National Renewable Energy Laboratory
Innovation for Our Energy Future

A Bright Future for CPV

NREL

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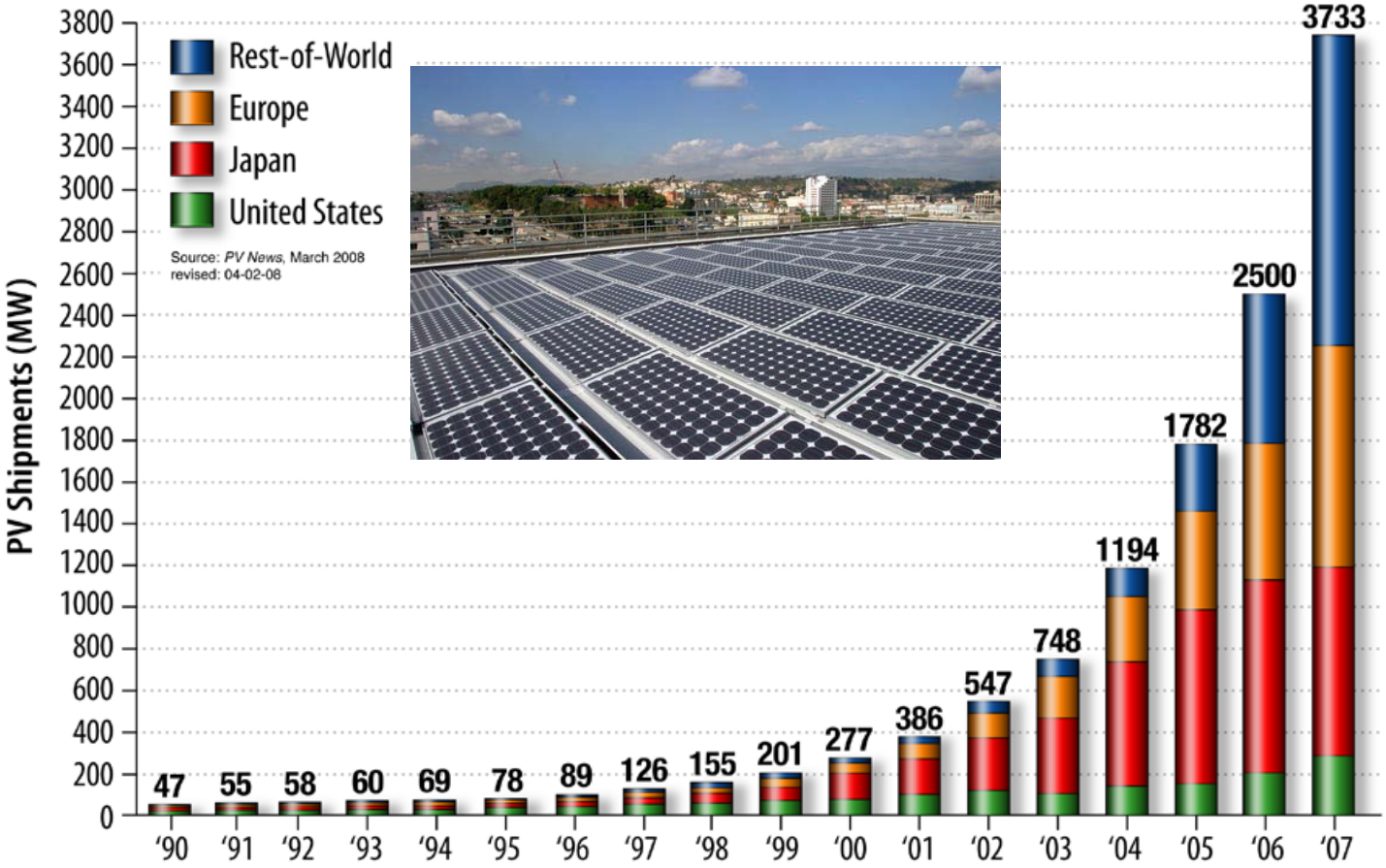
Outline

- Solar
  - a huge success, but still a long way to go
  - can CPV help PV grow to significance?
  - CPV is positioned to go far
- The challenge of product development in CPV – why is it so hard?
  - Infrastructure not there
  - Many interconnected design details:
    - Design with the bird's eye view
    - Troubleshoot from the worm's eye view
  - Some detailed suggestions
- Are we at the turning point for CPV?

