HDIAC
Homeland Defense & Security
Information Analysis Center

HDIAC Alternative Energy Webinar: Advancements in Solar Photovoltaics

June 25, 2015

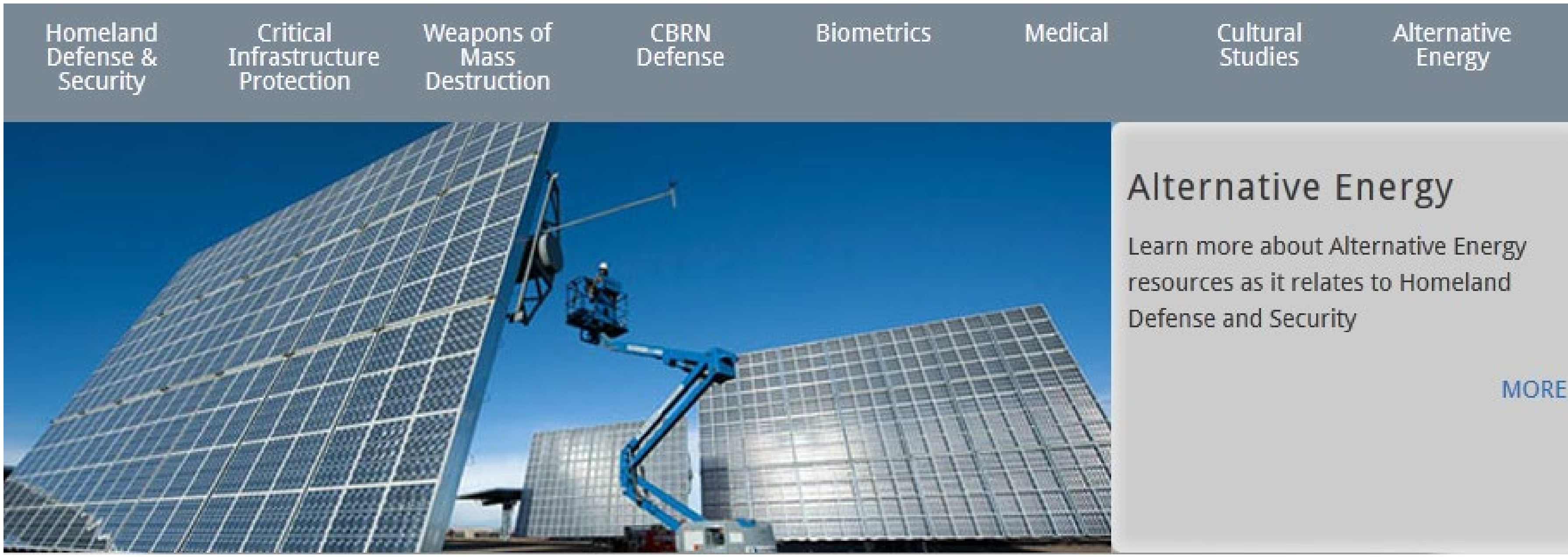
Chris Doran
Alternative Energy
Subject Matter Expert
Northrop Grumman

Homeland Defense & Security
Information Analysis Center (HDIAC)
(865) 535-0088
www.hdiac.org

