

# NREL's Solar Energy Research



**Australia National University**

**October 31, 2011**

**Dr. Dan E. Arvizu  
Laboratory Director**

# National Energy Imperatives



# We Are Part of DOE's National Lab Complex

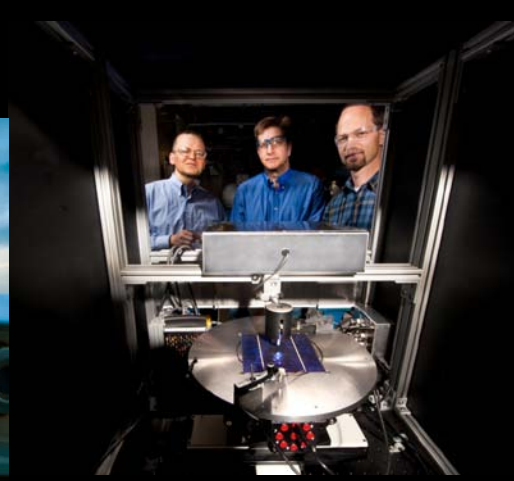
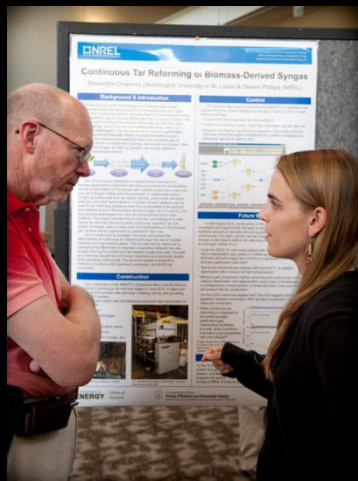
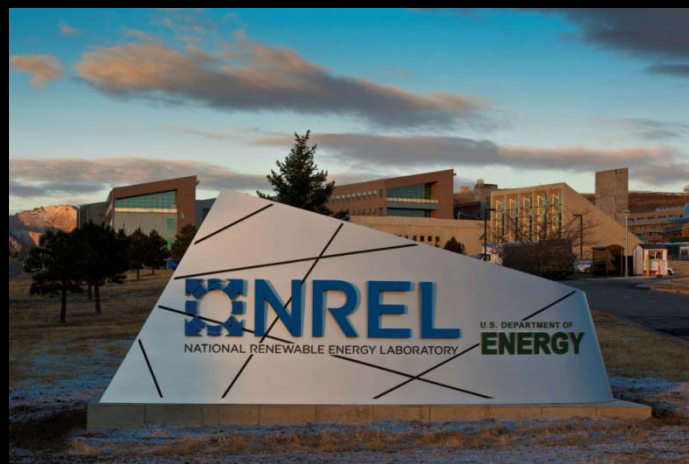


**National Renewable Energy Laboratory is operated for the U.S. Department of Energy by the Alliance for Sustainable Energy, LLC**



# NREL's Mission is Unique

NREL develops renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals.



# National Goals and NREL's Role

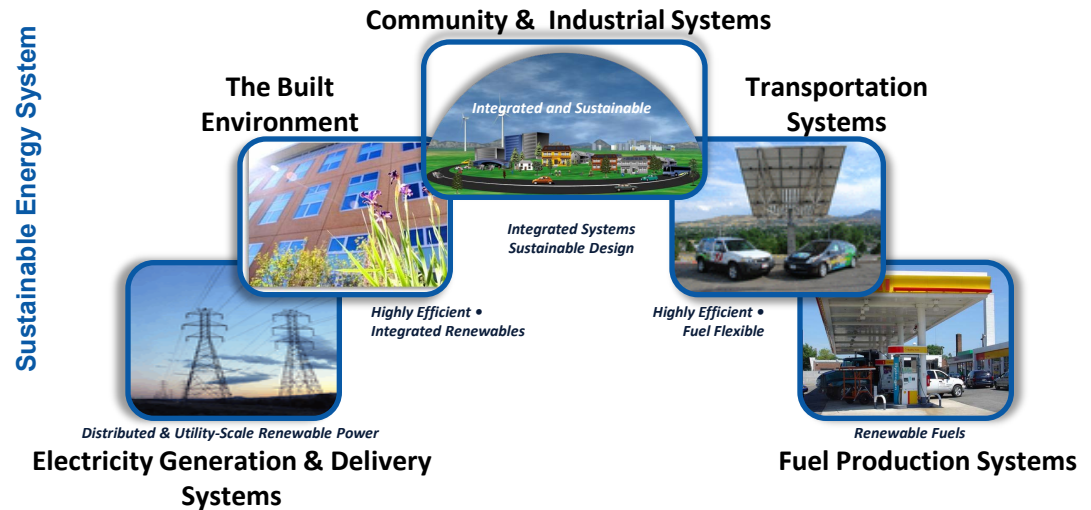
By 2035, 80% of America's electricity will come from clean energy sources

Support deployment of 1 million electric vehicles (EVs) on the road by 2015

Double renewable energy generation by 2012

Reduce our daily petroleum consumption in 2020 by 3.5 million barrels (18%)

Reduce energy-related greenhouse gas emissions by 17% by 2020 and 83% by 2050, from a 2005 baseline



**NREL Roles and Strategic Intent**

Provide Credible and Objective Data and Analyses to Inform Policy and Investment Decisions

Deliver Market-Relevant Scientific and Technical Knowledge and Sustainable Energy Innovations

Enable Integration of Renewable and Efficiency Technologies in Systems at all Scales

Increase the Speed of Commercialization and the Scale of Deployment

Create the Lab of the Future to Support Innovation and Serve as a Leadership Example for Sustainable Development

# The Role for Clean Energy—A Decade of Real Progress

Wind power capacity increased by more than a **factor of 10 to more than 200 GW.**

