Chapter 1

# Introduction to Photovoltaic Systems

**Solar Technologies ● History and Development ● Markets and Applications ● Industry Sectors**

# Overview

- Classifying solar energy technologies and types of PV systems.
- Recognizing the benefits and limitations of PV systems compared to other generation sources.
- Identifying common applications for both stand-alone and utility interactive PV systems.
- Characterizing various segments of the PV industry and their roles.
- Understanding market trends and opportunities for PV systems.

# Solar Energy Technologies

- **Solar-Thermal Systems**
  - Heat fluids for domestic hot water, pools, space conditioning or concentrating designs for power generation.

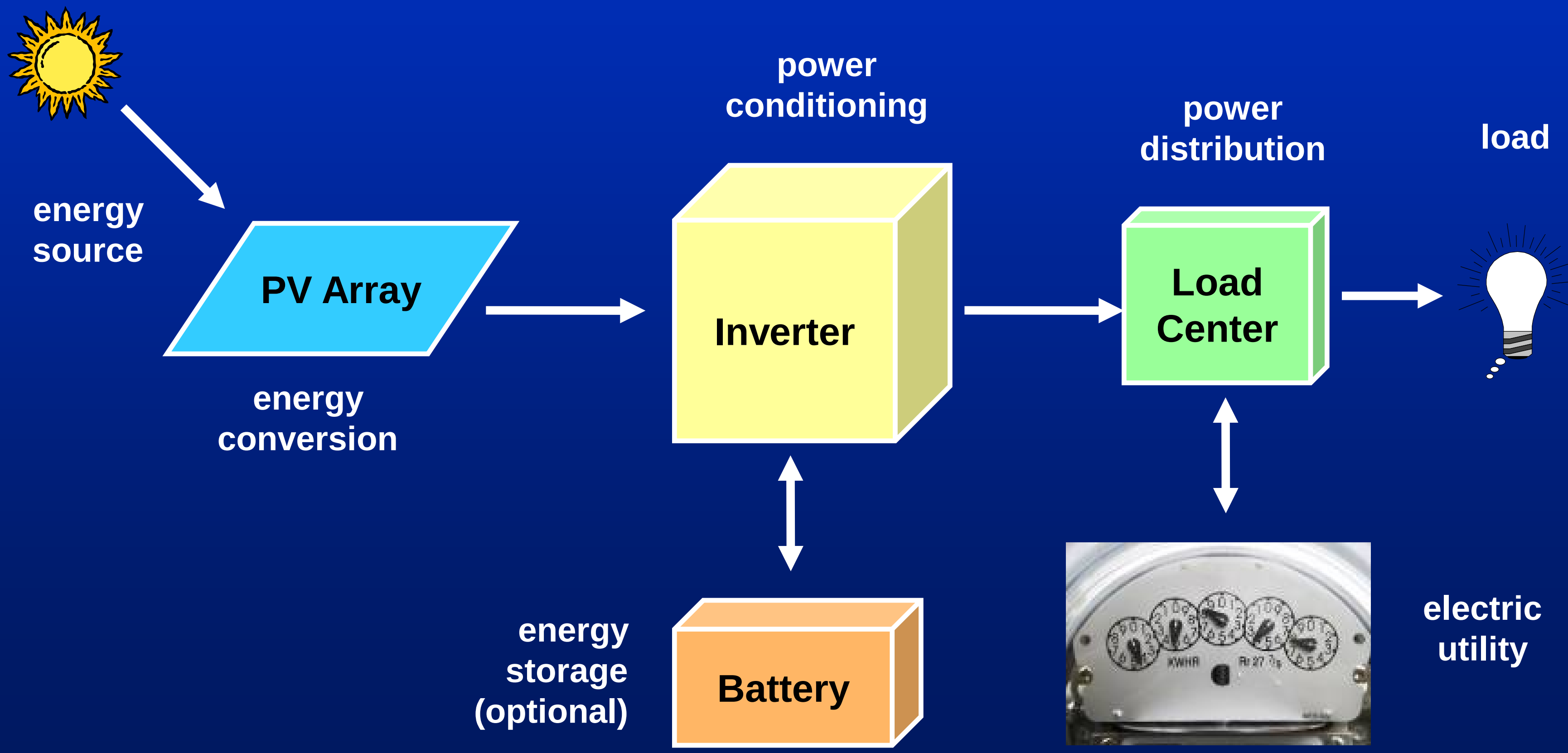
- **Solar-Electric, or Photovoltaic (PV) Systems**
  - Generate electricity to supply dedicated loads or interface with other electrical systems.

# Types of PV Systems

- **Stand-Alone Systems**
  - Operate off-grid
  - Sizing based on electrical loads
- **Interactive Systems**
  - Operate in parallel with the electric utility grid
  - Supplement utility power to site loads

# Solar Photovoltaic (PV) Systems

- PV systems convert solar energy into electrical energy using various components.