DoDIACs
Department of Defense Information Analysis Centers

Homeland Defense & Security Information Analysis Center

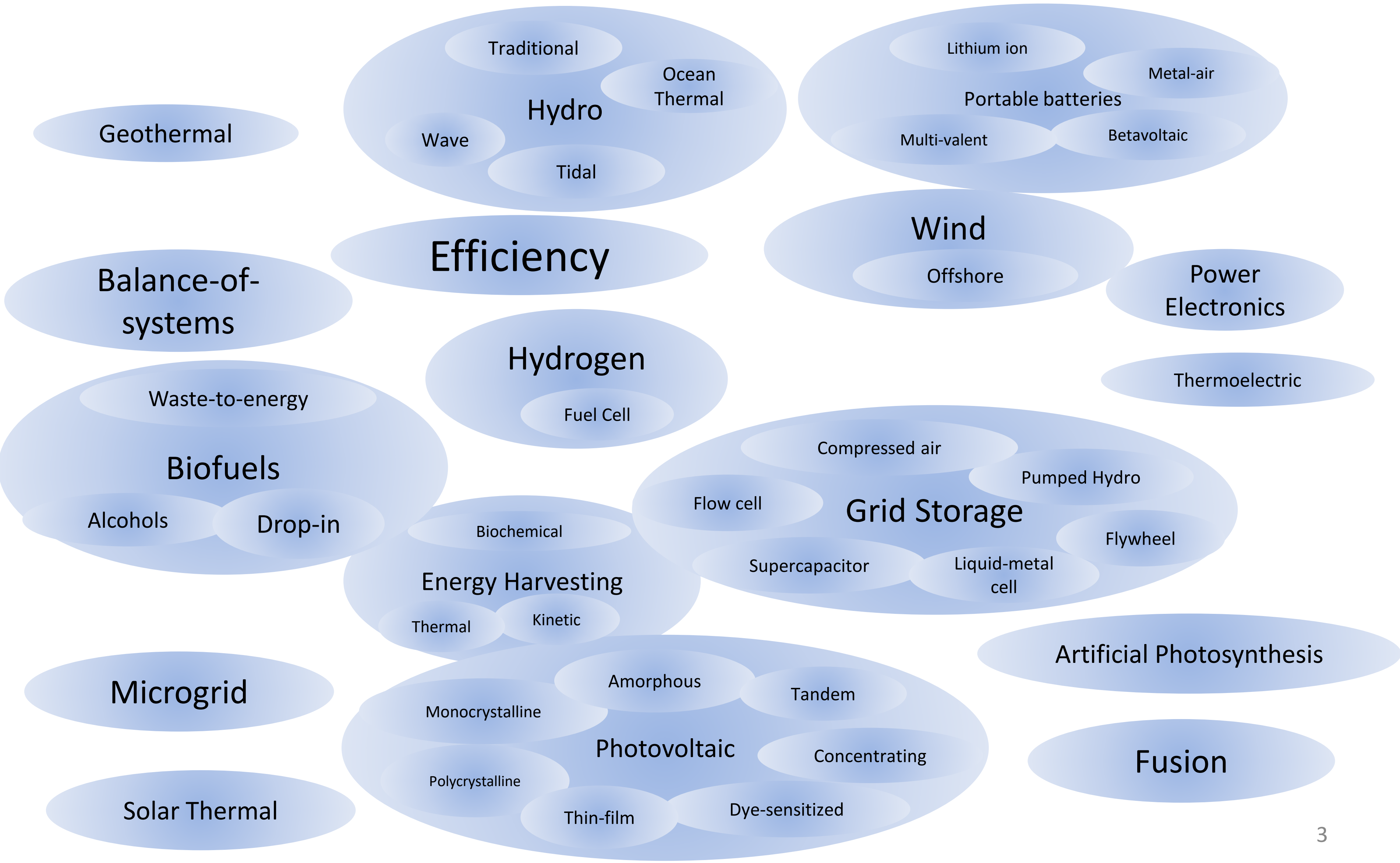
HDIAC Overview



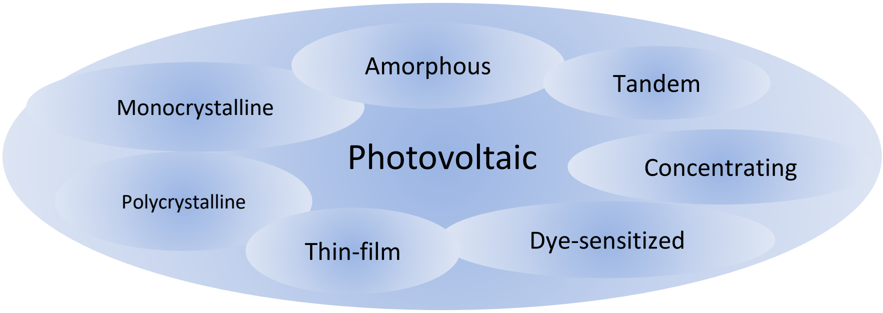
For more information, watch the HDIAC 101 webinar or visit www.hdiac.org.

Homeland Defense & Security Information Analysis Center

Alternative Energy



Alternative Energy



Solar Power Conversion

Solar energy can be converted from:

- Light
  - via photovoltaics
- Heat
  - via thermal concentrators (e.g.)

An 82-acre tract in south central Colorado, near the New Mexico border, is the site for one of the largest photovoltaic power plants in the United States. *Credit: Steve Wilcox, NREL*

Source: U.S. Department of Energy, Loan Guarantee Program Office

The Value of Solar Photovoltaics

- Renewable
- Flexible scalable deployment
- Low operational cost

Image source: army.mil

Image source: whitehouse.gov

The Photoelectric Effect

- Electrons exist in discrete energy states
- Semiconductors have well-defined energy bands
  - And well-defined bandgaps
- In an incident photon strikes an electron with sufficient energy, the electron can jump over the bandgap
  - The electron leaves an empty "hole" in its place

