

# Perovskite based Solar Cells

## Boosting efficiencies of Si-solar cells > 30%

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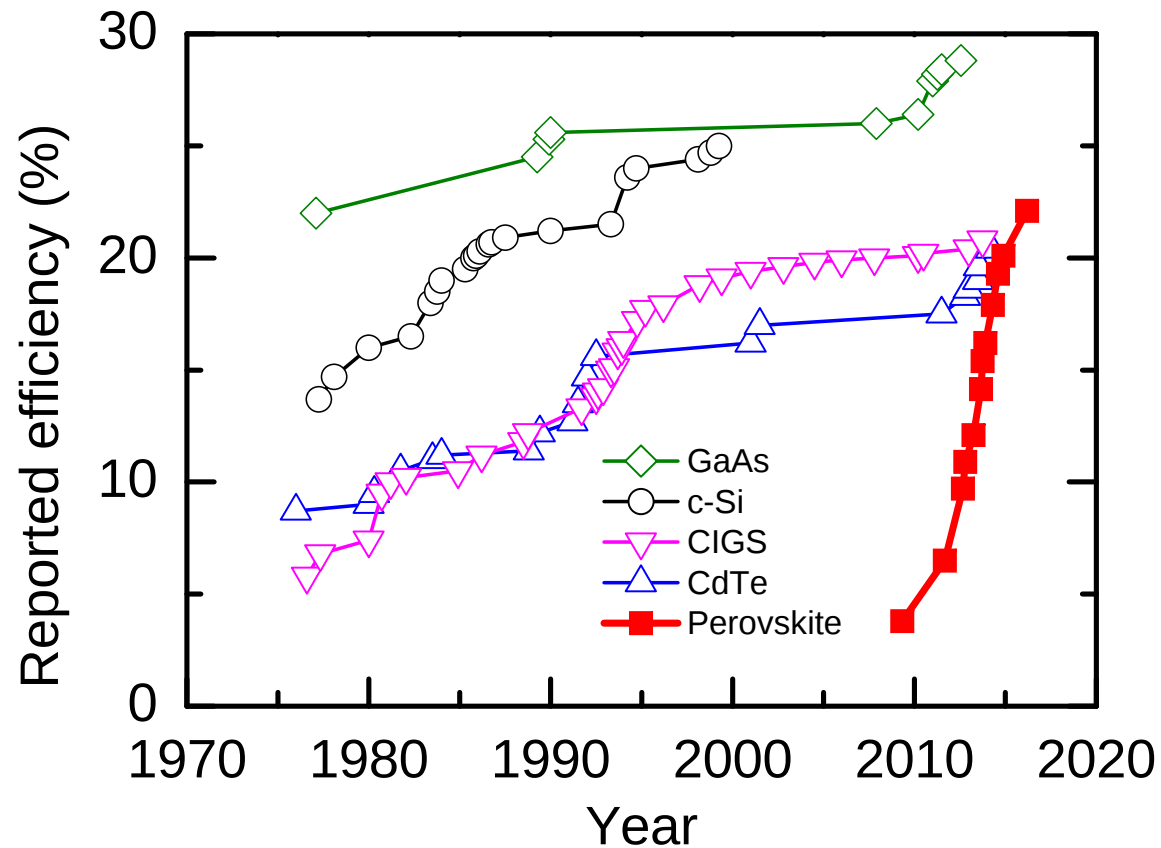
Prof. David Cahen (Weizmann Institute of Science, Israel)



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# Perovskite solar cells: Remarkable Newcomer

**30% theoretical maximum**

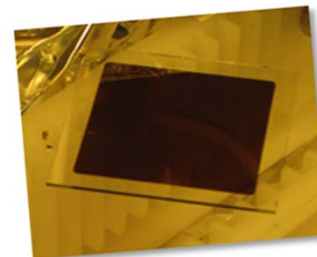
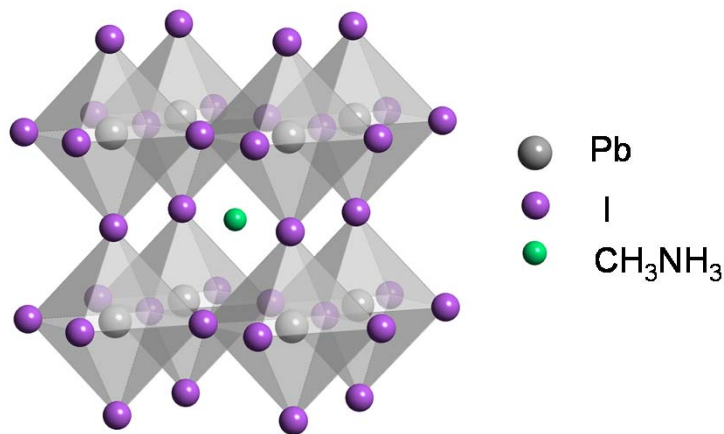


