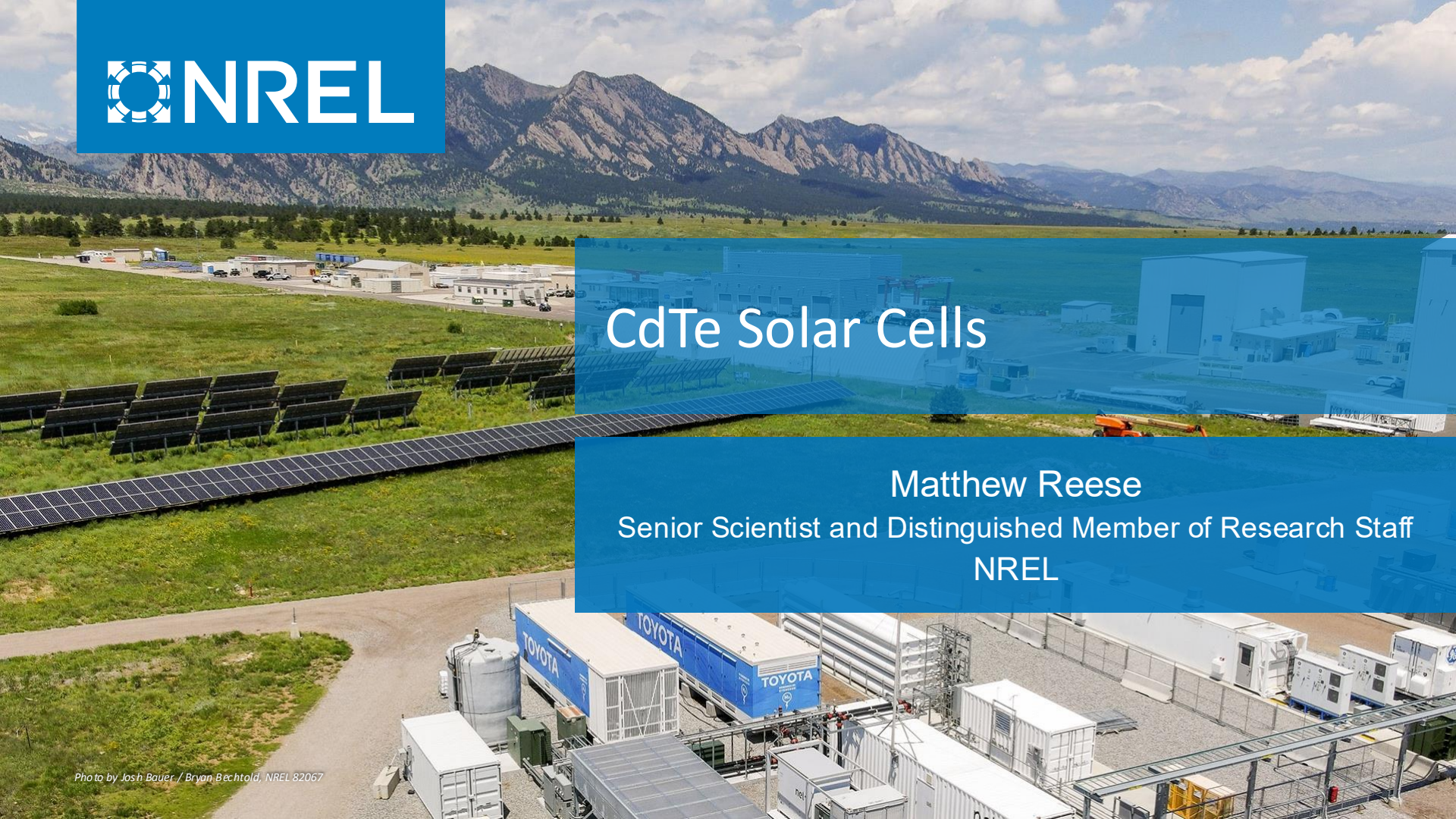


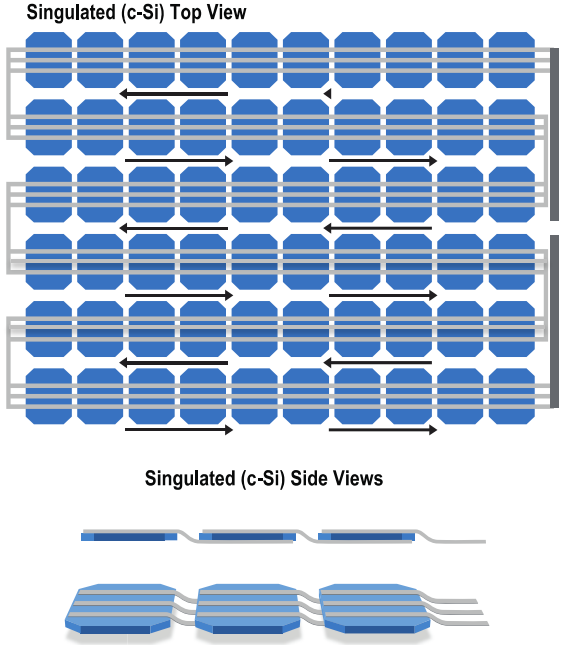
CdTe Solar Cells

Matthew Reese
Senior Scientist and Distinguished Member of Research Staff
NREL

Photo by Josh Bauer / Bryan Bechtold, NREL 82067

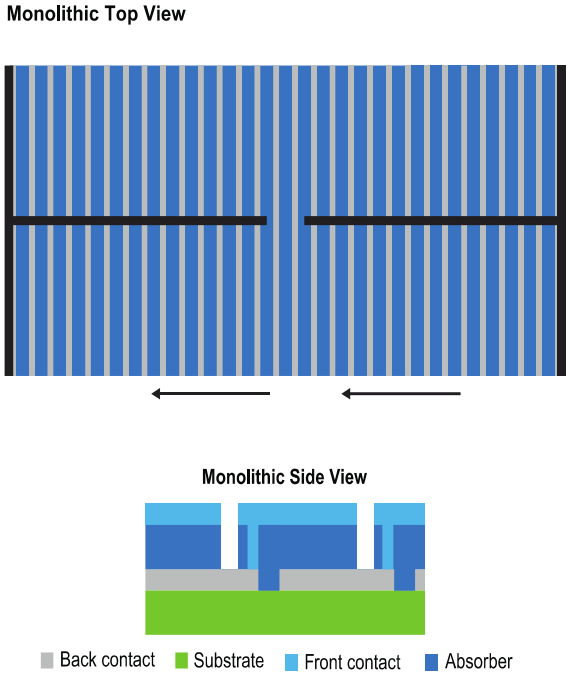
Module Differences: Singulated vs Monolithic

