Solar Cells
-- Silicon & Beyond

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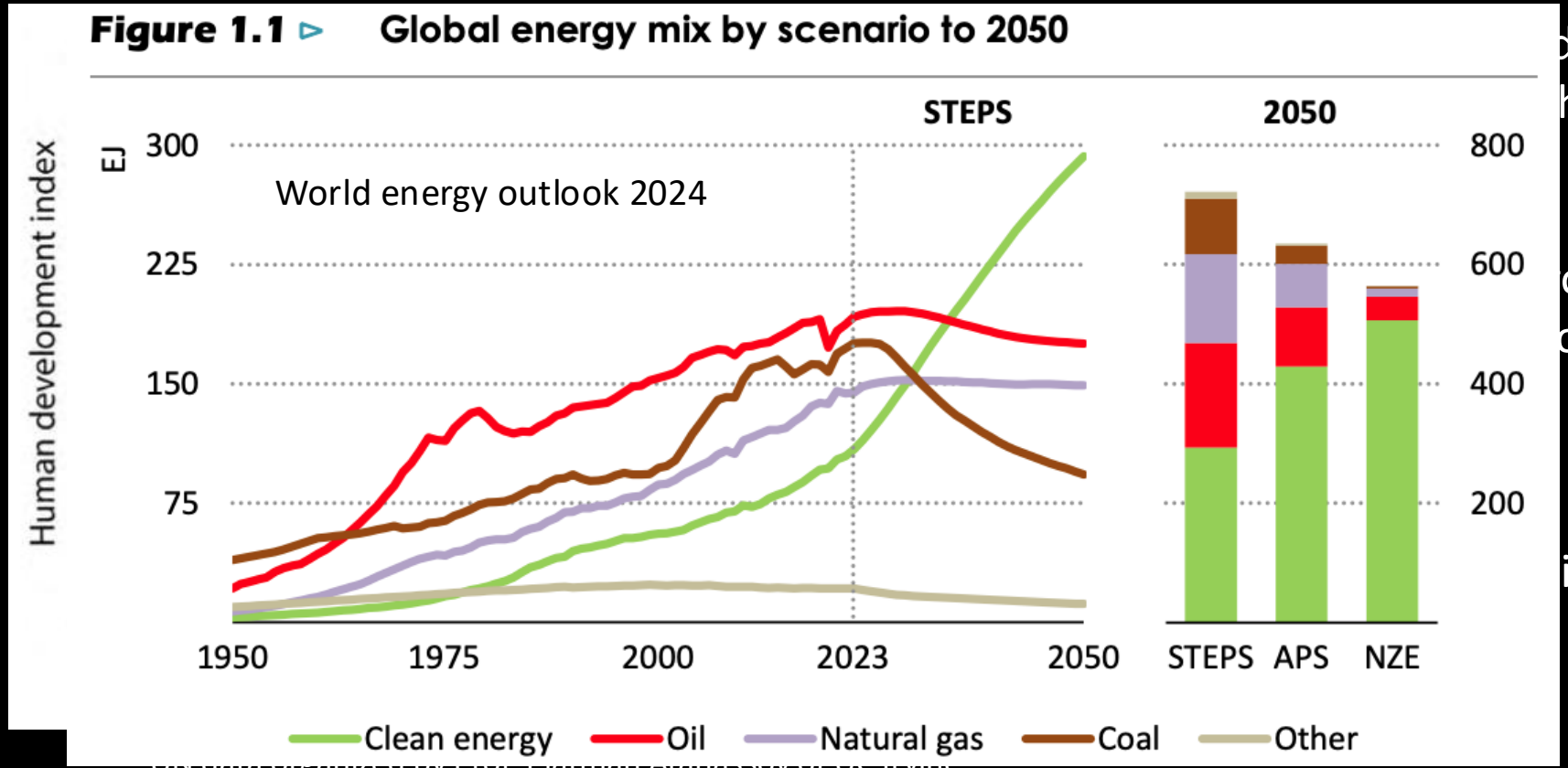
Materials Science & Engineering

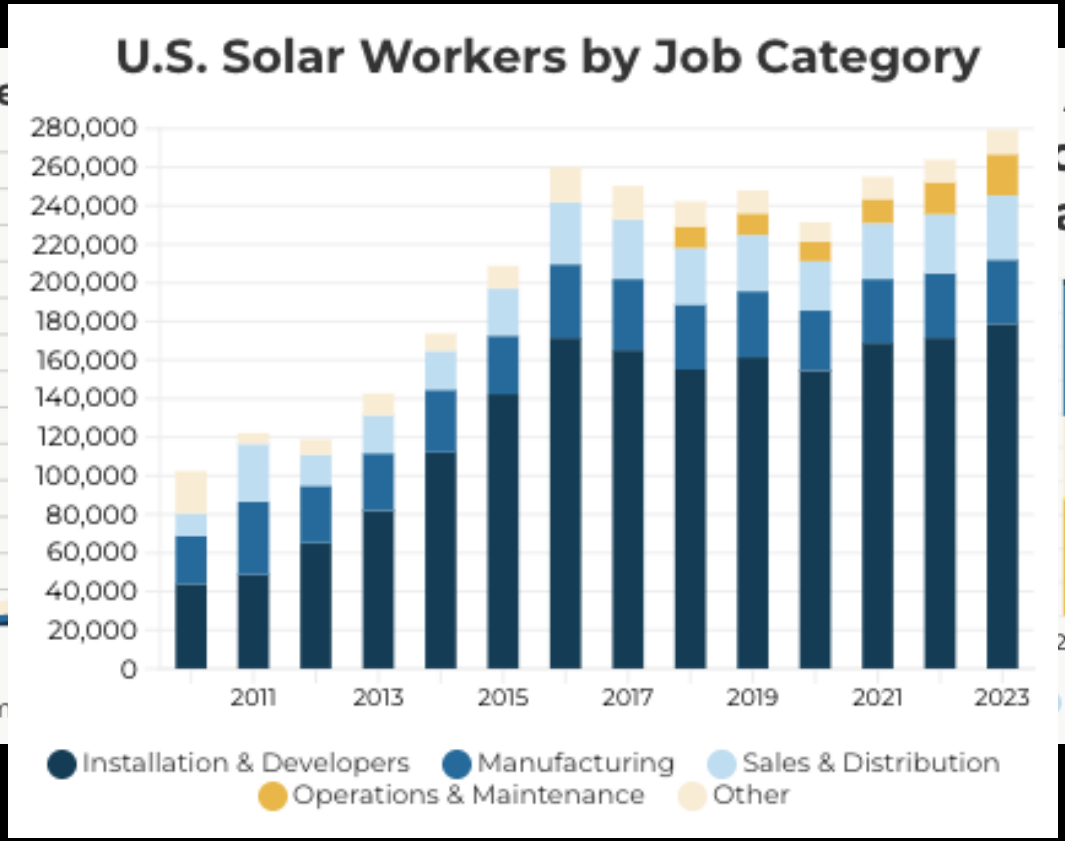
- https://mse.utdallas.edu/ (https://youtu.be/zX7WCCYtse8)
- Currently 17 tenured & tenure-track faculty
  - Computational (4.5) and experimental (12.5); Electronic materials; Surface & interfacial sciences; Biomedical, energy, environmental applications; Micro/nanoelectronic devices based on new materials
  - 2018-2021 publications: 368
- Total research expenditure in FY2024: $13.3M ($11.2M Federal)
- Graduate students (Fall 2024):
  - MSEN: 53 (47 PhD, 6 MS)
  - Graduate students from other (Physics, Chemistry, EE, MechE) programs supported/supervised by MSE faculty: ~ 10
  - *B.S. will start Fall 2026*

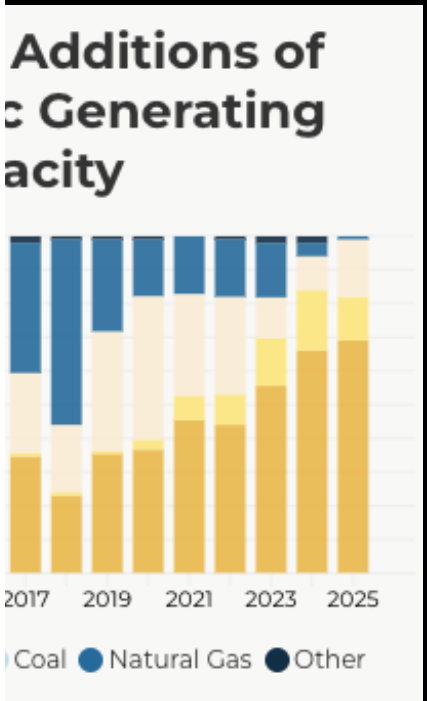
Why do we need solar?