# Perovskites

Perovskite is **calcium titanium oxide or calcium titanate**, with the chemical formula  **$\text{CaTiO}_3$** . The mineral was discovered by Gustav Rose in 1839 and is named after Russian mineralogist **Count Lev Alekseevich Perovski** (1792–1856)."

All materials with the same crystal structure as  $\text{CaTiO}_3$ , namely  **$\text{ABX}_3$** , are termed perovskites:

For solar cells: **alkylammonium lead halide perovskites**.

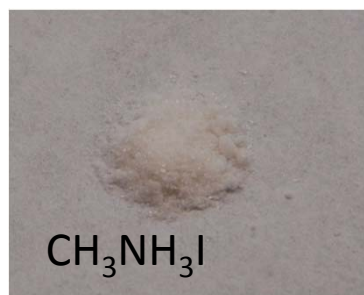


# HOT area!

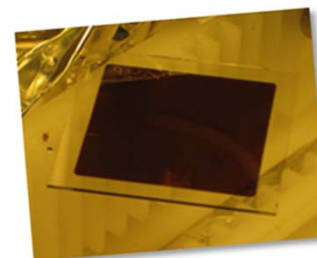
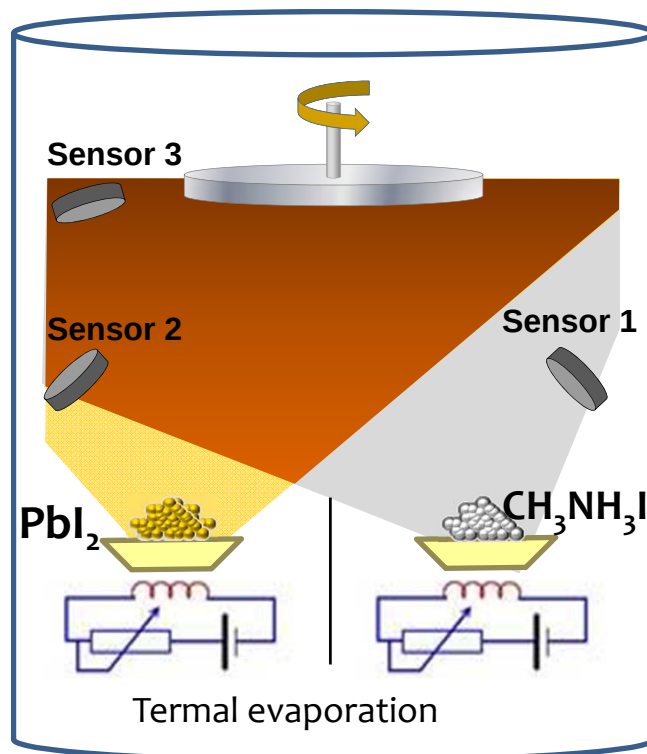
- A. Kojima et al. *Journal of the American Chemical Society*, 2009, **131**, 6050
- M. M. Lee, et al., *Science*, 2012, **338**, 643-647.
- H. S. Kim, et al., *Scientific Reports*, 2012, **2**.
- I. Chung, et al., *Nature*, 2012, **485**, 486-U494.
- Heo, J. H et al., *Nature Photon* **2013**, 7, 486.
- J. Burschka, et al., *Nature*, 2013, **499**, 316-319.
- M. Liu, et al., *Nature*, **501**, 395-398 (2013).
- Stranks, S. D. et al. *Science* **342**, 341-344 (2013).
- Xing, G. et al. *Science* **342**, 344-347 (2013).
- Malinkiewicz, O. et al. *Nature Photon* **8**, 128-132 (2014).
- Liu, D. & Kelly, T. L. *Nature Photon* **8**, 133 (2014).
- Jeon et al, *Nature Materials* **13**, 897–903 (2014)
- H. Zhou, et al. *Science* **2014**, 345, 6196
- Mei, A. et al., *Science* **2014**, 345, 295.
- Tan, Z. et al., *Nature Nano* **2014**, 9, 687.
- Jeon, N. J. et al., *Nature*, **2015**, doi:10.1038/nature14133
- Shi, D. et al., *Science* **2015**, 347, 519.
- Nie, W. et al., *Science* **2015**, 347, 522.