Singulated (Wafer-based) Architecture



Pro: Can sort cells to match performance
Con: More handling and failure points

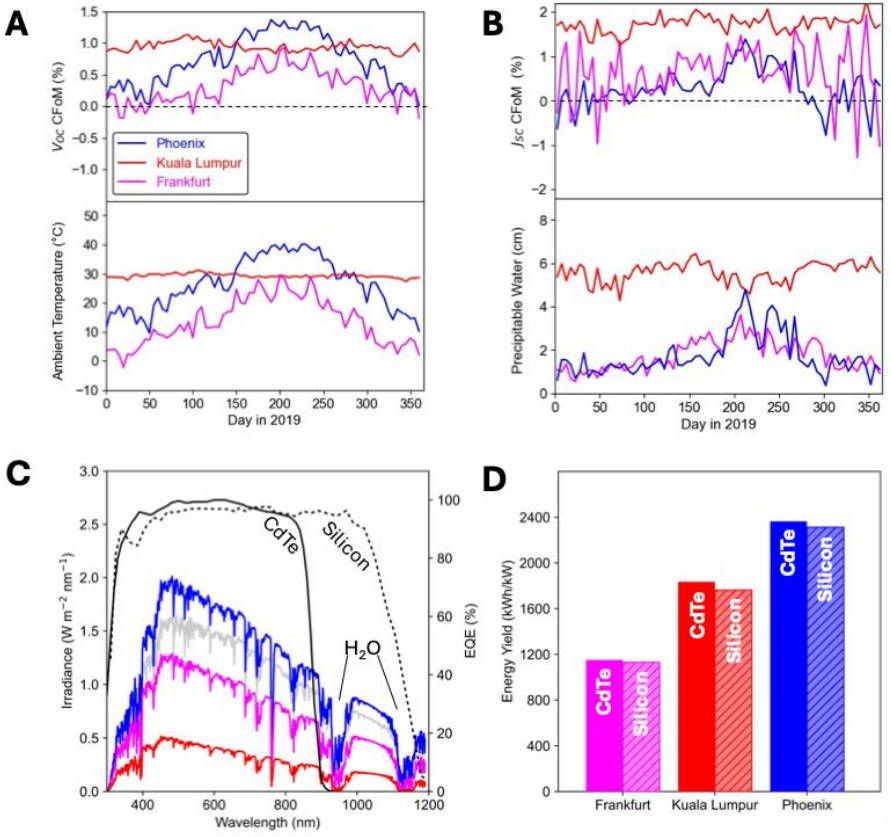
Monolithic (Thin-film) Architecture



Pro: All but connection to j-box is automatic
Lower cost, fewer failure points
Con: Large area uniformity can be challenging