UN data organized by Prof. Platman Atanassov of UC Irvine

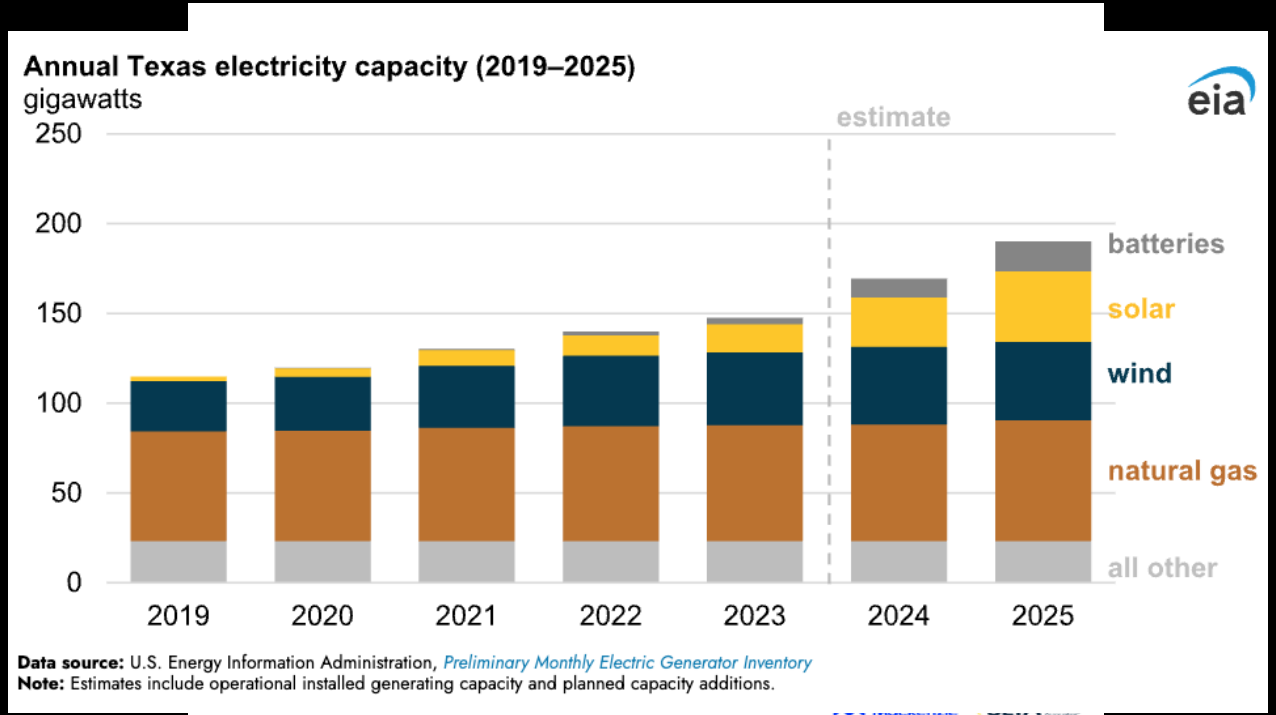
Solar Growth in US





Solar Industry Research Data – SEIA

Adoption in Texas



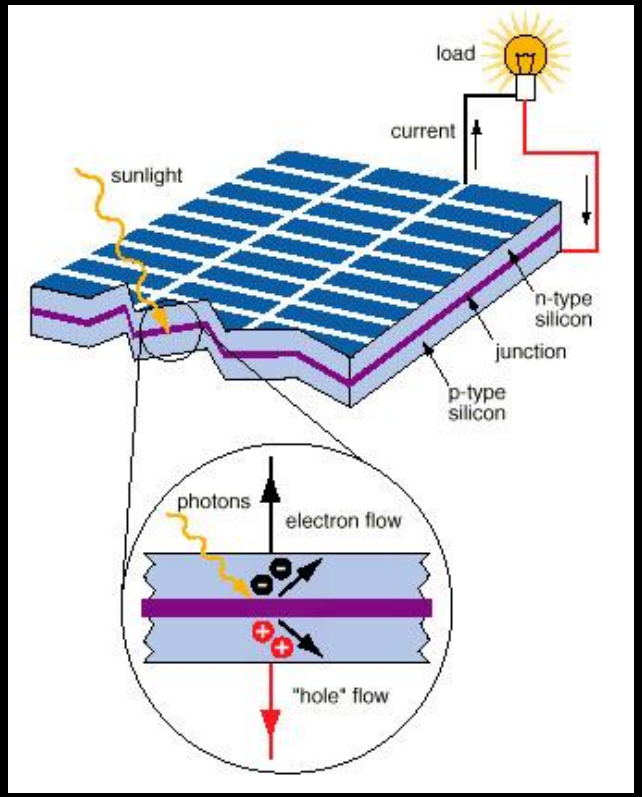
Solar capacity additions are changing the shape of daily electricity supply in Texas - U.S. Energy Information Administration (EIA)

Solar Cells Everywhere

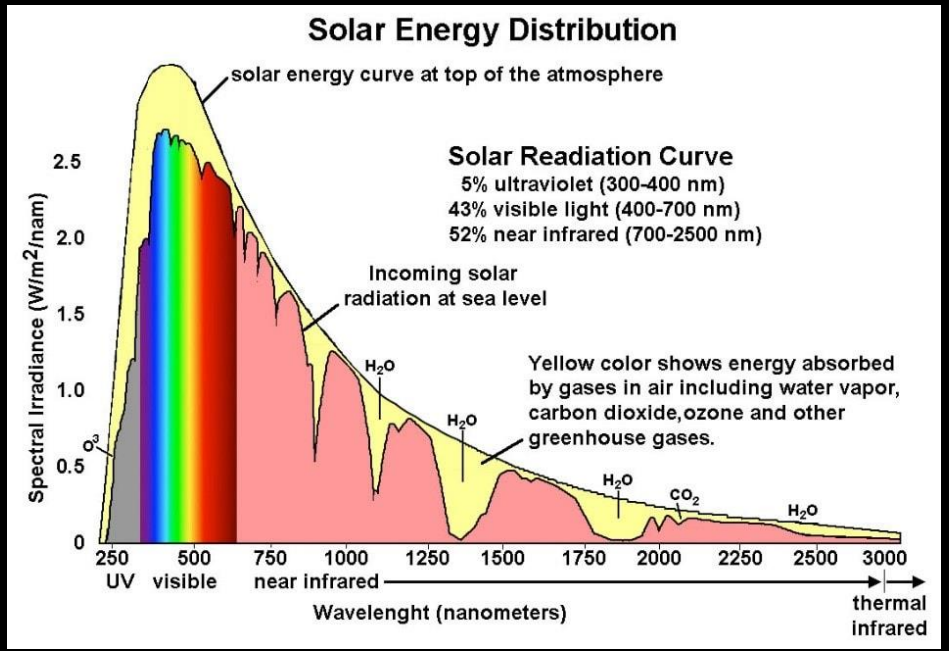
Residential

Utility: Solar Farm

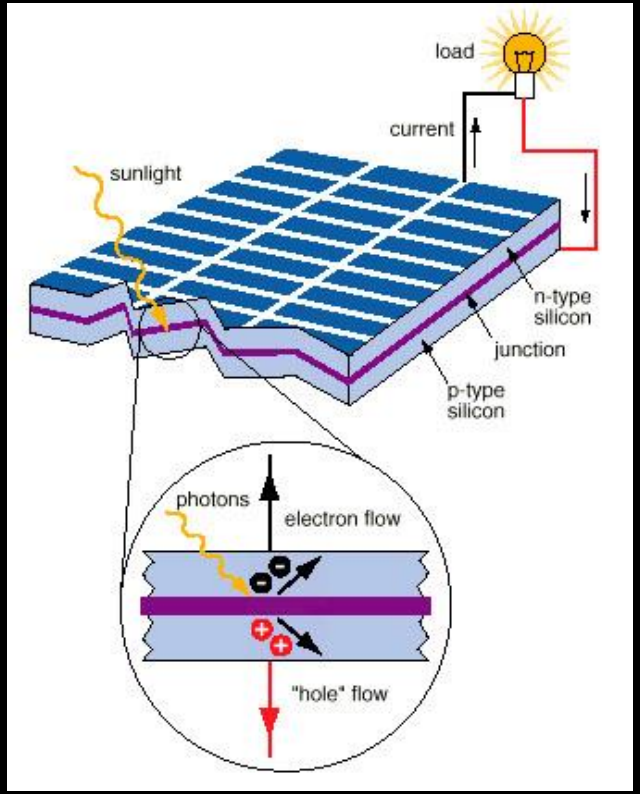
How Do Solar Cells Work?