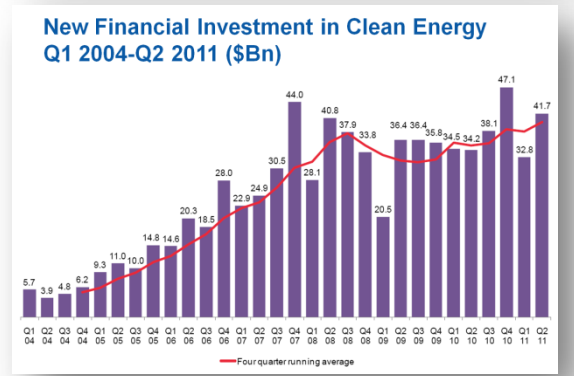
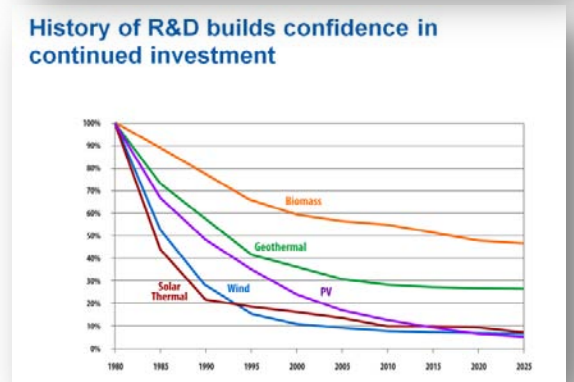
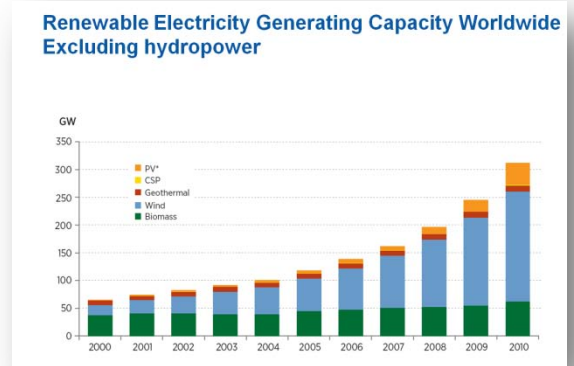
Solar PV global installed capacity **grew by factor of almost 30** to about 35 GW in 2010.

Biofuels emerged as a **major global industry** (~28 billion gallons/year)

**LEED-certified** commercial buildings grew to more than 10,000

**Costs** have been significantly reduced and are **approaching grid parity**

Clean energy grew from \$1B/year to a **\$211B/year market**





# NREL's Program Portfolio

## Strategic Analysis



### Efficient Energy Use

- Vehicle Technologies
- Buildings Technologies

- Federal Energy Management
- Integrated Deployment



### Renewable Resources

- Wind and Water
- Solar
- Biomass
- Hydrogen
- Geothermal



### Delivery & Storage

- Smart Grid and RE Grid Integration
- Battery and Thermal Storage

- International
- Other Intergovernmental

## Foundational Science

# NREL Uses R&D to Boost Return on Investment





# Near-Term Impact: Harvest Past R&D Energy Investments

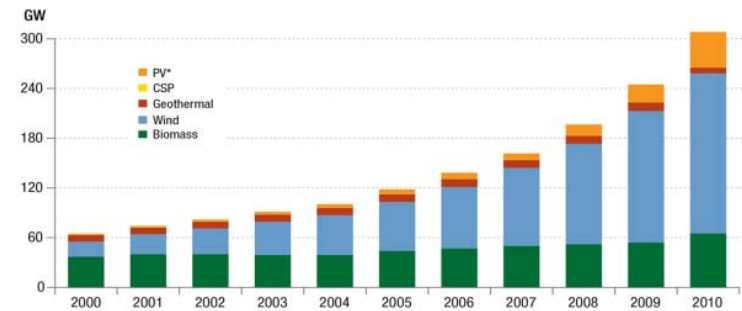
## Remove Barriers to Broad Deployment

- Fuels Economic Recovery
- Creates Jobs

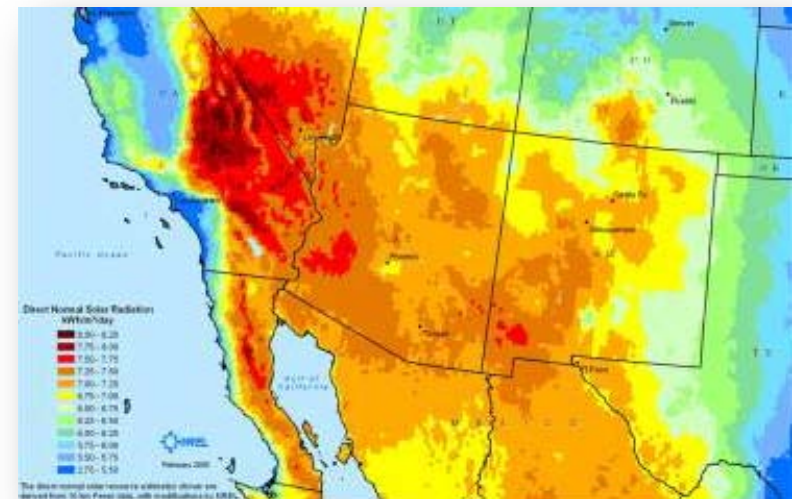
## NREL Provides Data, Tools and Technical Assistance

- Educate and inform
- Develop codes and standards
- Inform policy options, program design,  
and investment choices
  - Resource Assessment
  - Technology Analysis
  - Policy Analysis

Renewable Electricity Generating Capacity Worldwide  
(excluding hydropower)



\*Grid-tied capacity.  
Sources: REN21, GWEC, GEA, SEIA, EIA



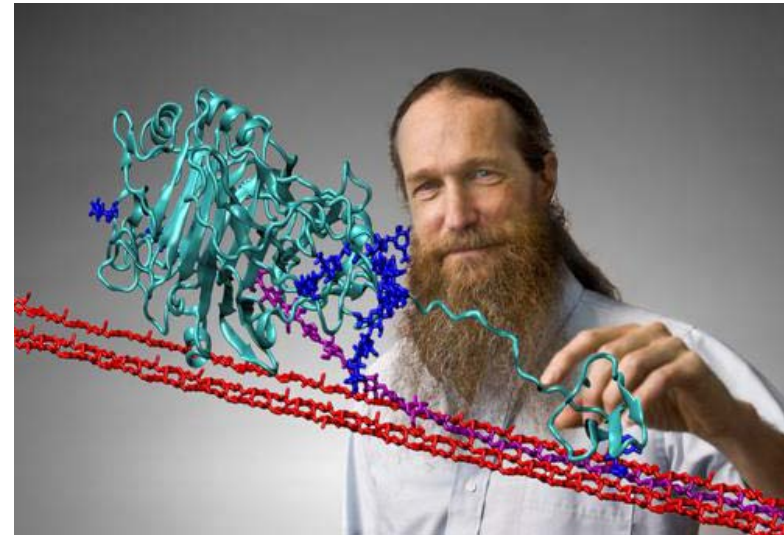
# Mid-Term Impact: Accelerate Next- Generation Technology to Market

- NREL Focus on Technology and Systems Development
- Unique Partnering Facilities
- Testing and Validation Capabilities



# Long-Term Impact: Requires Breakthrough/ Translational Science

Translational science at NREL focuses on renewable energy and energy efficiency innovations that will most benefit the nation in practical applications.