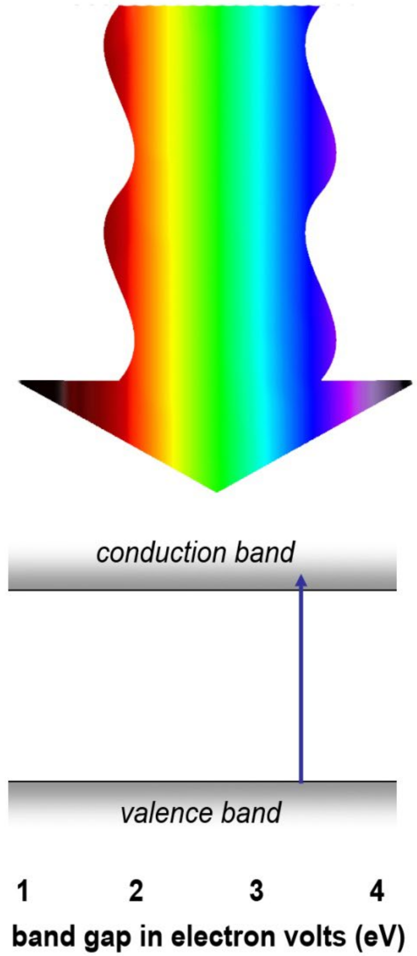
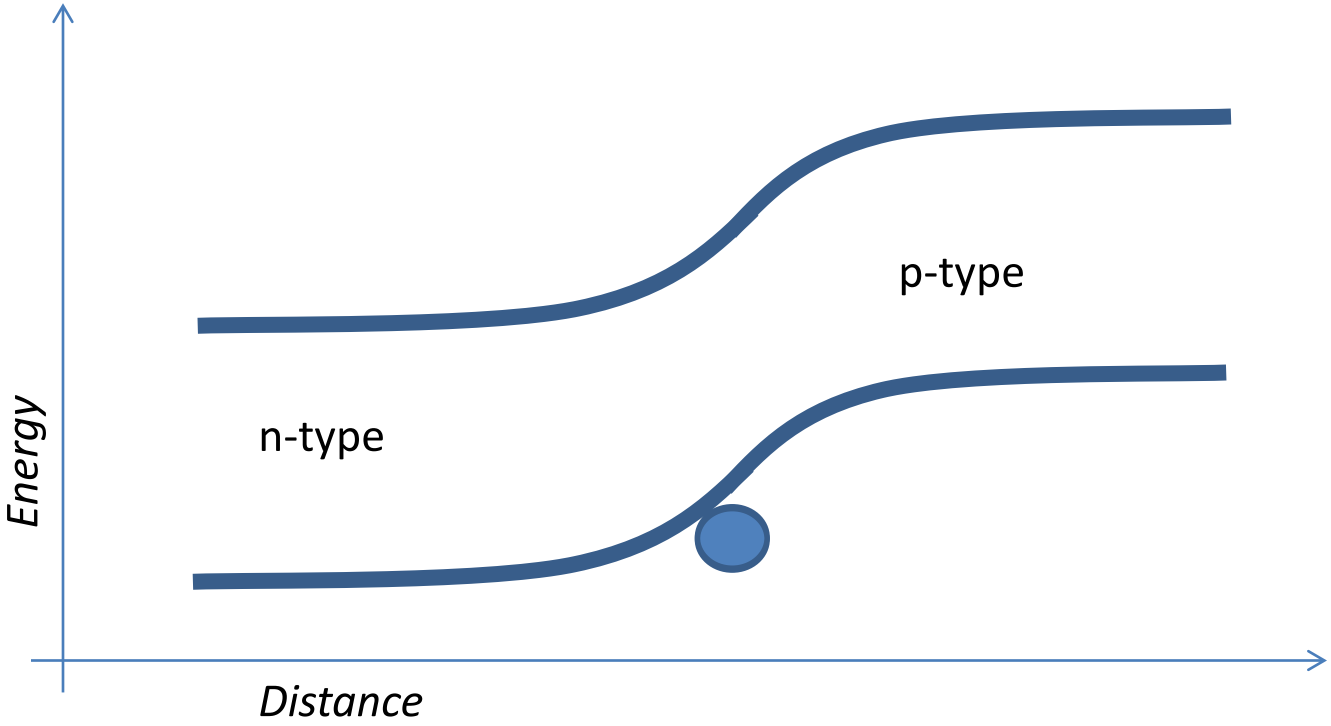


Image source: Lawrence Livermore National Lab

The Physics of Photovoltaics

- Putting positive- and negative-doped semiconductors together creates a one-way valve for current
- Excited electrons jump the bandgap and only go one direction