Growth of photovoltaic (PV) industry



0.01%-0.1% of electricity now comes from PV – want to be closer to 10%

Key to creating the needed business climate may be lower capital requirements

CPV has lower capital requirements

CPV progress

Multijunction cells 41% in lab; 37-39% in production

About a dozen multijunction cell companies

About three dozen companies putting these cells into systems

Complementary approach uses silicon cells under lower concentration – not the topic of this talk, but a strong partner

Some companies working on 1 MW installations

Why does it take so long???

Why so hard? – need infrastructure

In 1990s, PV community decided that building-integrated, customer-owned, customer-sited would be the future: little interest in CPV, so little funding

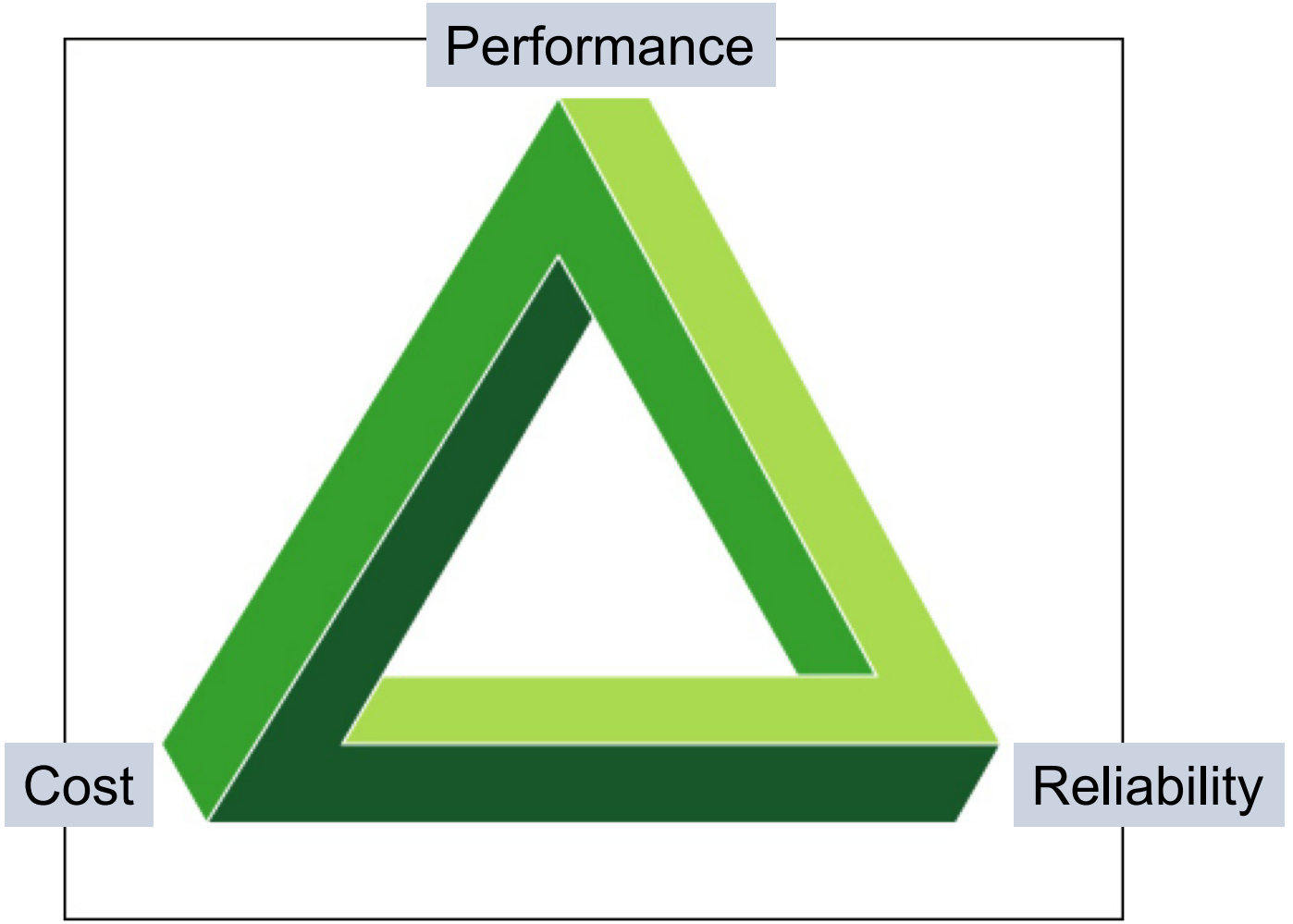
Investment in CPV came later than for other technologies, so CPV infrastructure development lags

Work together to define useful reliability tests, component suppliers, definition of new markets, etc.

