High-efficiency solar cells for large-scale electricity generation

Outline

- Solar is growing very fast
- Optical concentration
  - Reduces semiconductor material
  - Allows use of more efficient (expensive) cells
- The physics high-efficiency solar cells
  - Why using multiple junctions increases efficiency
  - Success of GaInP/Ga(In)As/Ge cell
  - New designs (GaInP/GaInAs/GaInAs) reach 40.8%
- Potential for large-scale solar electricity generation




SAN BERNARDINO COUNTY
CALL
BOX
395 : 472



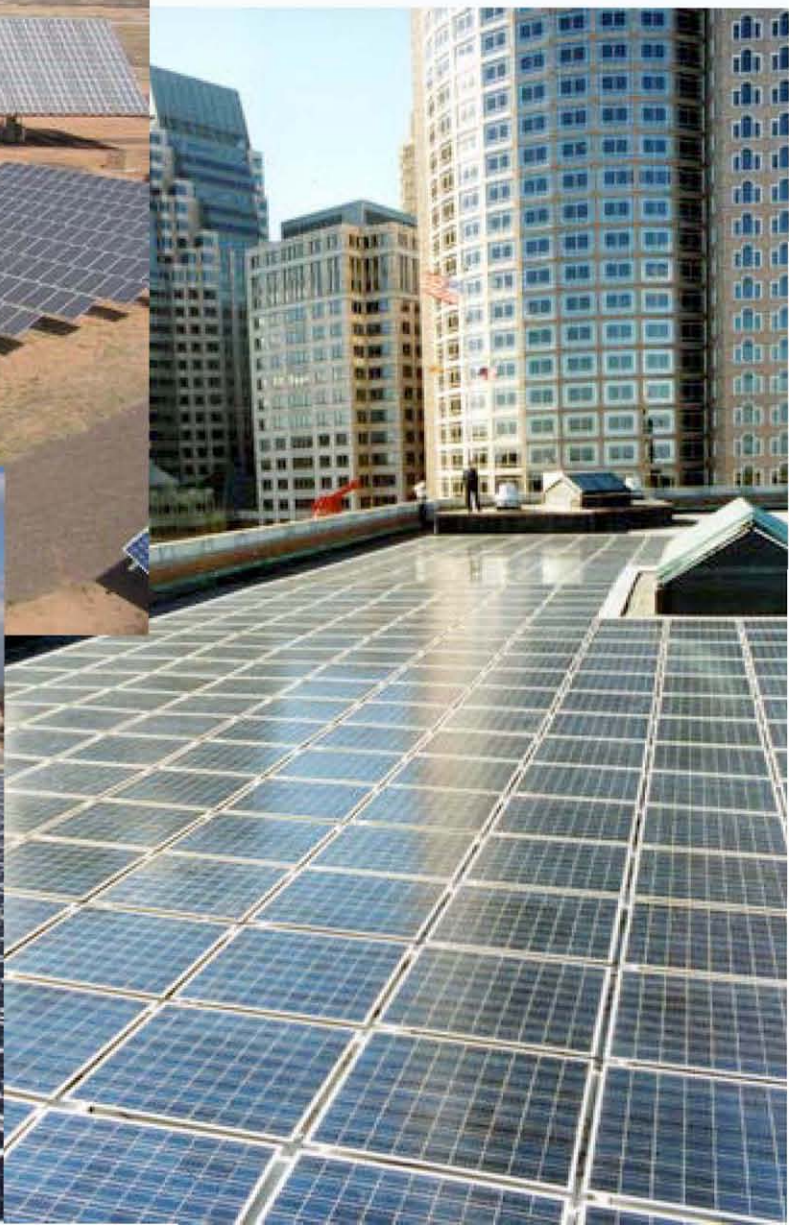




SOLAR
DECATHLON







Growth of photovoltaic industry

~0.1% of electricity now comes from solar - extrapolates to > 5% in 2020

competitive with conventional electricity for 0.1% - 1% of market; more in future

Rogol, PHOTON International August 2007, p 112.

