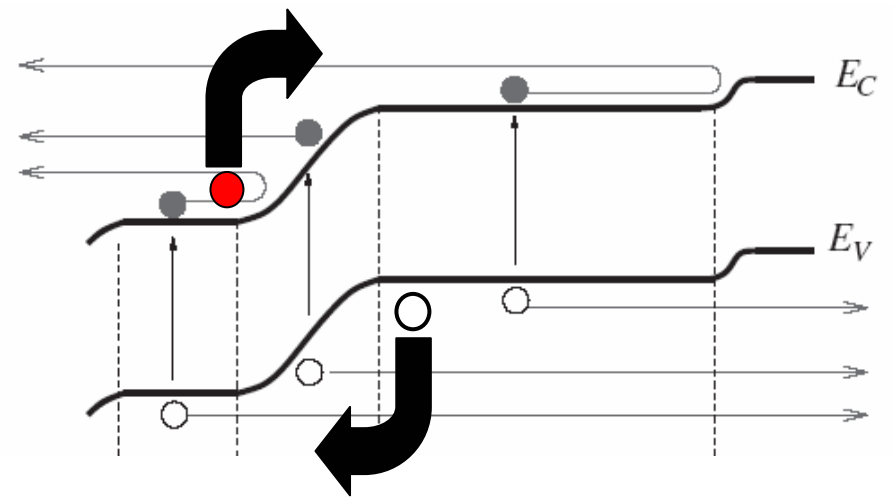


Why is there a maximum in the relationship?

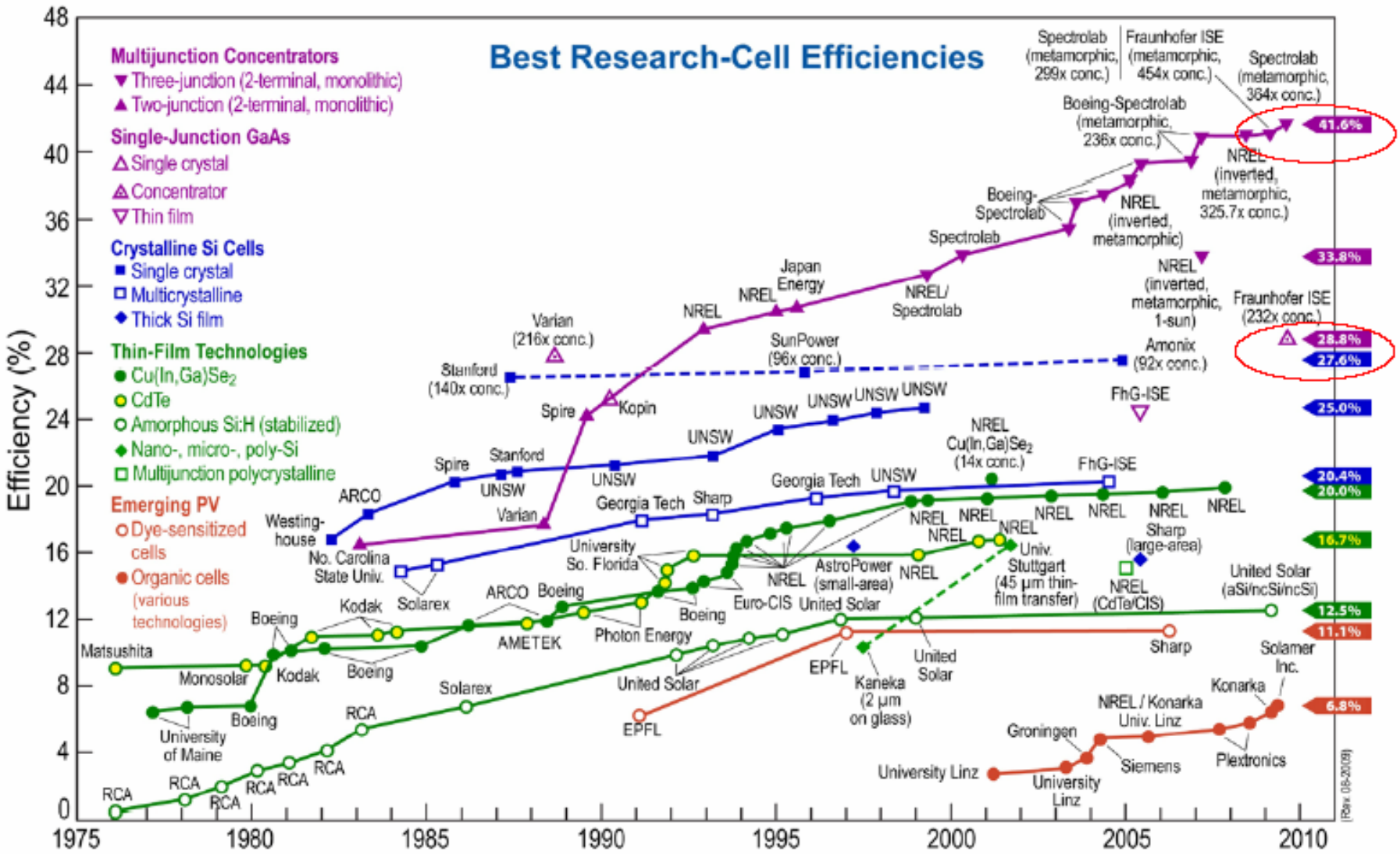
UMTD [Sec. 7.5.1]

