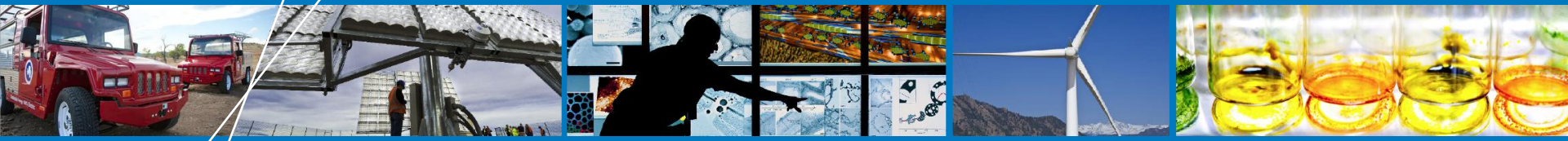
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL's Solar Energy Research

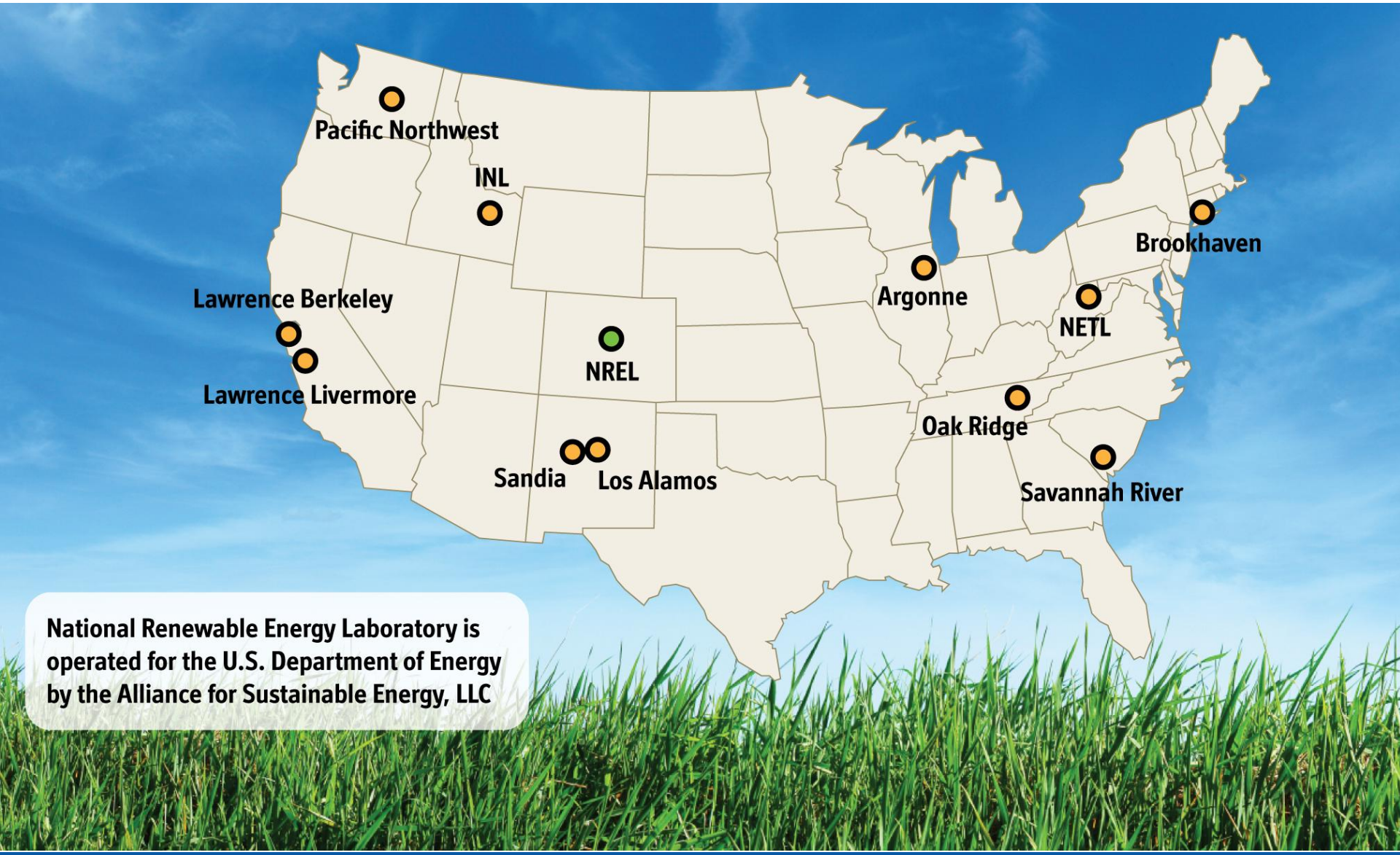


Australian Solar Institute

November 1, 2011

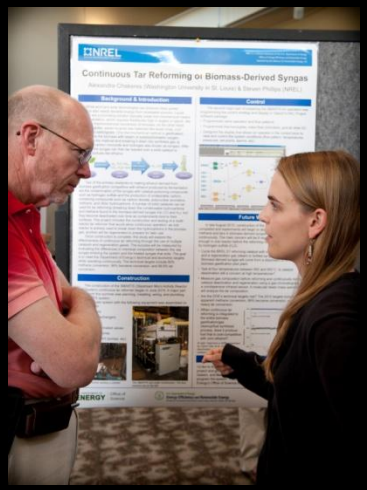
Dr. Dan E. Arvizu
Laboratory Director

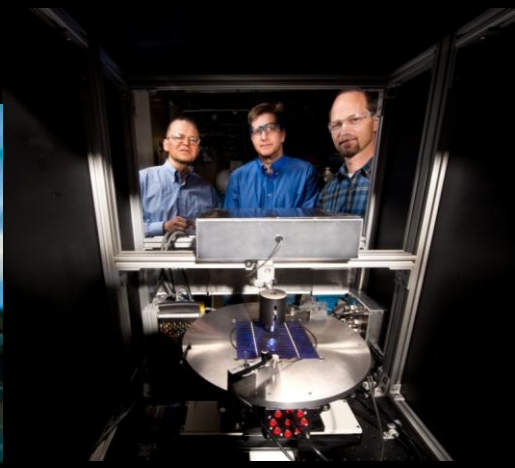
We Are Part of DOE's National Lab Complex



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

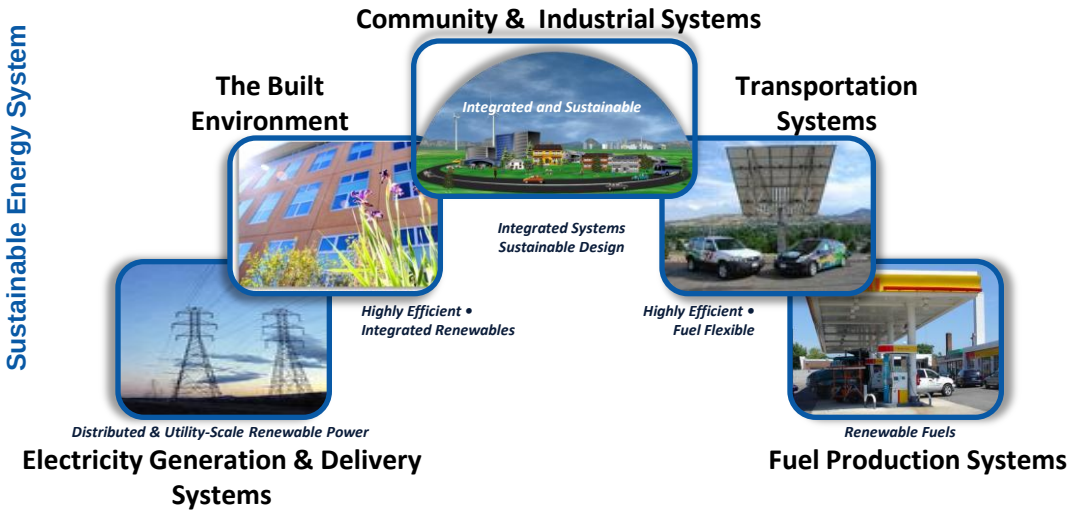
By 2035, 80% of America's electricity will come from clean energy sources

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 Intents

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

NREL's Program Portfolio

Strategic Analysis

Efficient Energy Use

- Vehicle Technologies
- Buildings Technologies

Renewable Resources

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

Delivery & Storage

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

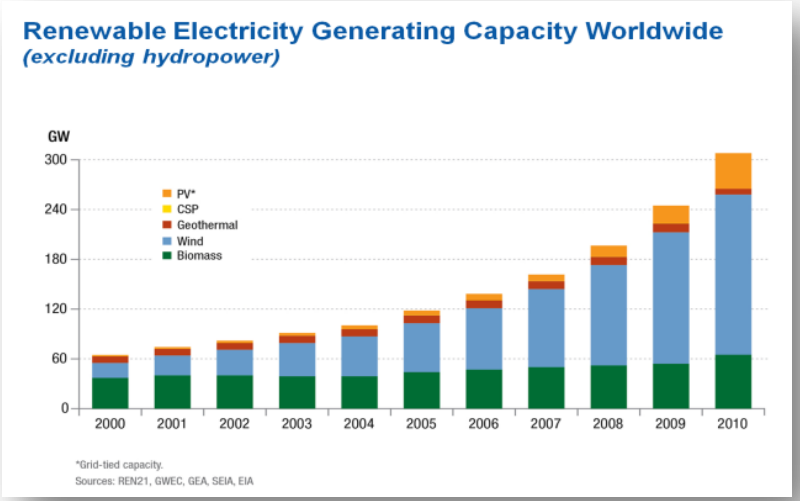
- Federal Energy Management
- Integrated Deployment
- International
- Other Intergovernmental