Industry growth is currently constrained by Si availability, motivating us to reduce semiconductor material

Front

Solar cell

Thin film

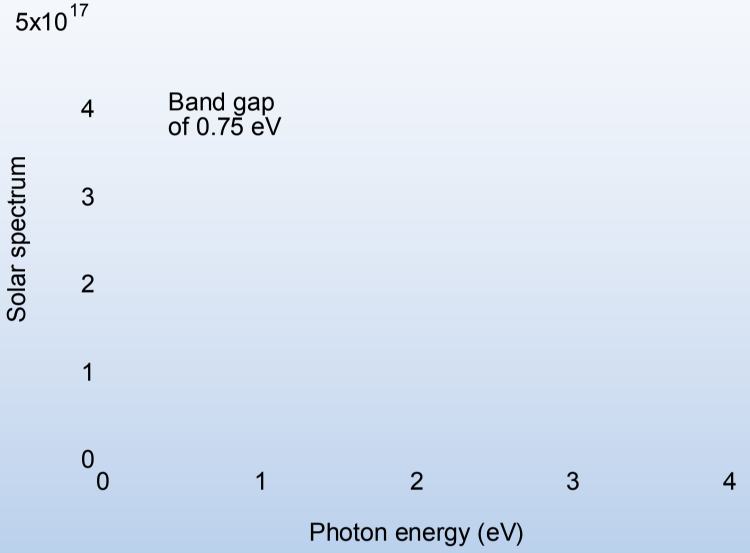
Back

Concentration:

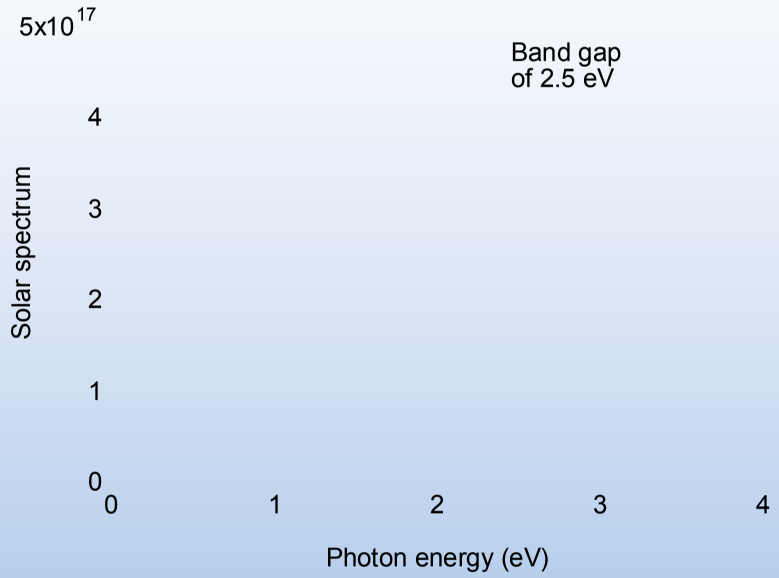
1. Reduces semiconductor use
2. Allows use of higher efficiency cell (higher system efficiency)

Concentrator

Why multijunction?
Power = Current X Voltage



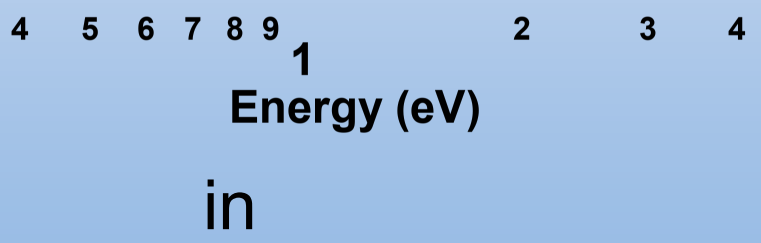
High current,
but low voltage
Excess energy lost to heat