Optimum bandgap



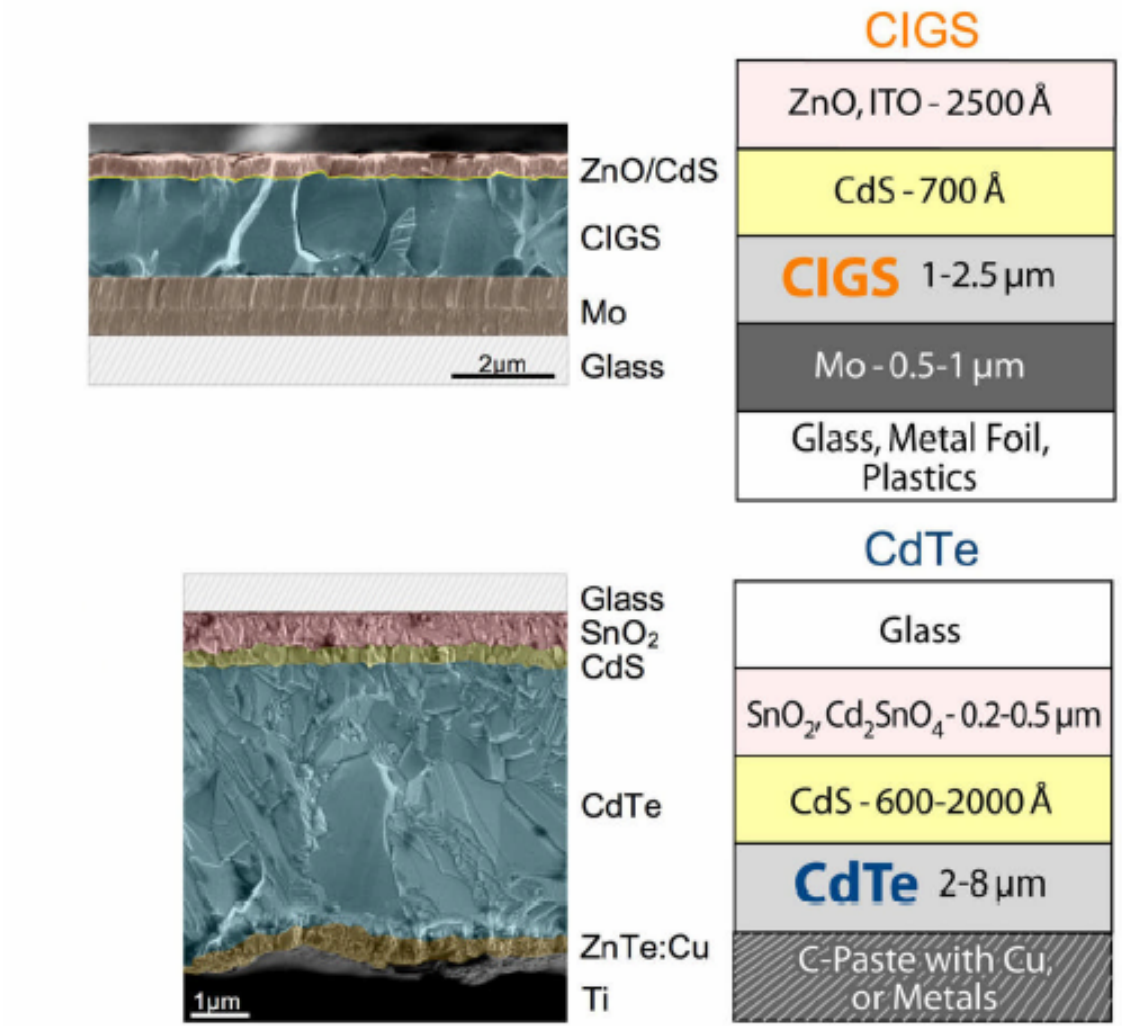


Solar-cell efficiencies



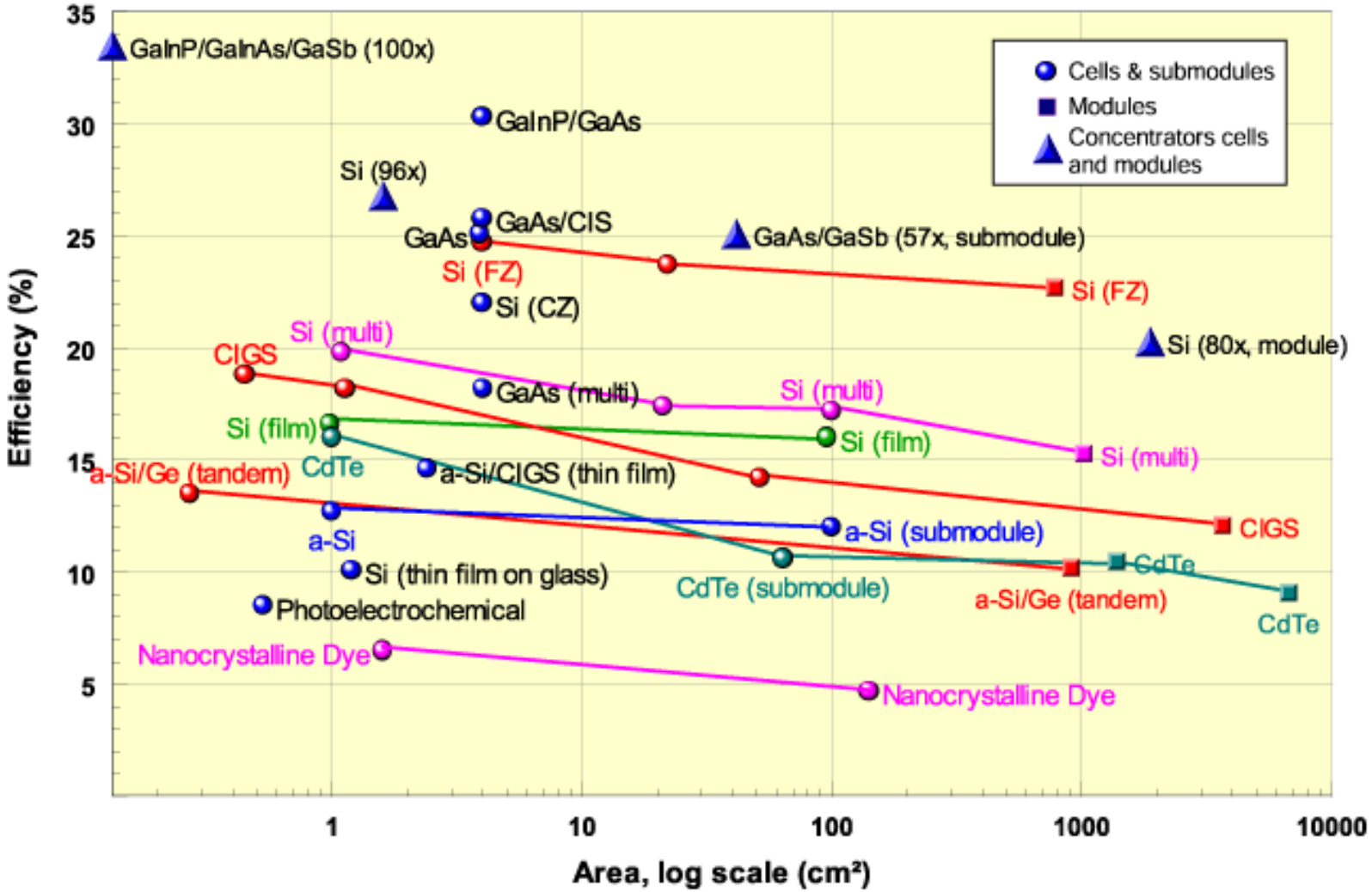
Sarah Kurtz NREL/PR-520-46924

CIGS and CdTe: thin-film contenders