Balance between competitive edge and partnership

There's enough market for all companies if we can get the cost down; Let's work together to develop the infrastructure!

Why so hard? – many tradeoffs

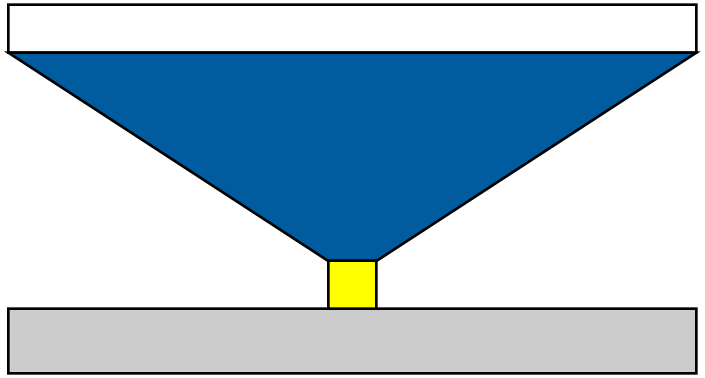


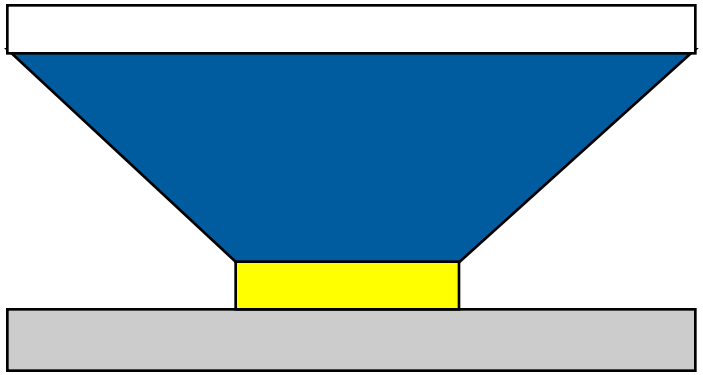
Sarah's advice – use two views

Design
Bird's eye view

Diagnose
Worm's eye view

Bird's eye view – concentration ratio





Cell cost: > 1000X

Mechanical: < 400X

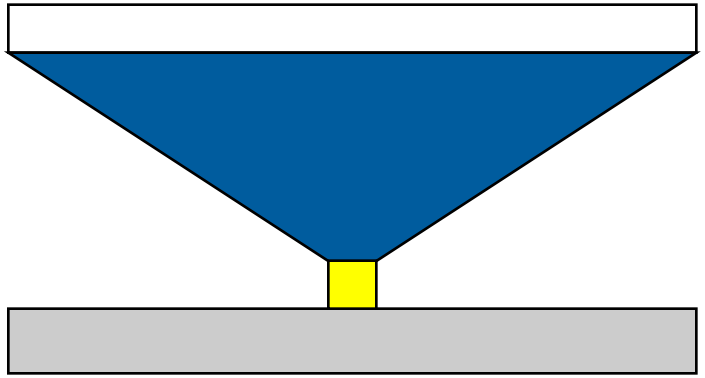
Can cell cost decrease?

Smart tracker isn't enough

- thermal expansion
- wind
- cost of rigid structure

Sarah's advice: If you're designing for over 500X, ask yourself why you'll be successful