# Why so much attention?

- Abundant and cheap starting materials



- Low cost processing



Ref:  
Nature Photon. **8**, 128 (2014)  
Adv. Ener. Mater. **2014**, 1400345  
Energy and Environmental Science,  
**2016**, DOI:10.1039/C6EE02100J.

**Very cheap electricity: < 0.04 Euro/kWh**

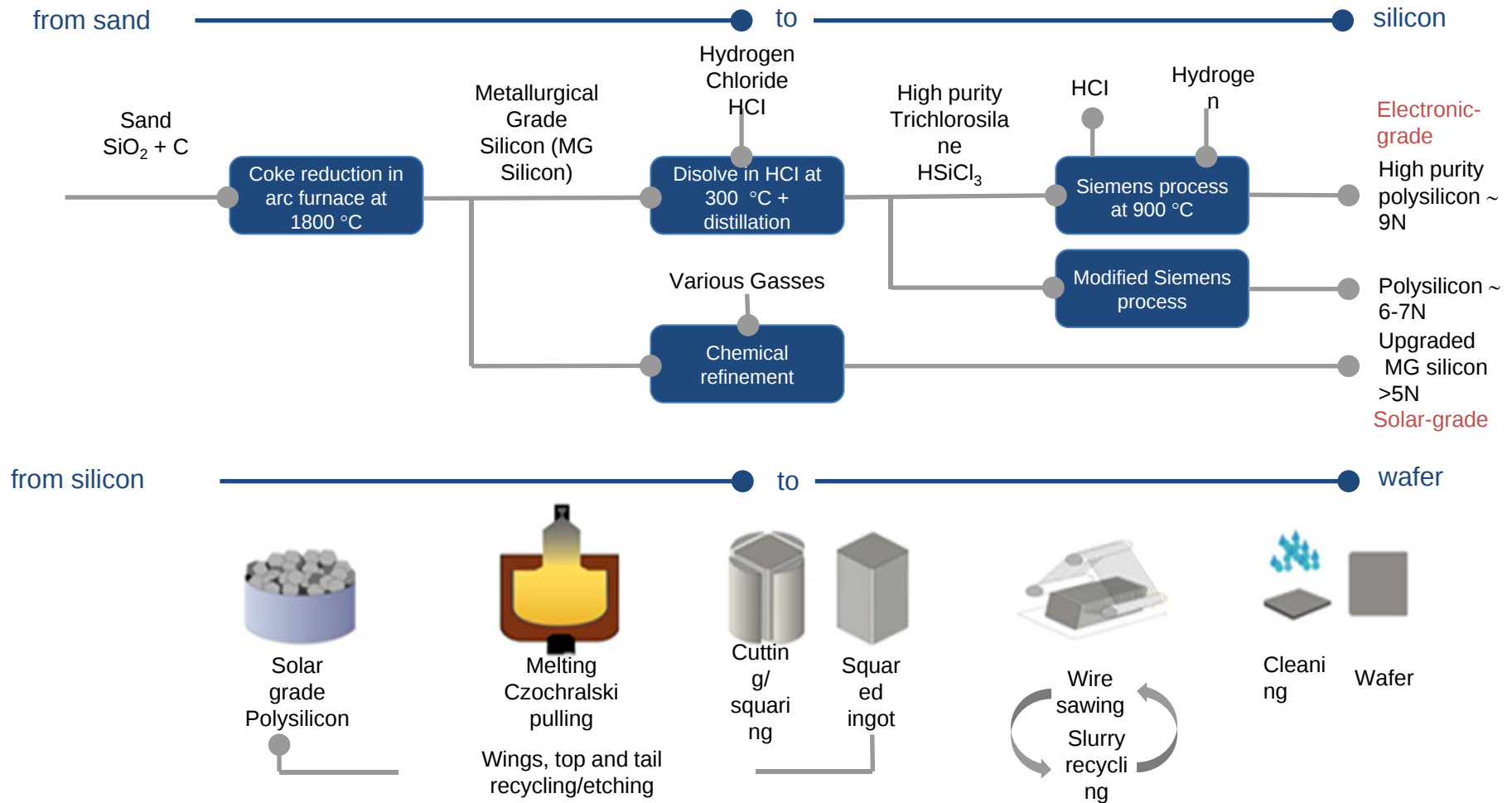
Is this the future?