Michael Crowley, a senior scientist with the Chemical and Biosciences Center, created an animated model of Cel7A, nature's primary enzyme for decaying plants.

**NREL: Managing the  
science-to-technology interface**



# The promise of the technology: A look at solar PV



# Solar Electricity: *State of the Technology*



## Photovoltaics (PV)

Market: Residential; Commercial, Utility. Geographically diverse.

1 kW to 250 MW > GW

U.S. Capacity: 2.4 GW

U.S. Forecast: 10+ GWs in pipeline.

Costs. \$4 to \$8/W : \*LCOE 10 to 20¢/kWh.

Technologies: Conversion; thin-films, crystalline silicon. Storage; battery.

\*With various incentives; e.g. the FTC.



## Solar Thermal Electric (CSP)

Market: Commercial; Utility.

Geographically confined to “sun bowls”.

25 MW to 250 MW > GWs

U.S Capacity: 0.5 GW.

U.S. Forecast: 10+ GWs in pipeline.

Costs. \$4 to \$8/W : \*LCOE 12 to 20 ¢/kWh.

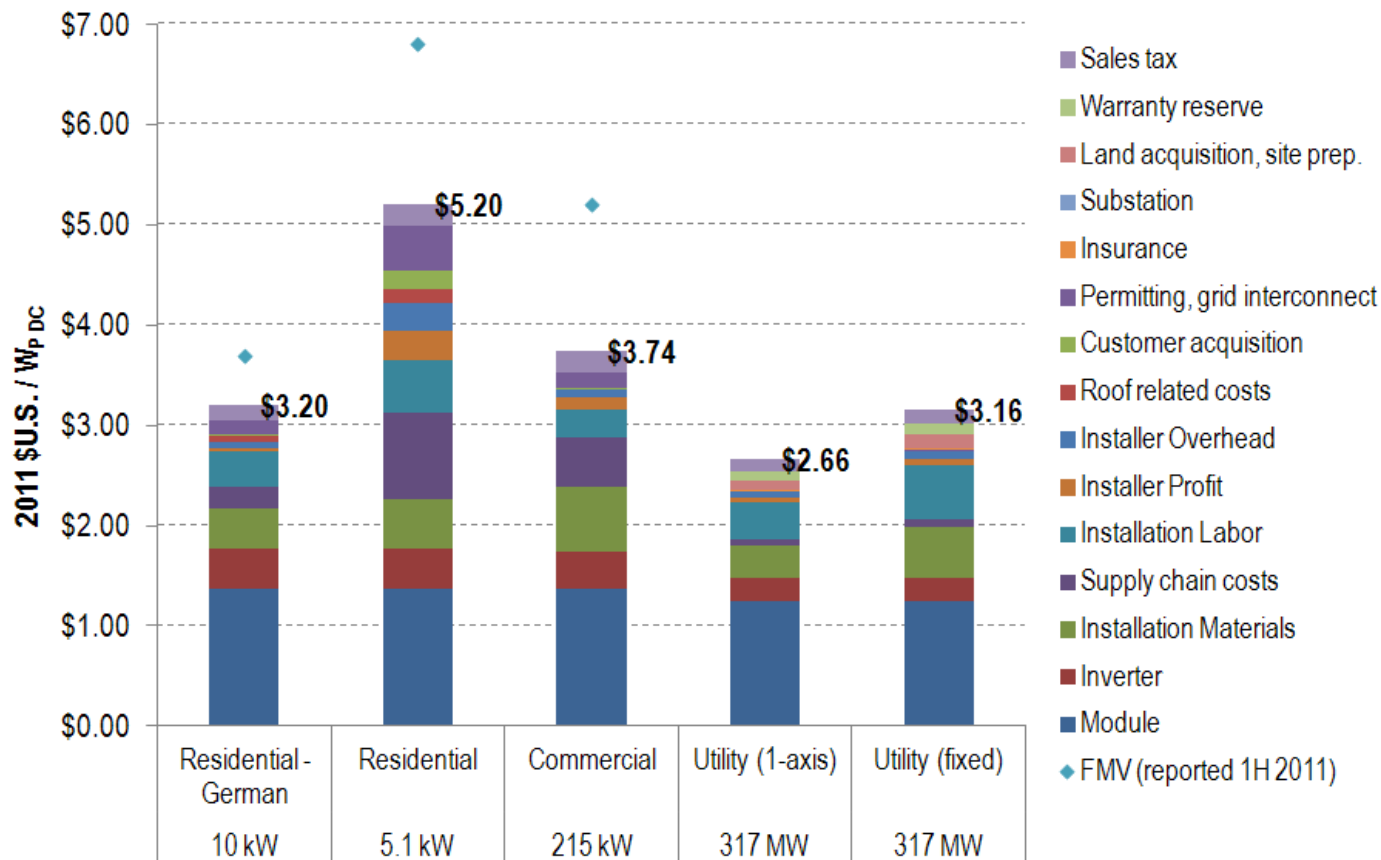
Technologies. Conversion; parabolic troughs, central receivers, dish. Storage; thermal, up to 15 hours.

# 2011 Installed system prices

Excludes financing costs (cash purchase), without subsidy. Typical cost results based on national average labor rates.

## 2011 U.S. Installed Solar PV System Prices

2H 2011 Residential and Commercial Rooftop, Utility Scale Ground Mount (fixed- and 1-axis tracking), Residential German Benchmark, Standard c-Si Modules (14.9% efficiency)



- Calculated 2011 Residential Fair Market Value (FMV):  $\$9.60/W_{p DC}$   
5 kWp DC, California (per kWh rates: \$0.16 retail, \$0.27 PPA), 30% ITC grant, \$0.95/kWh SCE rebate, 6.3% cost of capital (IRR)

Source

NREL internal cost models.