Bandgaps Matter

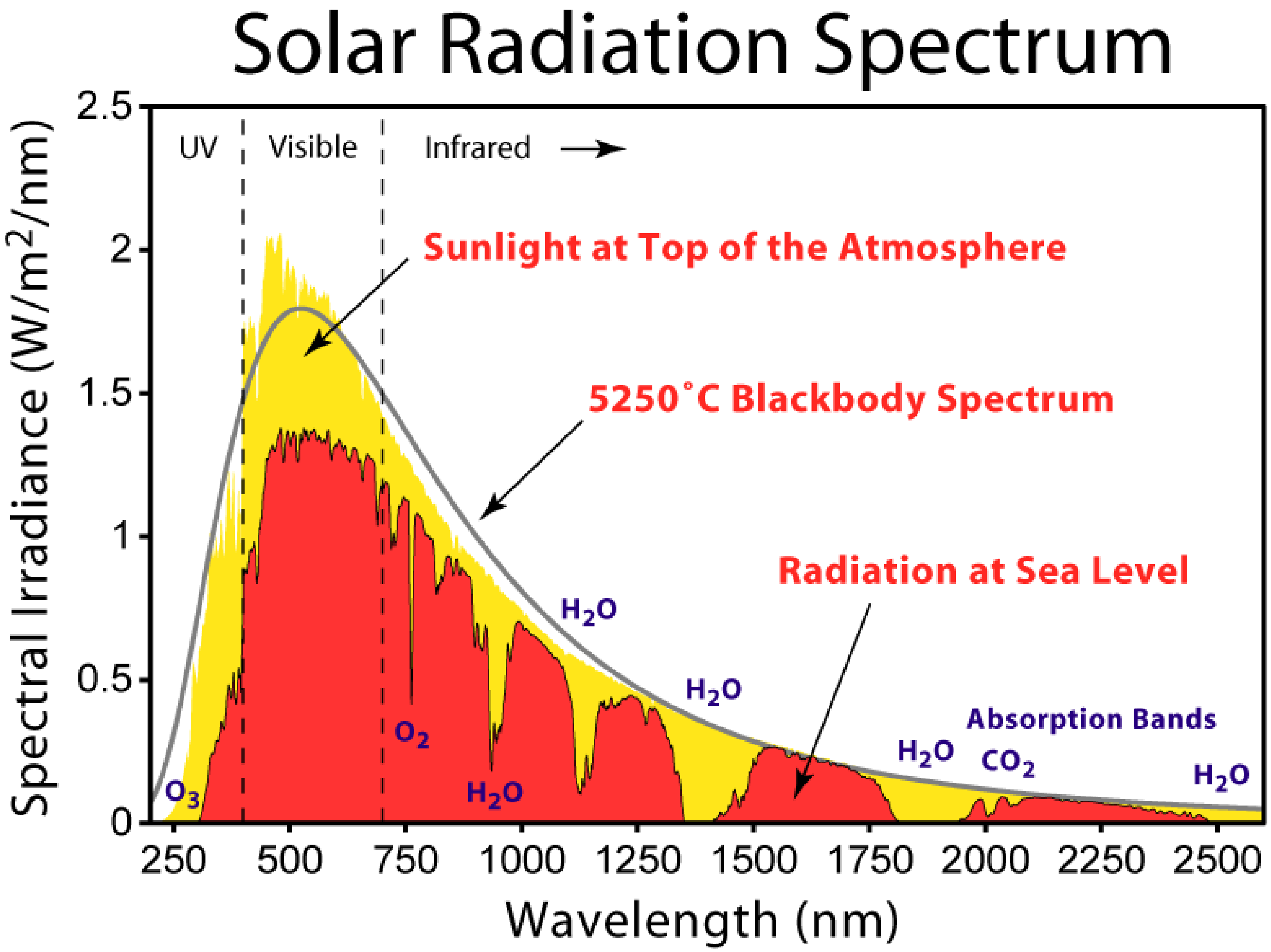


Image source: Sandia National Labs

First-Generation: Crystalline

- Silicon dominates the market
  - Classical pn-junction architectures
  - Well characterized
  - Typical efficiencies 15-25%
    - Theoretical upper limit of 34%

Image source: spinoff.nasa.gov

Second Generation: Thin Film

- Designed to cost
  - 1% the amount of semiconductor material
  - Typically vacuum-deposited onto glass or steel
  - “Roll-to-roll” manufacturing is possible

- Technologies include:
  - Cadmium telluride (CdTe)
  - Copper indium gallium diselenide (CIGS)
  - Amorphous silicon (a-Si)

Image source: energy.gov

Third Generation: Exotics

- Third generation PV designs diverge drastically

- Technologies include:
  - Multi-Junction
  - Organic
  - Dye-Sensitized

Organic Photovoltaics

- Organic electron donor and acceptor materials in place of n-type and p-type crystals
- Potential advantages of low cost, large area manufacturing, and flexibility
- Progress has lagged behind inorganic cells
  - Low lab efficiencies
  - Stability
  - Recent advances in organic LED tech may benefit PV

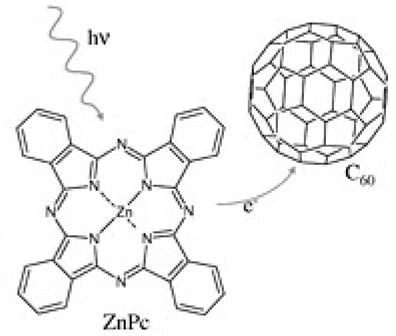
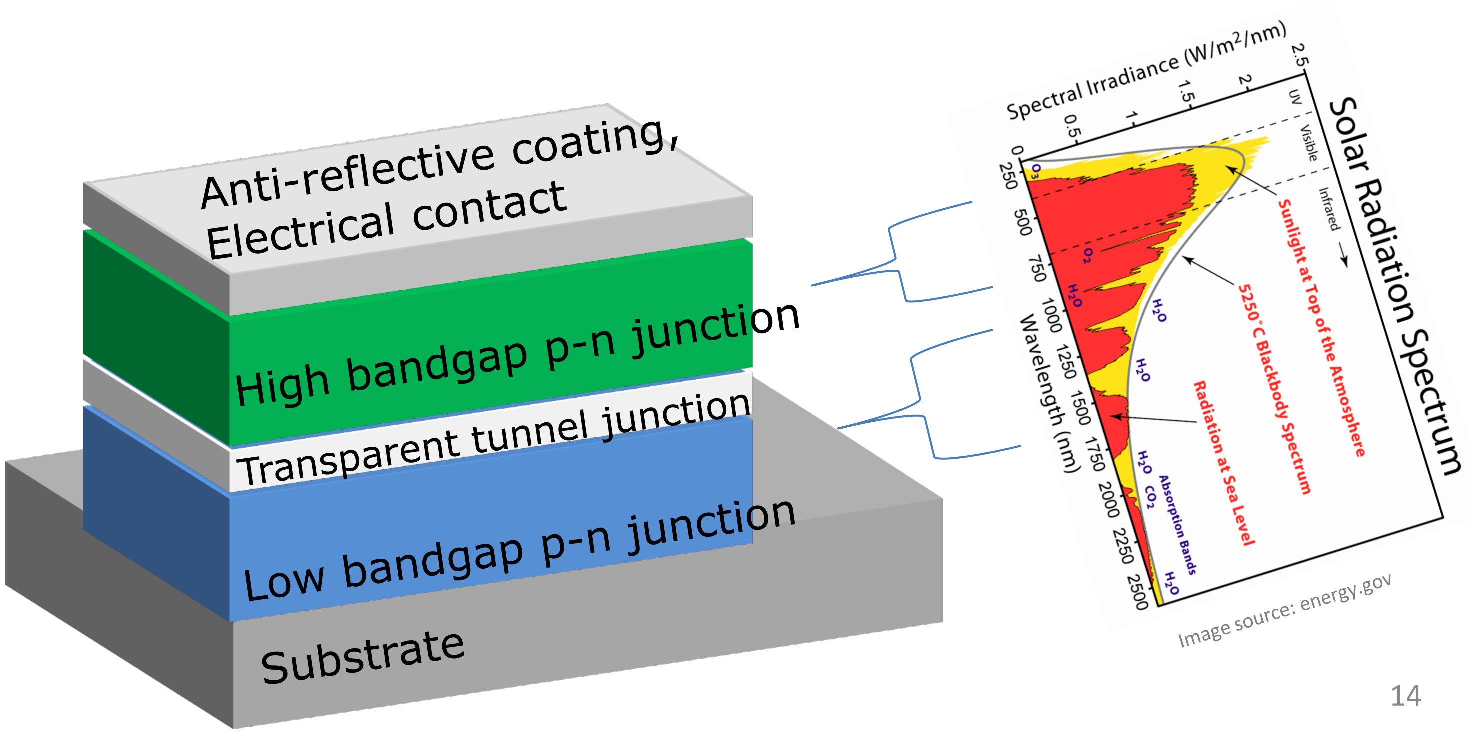