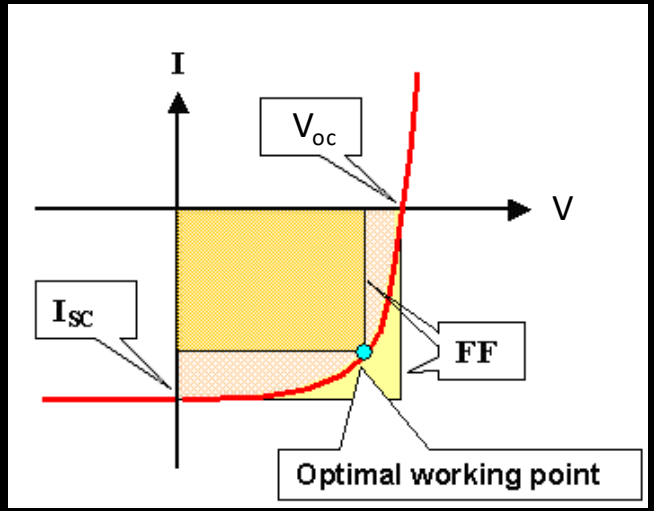
- Convert the energy of sunlight directly into electricity
- Need: An electrode to let sunlight in
  Something to absorb sunlight & generate charges
  Device design to separate charges



How Does It Work?



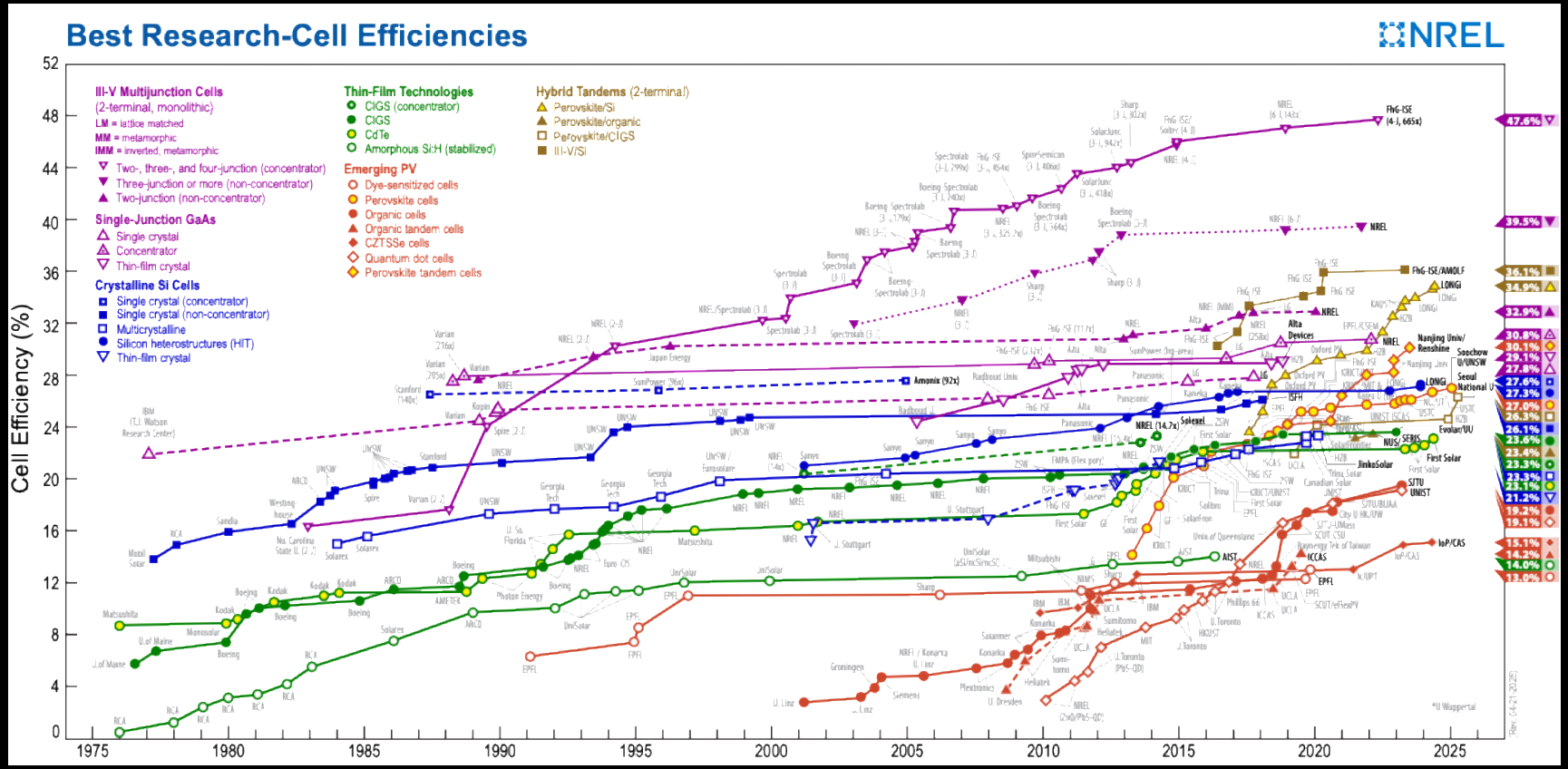
- > 90% commercial solar cells are made of Si
- How to separate photogenerated electrons and holes?
- 1883: Charles Fritts, Au:Se Schottky juntion
- 1954: Chapin, Fuller, Pearson @ Bell Labs, diffused Si p-n junction