# Perovskites v Silicon

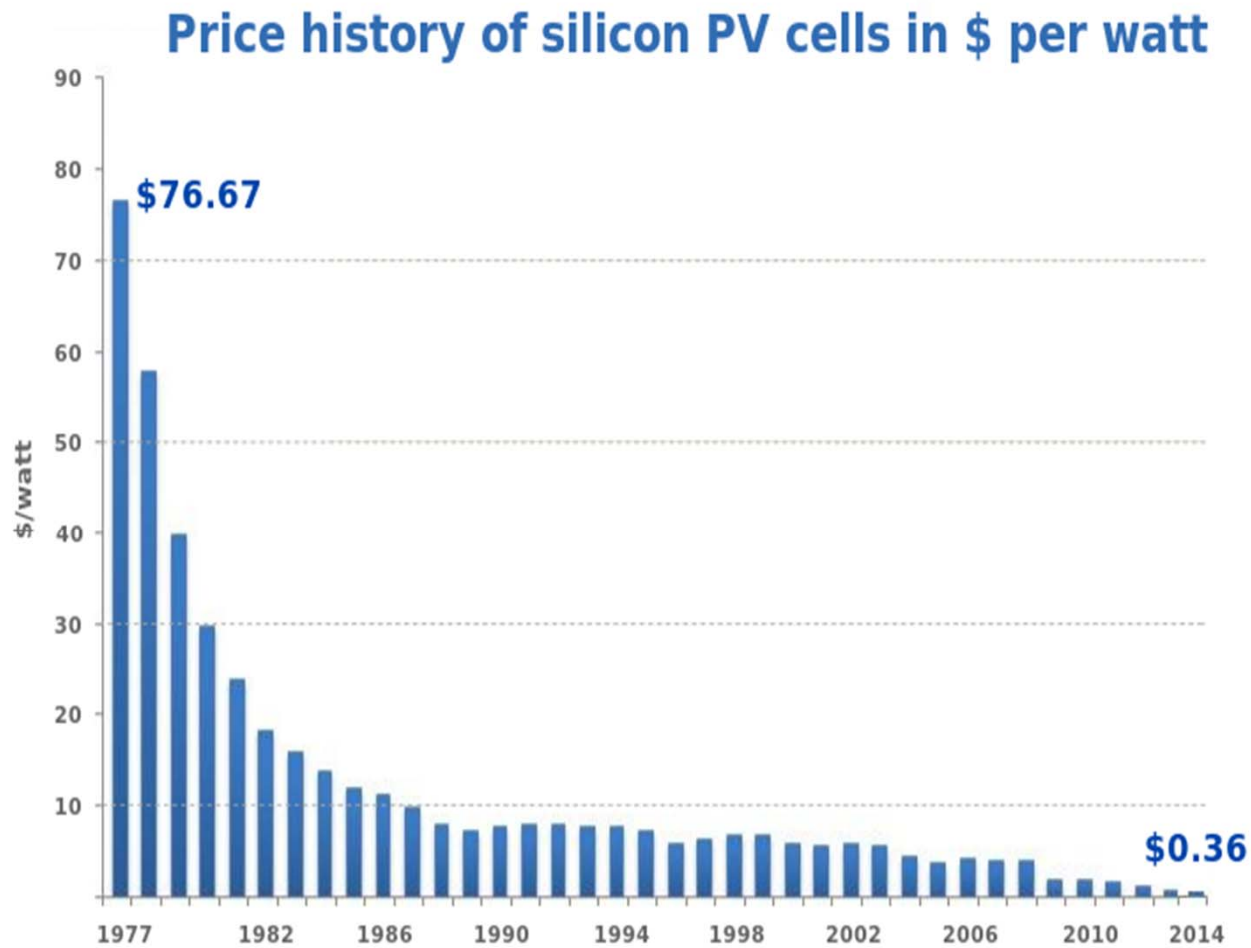


# Production of silicon and silicon wafers:

Expensive, high-energy process generating high levels of waste material



But...