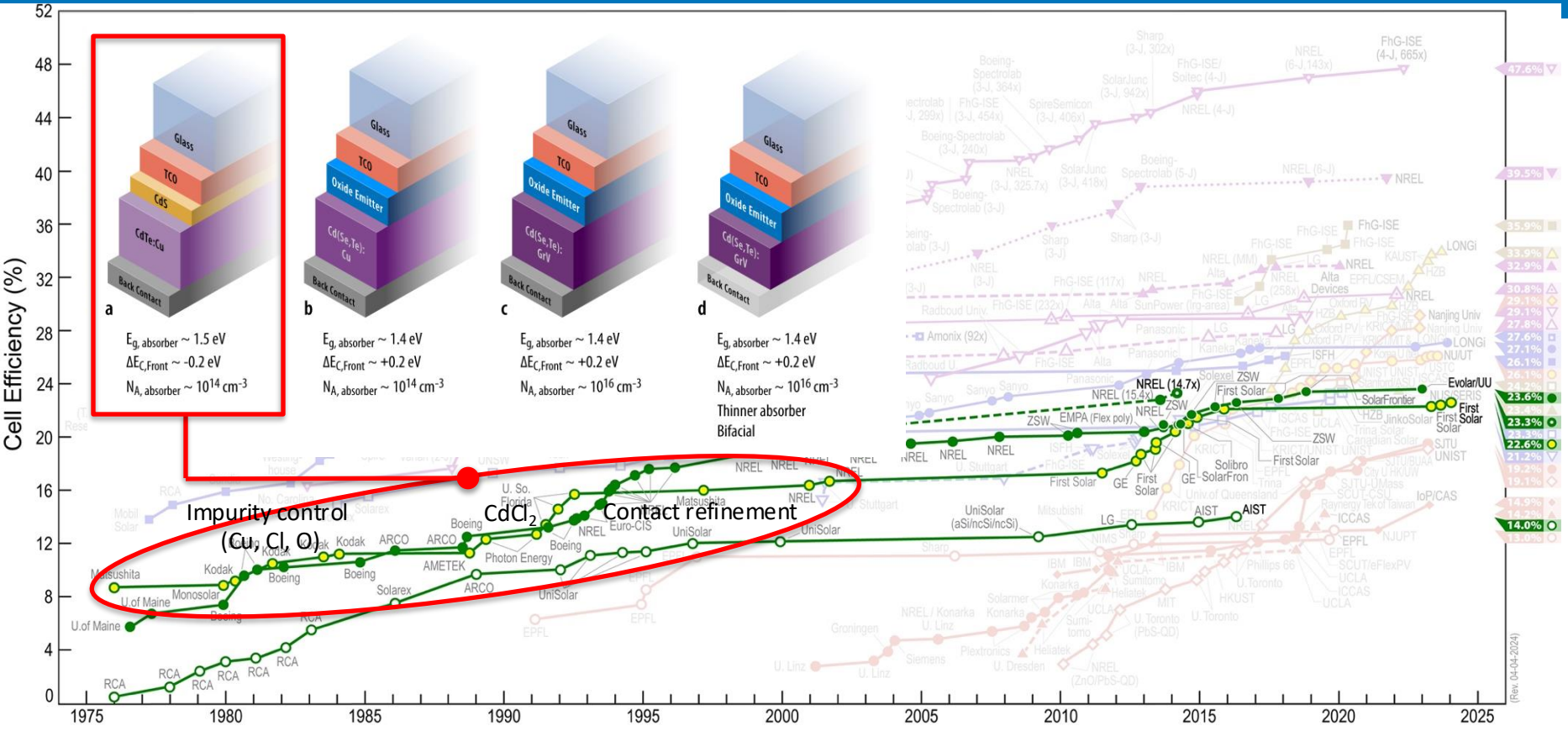
Comparative Energy Yield of CdTe Relative to Si

- CdTe has a favorable temperature coefficient (-0.32%/˚C vs -0.34%/˚C)
  - TOPCON → -0.29%/˚C
  - SHJ → -0.21%/˚C
  - Cd(Se,Te):As → -0.23/˚C
- CdTe has less spectral dependence from humidity
- CdTe has lower bifaciality
  - Si → 80-90% bifaciality
  - CdTe → ~15% bifaciality (today)