$$PCE = \frac{V_{oc} \times J_{sc} \times FF}{P}$$

Maximum power point

State of the Art Solar Cell Efficiency



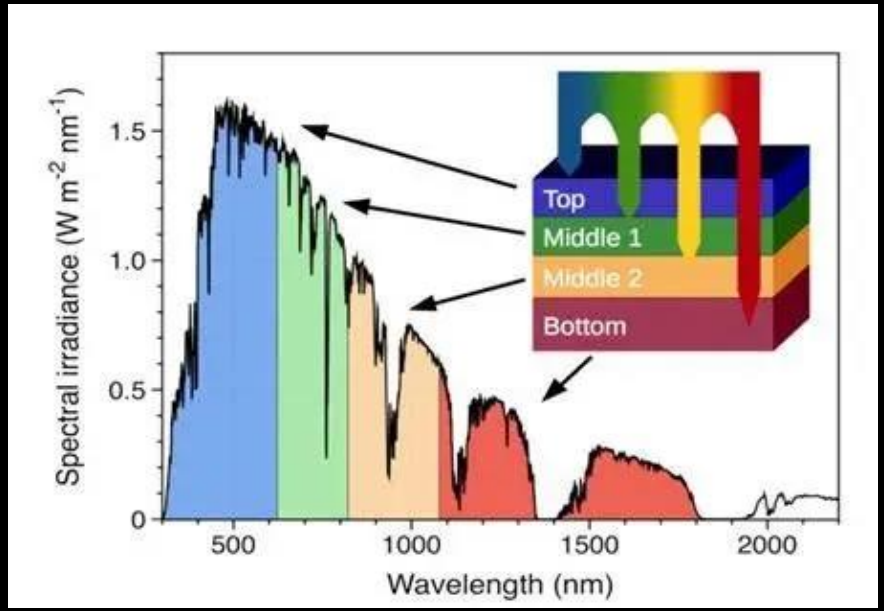
Si Solar Cells

Residential

Utility: Solar Farm

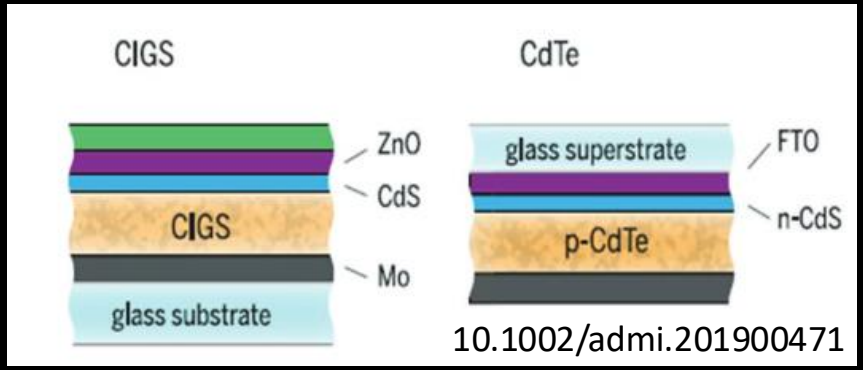
III-V and Multi-junction Solar Cells

- Si is an indirect bandgap material
- III-V (GaAs, InP) Solar Cells: high efficiency due to direct bandgap, high cost, mostly used for space applications
- 2-, 3-, and 4-junction tandem solar cells