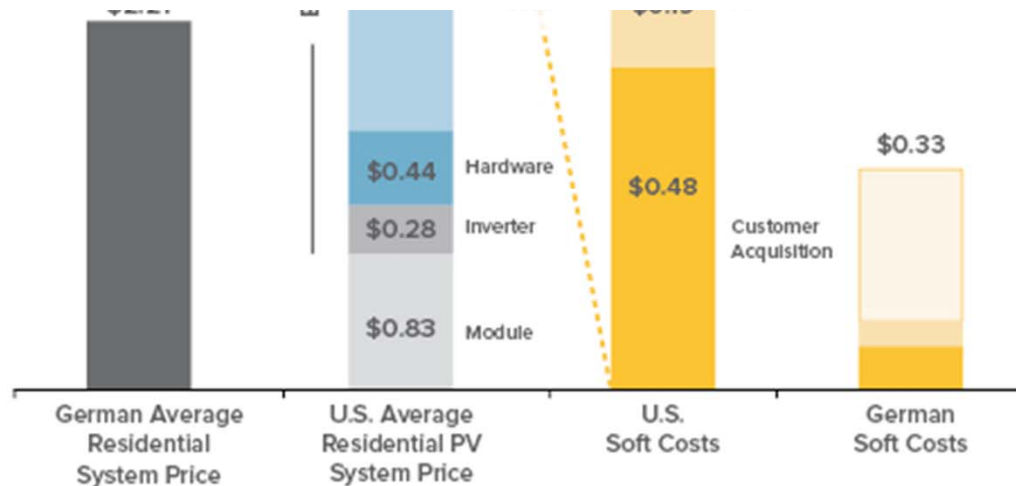
Source: Bloomberg, New Energy Finance & pv.energytrend.com

# What does PV need most?

## Solar PV Costs in the USA and Germany (2013)



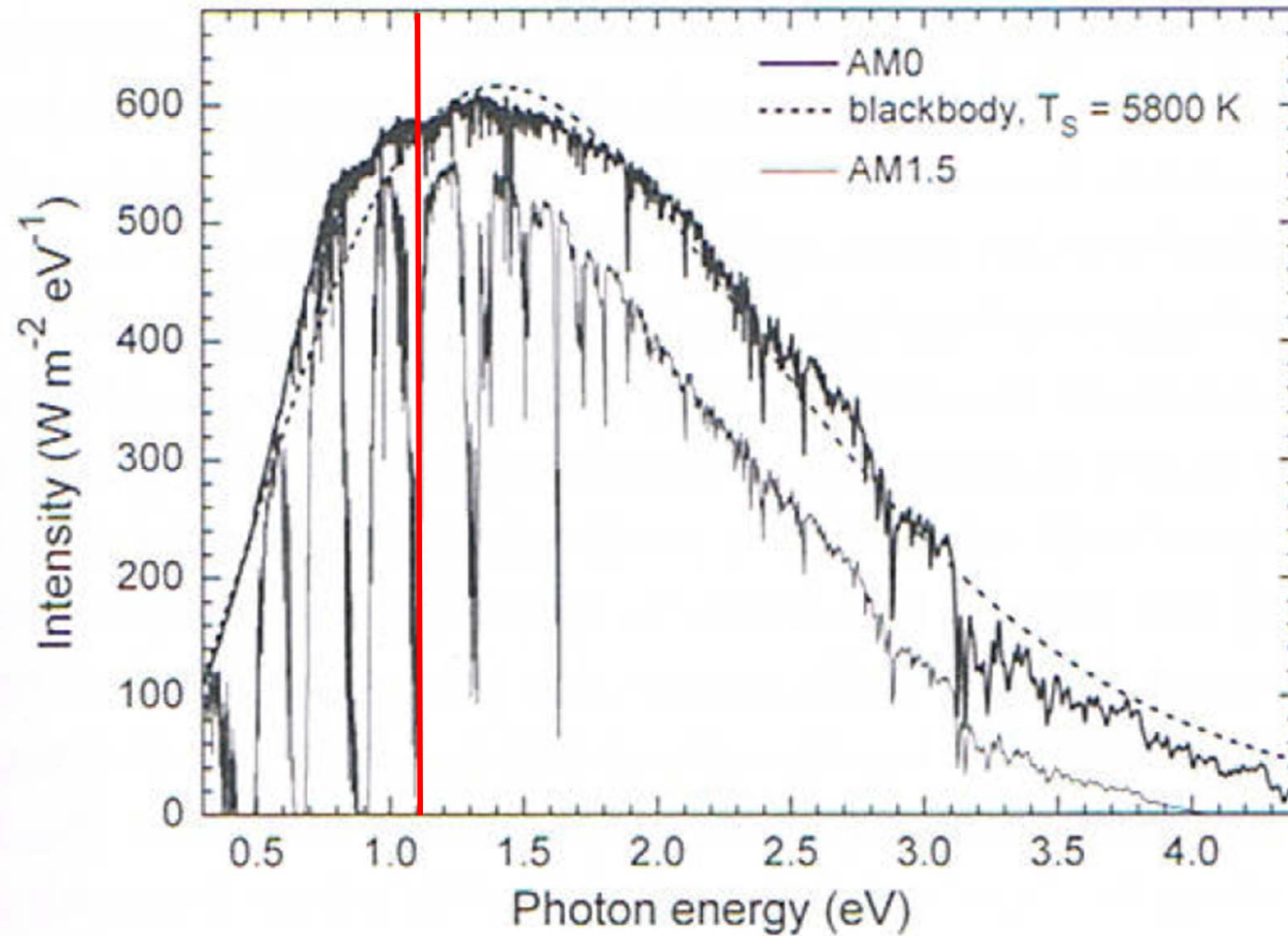
To minimize all non-PV costs,  
we need more W (& Wh) / € \$ ¥ £