Bird's eye view – cell size



Large cells and optics

Reduced part count

Rigid structure

Can use active cooling

Modularity can be advantage

Small cells and optics

Reduced materials cost

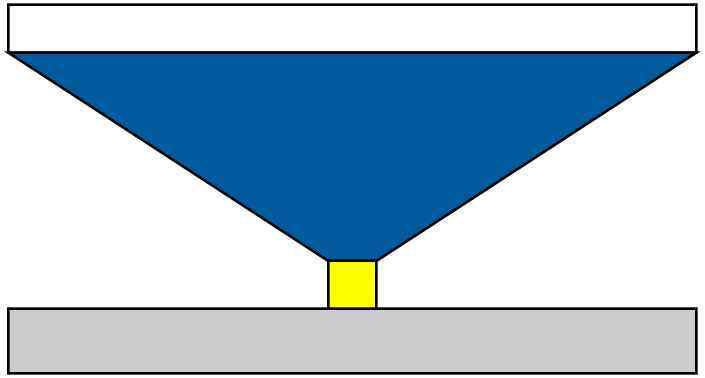
Aesthetic appeal

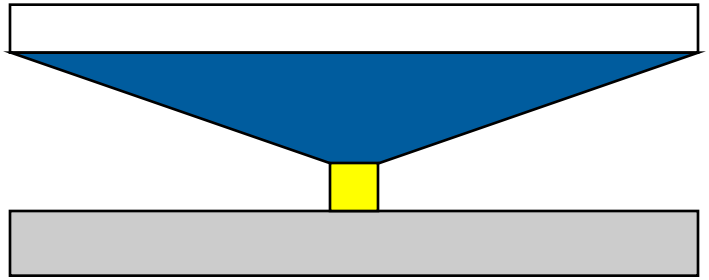
Heat is distributed

Smaller currents

Sarah's advice: Think ahead to automation of manufacturing, alignment tolerances, performance

Bird's eye view – f number





Higher f number

Alignment tolerance is wider (bigger depth of fields)

Lower f number

Reduces thickness

Innovative designs may have aesthetic appeal

Sarah's advice: If you use low f number, analyze the effects of imperfect optics and alignment

Bird's eye view – factory vs installation

Build at the factory

Reduces installation costs

Build in the field

Reduces transport costs

Sarah's advice: Consider tradeoffs from beginning to end – "cradle to grave"; "design for reliability"

Bird's eye view – many tradeoffs

There are dozens of design tradeoffs/choices with no clear winners and optimum may change

New ideas/technologies will affect optimal design

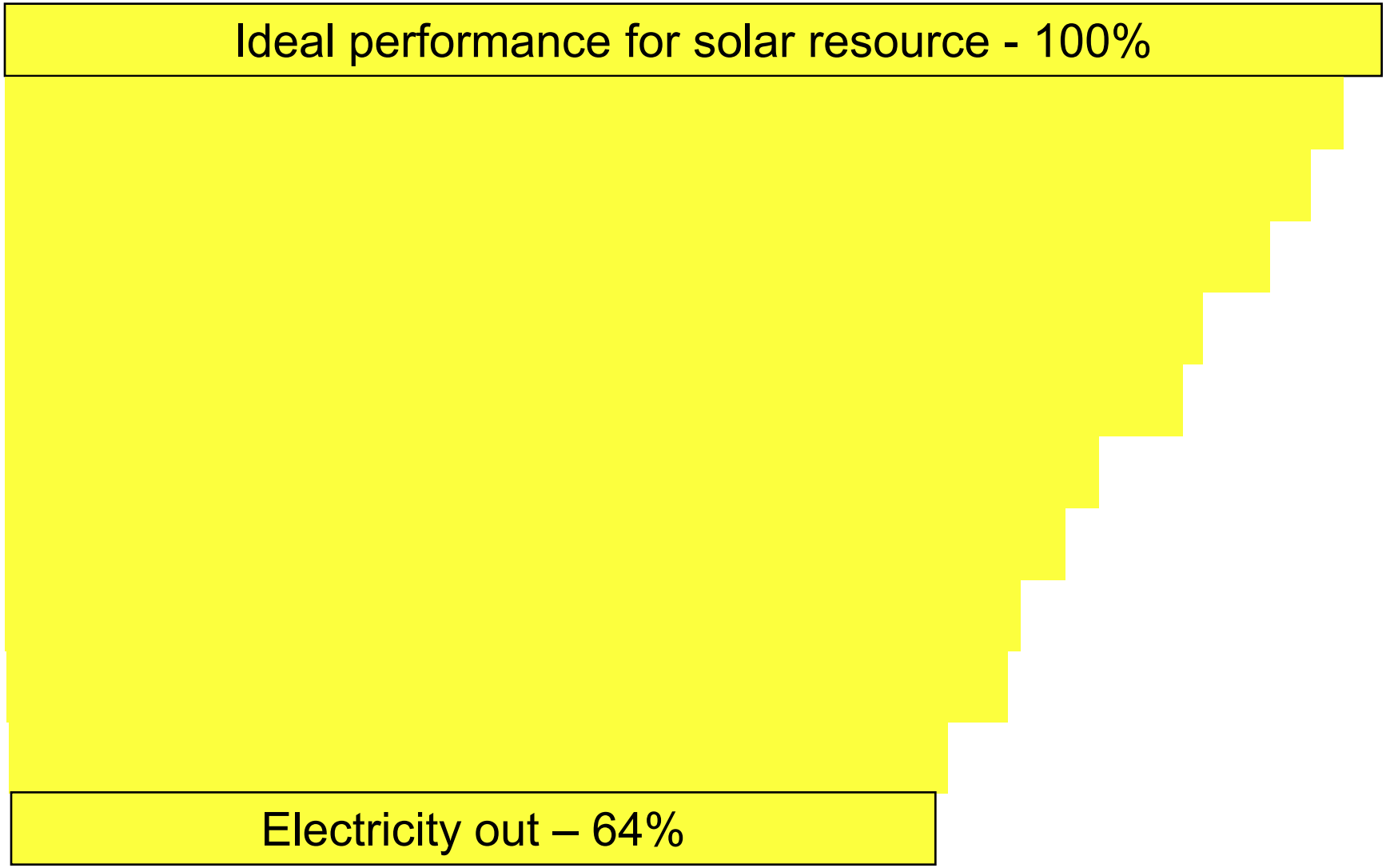
Optimal design is very dependent on application