Noufi and Zweibel, IEEE 4th World conf on PEC, 317-320, 2006

Efficiency comparison: materials and modules



http://www.udel.edu/igert/pvcdrom/index.html

Commercial CdTe: First Solar

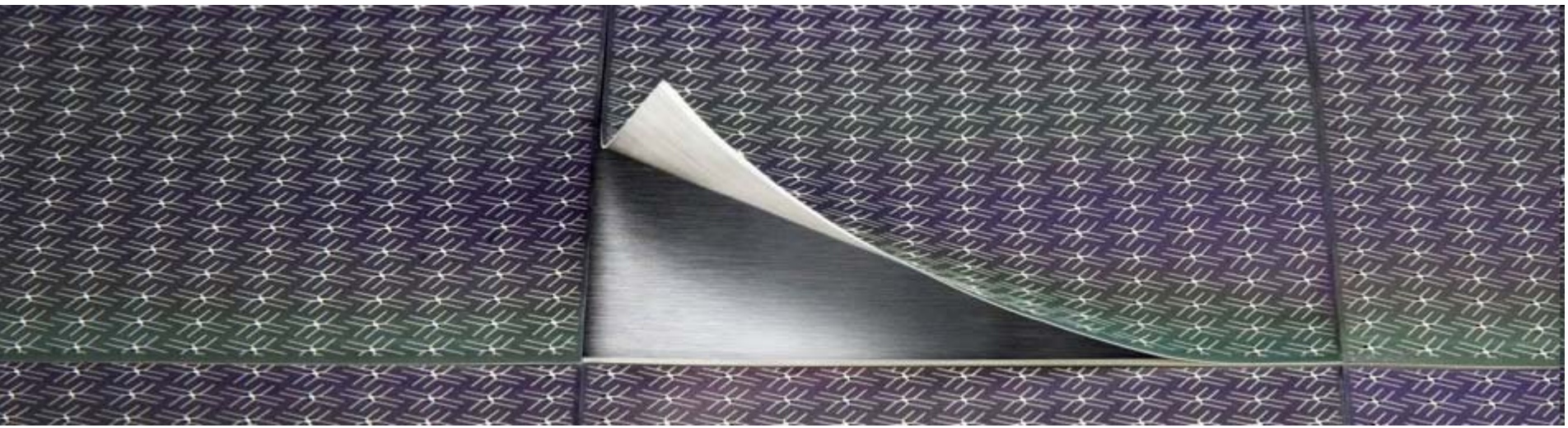
“Before First Solar's manufacturing innovations, cadmium-telluride photovoltaic cells were the size of postage stamps; now the company makes them as big as window panes.”