Image source: NIST

Multi-Junction Solar Cells

- Stack multiple semiconductors with different bandgaps
  - Optimize energy extraction across the solar spectrum



Third Generation: Dye-Sensitized

- Very different architecture
  - Photosensitive dye molecules absorb light and generate electron-hole pairs
  - Electrons injected to TiO2
  - Redox mediator restores dye's electron
- Potential advantages:
  - Tunable absorption
  - Low cost
- What's holding it back:
  - Lifetime
  - Complexity
  - Efficiency

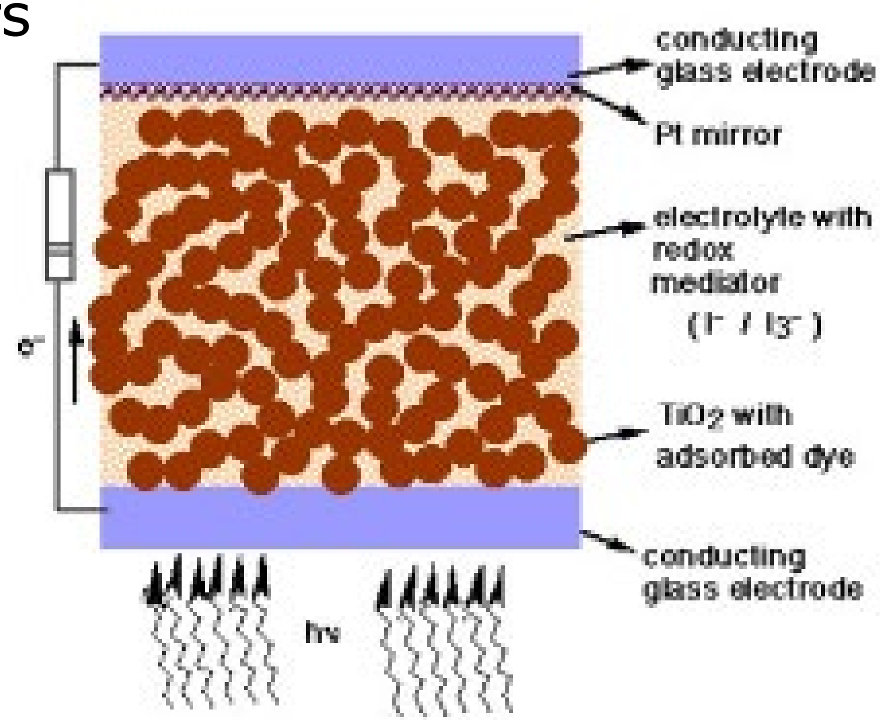


Image source: energy.gov

Quantum Dots

A quantum dot…

- is a nanoparticle containing 100-100,000 atoms.
- confines the motion of electrons in 3 dimensions.
- has a tunable bandgap