Each company reaches a different conclusion

What will CPV systems look like 100 years from now?

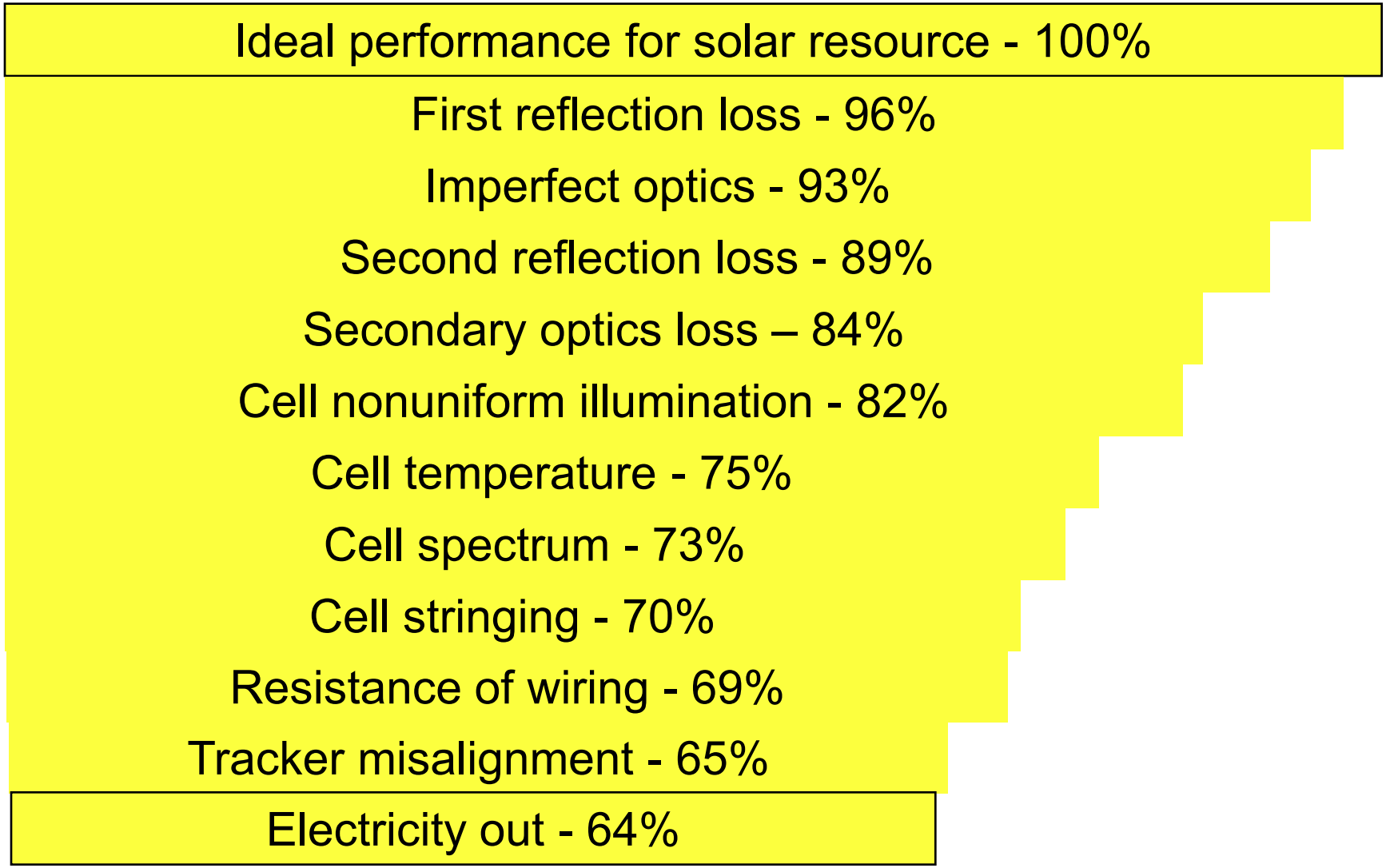
Sarah's advice: Examine each choice in the context of how it may affect other design choices; hire engineers to be a team