# Value of PV Systems

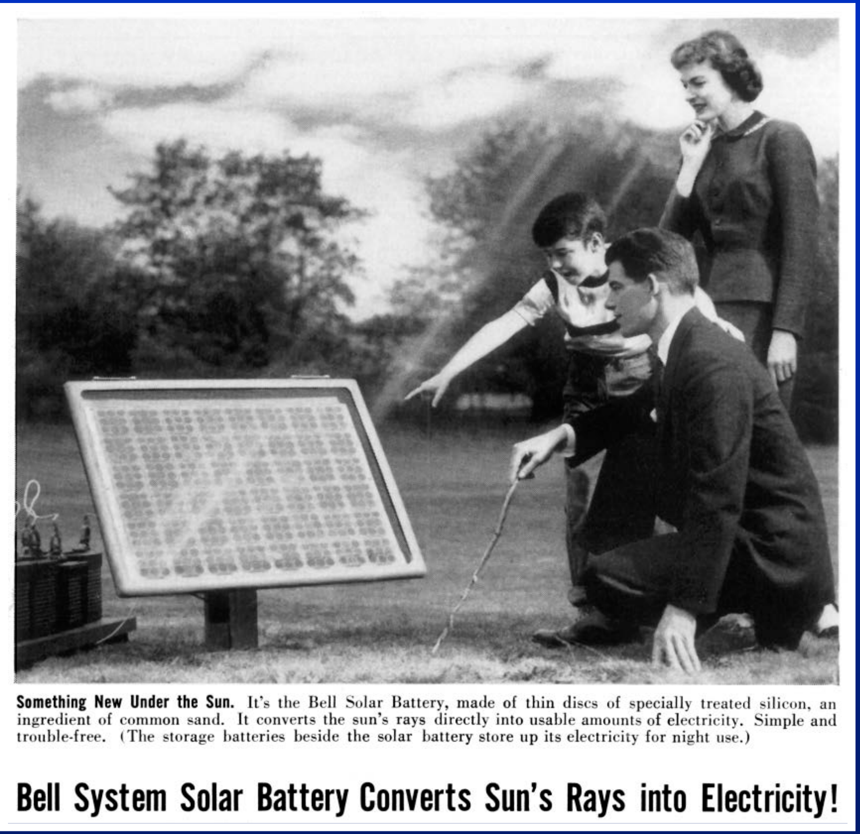
- **Advantages of PV systems include:**
  - Energy independence; sunlight is free.
  - Environmentally-friendly technology; no noise or pollution.
  - High-reliability, minimal maintenance and long lifetime.
  - Modular and expandable designs.
  - Dispersed energy production.
  - Reduced vulnerability to power outages with energy storage.
  - Can power dedicated loads or supplement grid power.

- **Disadvantages include:**
  - High initial costs compared with competing power options.
  - Low power densities require large array surface areas.
  - Energy production is dependent on location, time of day/year, array orientation and other factors.

# History of Photovoltaics

- **Silicon solar cells were developed at Bell Labs in 1954 by Gerald Pearson, Daryl Chapin, and Calvin Fuller (L-R).**

*Alcatel-Lucent / AT&T Bell Labs*




*Alcatel-Lucent / AT&T Bell Labs*

# PV System Applications

- **Spacecraft**
- **Consumer electronics**
  - Calculators, radios and watches
- **Rural development**
  - Health care facilities, schools and community centers
- **Off-grid power**
  - Lighting and appliances for remote homes and facilities
- **Agricultural uses**
  - Water pumping and irrigation
  - Fence charging
- **Lighting**
  - Signs, security and parking areas
  - Transportation, navigation and aviation aids
- **Specialty applications**
  - Remote monitoring, railway signals, security systems and water treatment
- **Telecommunications facilities**
- **Grid-connected systems**
  - Residential, commercial and utility-scale