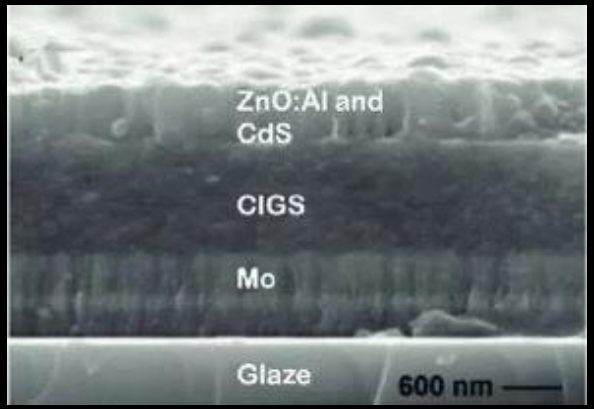


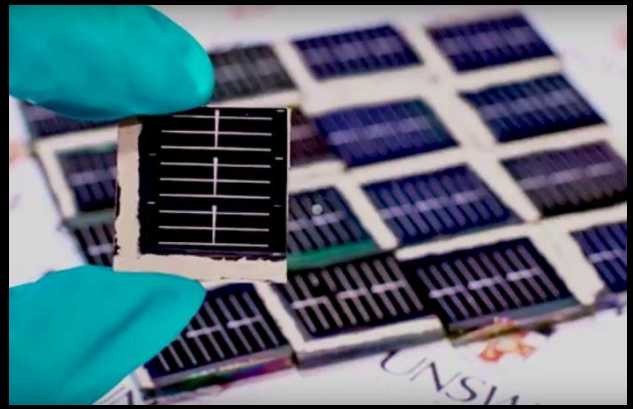
Thin Film Solar cells

- CdTe, $Cu(In_xGa_{1-x})(S,Se)_2$ (CIGS), amorphous Si



10.1002/admi.201900471

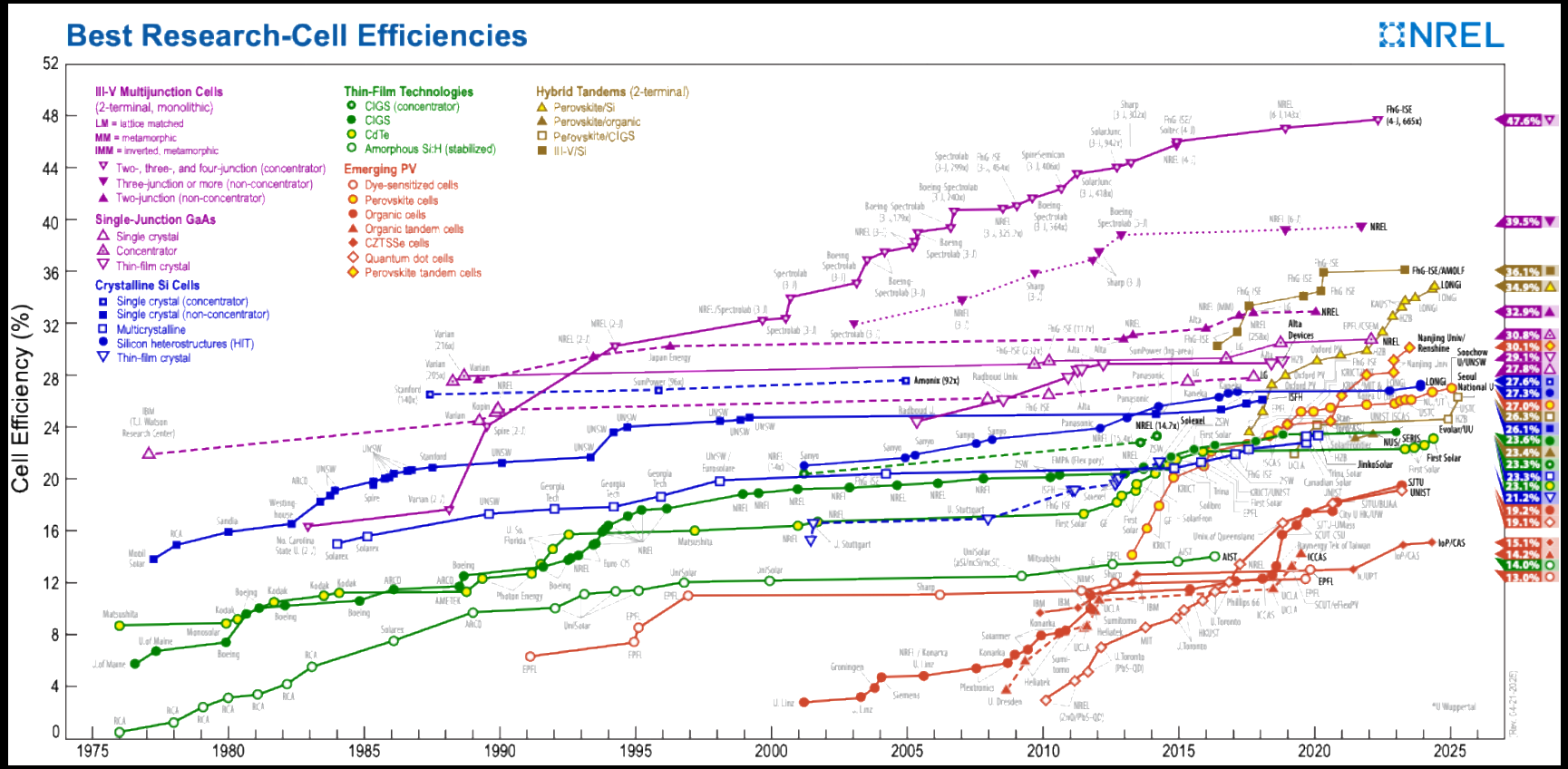




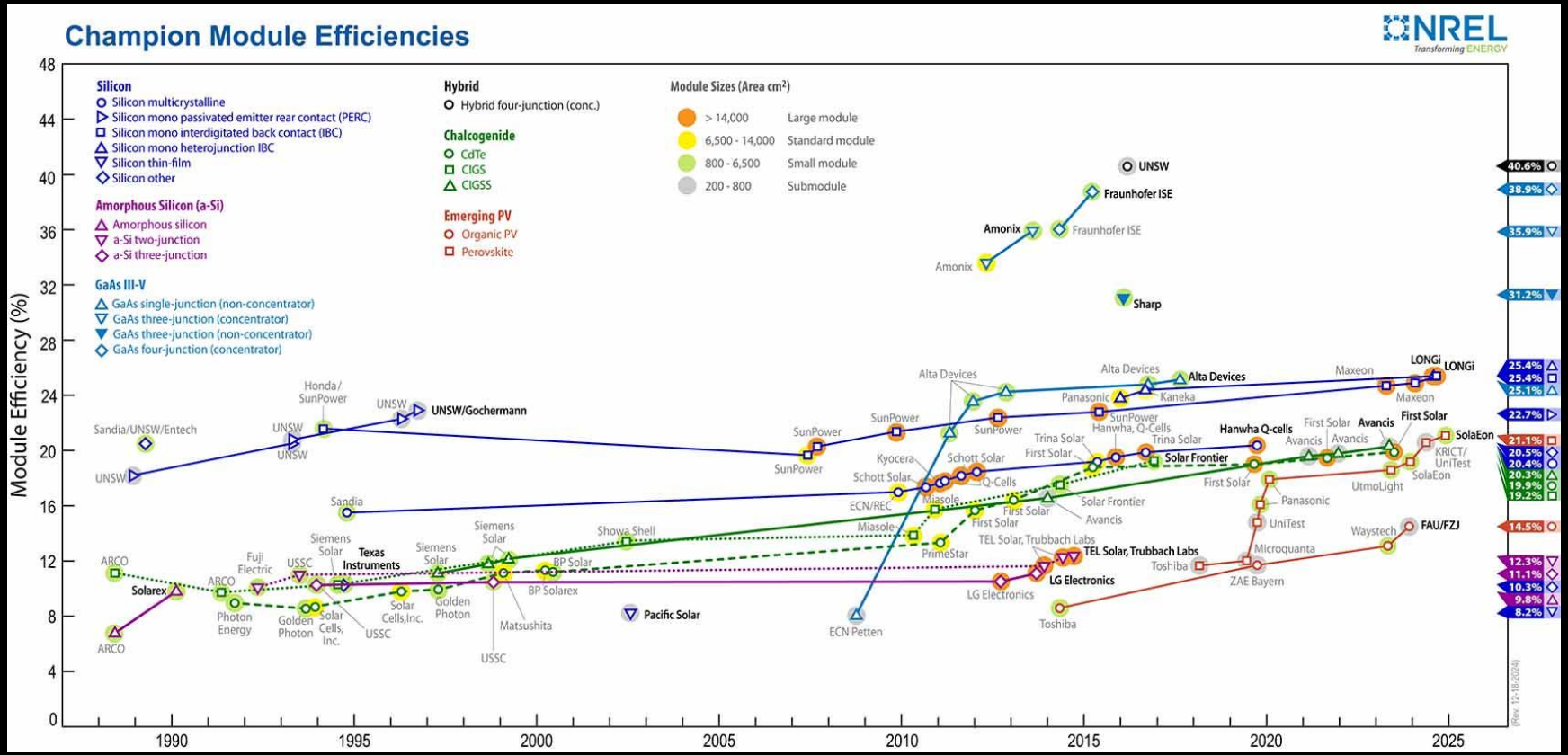
Concentrated Solar

Concentrated solar panels, often combined with solar thermal

State of the Art Solar Cell Efficiency

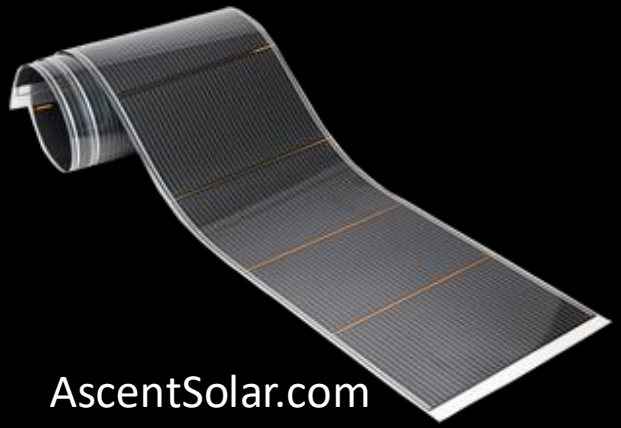


State of the Art Solar Module Efficiency

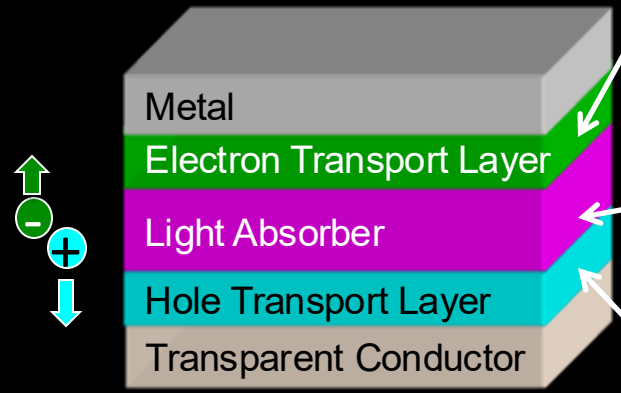


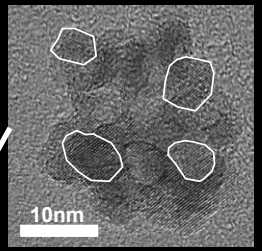
Emerging Photovoltaics

- Small molecules; Polymers; Dye sensitized; Perovskites ($CH_3NH_3PbX_3$); CuZnSn(S,Se) (CZTSS)
- Flexible, light-weight, bandgap can be designed => colors
- Solution processible, conducive to roll-to-roll manufacturing

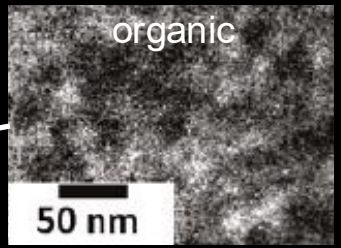


Different Device Structure

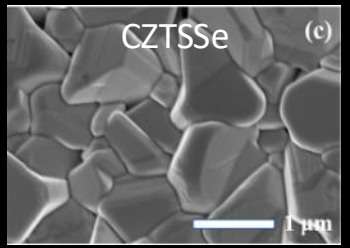




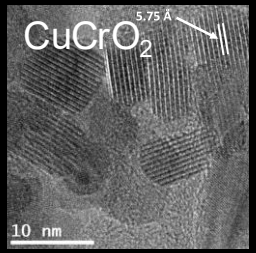
ZnO nanoparticles

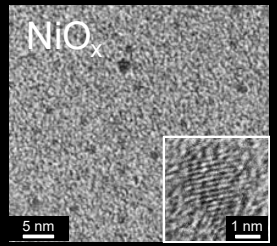


10.3390/cryst9090474



Metal oxide nanoparticles

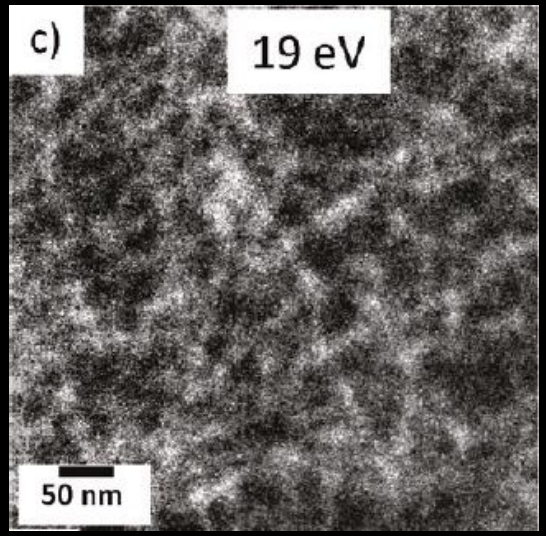




Organic Solar Cells

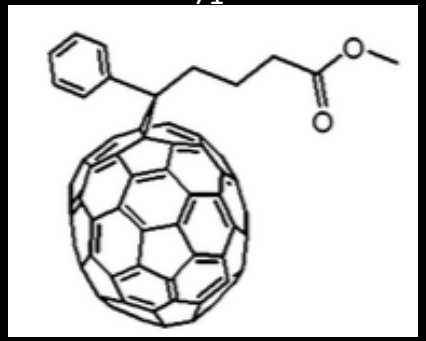
- A mixture (bulk heterojunction) of donors (donate electrons) and acceptors (accept electrons)
- First generation: Acceptors are C60 (bulky ball) based; donors are conjugated polymer
- Currently: Non-fullerene acceptors, much more complicated