Worm's eye view – what happened?



Many losses, what happened?

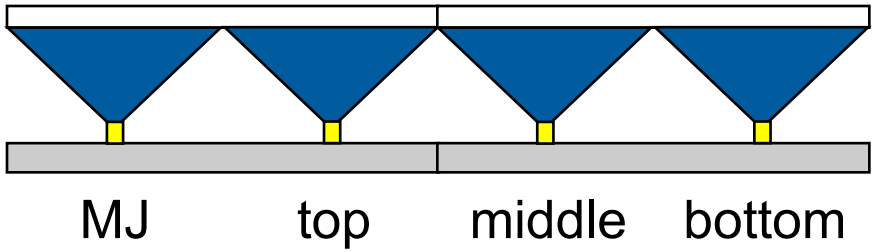
Worm's eye view – what happened?

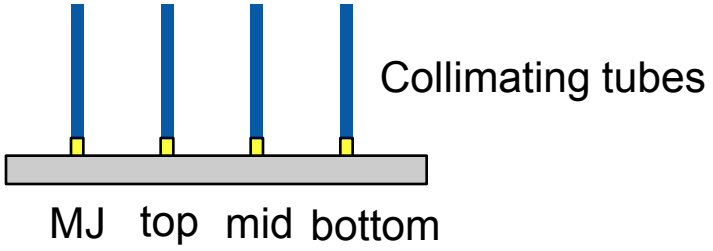


So many potential losses, how do we identify solutions?

Worm's eye view – Sarah's advice

Sarah's advice: demand matched reference cells from your cell supplier





Why use matched reference cells?

- Quantify optical efficiency for each junction
- Depth of field and acceptance angle may be different for each junction (Use special mount that allows you to move each cell)
- Evaluate current matching of multijunction cell for optical design (may vary as a function of alignment)
- Reference cells quantify variation in spectrum
- *Thorough characterization before start stringing cells*

Worm's eye view – Use all parameters

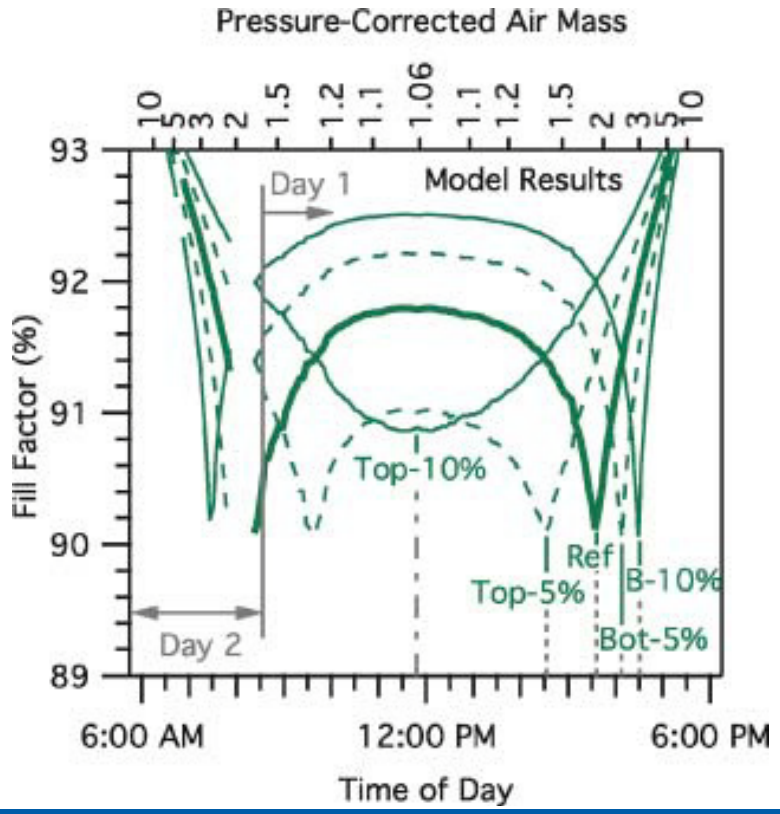
Short-circuit current - optical efficiency