Foundational Science

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

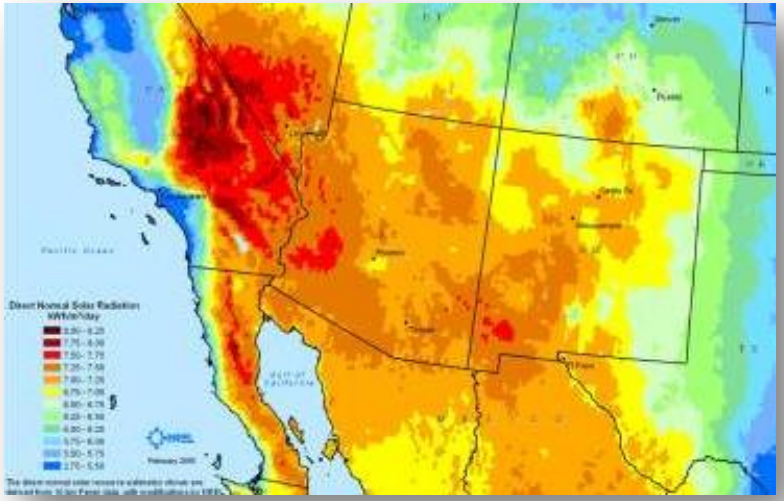
Remove Barriers to Broad Deployment

- 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

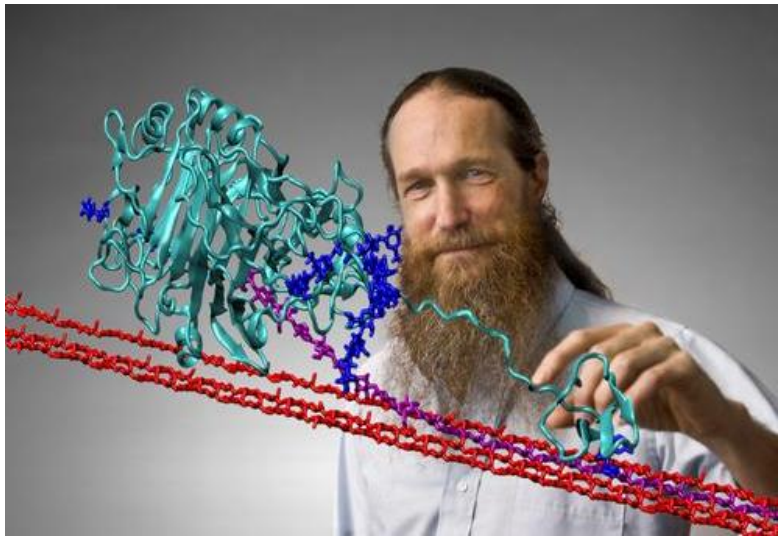


Mid-Term Impact: Accelerate Next-Generation Technology to Market

- 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¢/kWr.

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

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.

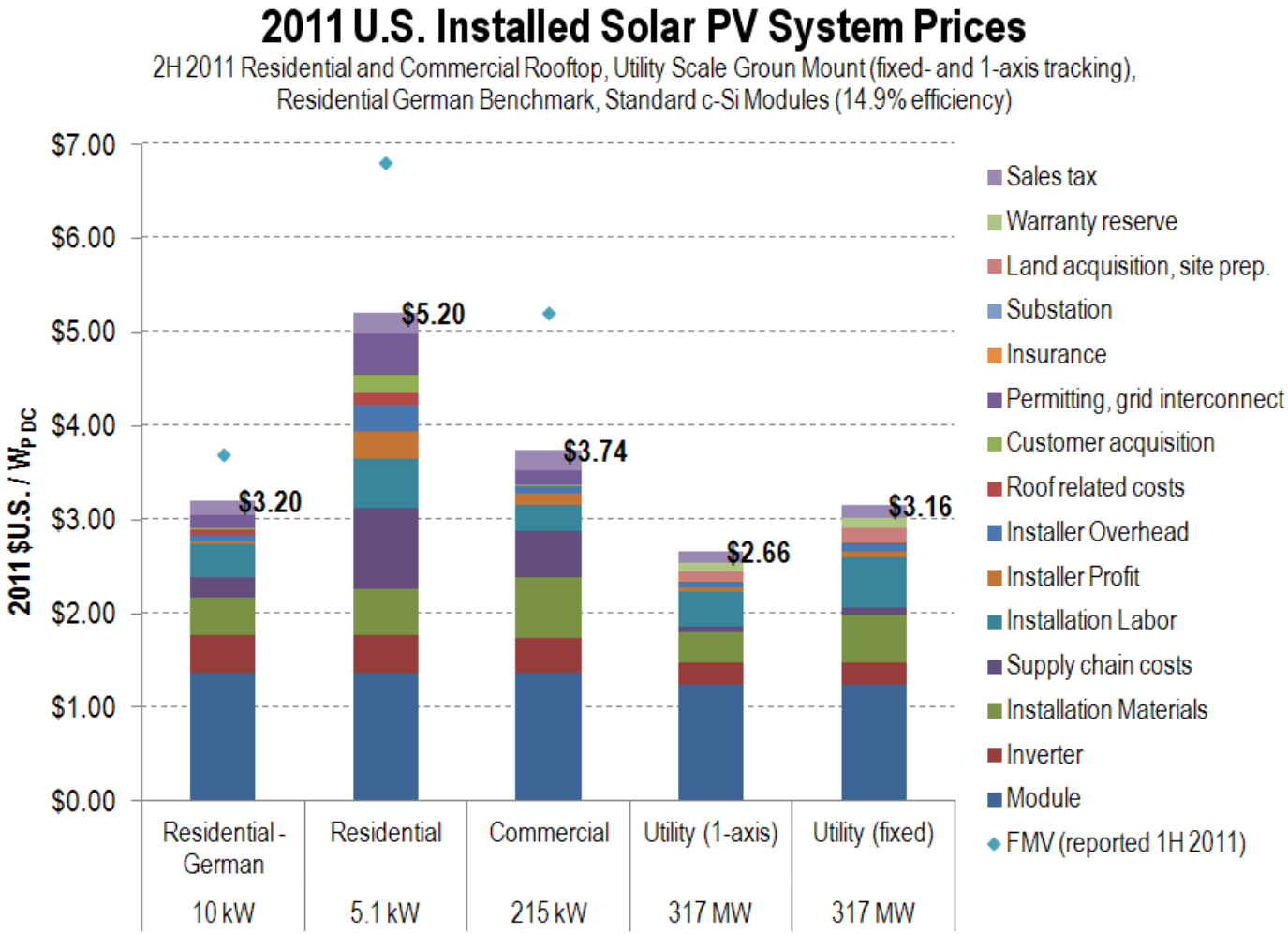
Costs. $4 to $8/W :*LCOE 12 to 20 ¢/kWr.

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

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

2011 Installed system prices

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



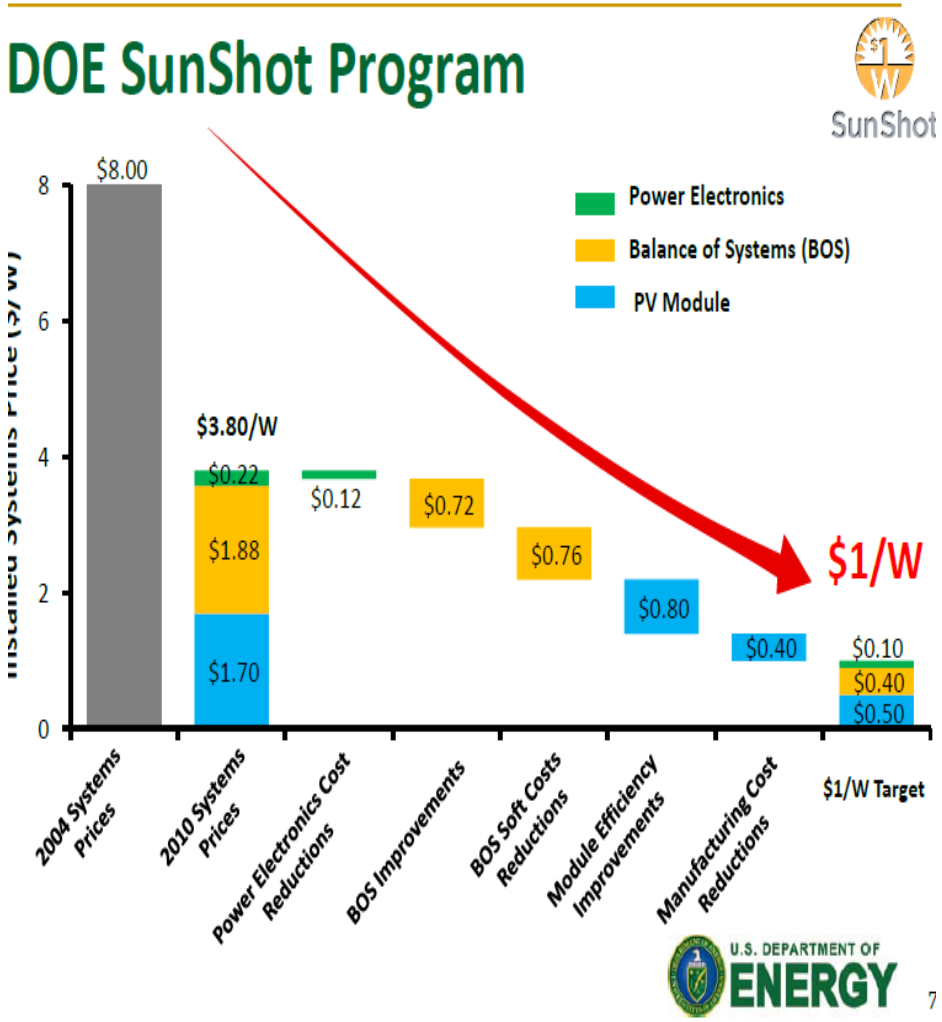
- Calculated 2011 Residential Fair Market Value (FMV): $9.60/$W_{P\ DC}$

  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)