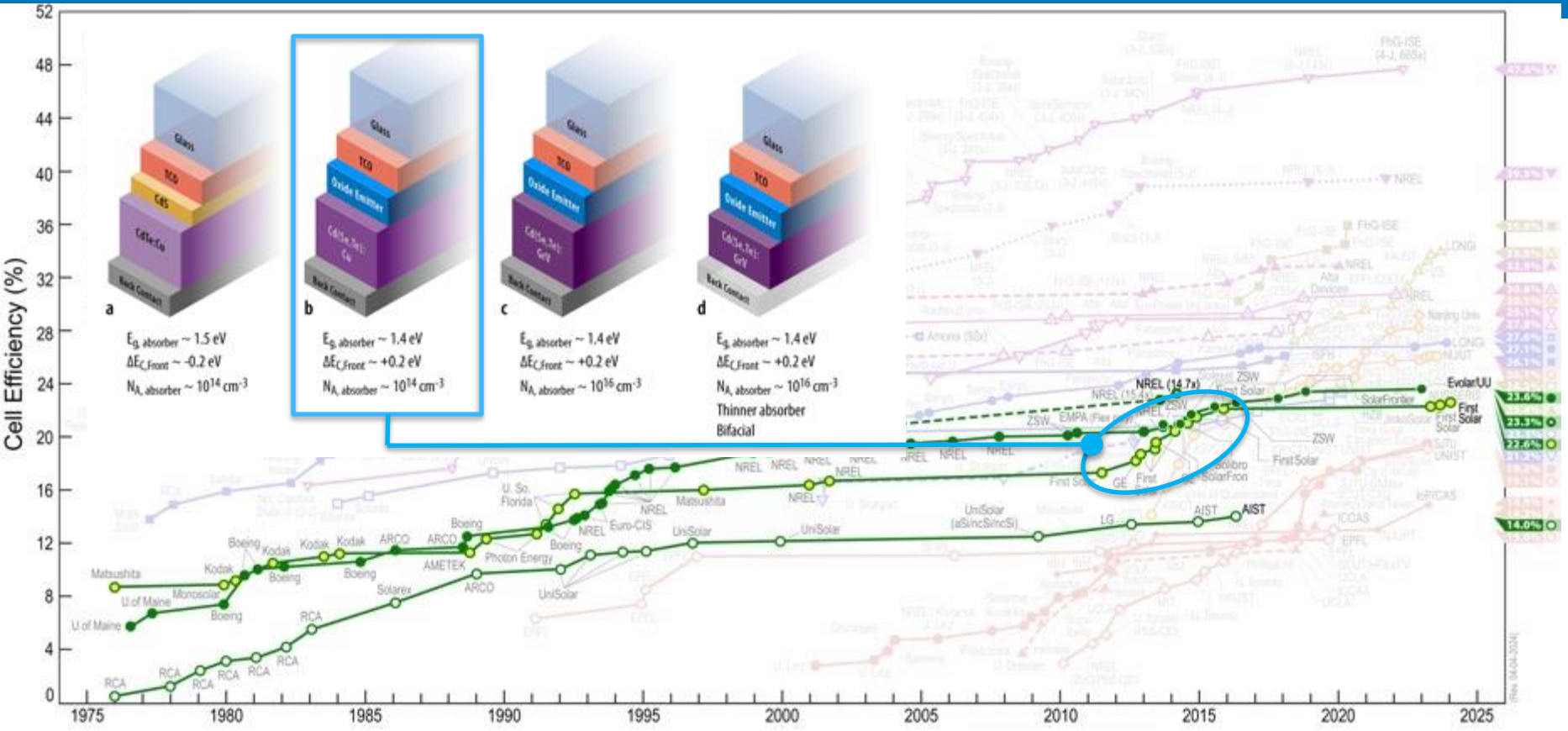
1. B.E. Sartor, et al. "Roadmap to 100 GW_{DC}: Scientific and Supply Chain Challenges for CdTe Photovoltaics " (under review)

Evolution of Cadmium Telluride Photovoltaics



P. Verlinden, et al., "Photovoltaic device innovation for a solar future" *Device, 1,* 100013 (2023). https://doi.org/10.1016/j.device.2023.100013

Evolution of Cadmium Telluride Photovoltaics



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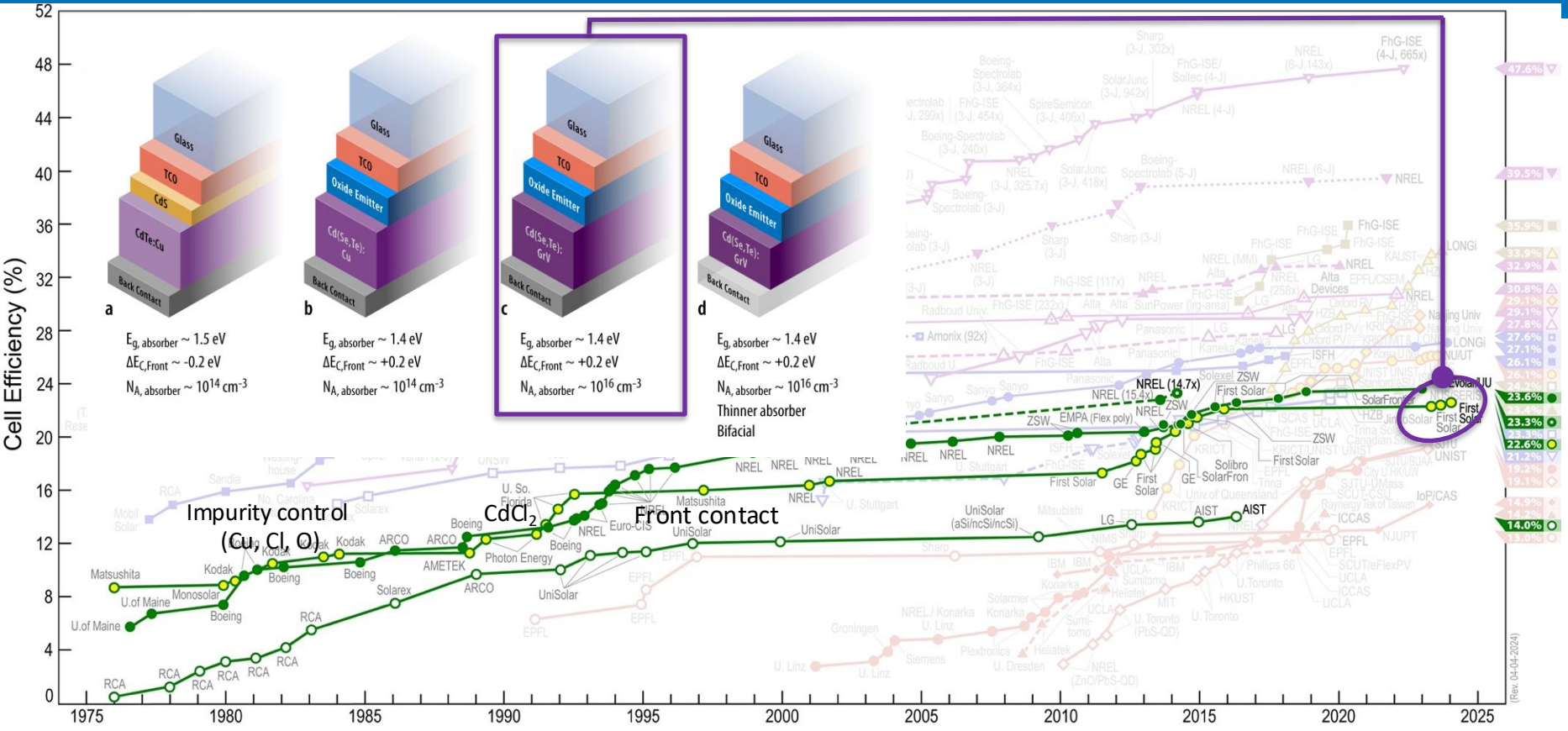
Evolution of Cadmium Telluride Photovoltaics