Open-circuit voltage – cooling (adjust for concentration using transient)

Fill factor for reference cells - electrical resistance or shorts; non-uniform illumination

Fill factor for multijunction cell – spectral effects

McMahon – PIP 2008



Worm's eye view – Sorting out a module

Be creative; cover the optics; use thin-film filters with partial transmission

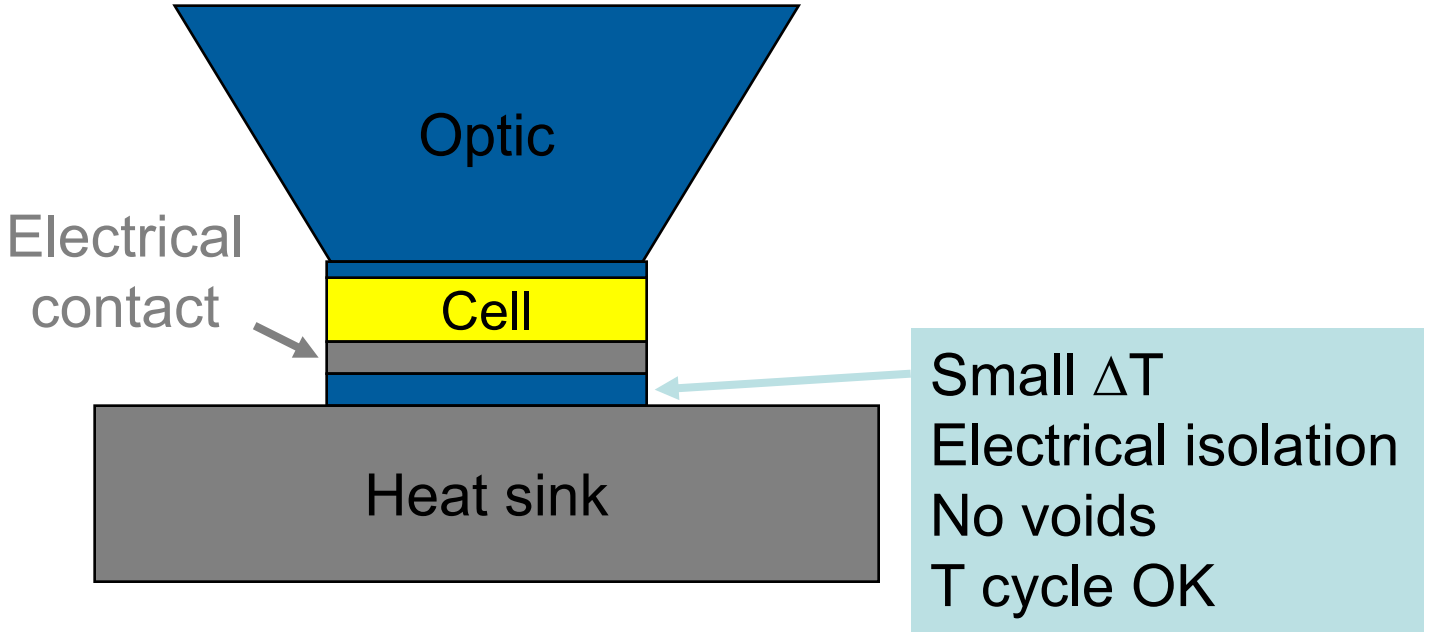
Characterize module at maximum power point – short-circuit will miss many problems

Module should have same acceptance angle as single cell/optic

If not, measure cell temperature or use filter to see which cell is limiting the current; bypass diodes should not be hot; fill factor of module should be similar to ff of single cell without showing evidence of bypass diodes turning on

Forward bias should be consistent

Reliability - bond to heat sink



- Borrowing experience from power electronics and DBC (direct bonded copper) makes this a smaller issue

Work together to define improved tests

Concentrators – reliability challenges

- Wide variety of designs
- Qualification test is not well established
- Companies spend time developing their own accelerated tests to speed product development cycles
- Very few companies have heritage with field testing
- Everyone wants to bring a product to market immediately