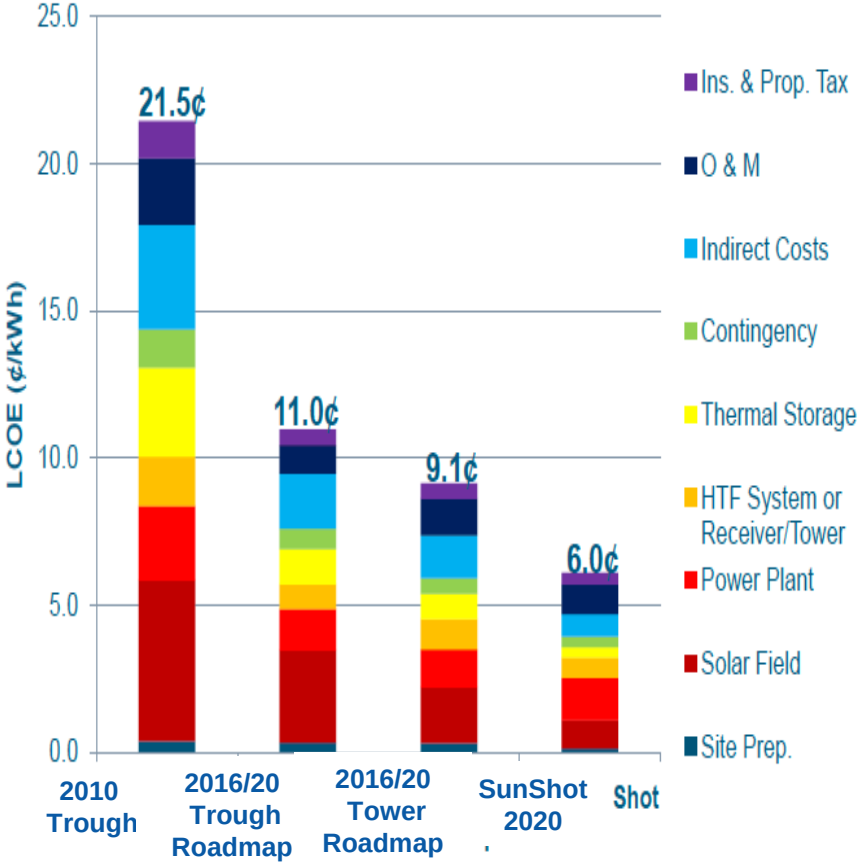
Source NREL internal cost models.
(FMV reported 2011, partial year): Barbose et al (2011). "Tracking the Sun IV/" Lawrence Berkeley National Laboratory.

Solar Electricity: R&D Thrusts

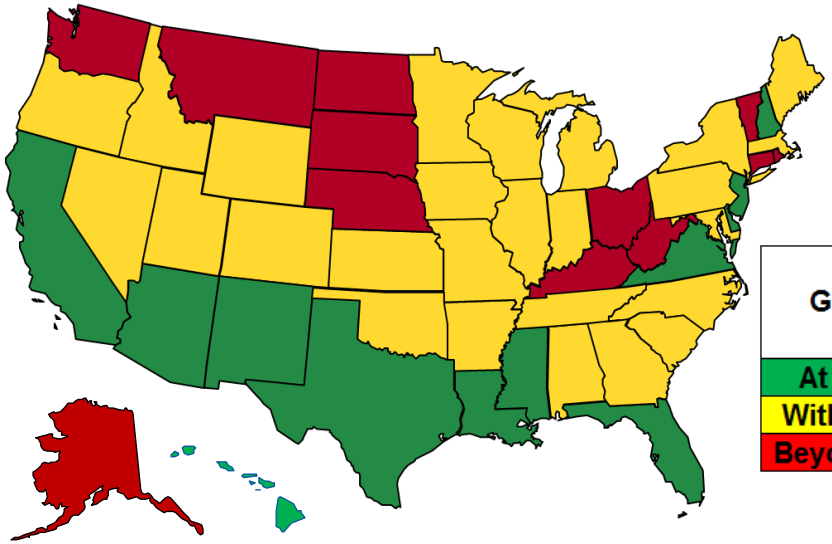
Photovoltaics

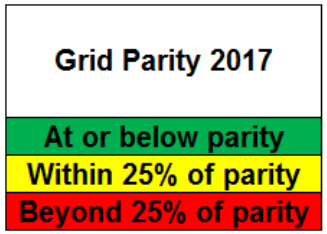


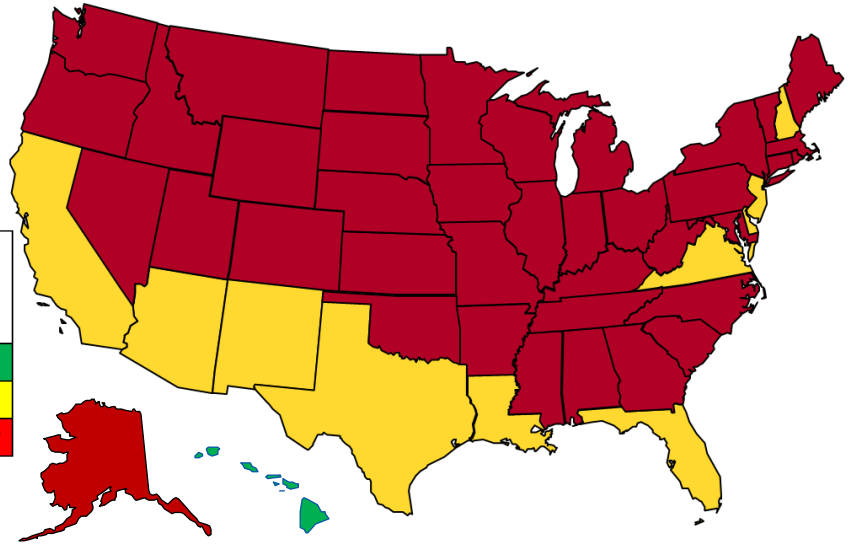
CSP



Grid Parity with $1 / Watt







$1 / Watt Scenario

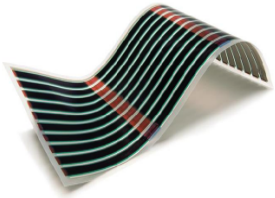
Current Projection

- 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

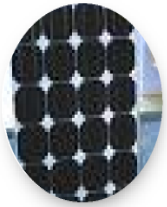


Organic PV

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

Next Generation

Investigating advanced concepts aimed at delivering revolutionary performance improvements



Crystalline Silicon

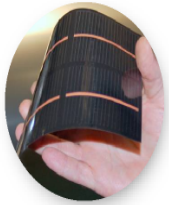
Developing higher efficiency devices and lower cost processing methods for traditional silicon cells

Concentrating PV

Combining new, lower cost multijunction cells and innovative optical packages

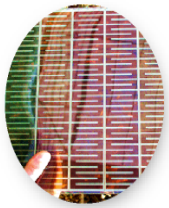
Thin Films (CIGS)

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



Dye-Sensitized Cells

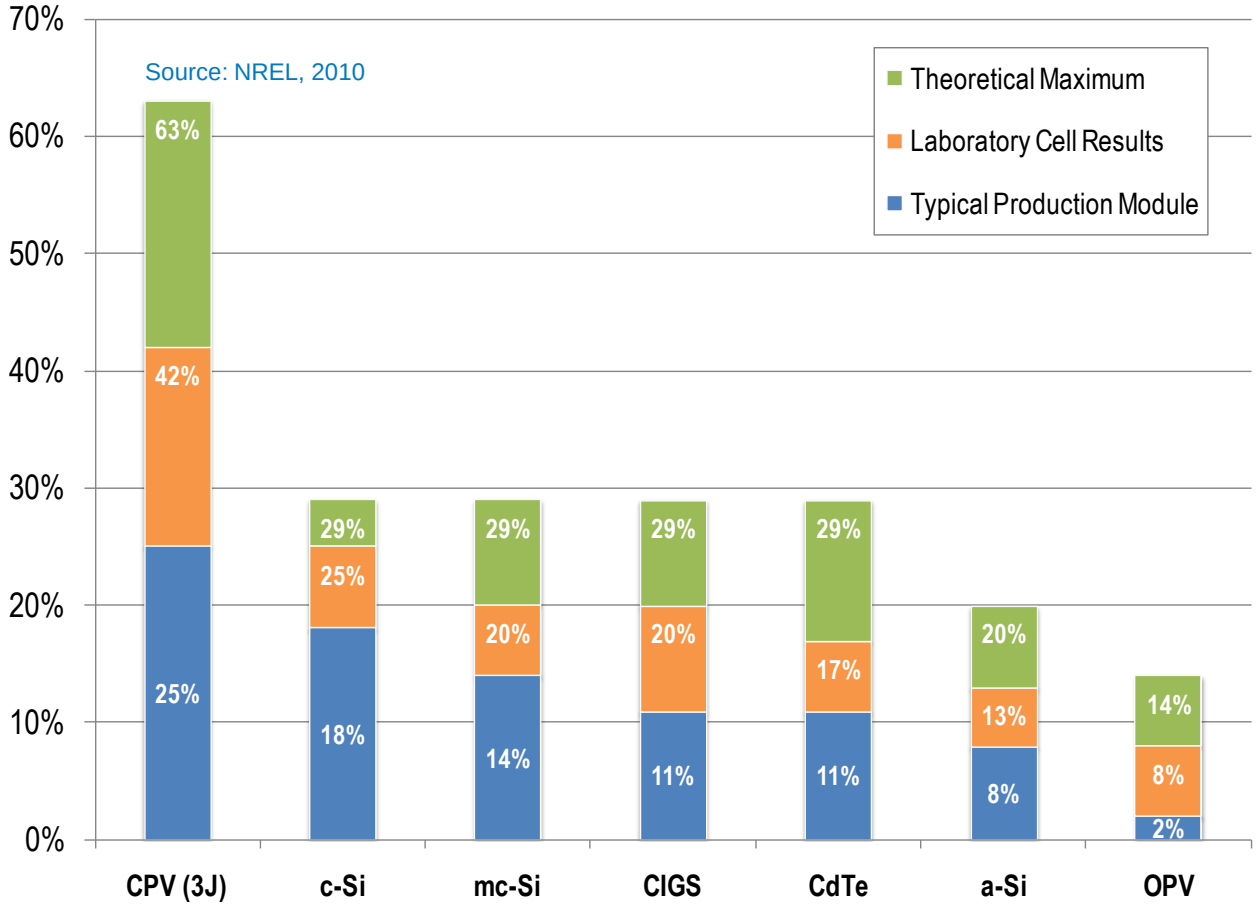
Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures