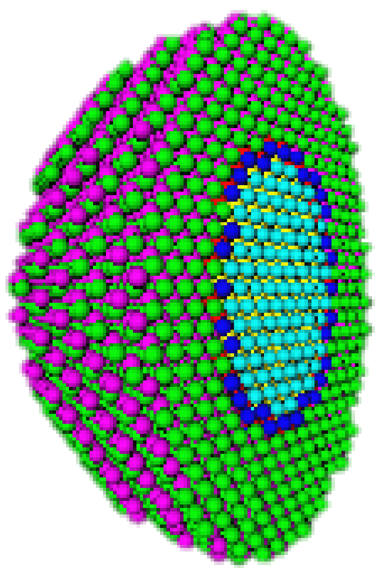


Image source: nasa.gov

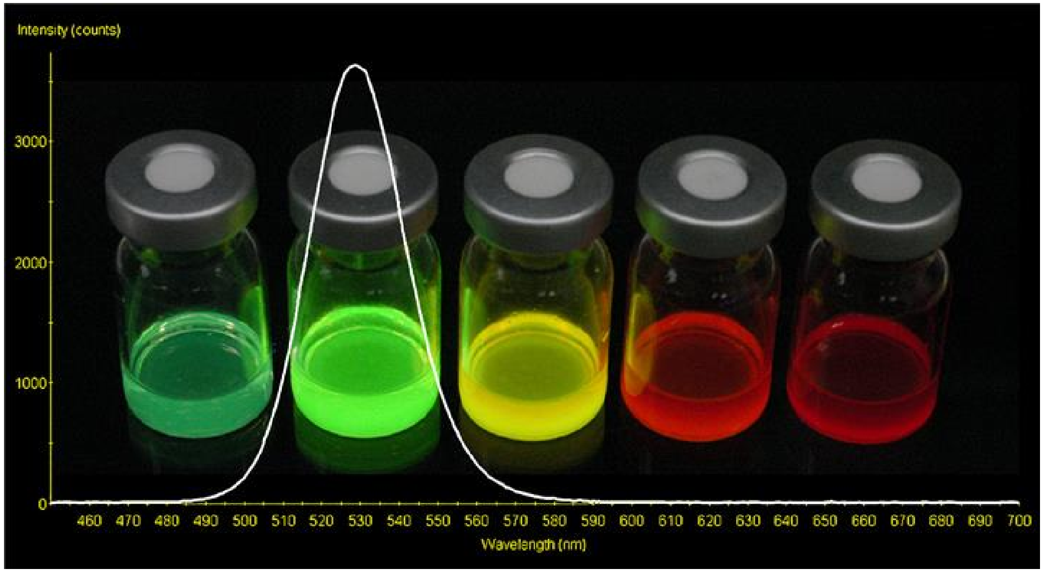


Image source: NIST

Quantum Dot Solar Cells

Quantum dots get around the 1-photon ←→ 1-electron rule via:

- intermediary band levels
- multiple-exciton generation

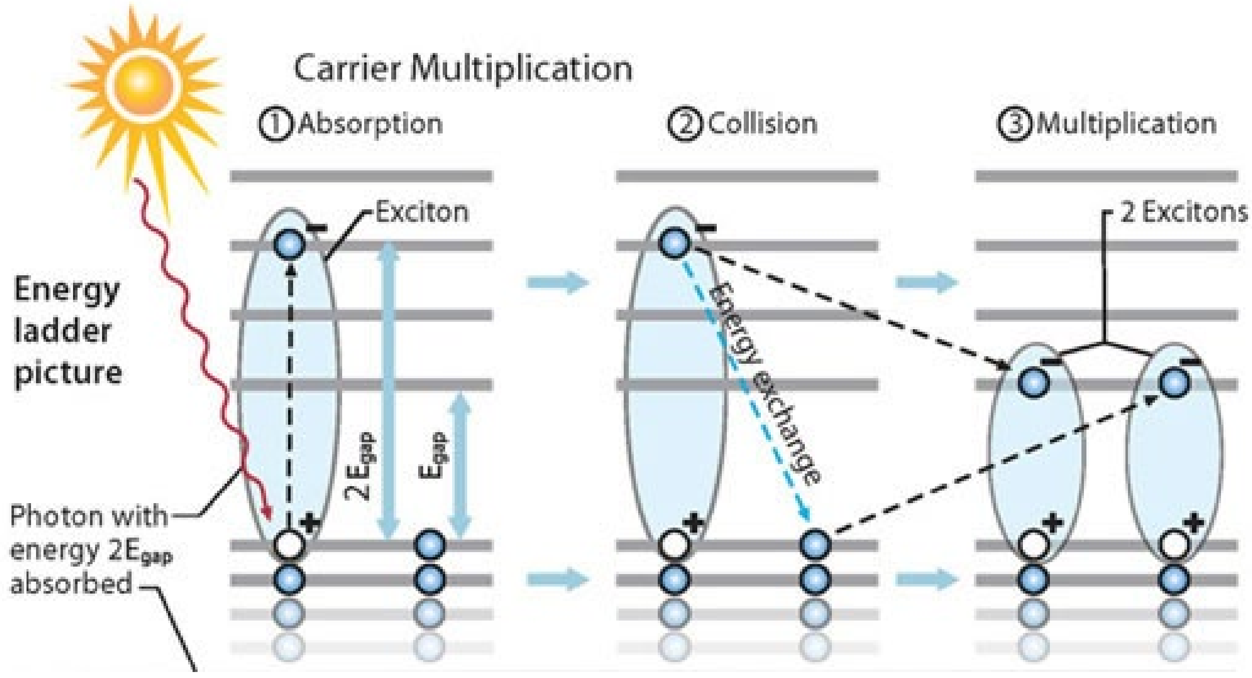


Image source: Lawrence Livermore National Lab

Perovskites

- ABX_3 stoichiometry
  - Most commonly studied is $CH_3NH_3PbI_3$
- Advantages:
  - Carrier diffusion length is 10X the absorption depth!
  - Possibility of simple preparation from abundant materials
- What's holding it back:
  - Stability, especially near oxygen and water
  - Lead