- However, modularity of CPV may be an advantage

NREL has multiple capabilities

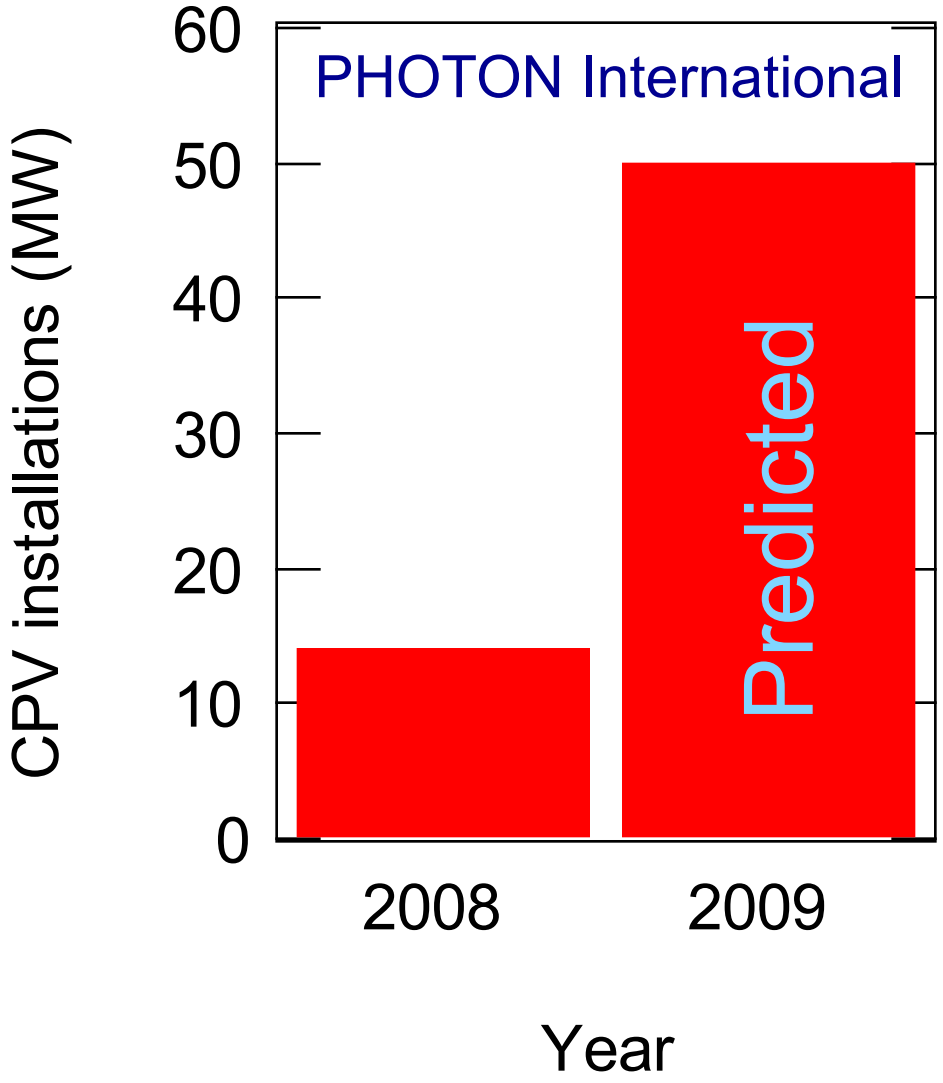
Solar resource assessment
http://www.nrel.gov/solar_radiation/

Cell measurements
www.nrel.gov/pv/measurements/device_performance.html

Indoor and outdoor module testing
www.nrel.gov/pv/facilities_otf.html

Multijunction cell development
www.nrel.gov/pv/electronic_materials_devices.html

Turning point for industry?



Is the CPV industry ready to ramp production?

PHOTON International predicts 50 MW in 2009

Summary

- Solar is growing rapidly and could become a significant source of electricity within our lifetimes
- CPV may be able to play a significant role because of scalability
- CPV product development is slowed because of the interactions of different design parameters
- Take a bird's eye view for the design and a worm's eye view for diagnosis
- Ask cell suppliers for matched reference cells

- Bright future – 50 MW in 2009?

What will CPV look like 100 years from now?

Olson: "Many options are a curse and a blessing"

Let's work together to make CPV a success

Thank you for your attention and thank you for sharing your wisdom!