Building Integrated PV

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

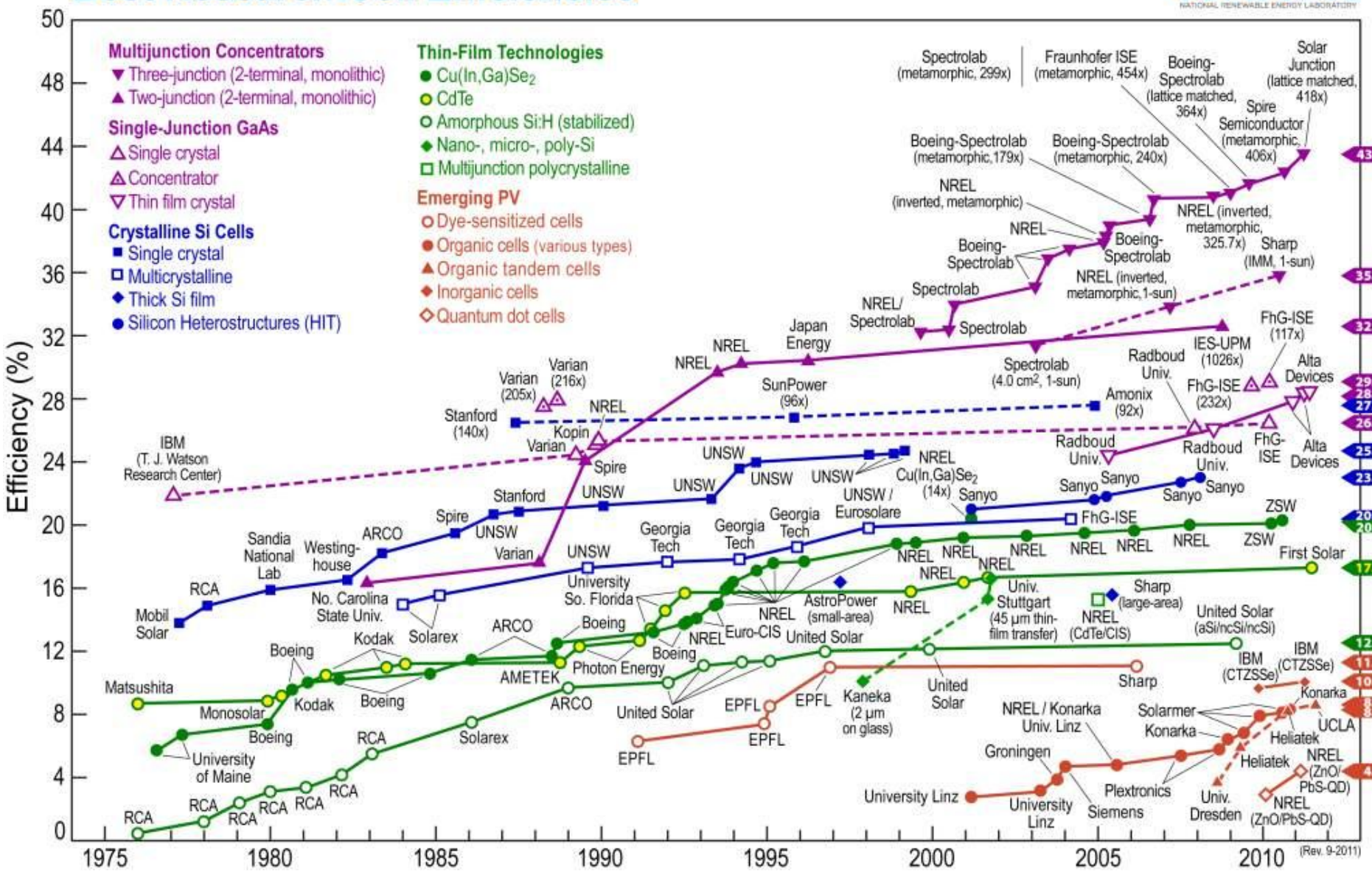
Challenge of TF PV: close the gap



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

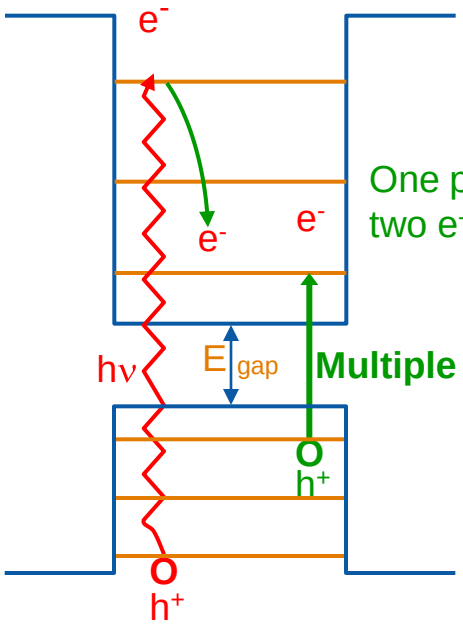
- Technical barriers? Solutions?
- Do solutions translate to commercial production? Cost?

Best Research-Cell Efficiencies



Quantum Dot Solar Cells

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

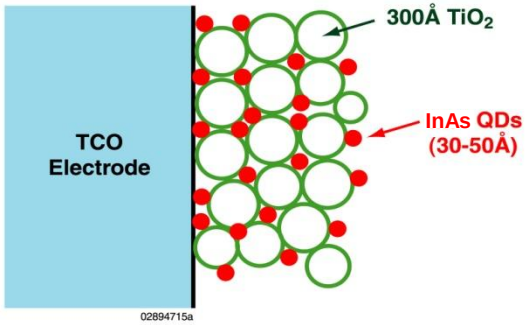


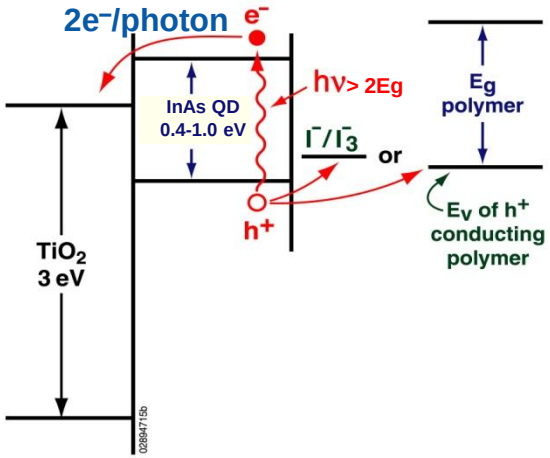
One photon yields two e^-–h^+ pairs

Multiple Exciton Generation (MEG)

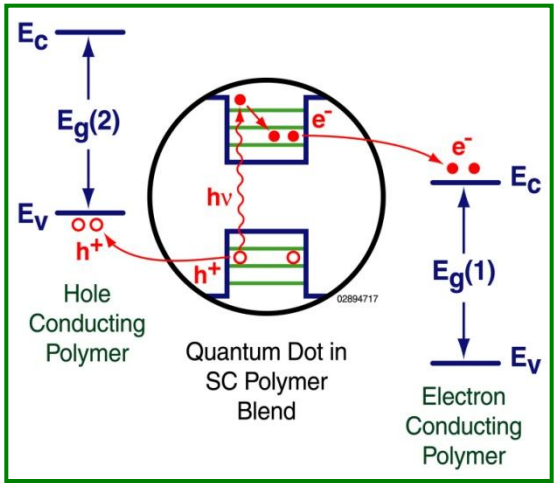
A.J. Nozik, *Physica E* **14**, 115 (2002);

QD-Sensitized Nanocrystalline TiO_2 Solar Cell

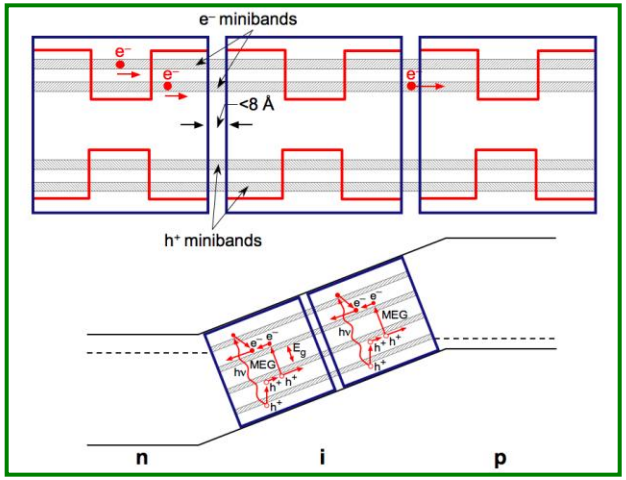




QD-Conducting Polymer Blend Solar Cell



p-i-n QD Array Solar Cell



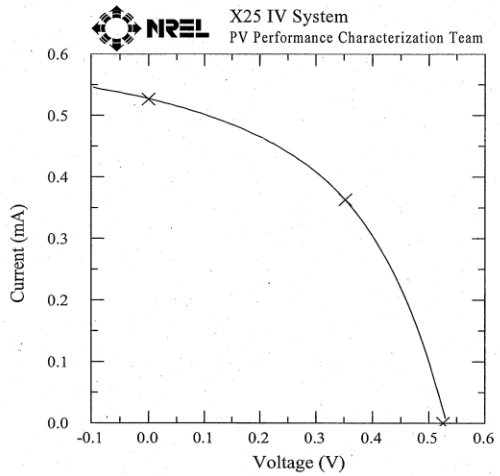
p-n Junction Quantum Dot Solar Cell with a Record Certified Record Conversion Efficiency of 4.4%