High voltage,
but low current
Subbandgap light is lost

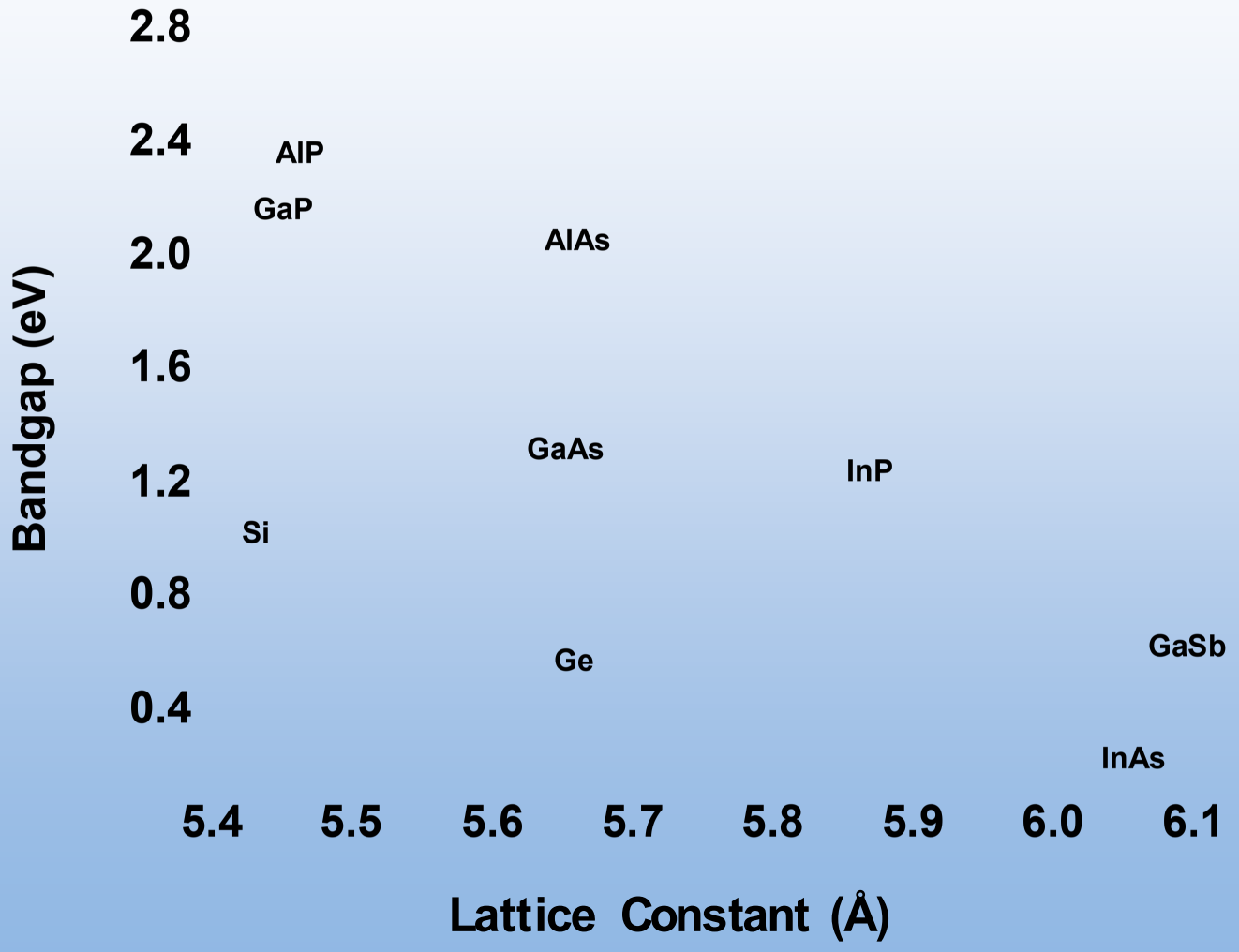
Highest efficiency: Absorb each color of light with a material that has a band gap equal to the photon energy