http://spectrum.ieee.org/energy/renewables/first-solar-quest-for-the-1-watt

Towards commercial CIGS: Nanosolar

NREL Certifies 15.3% Nanosolar Foil Efficiency

By Nanosolar Communications - September 9, 2009



http://www.nanosolar.com/technology

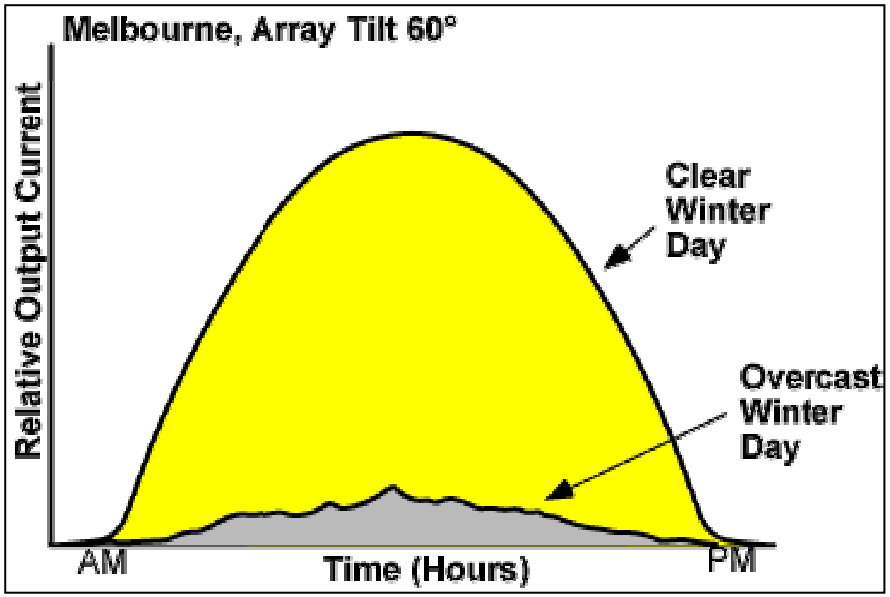
$/W for thin-film modules

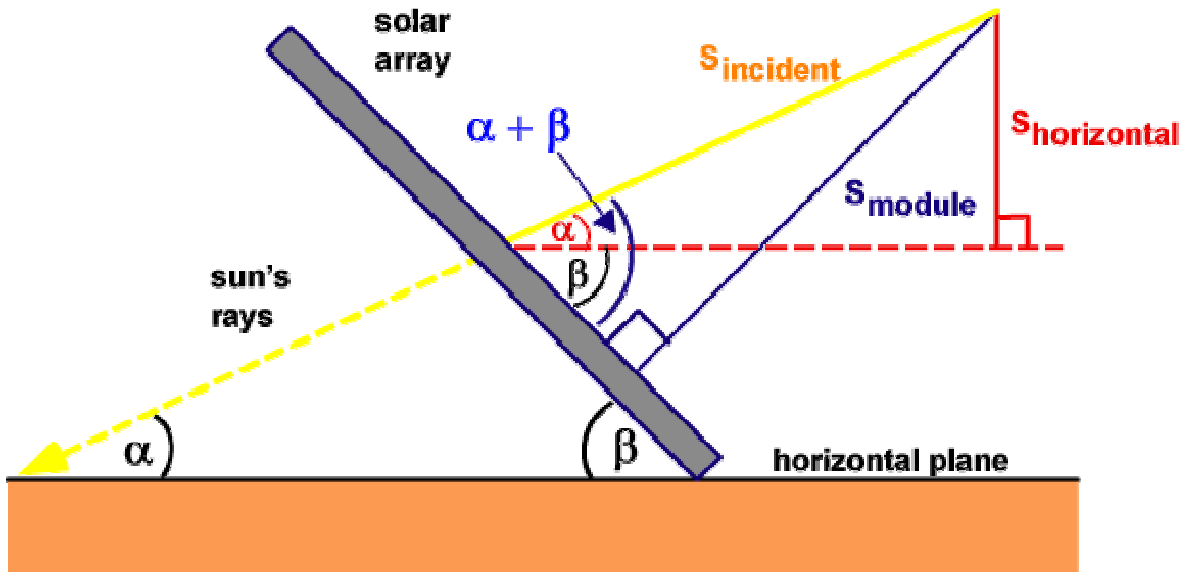
http://www.solarbuzz.com/Moduleprices.htm (April 2010)