NREL

PbS Quantum Dot Cell

Device ID: JGAO-1
Mar 09, 2011 15:12
Spectrum: ASTM G173 global

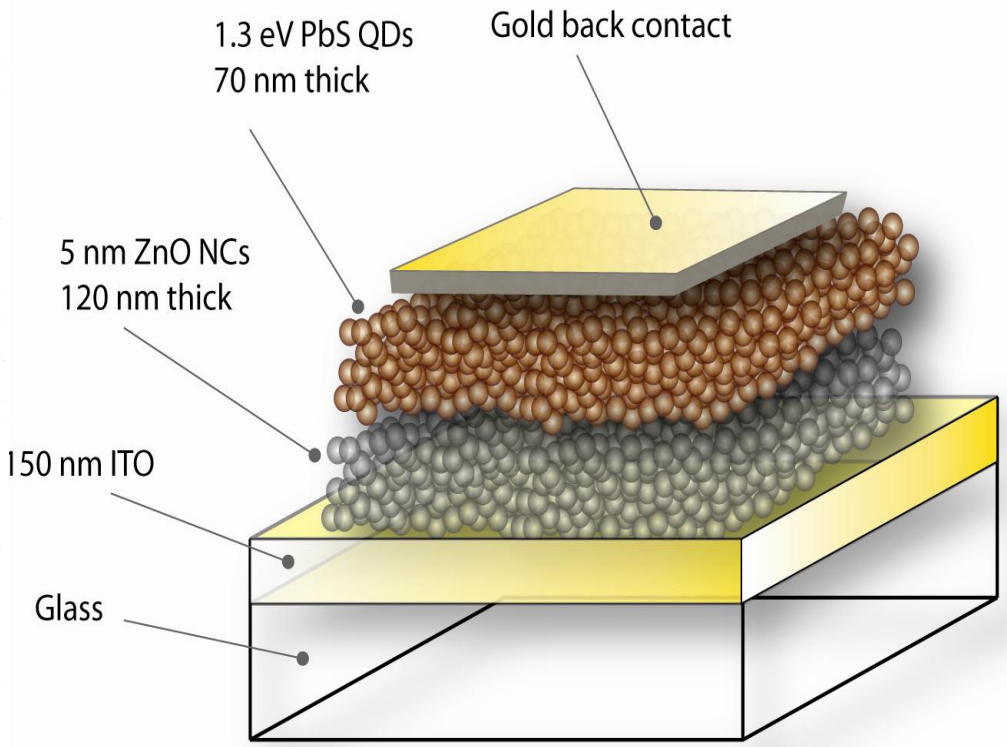
Device Temperature: 35.0 ± 0.5 °C
Device Area: 0.02901 cm^2
Irradiance: 1000.0 W/m^2



V_{oc} = 0.5254 V
I_{sc} = 0.52639 mA
J_{sc} = 18.145 mA/cm^2
Fill Factor = 46.20 %

I_{max} = 0.36303 mA
V_{max} = 0.3520 V
P_{max} = 0.12778 mW
Efficiency = 4.40 %

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



Luther et. al Adv Mater. 22, 3704 (2010)

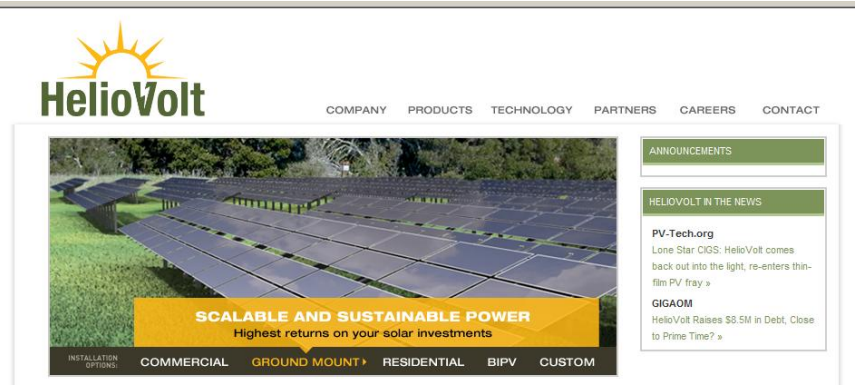
Market Relevant Process Innovation

"Black Silicon" Nanocatalytic Wet-Chemical Etch

2010 R&D 100

Flash Quantum Efficiency System

2011 R&D 100



Revolutionary CIGS thin-film manufacturing process using inkjet printing

HelioVolt

R&D 100 2008

Silicon Ink NREL Incubator Project

2011 R&D 100

innovation Impact: Partnering is Key


Smart Grid/Grid Integration

Current U.S. Status

The Grid

- 30,000 transmission paths; >180K miles of transmission lines
- 14,000 transmission substations
- Distribution grid connects substations to over 100 million loads

Utility Sector

- 3,170 traditional electric utilities (239 investor-owned, 2,009 publicly owned, 912 consumer-owned rural cooperatives, and 10 Federal electric utilities)

Artist Rendering of the Energy System Integration Facility

NREL Research Thrusts

DG Interconnection Standards

- IEEE Standards Development
- Standards Testing and Validation

Smart-Grid Data Hub

RE Grid Integration

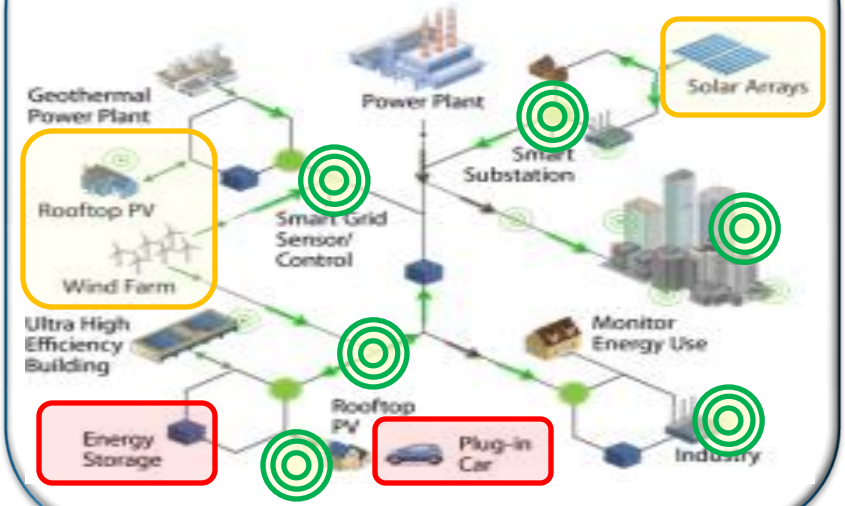
- Power Electronics for Interconnection monitoring and control
- Grid-to-vehicle interface

Updated 9/10

Why Energy Systems Integration?

Current Energy Systems

Future Energy Systems



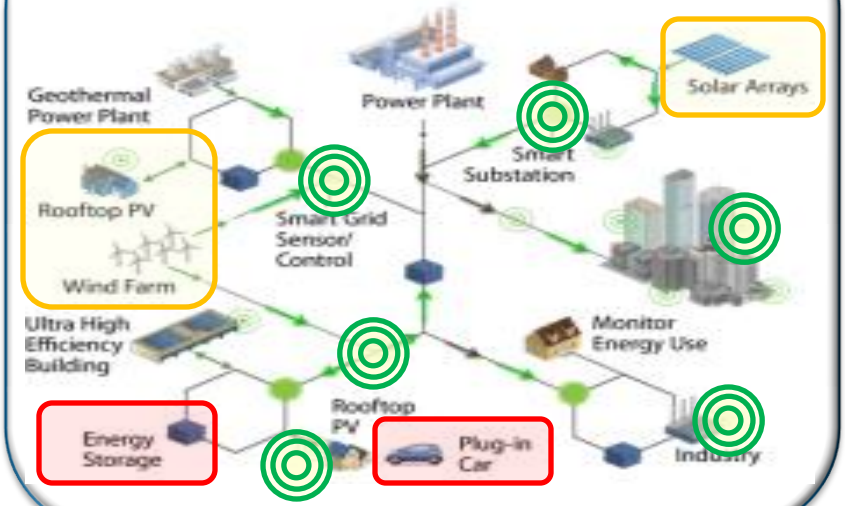
New Challenges – Need to tackle difficult problems

- Increasing penetration of variable RE in grid
- New communications and control models
- Electrification of transportation
- New energy technologies and services integrating energy storage
- Increasing system flexibility
- Understanding interactions between electricity/thermal/fuels

Why Energy Systems Integration?

Current Energy Systems

Future Energy Systems



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NREL PV Grid Integration Activities

NREL is working with Utilities, System Integrators, Universities and other National Laboratories to help integrate higher levels of PV into the electric power grid

- **Distribution Integration**
  - Monitoring real-world high penetration cases
  - Developing and validating models and simulations
  - Updating integration approaches and standards
- **Transmission Integration**
  - Collecting and validating field data
  - Conducting operational analysis and optimization
  - Developing models for new technologies
  - Integrating into transmission expansion planning

Utility Partners

- Southern California Edison (SCE)
- Sacramento Municipal Utility District (SMUD)
- Xcel Energy (Colorado)
- CPS Energy (San Antonio)
- Arizona Public Service (APS)
- Kauai Island Electric Cooperative (KIUC)
- Maui Electric Company (MECO)
- FPL/NextEra
- Sempra Energy

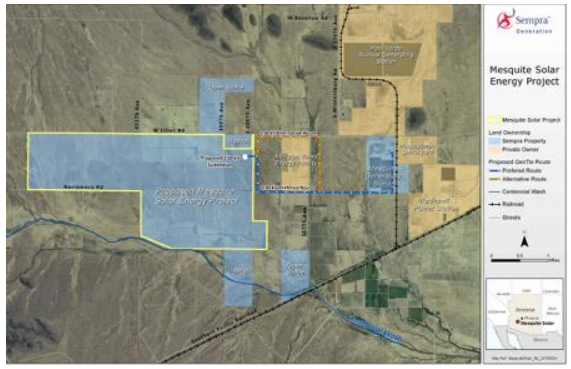
Sempra Energy

Sempra Energy has recently completed the U.S.'s largest photovoltaic power plant, the 48-megawatt Copper Mountain Solar facility near Boulder City, Nevada.

NREL is working with Sempra to understand large-scale system variability and transmission connected PV systems.

As PV plants in the US reach towards the 1GW level, the bulk-system impacts become extremely important in system operations.