Multijunction cells use multiple materials to match the solar spectrum



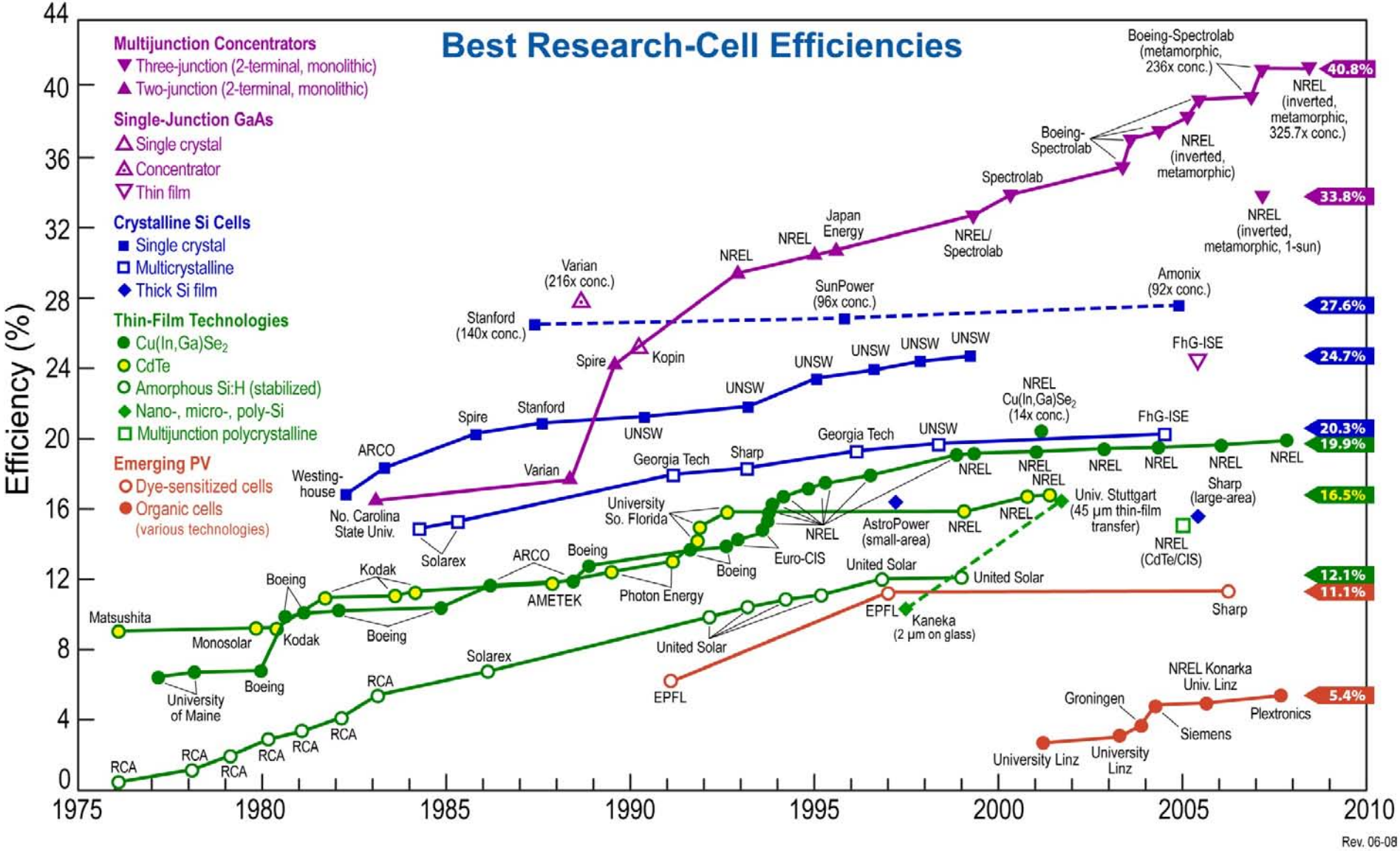
in

Multijunction cells use multiple materials - many possible combinations



Champion solar-cell efficiencies - Multijunction achieves highest

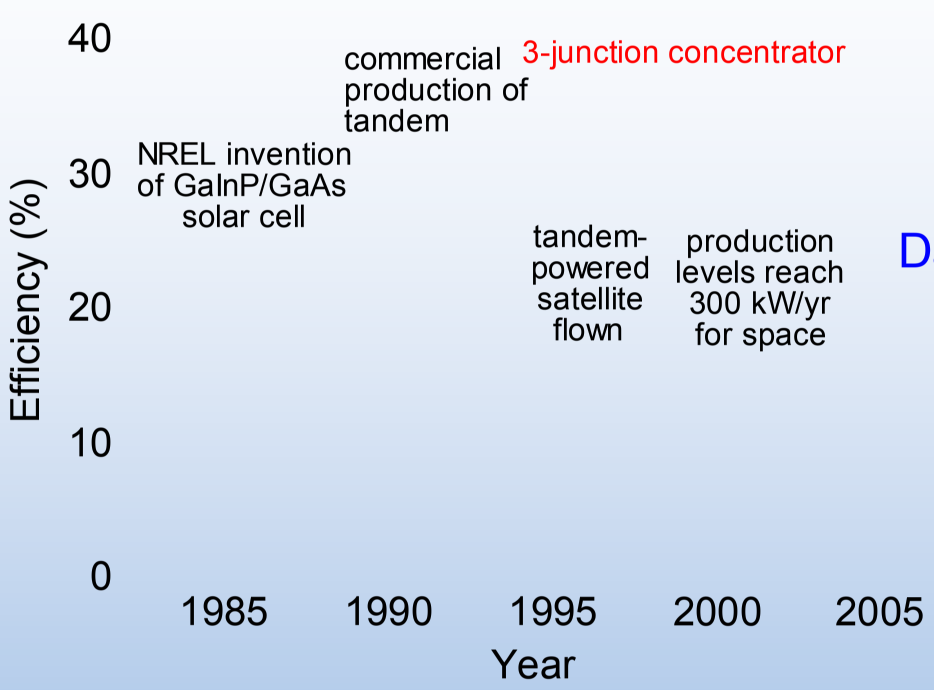
40.8% Geisz (NREL)



Historical perspective

- In 1984:
  - Multijunction approach is predicted to achieve higher efficiency
  - AlGaAs/GaAs is considered lowest-risk approach to implementing multijunction
  - Lattice mismatched combinations considered higher risk approach
  - GaInP alloys were “known” to be unstable
- Jerry Olson proposed GaInP/GaAs

Success of multijunction cells using GaInP



40.8%
Geisz
2008

Dan David Prize
2007
Olson, Kurtz

Mars Rover powered by multijunction cells

This very successful space cell is currently being engineered into systems for terrestrial use