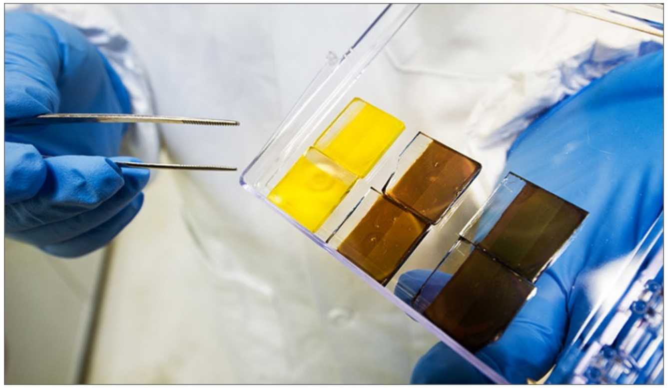
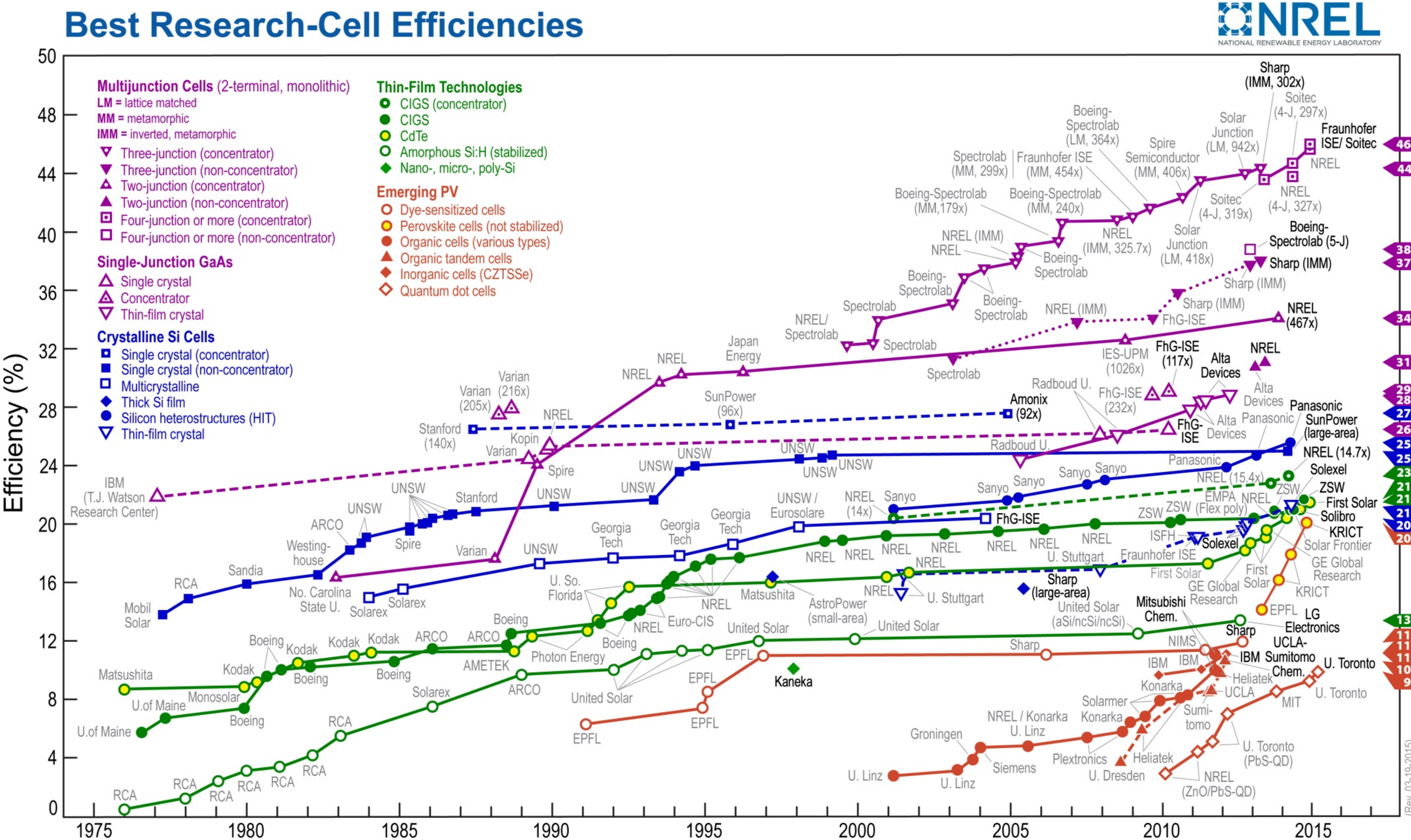