Copper Mountain 48MW PV plant



Plans for Mesquite 600MW PV site

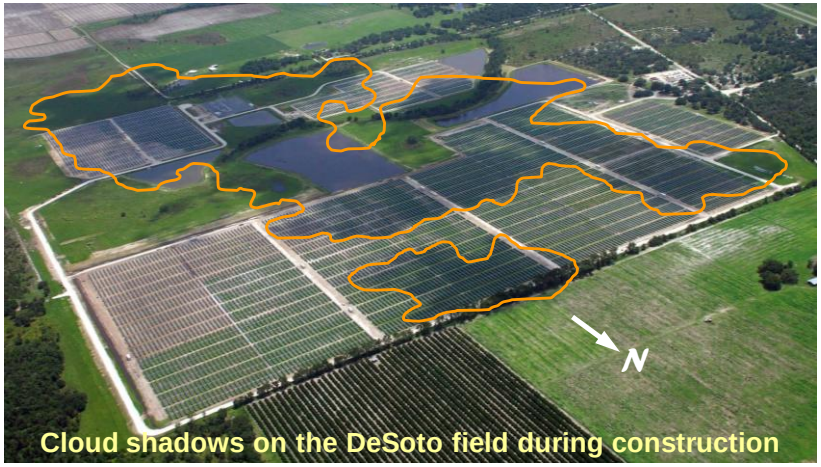
FPL/NextEra

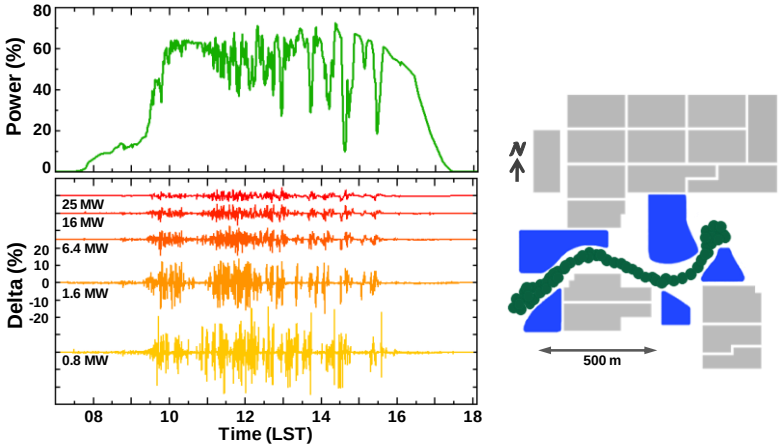
NREL is working with FPL/NextEra and WindLogics on understand the variability of very large-scale PV deployments.

The pictures show the 25MW PV plant in Desoto, Florida.

The graph shows the impacts of clouds over time for various MW sections of the system.

The ramps dampen as the MW increases because of spatial diversity.



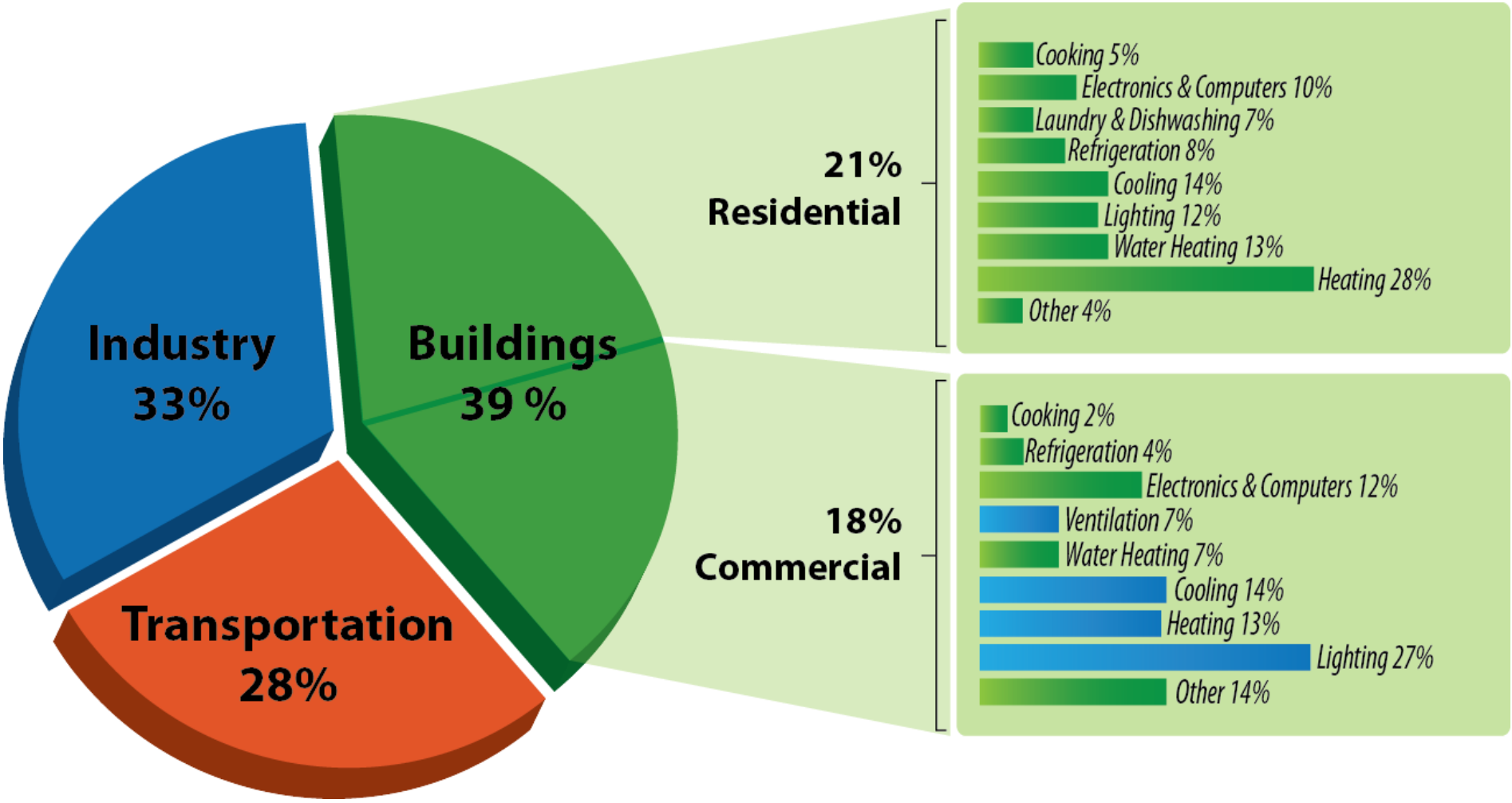


Ten second ramp rates dampen out as MW increase

Observed Impacts of Transient Clouds on Utility-Scale PV Fields, A. Kankiewicz, D. Moon and M. Sengupta, SOLAR 2010 , May 2010

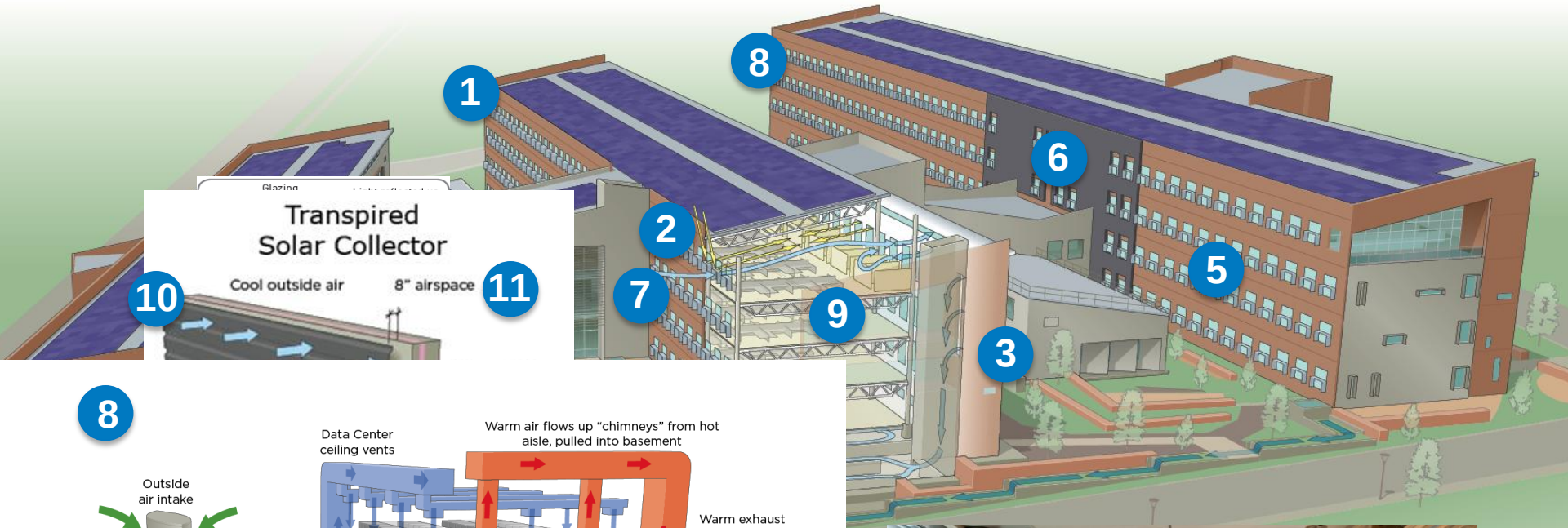
NREL Research Support Facility: A glimpse into the future

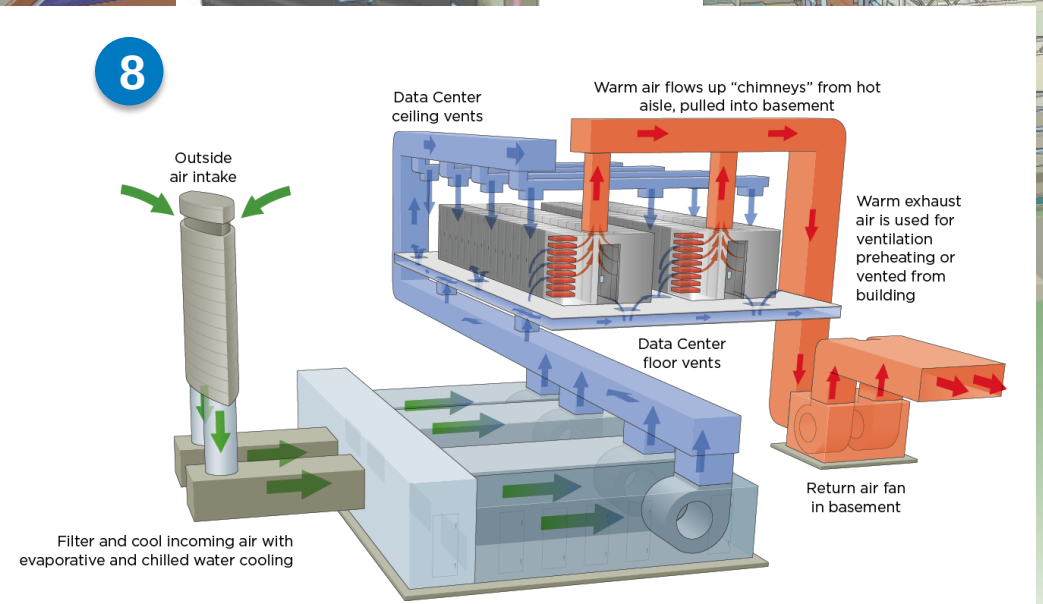
Energy Consumption in the U.S.