High-efficiency GaInP/Ga(In)As/Ge cells

Lattice matched

GaInP top cell 1.9 eV

GaInAs middle cell 1.4 eV

Ge bottom cell and substrate 0.7 eV

Metal 1.0 eV

40.4% King, 2006

Lattice mismatched

GaInP top cell 1.8 eV

GaInAs middle cell 1.3 eV

Grade

Ge bottom cell and substrate 0.7 eV

Metal

40.7% King, 2006

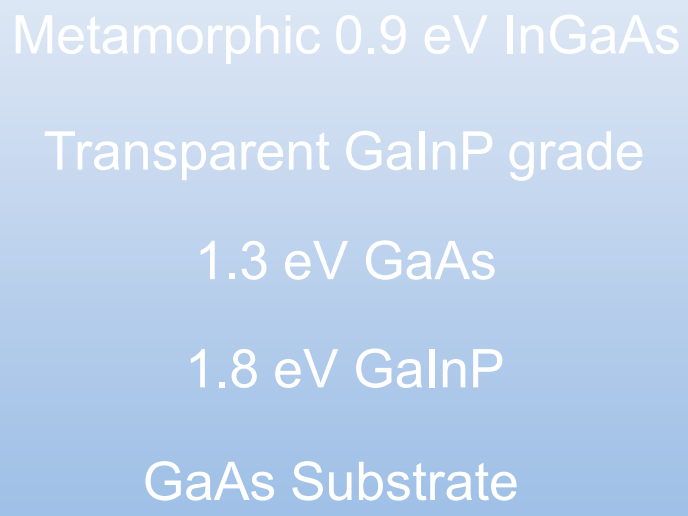
New research: from 40% to 50%

Inverted GaInP/Ga(In)As/GaInAs solar cell champion: 40.8%

- MOVPE growth on GaAs substrate.
- Inverted structure.
- Mounted on Si or glass handle.
- GaAs substrate selectively removed.
- Front-side processing completes cell.

Advantages:

- Higher efficiency
- Reuse of substrate or use of impure substrate can reduce cost

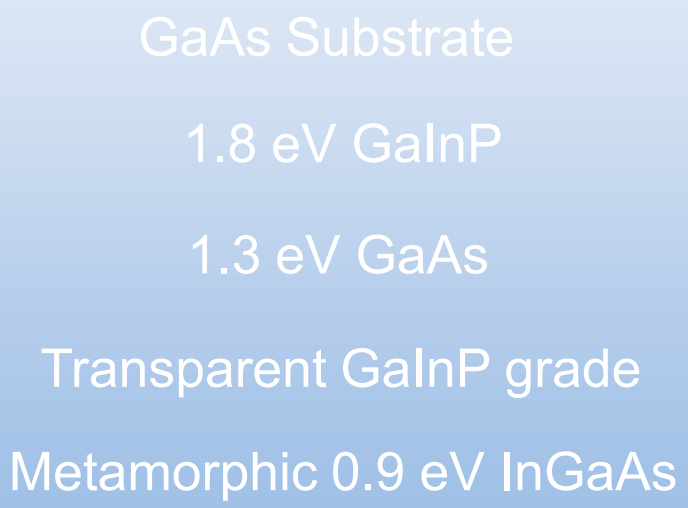


Inverted GaInP/Ga(In)As/GaInAs solar cell champion: 40.8%

- MOVPE growth on GaAs substrate.
- Inverted structure.
- Mounted on Si or glass handle.
- GaAs substrate selectively removed.
- Front-side processing completes cell.

Advantages:

- Higher efficiency
- Reuse of substrate or use of impure substrate can reduce cost



Inverted GaInP/Ga(In)As/GaInAs solar cell champion: 40.8%

- MOVPE growth on GaAs substrate.
- Inverted structure.
- Mounted on Si or glass handle.
- GaAs substrate selectively removed.
- Front-side processing completes cell.

Advantages:

- Higher efficiency
- Reuse of substrate or use of impure substrate can reduce cost



Solar for large-scale electricity generation

Convergence of utilities and photovoltaic companies?

- Recent trends
  - Multi megawatt systems becoming common
  - Dominance of building integration is no longer assumed
  - More systems are ground mounted
  - More systems are tracked
- Interest from utilities is growing