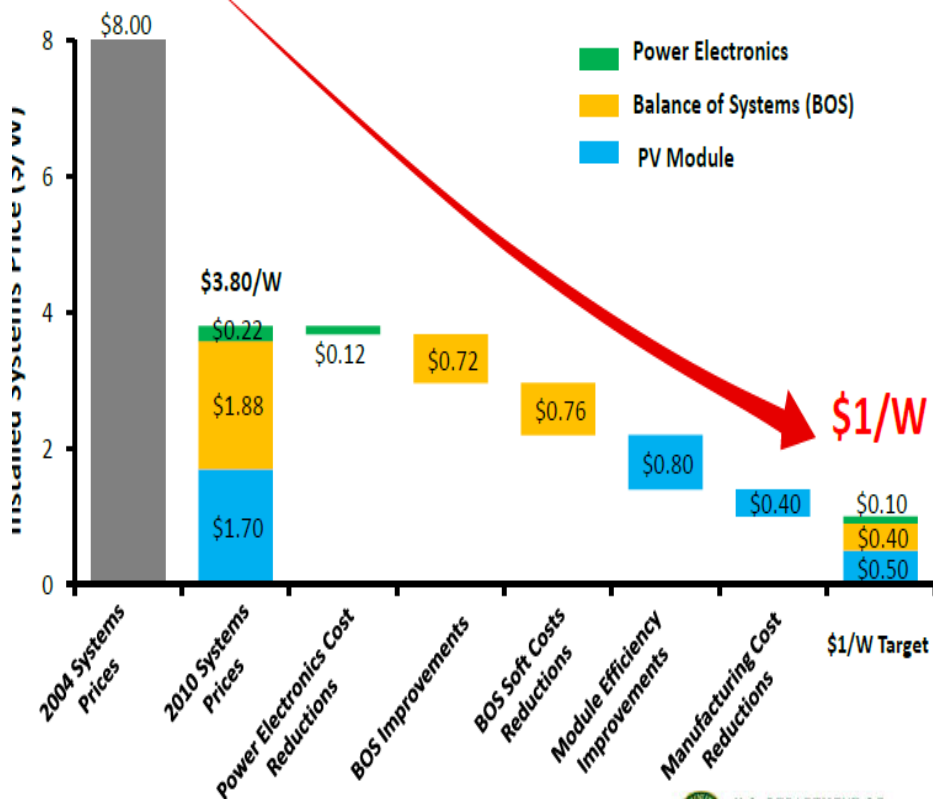
(FMV reported 2011, partial year): Barbose et al (2011). "Tracking the Sun IV/" Lawrence Berkeley National Laboratory.