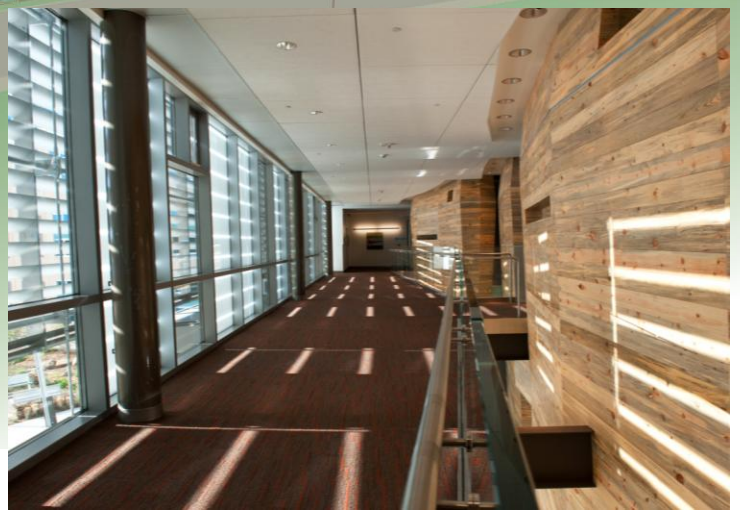


Source: Buildings Energy Data Book, 2006

The Path to Net Zero Energy

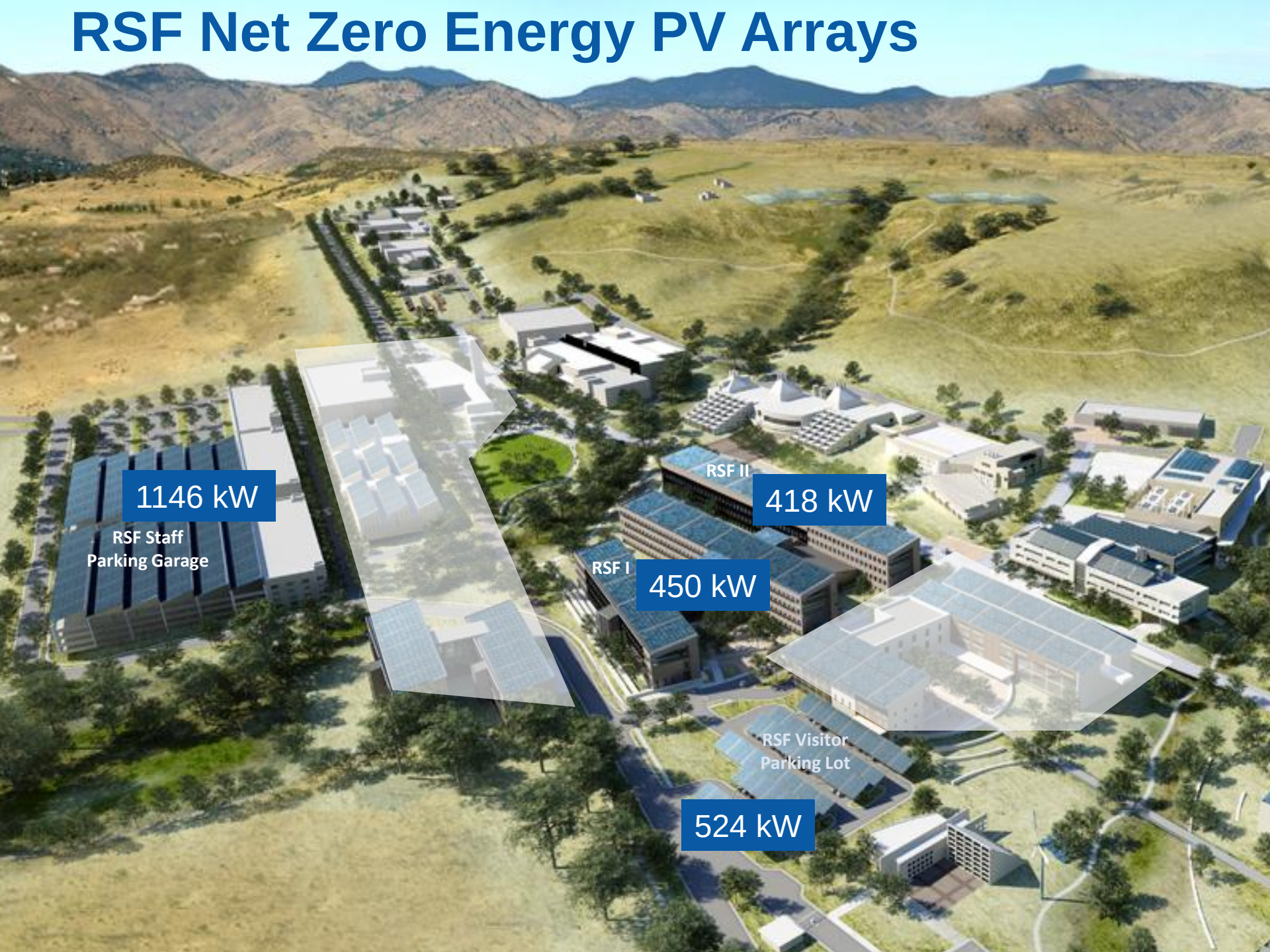




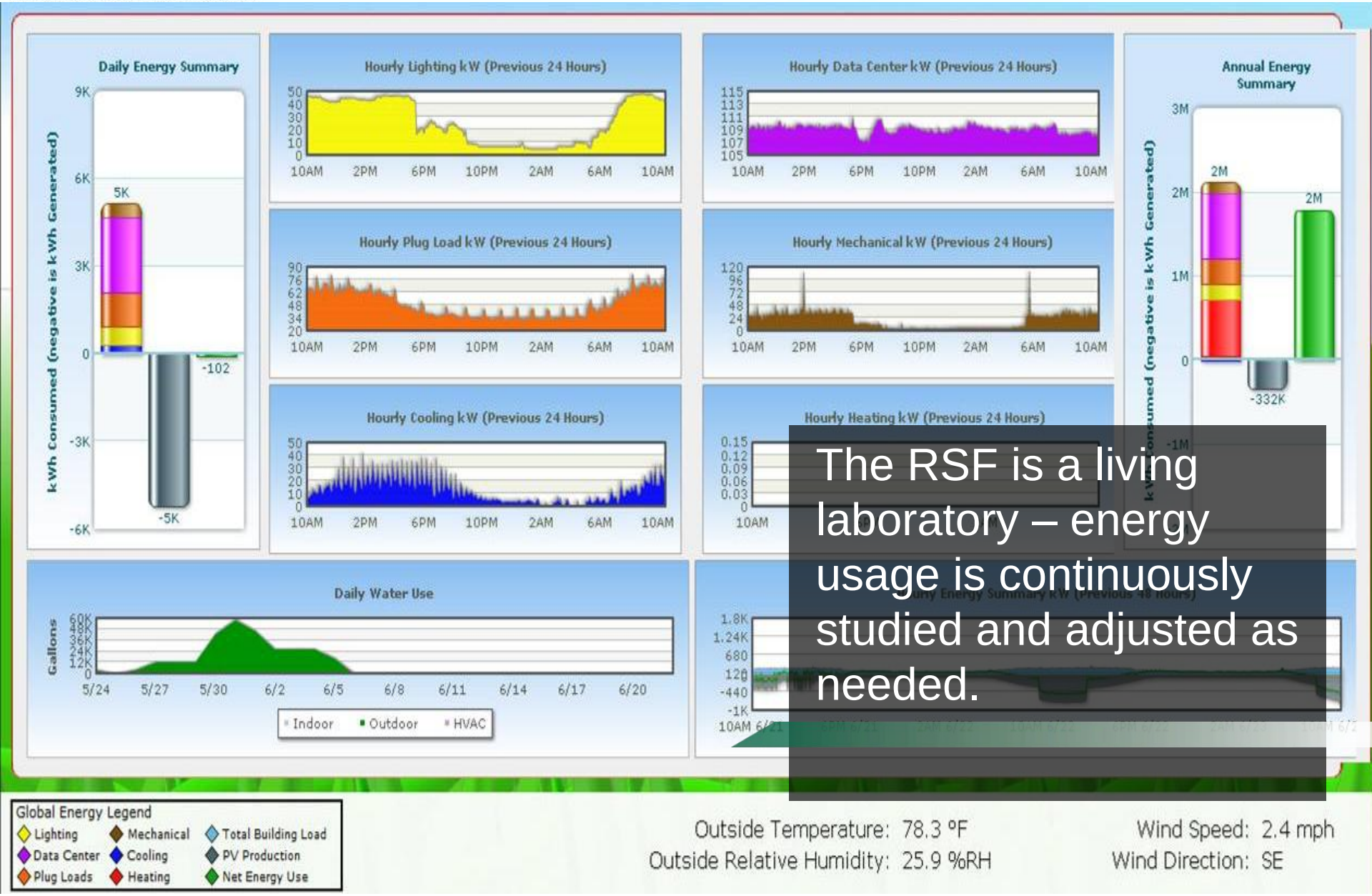


10. Slab

RSF Net Zero Energy PV Arrays

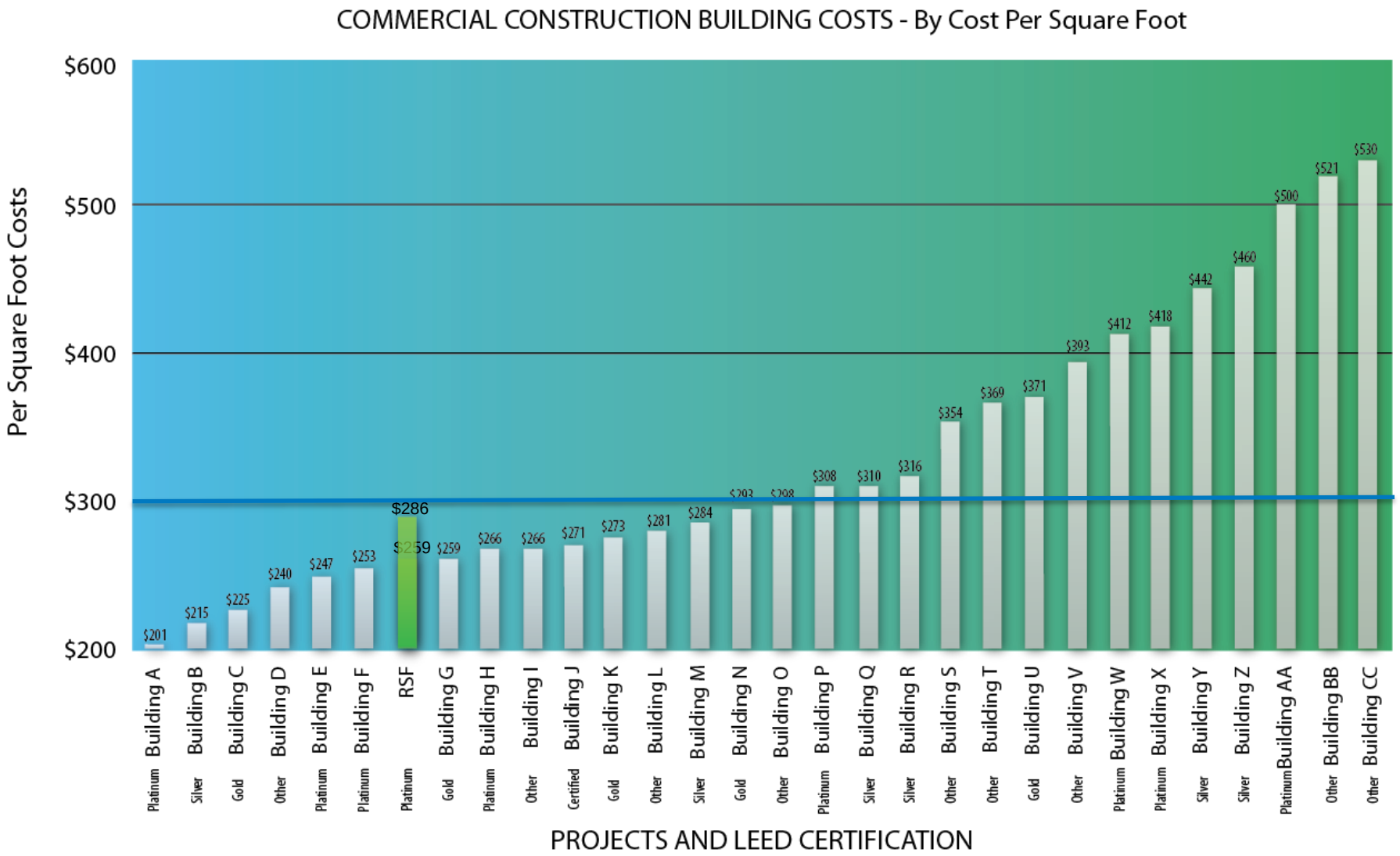


RSF Energy Monitoring



The RSF is a living laboratory – energy usage is continuously studied and adjusted as needed.

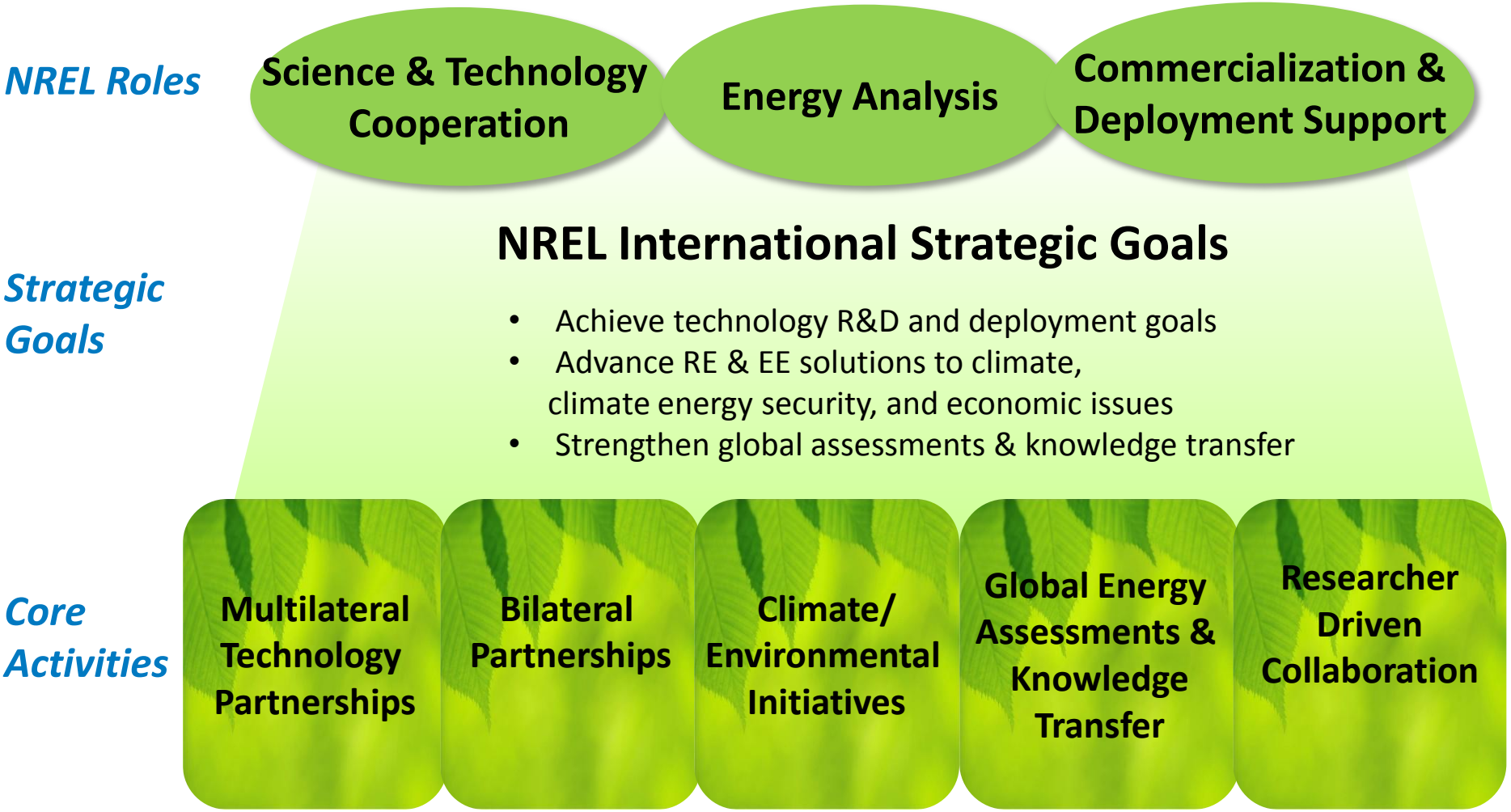
Construction Costs



A glimpse into the future

If all commercial buildings operated in this fashion, the percent renewable energy contribution to the energy mix would be a game changer.

NREL International Framework