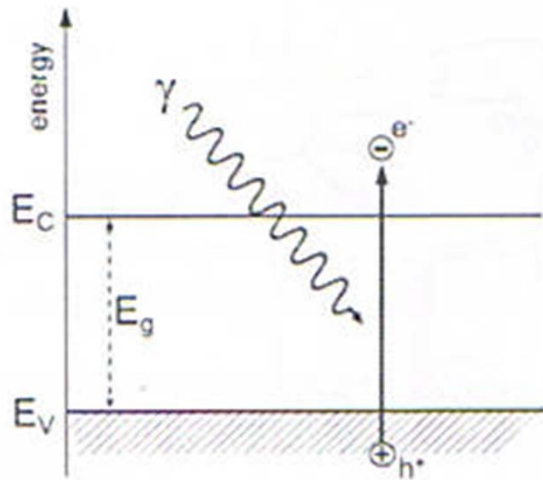
\*Permitting, Inspection, and Interconnection costs

\*\* Includes Installer and Integrator margin, legal fees, professional fees, financing transactional costs, O+M costs, production guarantees, reserves, and warranty costs.

# Solar spectrum outside and on earth

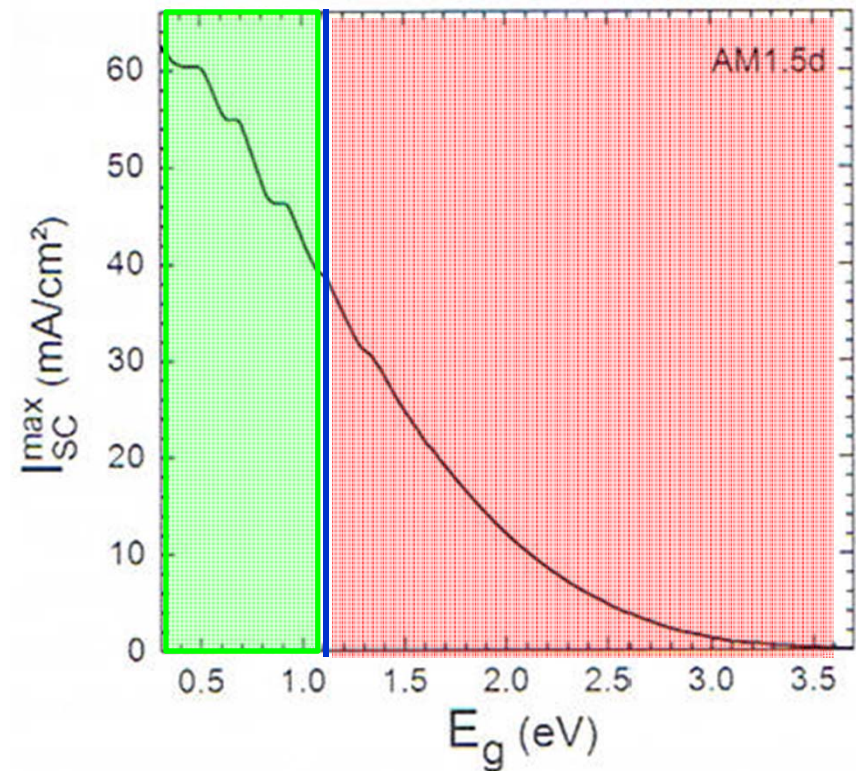


# Maximum achievable photocurrent



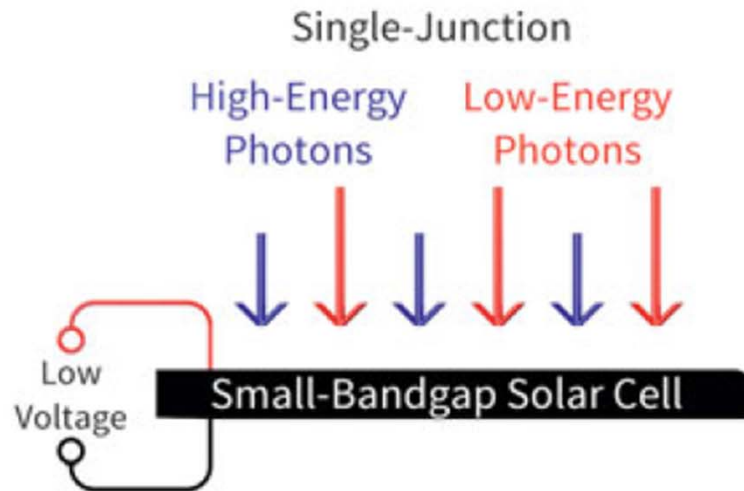