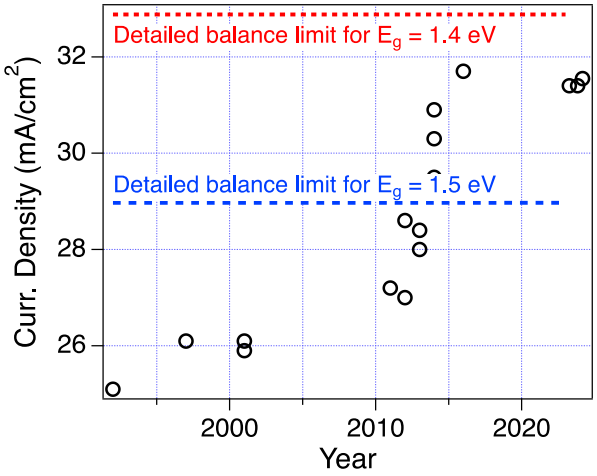


P. Verlinden, et al., "Photovoltaic device innovation for a solar future" *Device, 1,* 100013 (2023). https://doi.org/10.1016/j.device.2023.100013

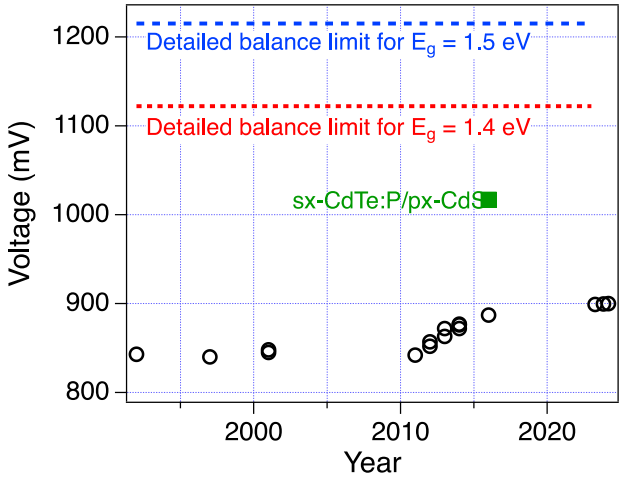
Entitlements

Detailed balance limit (25˚C, 1 sun, AM1.5G)[1]

	E_g (eV)	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	Eff. (%)
CdTe	1.5	28.97	1215	89.9	31.64
CdSeTe	1.4	32.88	1122	89.3	32.91



Present record (31.66 mA/cm^2): ~95% of current entitlement



Present record (904.8 mV): ~80% of voltage entitlement

Voltage has ***appeared*** flat… ~100 mV increase relative to entitlement has been realized

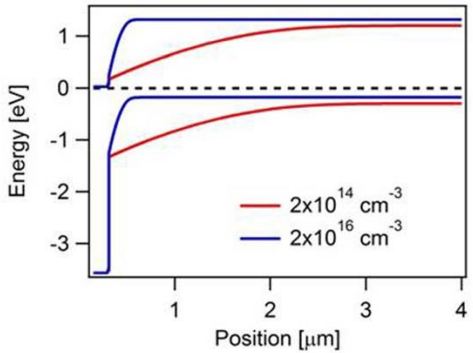
Why the historic gap?