P3HT:PCBM

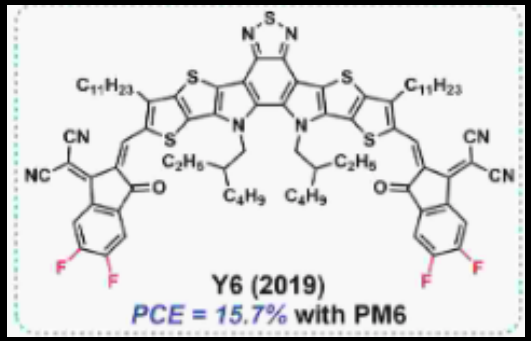


L. Drummy, Chem. Mat. 23, 908 (2011)

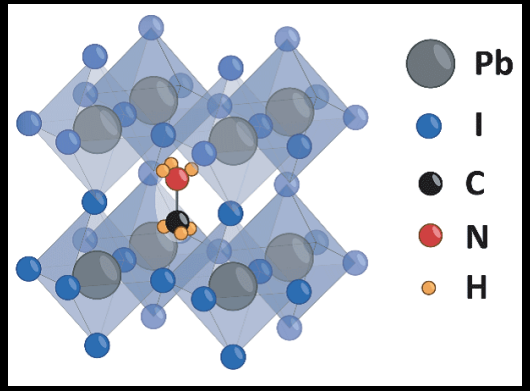
$PC_{71}BM$

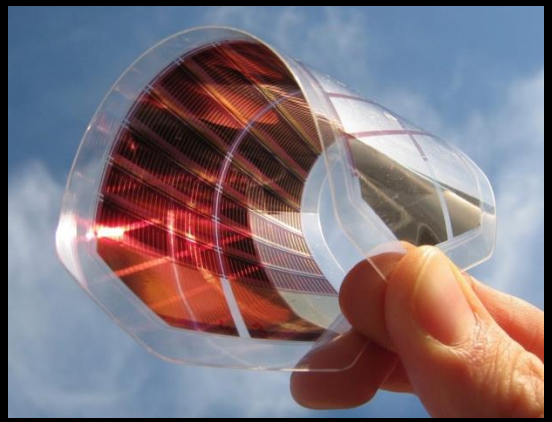


Y6

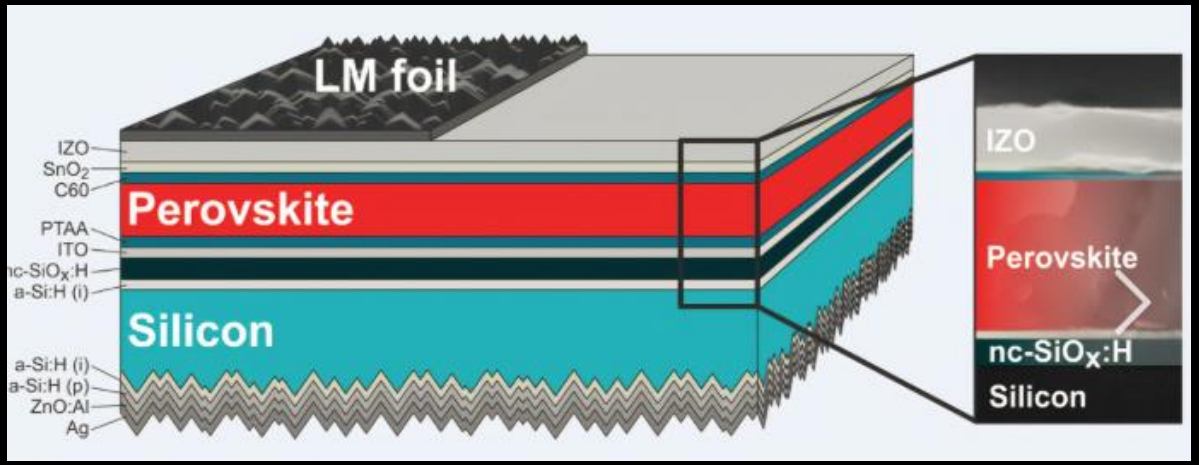


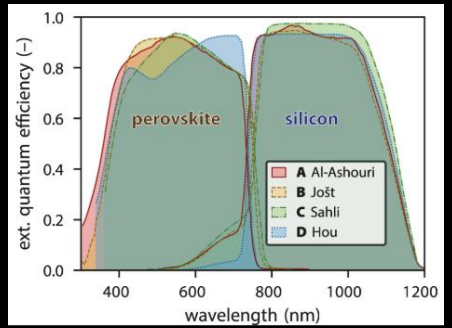
Halide Perovskite Solar Cells





Si-Perovskite Tandem

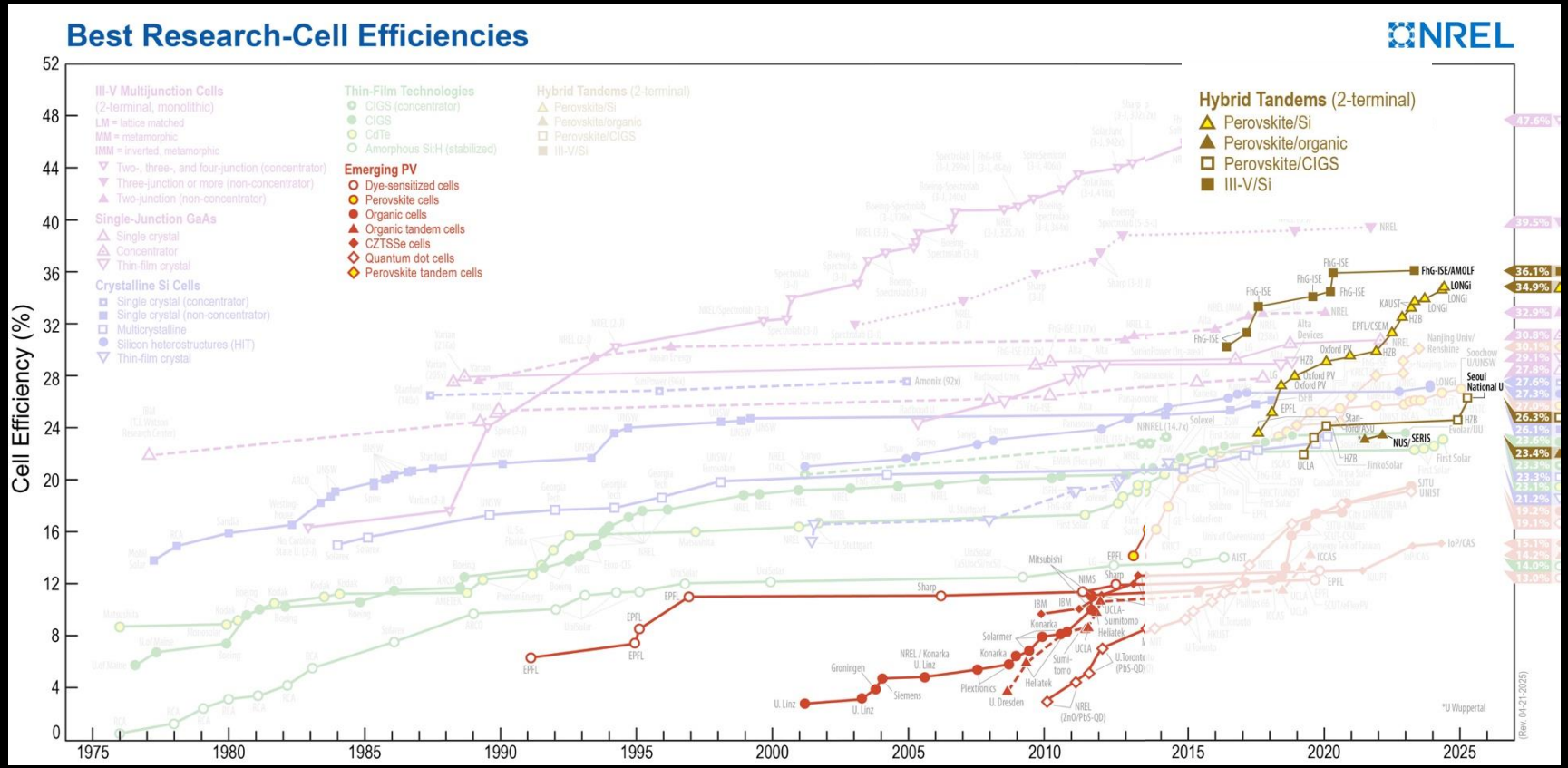




State of the art efficiency:

- Perovskite: 27%
- Si: 26.1%
- Perovskite – Si tandem: 34.9%

Emergent Solar Cell Efficiency



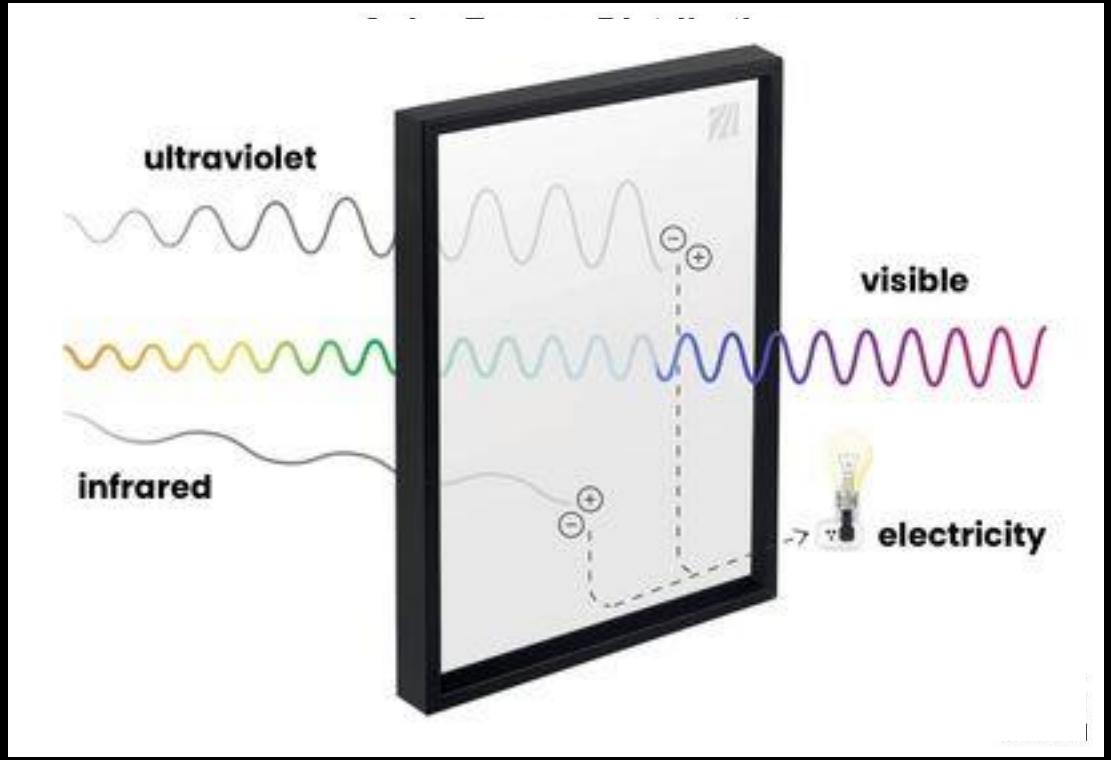
OPV Applications

Expo 2020 Dubai

Power Generating Windows

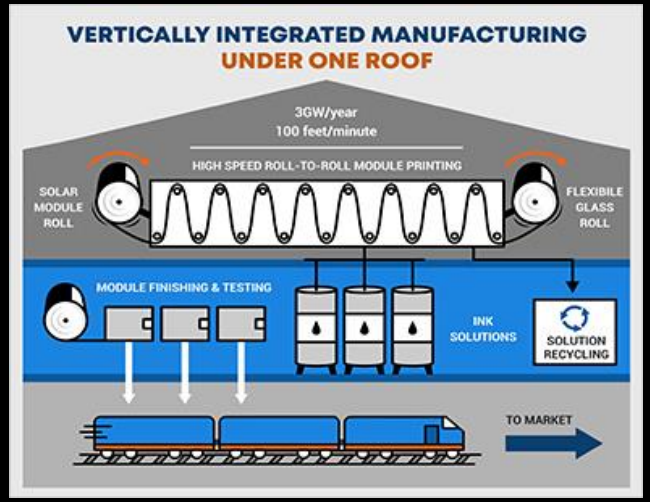
Next Energy Technologies

How does it work?

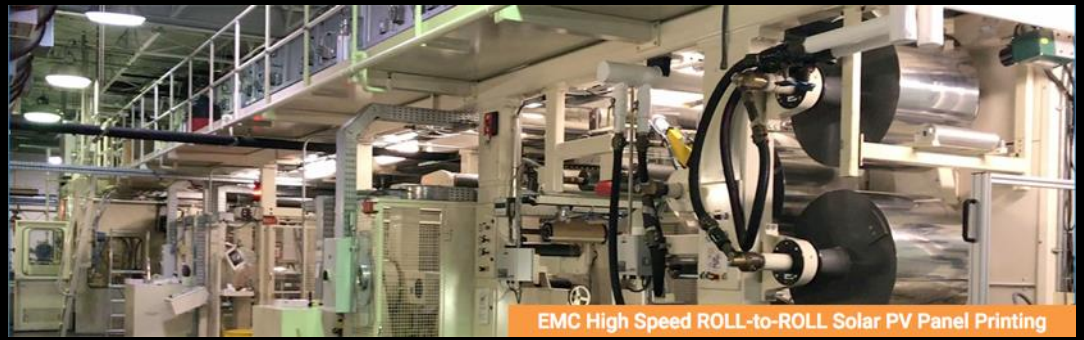


Agrivoltaics

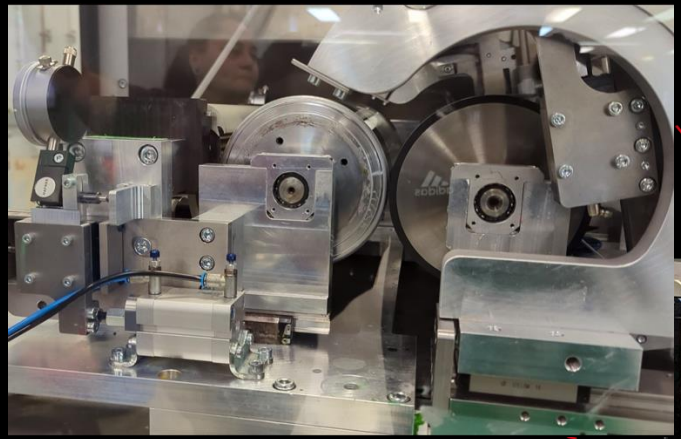
Increasing Perovskite Solar Cell Production

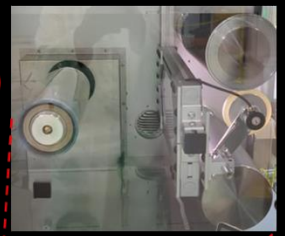


- Take advantage of excellent materials properties from solution processing, high-speed solution coating methods, and economy of scale
- One manufacturing line may produce 4 GW of solar panels per year @ $0.15/W (1.5 m web at ***30 m/min***)
- 10% of the capital cost of silicon solar panel manufacturing



Roll-to-Roll Manufacturing





1. Unwinder
2. Edge guide
3. Doctor Blade
4. Anilox roller
5. Hot air oven
6. Rewinder
7. Light table

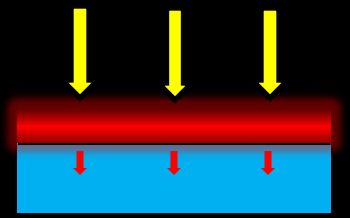
Thermal Annealing Is Too Slow

https://www.sheknows.com/food-and-recipes/articles/1122129/worlds-longest-pizza/

- 1.15 mile long, took 11 hours => ***2.8 m/min***
- 5 ovens
- Speed limited by the slowest step, i.e., time in the oven and oven size
- At 30 m/min, 20 min annealing translates to 600 m long ovens!