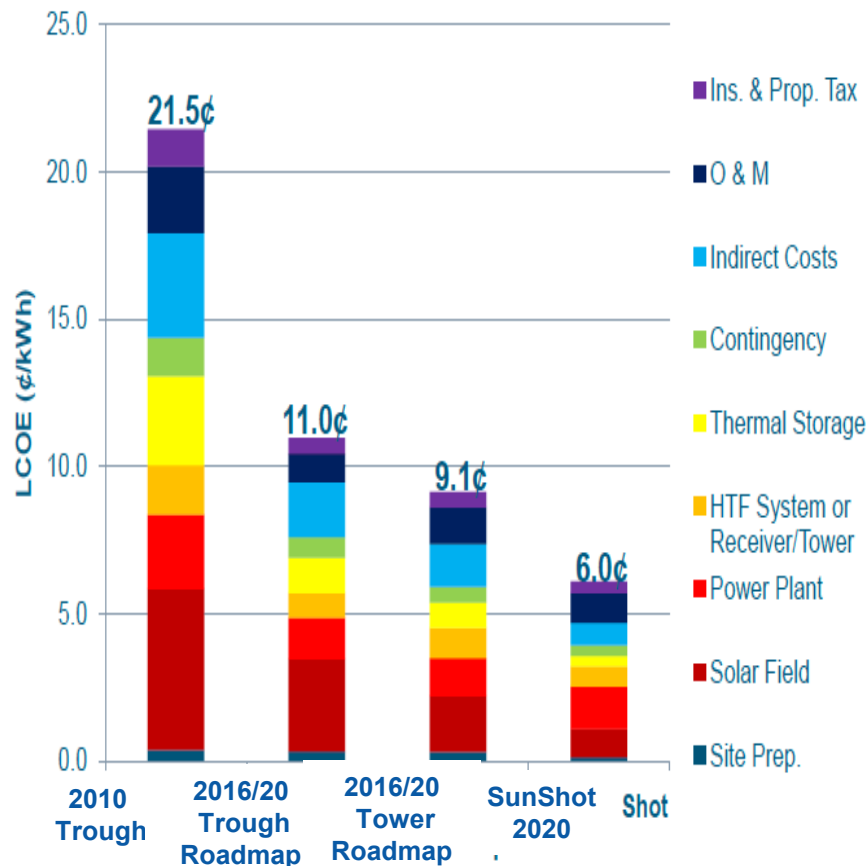
# Solar Electricity: R&D Thrusts

## Photovoltaics

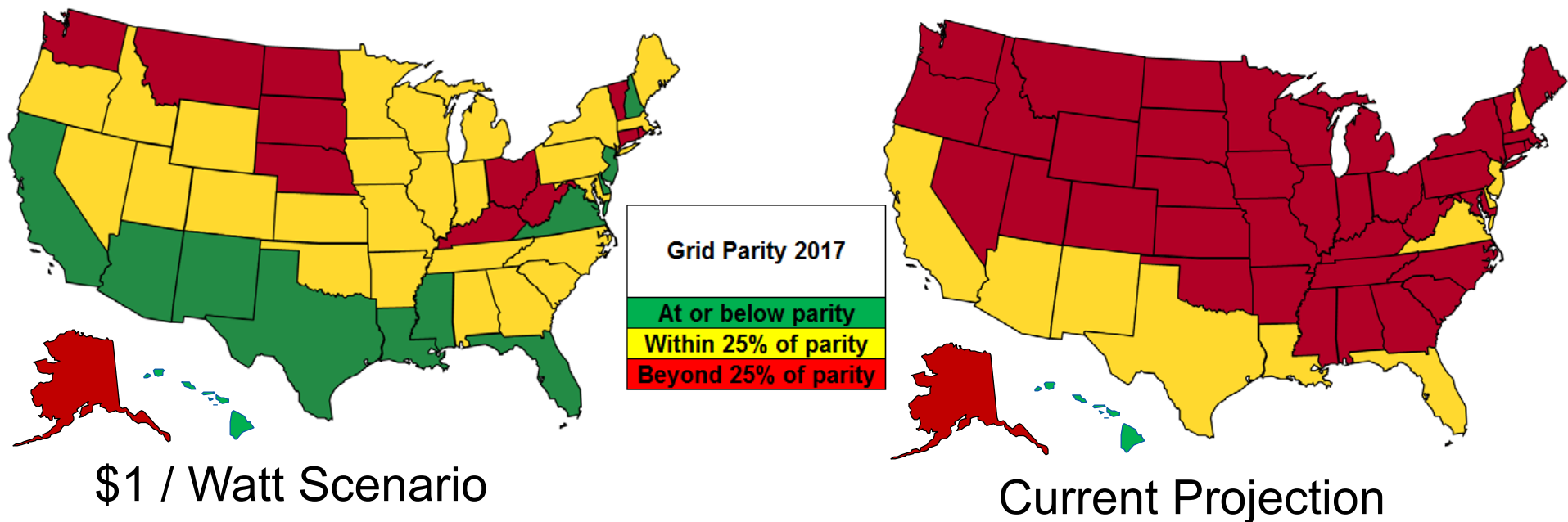
### DOE SunShot Program



## CSP



# Grid Parity with \$1 / Watt



- Assumes no Federal, State, Local, and Utility incentives
- Assumed an installed system size of 20 MW, and an 86% conversion factor between DC and AC module capacity.
- Utilized weighted average wholesale electricity prices from the 2008 EIA-861 Data. The data were escalated to 2017 prices based on an annual electricity escalation rate of 1%.
- Current projection for utility scale PV is assumed to be \$2/Watt by 2017.

# PV Conversion Technology Portfolio

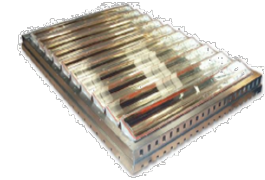


## Thin Films (aSi)

Advancing amorphous and wafer replacement crystal silicon film solar cells on low-cost substrates

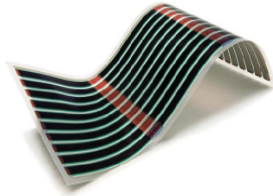
## Concentrating PV

Combining new, lower cost multijunction cells and innovative optical packages



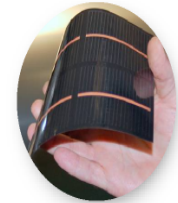
## Organic PV

Customizing molecules, substrates, and deposition techniques to yield ultra low-cost modules



## Thin Films (CIGS)

Supporting the manufacture of non-vacuum processes and transferring record efficiency device performance into large area commercial modules



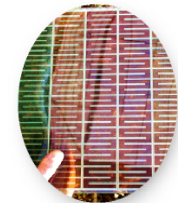
## Next Generation

Investigating advanced concepts aimed at delivering revolutionary performance improvements



## Dye-Sensitized Cells

Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures



## Crystalline Silicon

Developing higher efficiency devices and lower cost processing methods for traditional silicon cells



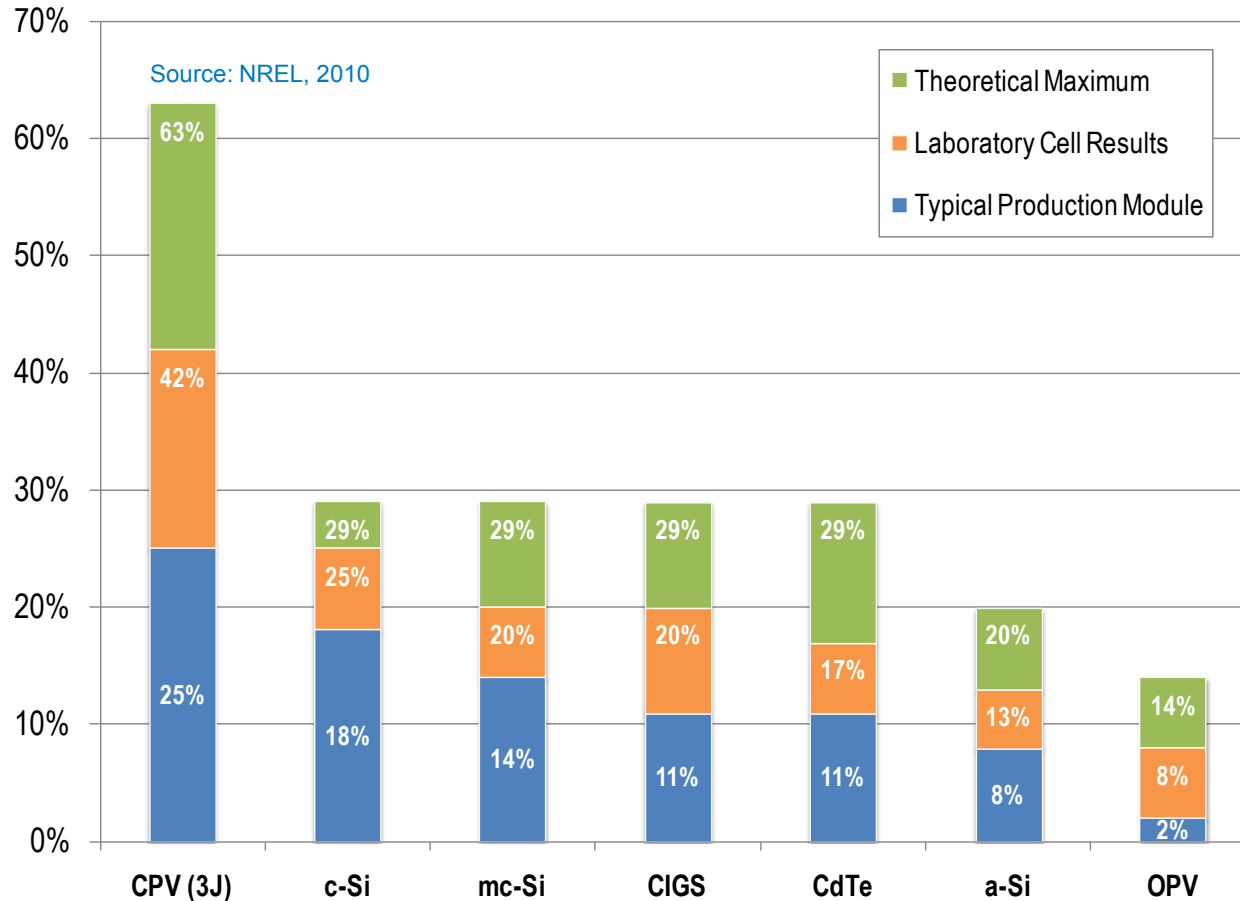
## Building Integrated PV

Creating module form factors aimed at dramatically reducing or eliminating solar installation costs