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_2 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 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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National Energy Imperatives

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.**

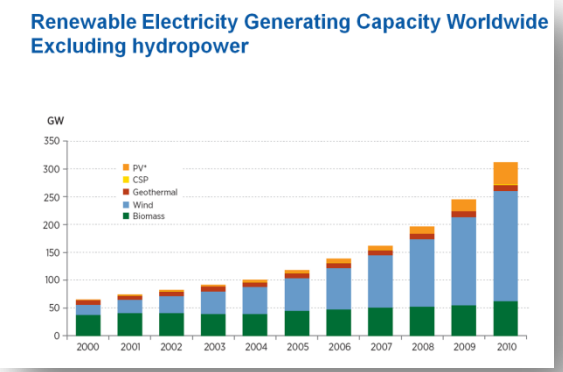
Solar PV global installed capacity **grew by factor of almost 30** to about 35 GW in 2010.

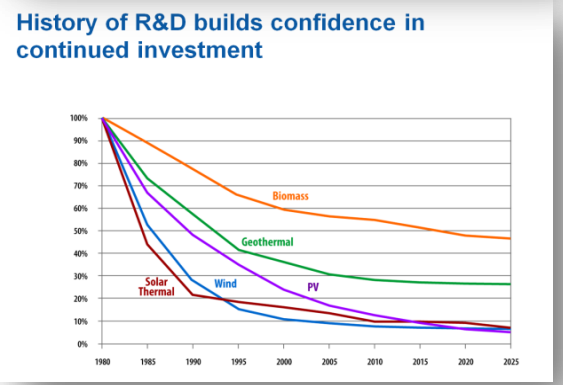
Biofuels emerged as a **major global industry** (~28 billion gallons/year)

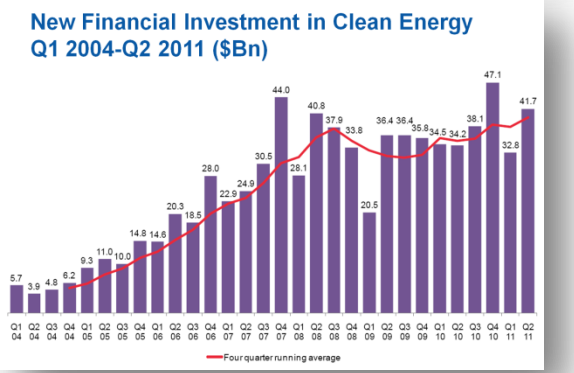
LEED-certified commercial buildings grew to more than 10,000

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

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







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NREL Uses R&D to Boost Return on Investment