The lowest thin film module price remains at $1.76 per watt (€1.30 per watt) from an Asia-based retailer. As a general rule, it is typical to expect thin film modules to be at a price discount to crystalline silicon (for like module powers). This thin film price is represented by a 130 watt module.

- Recall the latest, lowest $/W figures for Si cells.

Diurnal, seasonal, and angular variation





http://www.udel.edu/igert/pvcdrom/index.html

Stand-alone requires battery storage

http://www.udel.edu/igert/pvcdrom/index.html

Add PV to the mix: fusion and fission

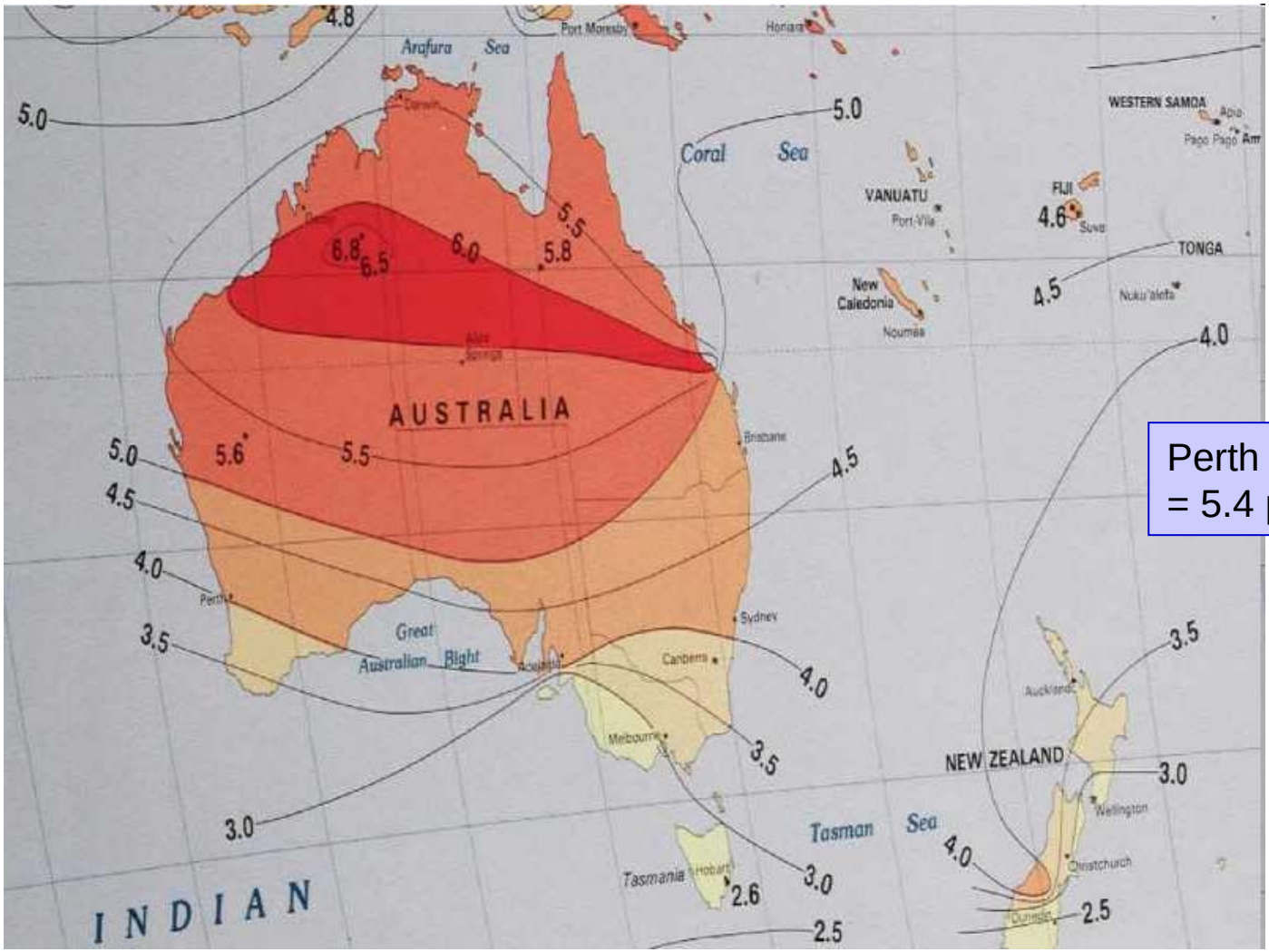
Nuclear in a "green" country

German Chancellor Angela Merkel pauses before a two-days party leaders meeting of the conservative Christian Democratic Union (CDU) in Berlin July 2, 2007. Merkel is preparing to perform a major U-turn by scrapping plans to abandon nuclear power. REUTERS/Fabrizio Bensch (GERMANY)

Mrs Merkel's dramatic change of heart surfaced at an energy summit attended by government and industry heads in Berlin last week, when it became clear that her ruling grand coalition's aim of closing Germany's 17 nuclear power plants by the early 2020s were at odds with targets for the reduction of CO_2 emissions.

http://www.world-nuclear.org/info/inf43.html

Final appraisal: average low peak-sun hours