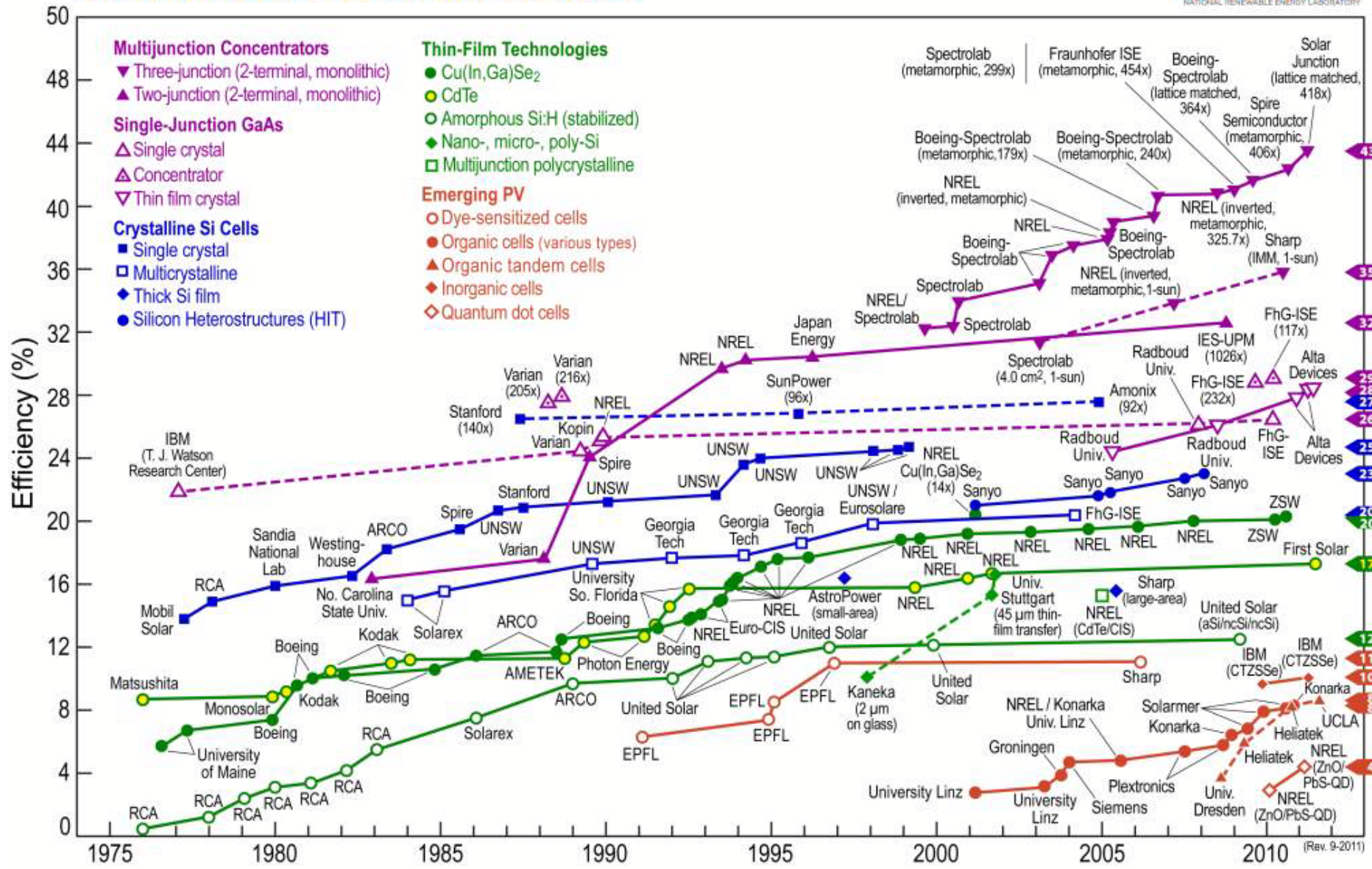
# Challenge of TF PV: close the gap



Lab (69%) of theoretical, production (60%) of laboratory

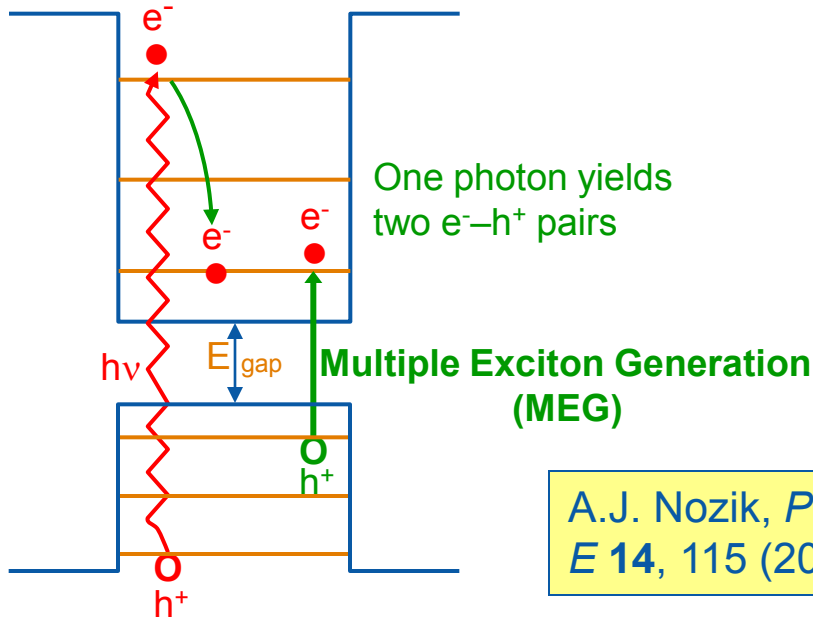
- Technical barriers? Solutions?
- Do solutions translate to commercial production? Cost?