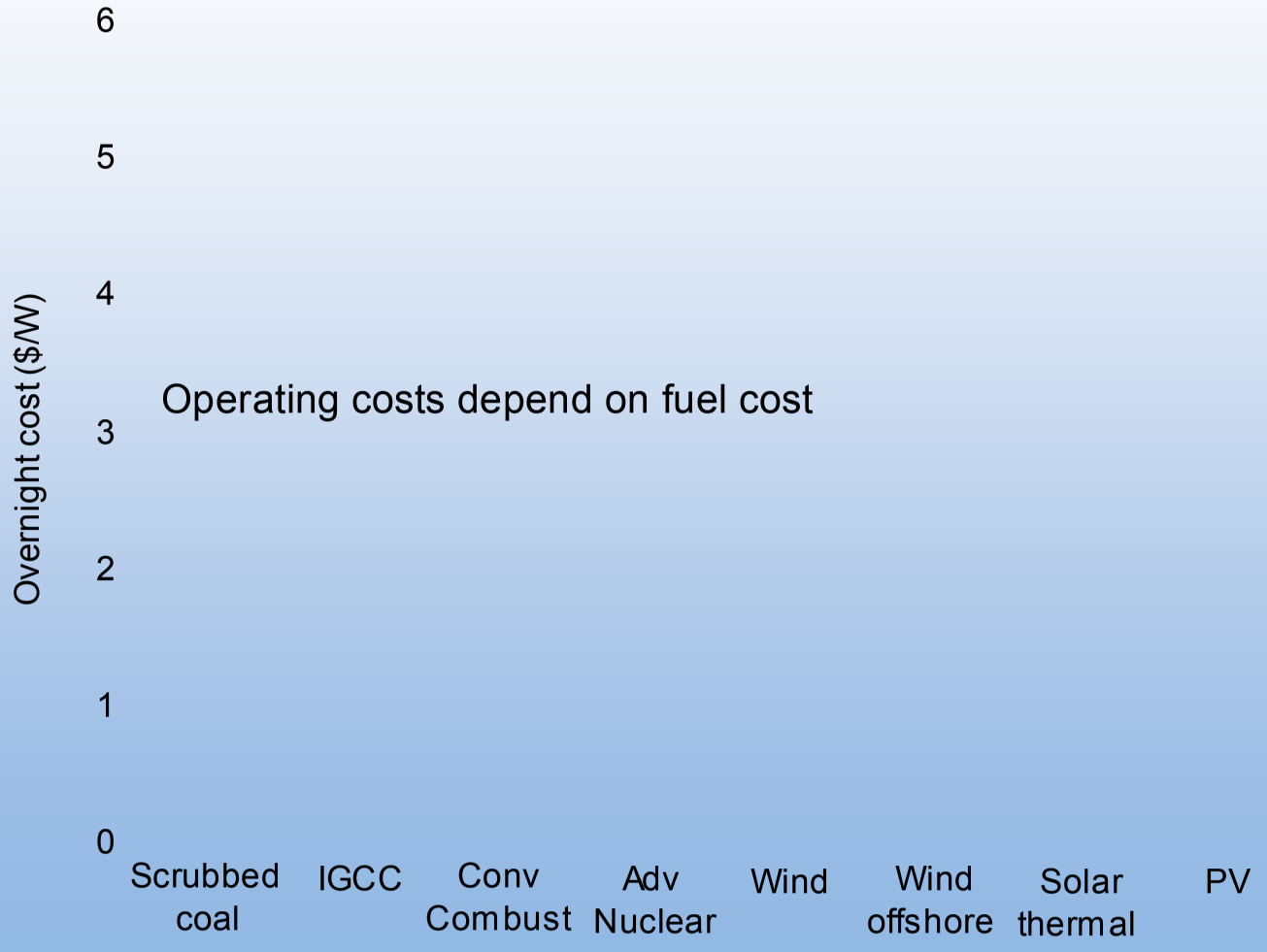
How can multijunction cells make a difference?

- Use less semiconductor material
  - Capital investment can be less
  - If other costs can be reduced, then may be able to achieve very low cost
- High efficiency has potential to generate the most electricity per area
- Commercial investment involves more than 50 companies with total investment on order of $1B

- Deployment in 2008 expected to be ~ 1 MW

Electricity costs are going up, but PV is still expensive

source: http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/electricity.pdf#page=3



Summary

- Photovoltaic industry is doubling every two years
- Using concentration may help the solar industry grow even faster
- Multijunction cells provide the path to high efficiency; > 40% and are still increasing
- Solar industry is moving into large-scale, utility applications; multijunction cells may hasten this trend

Flying high with high efficiency

Cells from Mars rover
may soon provide
electricity on earth

High efficiency, low cost,
ideal for large systems