- Minority carrier lifetime ~ ns
- Doping ~ mid-10^{14} cm^{-3}
- Recombination at interfaces
- Electronic disorder

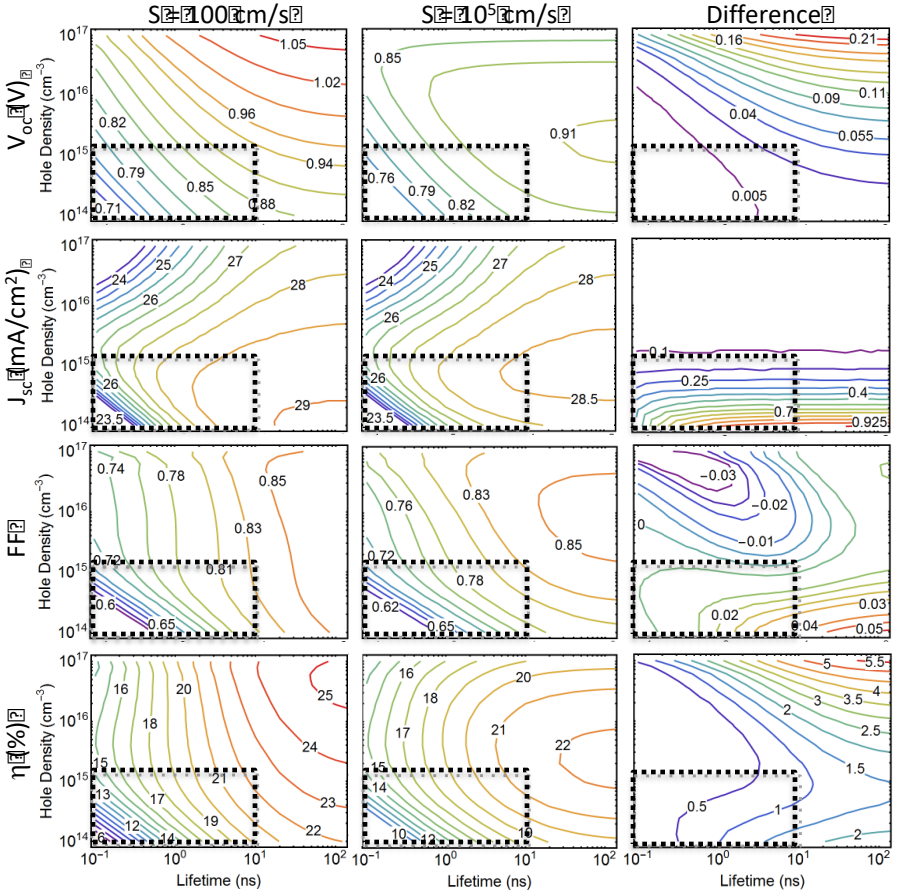
1. S. Ruhle "Tabulated values of the Shockley–Queisser limit for single junction solar cells" *Sol. Energy* 130 (2016) 139-147.
2. M.A. Green, et al. *Prog. Photovolt.: Res. Appl. Solar Cell, "Solar Cell Efficiency Tables"; https://www.nrel.gov/pv/interactive-cell-efficiency.html*

A Method to Improve Voltage

- First generation devices confined to dashed boxes,
- Se-alloying enables higher lifetime,
- Realizing significant improvements requires (simultaneously):
  - High lifetime
  - High doping
  - Low interface recombination (S)