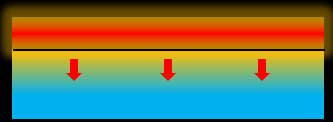
Use light instead of heat

Using Photons for Thin Film Processing



0 – 0.5 ms

Film temperature depends on energy applied (light pulse) and lost (transfer to substrate) during pulse

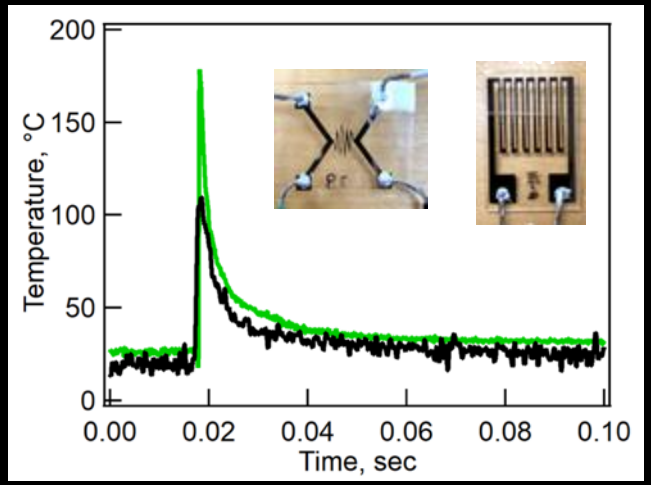


0.5 – 50 ms

Heat transfer to substrate continues after pulse

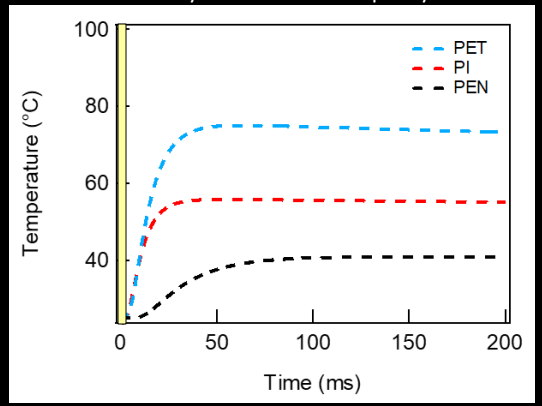
100 ms

Substrate temperature depends on energy applied and substrate heat capacity



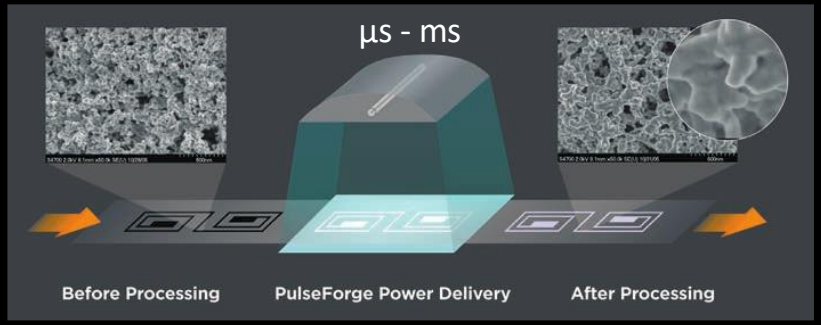
Substrate temp:

dictated by substrate heat capacity



- High intensity but low energy due to short pulse
- Film surface can reach high T with minimal substrate heating
- Arrhenius Law => higher T, higher reaction rate

Optimize Photonic Curing Outcome

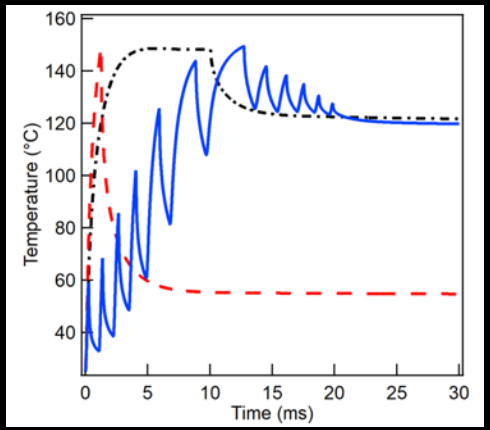


NovaCentrix.com

Key Variables:

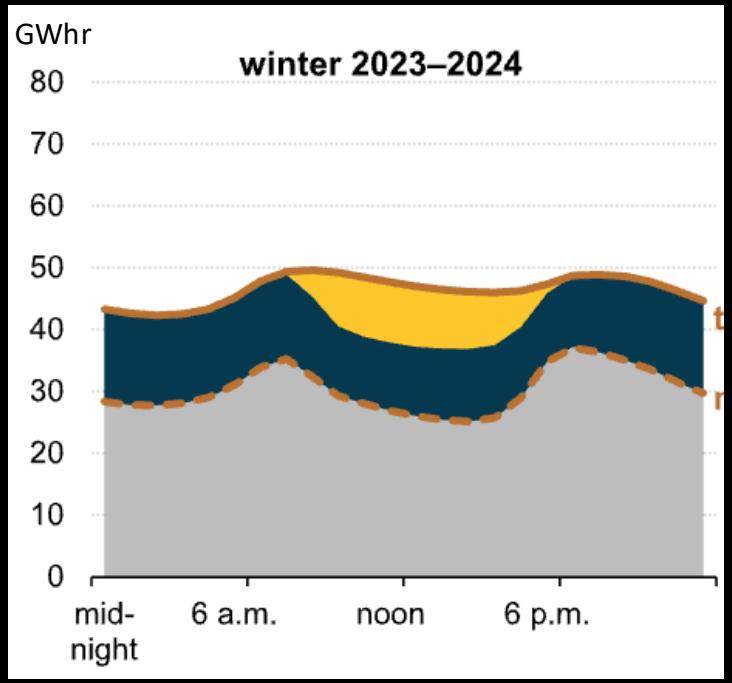
- Lamp voltage (light intensity)
- Pulse length (20 µs – 100 ms)
- Number of pulses (1 – n)
- Micropulses (0 – 30)
- duty cycle
- Pulse rate (< 1 Hz – 50 kHz)

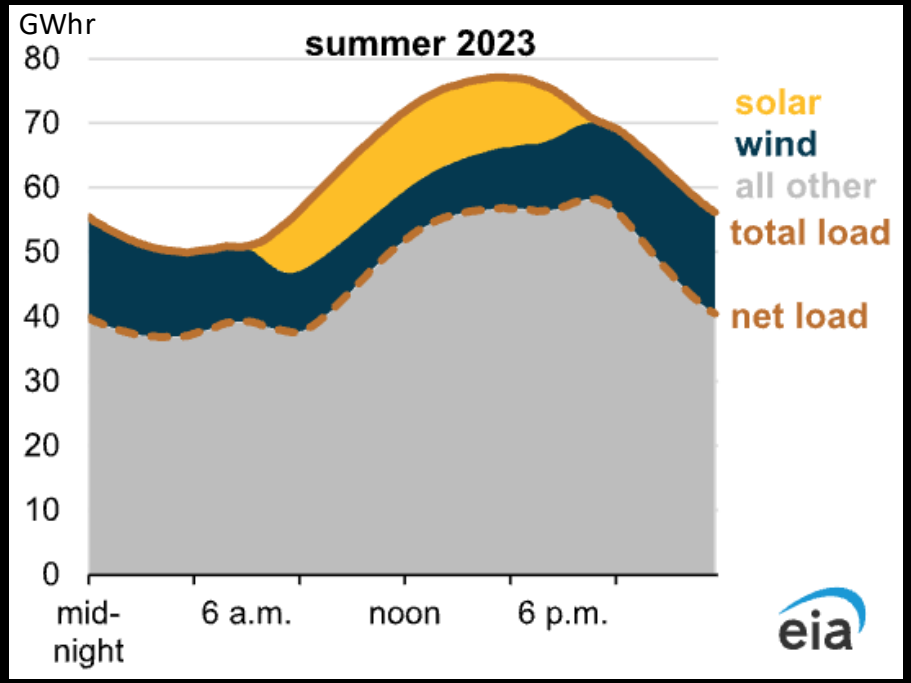
- Too many variables to optimize using traditional grid search method by varying one variable at a time
- Adopt Bayesian optimization framework in machine learning to find the processing condition that can produce the best result
- This approach can be adapted to all processing



Sun Doesn’t Shine All the Time

Solar capacity additions are changing the shape of daily electricity supply in Texas - U.S. Energy Information Administration (EIA)





Energy Storage is critical!

Thank You

Questions?