# Best Research-Cell Efficiencies

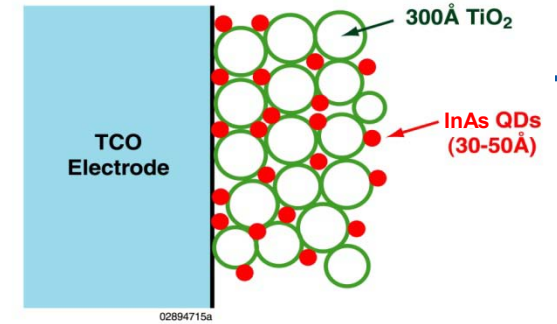


# Enhanced Photovoltaic Efficiency in Quantum Dot Solar Cells by Inverse Auger Effect (MEG)

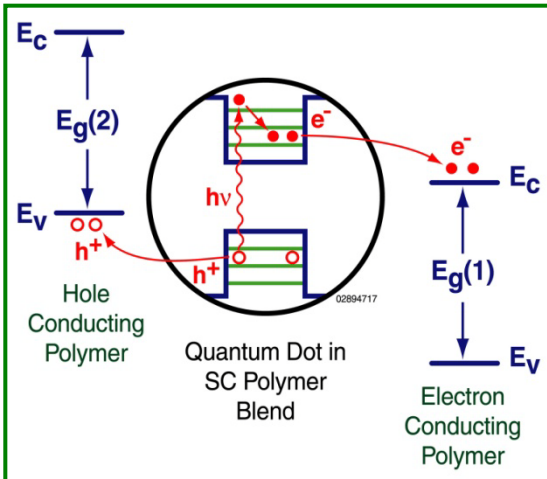
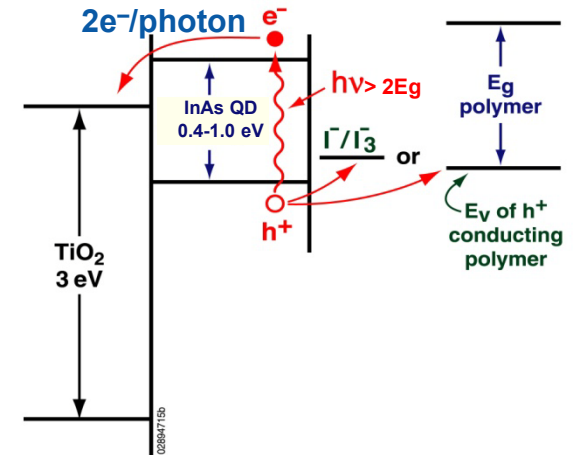
# Quantum Dot Solar Cells



A.J. Nozik, *Physica E* 14, 115 (2002);

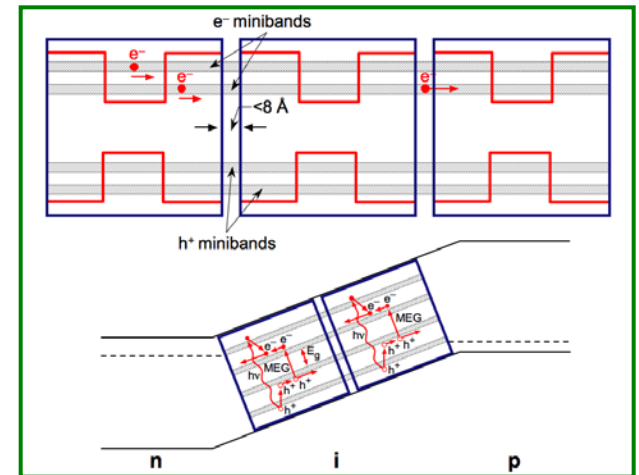


## QD-Sensitized Nanocrystalline $TiO_2$ Solar Cell



## QD-Conducting Polymer Blend Solar Cell

## p-i-n QD Array Solar Cell






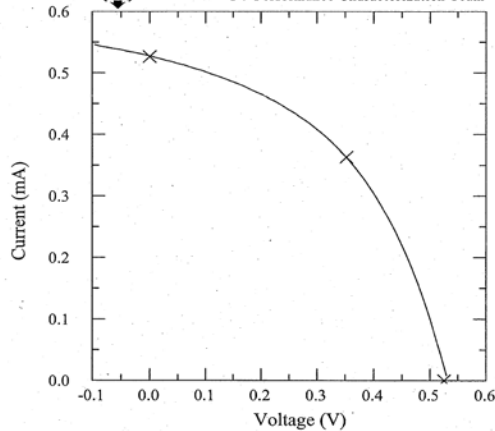
# p-n Junction Quantum Dot Solar Cell with a Record Certified Record Conversion Efficiency of 4.4%

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## NREL PbS Quantum Dot Cell