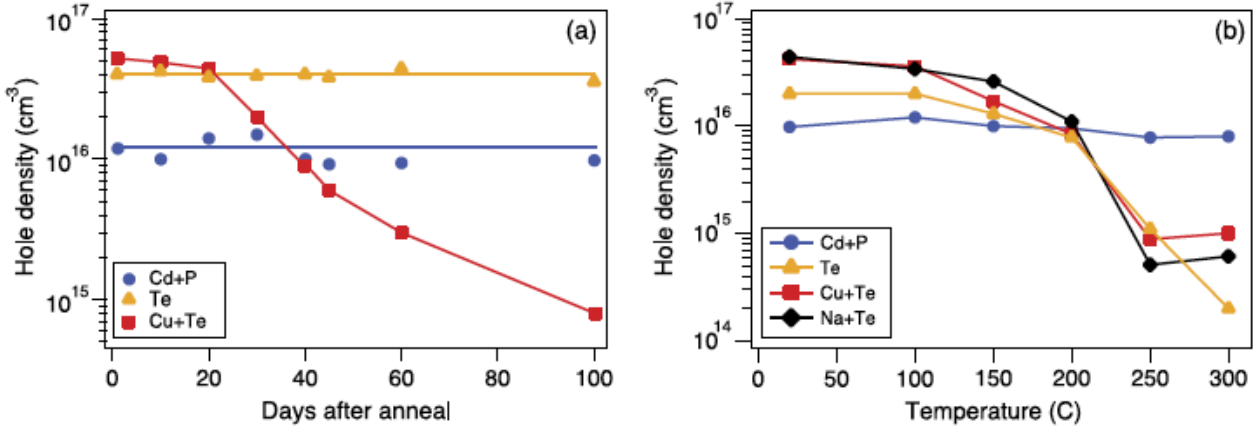


A. Kanevce, M.O. Reese *et al.* J. Appl. Phys. **121** (2017) 214506.



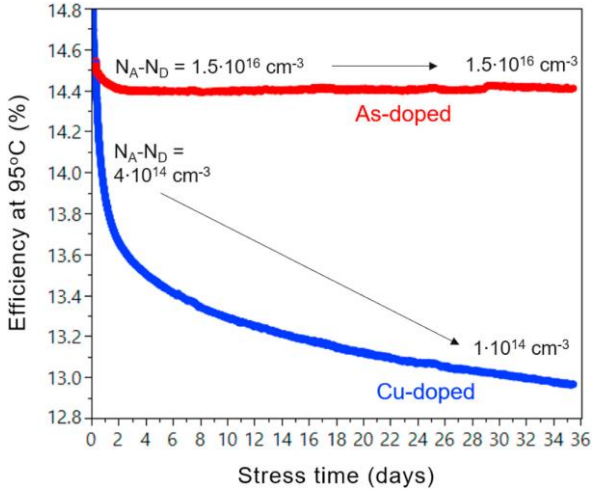
Finding a Replacement for Cu Doping

Doping in Single Crystals



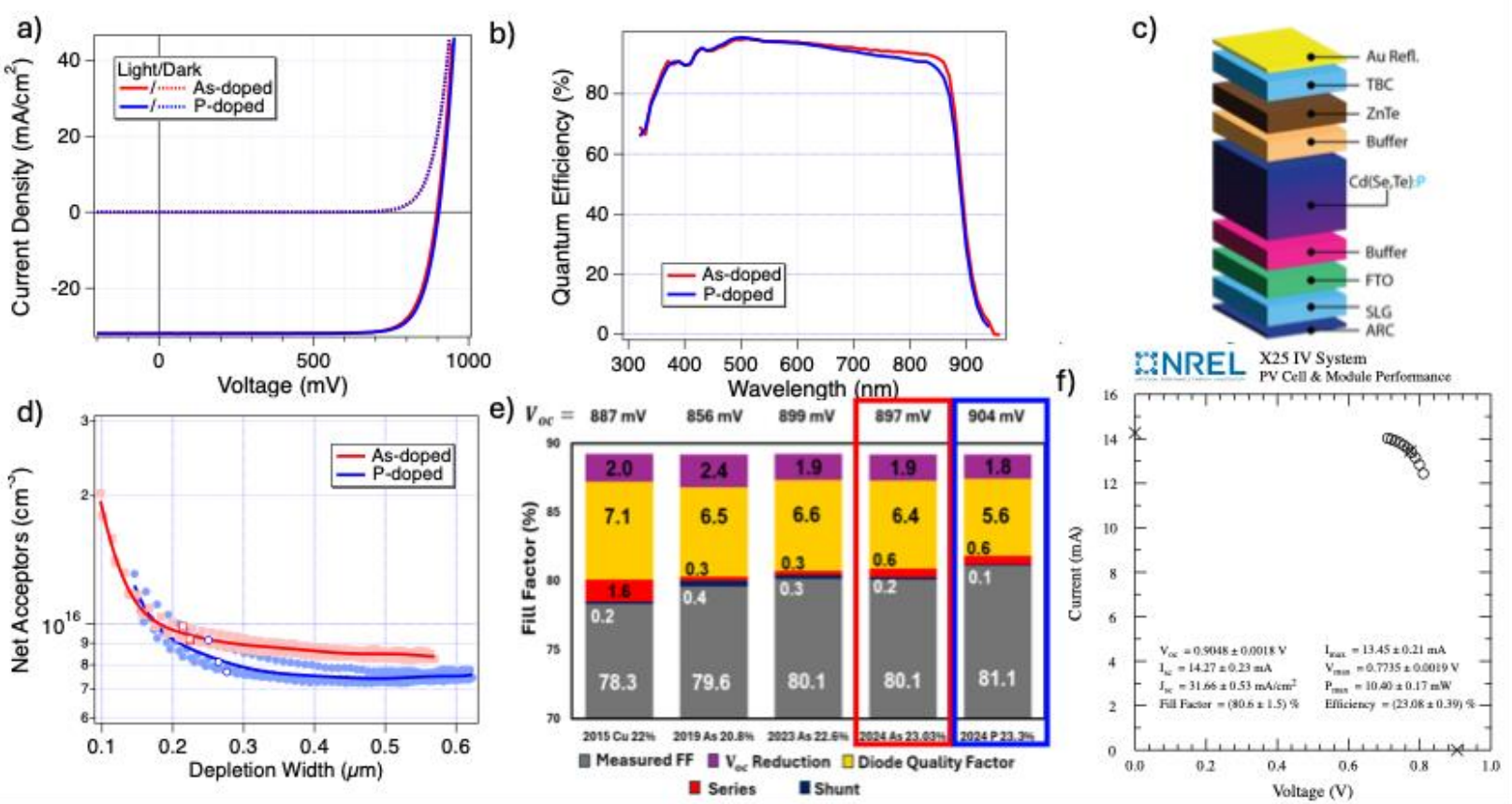
Cu is unstable with time & temperature even in single crystals

pX Thin-Film Devices



1. J.M. Burst, et al. *APL Mater.* **4** (2016) 116102.
2. D. Krasikov, et al. Sol. Energy Mater. Sol Cells 224 (2021) 111012.