Perth mean average = 5.4 pk-sun h

http://www.solar4power.com/map8-global-solar-power.html

Levelized energy cost

e.g. { 10% cost of capital, 4% interest rate, depreciation over 20 years, 1% O & M cost.

Cost	Insolation 2400 kWh/kWp•y	2200 kWh/kWp•y	2000 kWh/kWp•y	1800 kWh/kWp•y	1600 kWh/kWp•y	1400 kWh/kWp•y	1200 kWh/kWp•y	1000 kWh/kWp•y	800 kWh/kWp•y
200 $/kWp	0.8	0.9	1.0	1.1	1.3	1.4	1.7	2.0	2.5
600 $/kWp	2.5	2.7	3.0	3.3	3.8	4.3	5.0	6.0	7.5
1000 $/kWp	4.2	4.5	5.0	5.6	6.3	7.1	8.3	10.0	12.5
1400 $/kWp	5.8	6.4	7.0	7.8	8.8	10.0	11.7	14.0	17.5
1800 $/kWp	7.5	8.2	9.0	10.0	11.3	12.9	15.0	18.0	22.5
2200 $/kWp	9.2	10.0	11.0	12.2	13.8	15.7	18.3	22.0	27.5
2600 $/kWp	10.8	11.8	13.0	14.4	16.3	18.6	21.7	26.0	32.5
3000 $/kWp	12.5	13.6	15.0	16.7	18.8	21.4	25.0	30.0	37.5
3400 $/kWp	14.2	15.5	17.0	18.9	21.3	24.3	28.3	34.0	42.5
3800 $/kWp	15.8	17.3	19.0	21.1	23.8	27.1	31.7	38.0	47.5
4200 $/kWp	17.5	19.1	21.0	23.3	26.3	30.0	35.0	42.0	52.5
4600 $/kWp	19.2	20.9	23.0	25.6	28.8	32.9	38.3	46.0	57.5
5000 $/kWp	20.8	22.7	25.0	27.8	31.3	35.7	41.7	50.0	62.5

What's the answer for Perth?

What's the answer for Vancouver?

http://en.wikipedia.org/wiki/Photovoltaics

Non-debatable: BIPV

Hong Kong Science Park

a-Si, thin-film cells

http://solarpowerauthority.com/2008/03/

Scheidegger
Building, Berne

https://wiki.brown.edu/confluence/download/.../15_SolarAltEnergy-ppt.pdf