<  $E_g$  not absorbed

>  $E_g$  thermalized

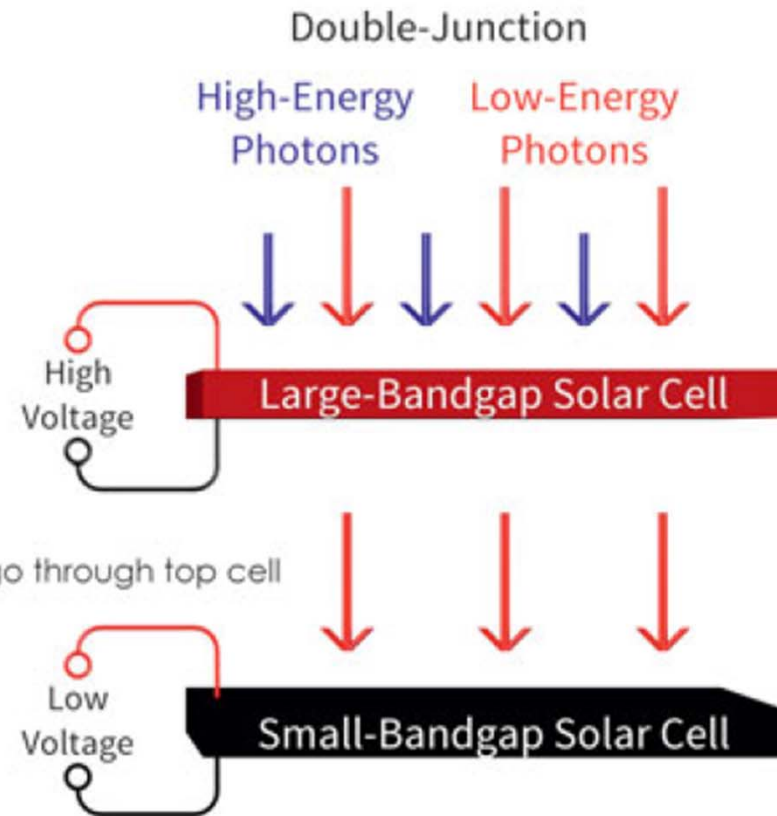


$$I_{SC}^{max} = q \cdot \int_{E_g}^{\infty} \Phi_{sun}(h\nu) \cdot d(h\nu)$$

# Tandem devices

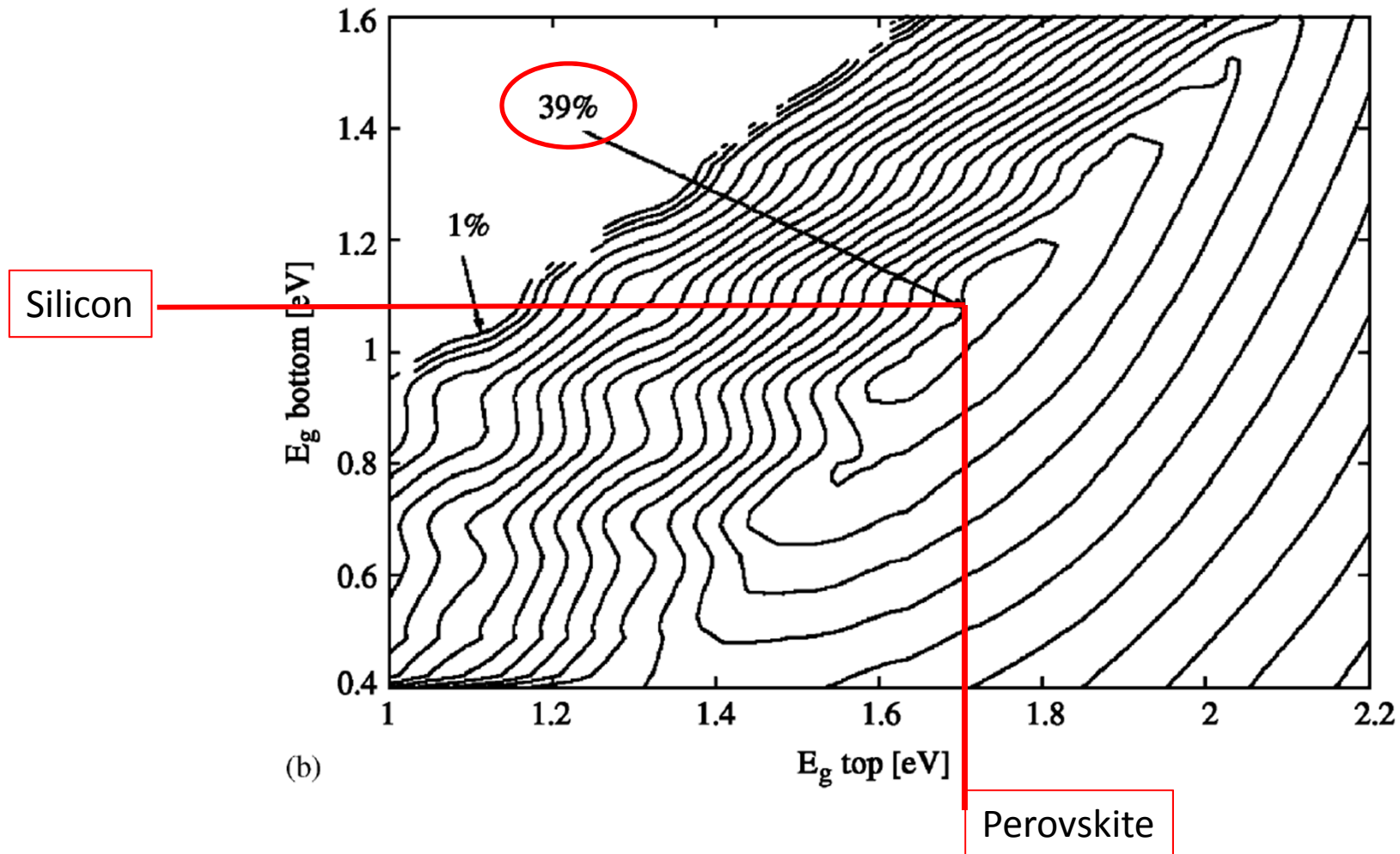


Efficiency Potential: 33.7%



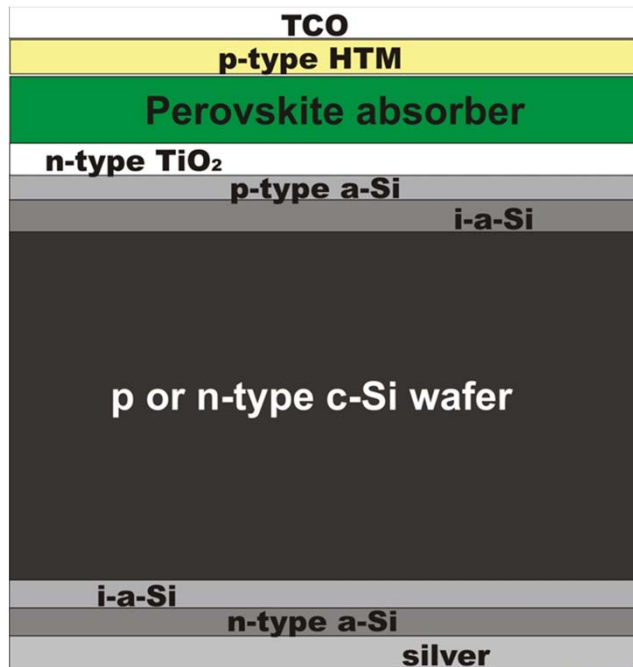
Efficiency Potential: 46.1%

# Tandem devices



# Utility Scale PV

Combining Perovskites and Si in a tandem architecture could lead to >30% efficient modules



# UVEG

- Vacuum processed perovskites (20%)
- Tandem Si-perovskite developments with:



# Acknowledgements

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2nd March 2017, Valencia (Spain)

Chairs: **Henk Bolink** (Valencia University)  
**David Cahen** (Weizmann Institute of Science)



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