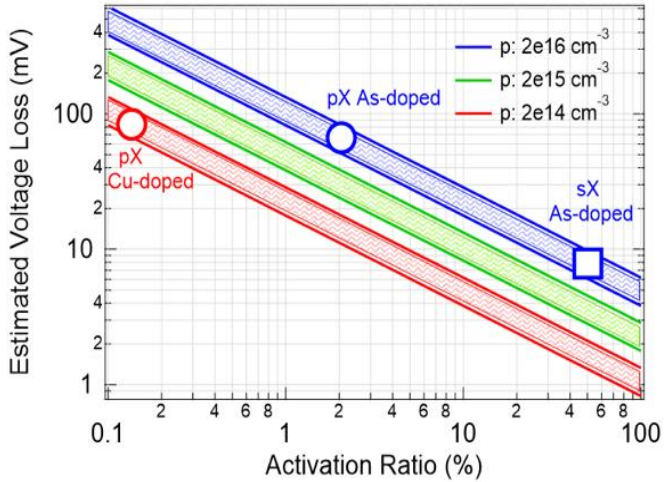
Recent CdTe Record Cells



D. Lu et al. (in preparation)

Present Opportunities for Improvement

Activation

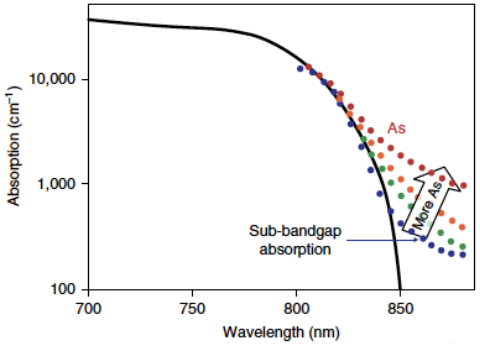


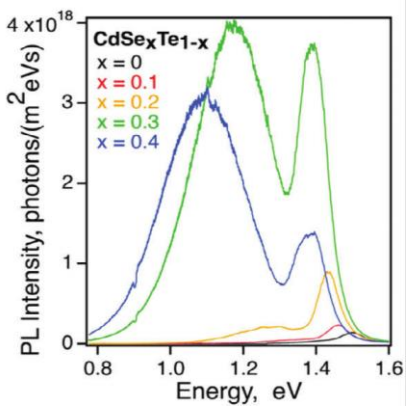
Low dopant activation may cause sizable Voc losses:

- P-doped ~ 20-50 mV
- As-doped ~ 50-100 mV

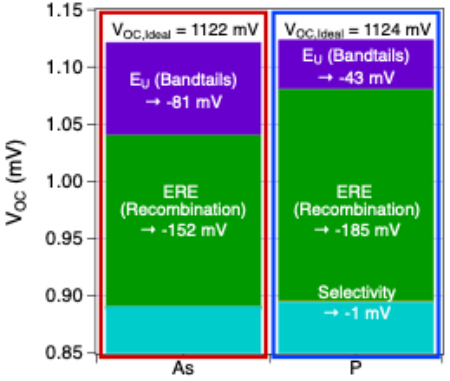
Activation is the ratio of electrically active carriers to chemically incorporated dopants

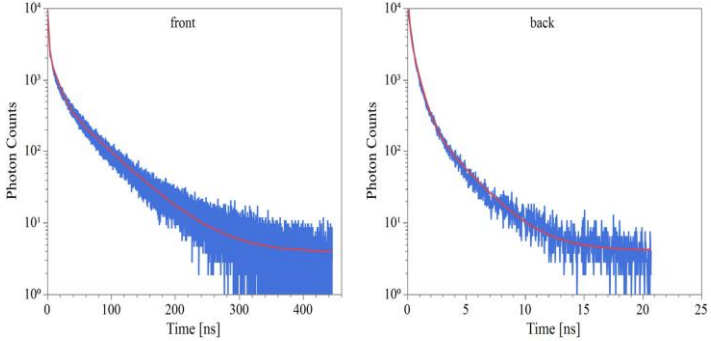
Electronic Disorder





Recombination





1. B.E. Sartor et al. (under review)
2. W.K. Metzger, et al. *Nat. Energy* 4 (2019) 837
3. D.L. McGott et al. *Adv. Sci.* (2024) 2309264.
4. D. Lu et al. (in preparation)
5. R. Mallick et al. *IEEE J. Photovolt.* 13 (2023) 510.