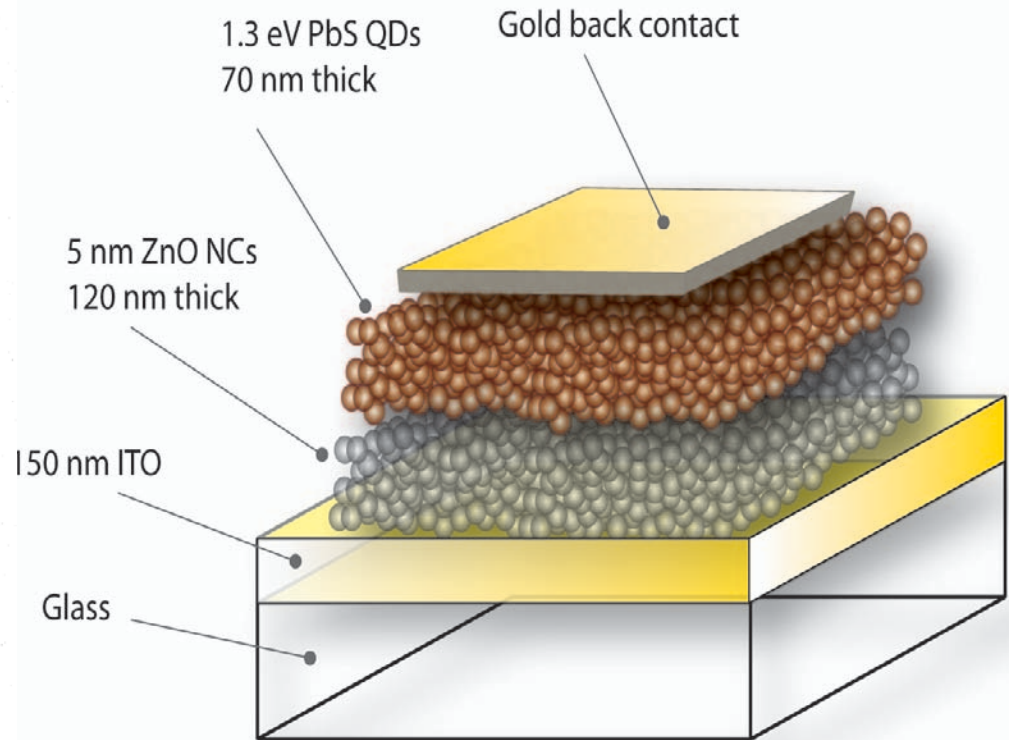
Device ID: JGAO-1      Device Temperature:  $35.0 \pm 0.5$  °C  
 Mar 09, 2011 15:12      Device Area:  $0.02901 \text{ cm}^2$   
 Spectrum: ASTM G173 global      Irradiance:  $1000.0 \text{ W/m}^2$

 X25 IV System  
 PV Performance Characterization Team



$V_{oc} = 0.5254 \text{ V}$        $I_{max} = 0.36303 \text{ mA}$   
 $I_{sc} = 0.52639 \text{ mA}$        $V_{max} = 0.3520 \text{ V}$   
 $J_{sc} = 18.145 \text{ mA/cm}^2$        $P_{max} = 0.12778 \text{ mW}$   
 Fill Factor = 46.20 %      Efficiency = 4.40 %

Kelvin connection on pin not labeled and pin labeled "B"  
 Fan blowing across device.

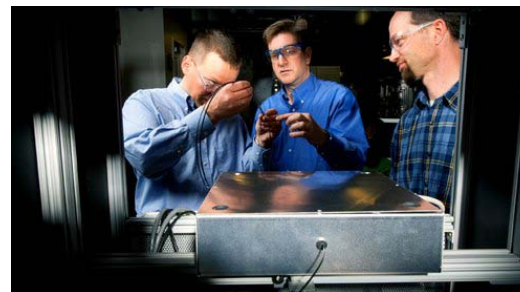


# Market Relevant Process Innovation

*“Black Silicon”  
Nanocatalytic  
Wet-Chemical  
Etch*



*Flash Quantum Efficiency System*



COMPANY PRODUCTS TECHNOLOGY PARTNERS CAREERS CONTACT



ANNOUNCEMENTS

HELIOVOLT IN THE NEWS

**PV-Tech.org**  
Lone Star CIGS: HelioVolt comes back out into the light, re-enters thin-film PV fray »

**GIGAOM**  
HelioVolt Raises \$8.5M in Debt, Close to Prime Time? »



English | 中文

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**THE WORLD'S  
BEST SOLAR CELLS  
JUST GOT BETTER**  
with Innovalight solar technology.

**Raise Efficiency and Lower  
Cost Per Watt in Under 90 days**

Innovalight's patented technologies cost effectively increase the conversion efficiency of crystalline silicon solar cells. The easy-to-implement technologies improve cell manufacturers' existing factory output and reduce production costs.

→ LEARN MORE

*Revolutionary CIGS thin-film  
manufacturing process using inkjet  
printing*



2008

*Silicon Ink  
NREL Incubator Project*



# innovation Impact: Partnering is Key



ABENGOA SOLAR

ALSTOM



JOHNSON  
MATTHEY



FedEx

JCPenney



PHOTON SOLAR POWER  
*The Art of The Sun*

Walmart  
Save money. Live better.



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OPTONY  
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# NREL International Framework

## *NREL Roles*

**Science & Technology Cooperation**

**Energy Analysis**

**Commercialization & Deployment Support**

## *Strategic Goals*

### **NREL International Strategic Goals**

- Achieve technology R&D and deployment goals
- Advance RE & EE solutions to climate, climate energy security, and economic issues
- Strengthen global assessments & knowledge transfer

## *Core Activities*

**Multilateral Technology Partnerships**

**Bilateral Partnerships**

**Climate/ Environmental Initiatives**

**Global Energy Assessments & Knowledge Transfer**

**Researcher Driven Collaboration**



# NREL Collaboration with Australian Organizations

## Solar Energy – Current Activities

- CRADA with University of Queensland to develop novel materials and architectures for organic PV systems
- Co-authorship with UNSW of record cell and module efficiencies in Progress in PV (38 editions to date)

## Solar Energy – Opportunities

- Joint proposal with ASI for support under US Australia Solar Energy Collaboration (UASEC) initiative on improving models for predicting yields of PV systems
- Joint proposal with CSIRO on developing design inputs for tower-mounted CSP receivers, construction of tower test facilities, and testing of super critical high temperature CO<sub>2</sub> systems

# NREL Collaboration with Australian Organizations

## Clean Energy Solutions Center

- The Australian Department of Resources, Energy, and Tourism co-sponsors with the U.S. DOE and the UN the Clean Energy Solutions Center and guides NREL's work as operating agent.
- The Clean Energy Solutions Center – [www.cleanenergysolutions.org](http://www.cleanenergysolutions.org) provides expert assistance and peer learning along with technical resources on clean energy policies for all countries around the world

## Biofuels

- Collaboration with CSIRO on algal biofuels, including scientific exchanges, characterization of algal cultures, and resource assessment
- Cooperation with Microbiogen on ethanol production from lignocellulosic materials and dialogue with University of Melbourne about collaboration in this area and algal biofuels

## Wind and Ocean Energy

- Collaboration with Australia's Clean Energy Council, Murdoch University, and Oceanlinx through IEA implementing agreements





NATIONAL RENEWABLE ENERGY LABORATORY

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