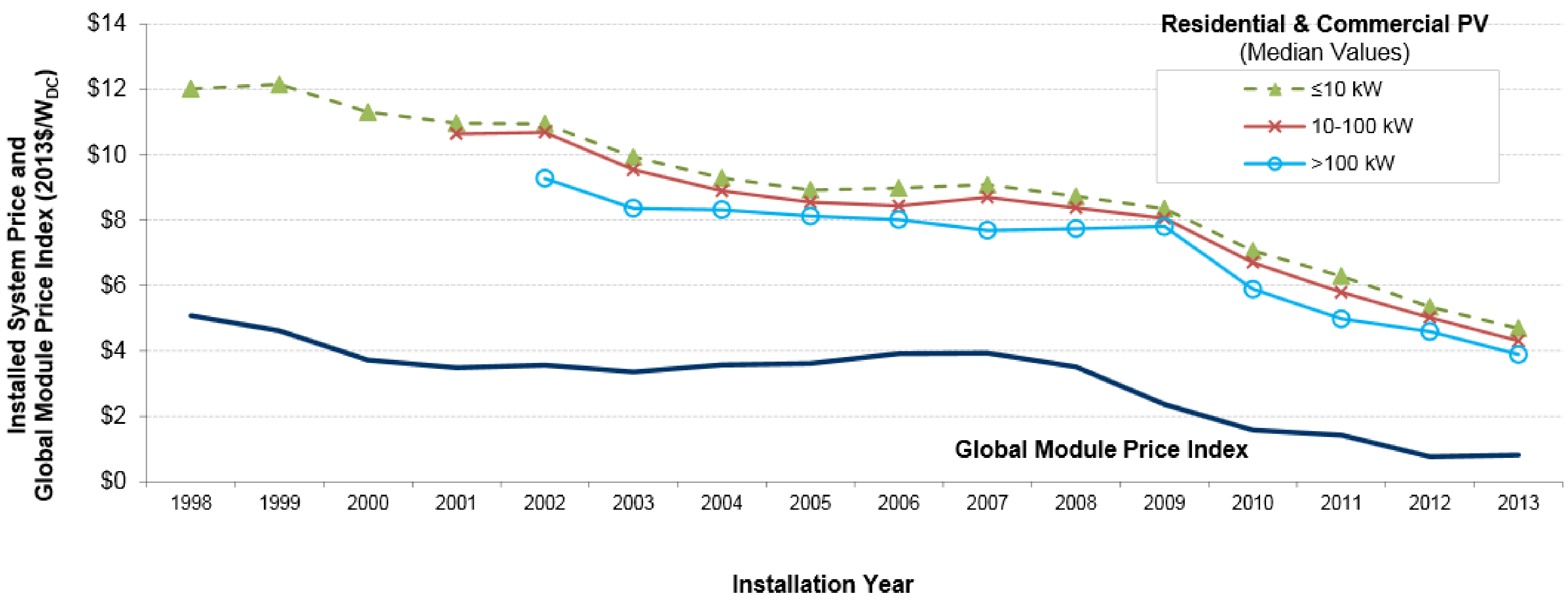
Image source: Dennis Schroeder, NREL

The All-Mighty η



This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO

Economic Trends

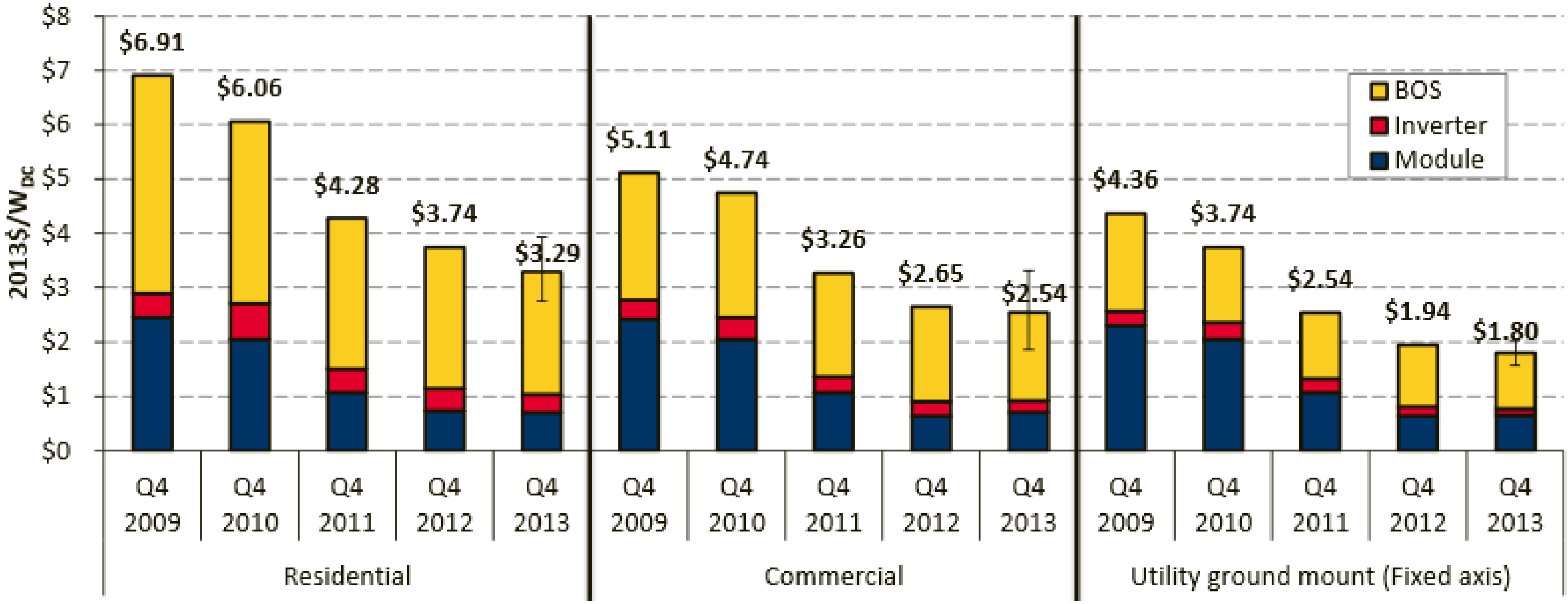


The success of solar PV technology is defined by its economics

- Swings in global supply/demand have dramatically shaped the industry

US Department of Energy SunShot 2014

Economic Trends



Much of the cost of solar installations is in the Balance of Systems (BOS):

- Installation labor
- Permitting
- Mechanical support structures
- Power electronics
- Wiring

US Department of Energy SunShot 2014

Homeland Defense & Security Information Analysis Center

Conclusions

- The diversity of photovoltaic technologies has exploded in the past decades
- Performance and cost improvements are forecast to continue over the coming decades
- There is more to advancing solar than improving cell technology

Image source: nasa.gov

Contact

Mr. Chris Doran
HDIAC Subject Matter Expert (Alternative Energy)
San Diego, CA
cdoran@hdiac.org

Mr. Stuart Stough
HDIAC Director
Oak Ridge, TN
sstough@hdiac.org

Department of Defense Information Analysis Centers

Website: www.hdiac.org
E-mail: info@hdiac.org