# Space Applications

**International Space Station**

*NASA*

**Hubble Space Telescope**

*NASA/Smithsonian Institution/Lockheed Corp.*

# Consumer Electronics


Utility Lights


Radios

Security Cameras


Watches


Cell Phones


Calculators

# Transportation Safety





# Navigation and Aviation Aids

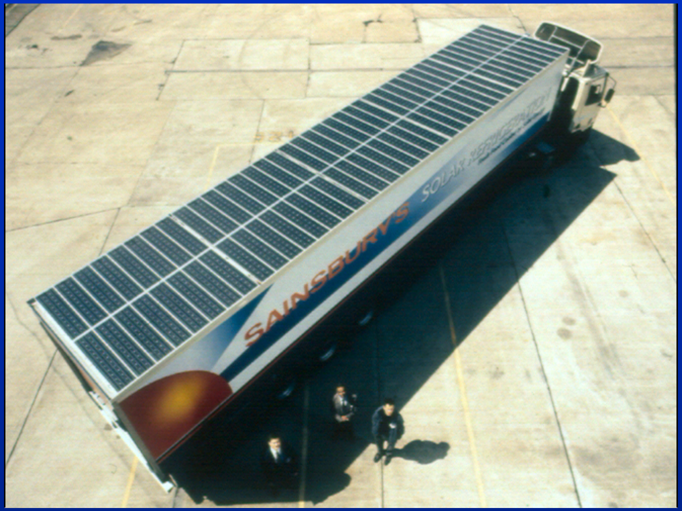


*Sandia National Laboratories*

*Northern Power Systems*

# Portable Applications

### Refrigerated Transport




*Sandia National Laboratories*

### Mobile Power

*Virgin Islands Energy Office*

### Electric Vehicles

*NREL / DOE, Byron Stafford*

# Recreational Vehicles

SolarWorld

SolarWorld

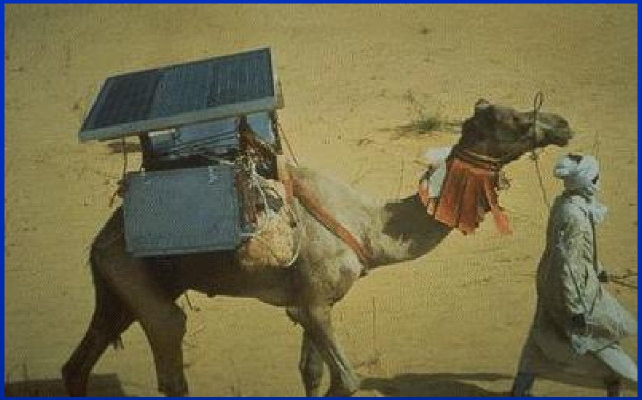

SolarWorld

# Rural Development

**Rural Health Clinic**

*NREL/Steve McCarney*

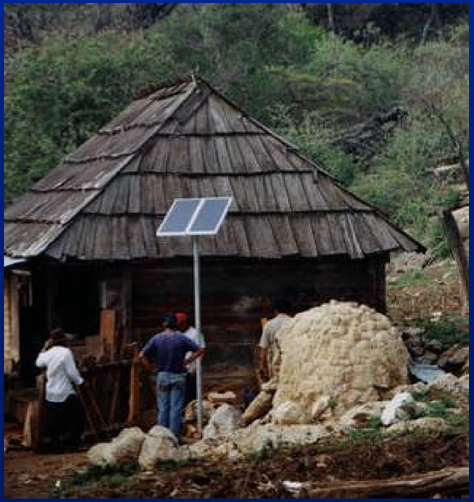
**Vaccine Refrigeration**



*SolarWorld*

**Water Pumping**

**Rural Home Lighting**



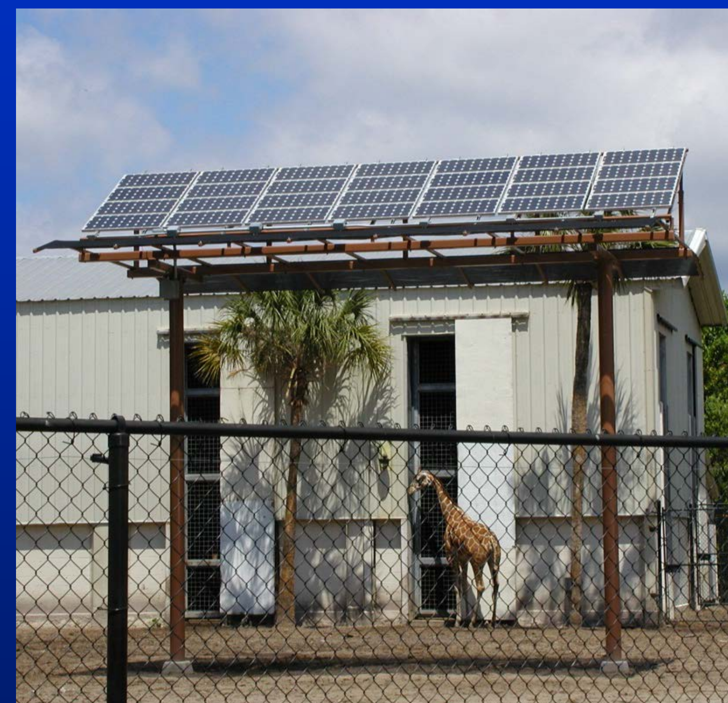
*United Solar Systems*

# Nature Centers

**Disney Wilderness Preserve, Kissimmee, FL**

*FSEC/Jim Dunlop*

**Jacksonville (FL) Zoo**



*JEA/Larry Wagner*

# National Parks

**Dangling Rope Marina, Lake Powell, UT**

*NREL/Warren Gretz*

**Dry Tortugas National Park, FL**

*National Park Service*

# Covered Parking

**Naval Air Station, San Diego, CA**

*NREL / DOE, SunPower*

**Cultural Center, Albuquerque, NM**

*Sandia National Laboratories*

# Telecommunications

**Carol Spring Mountain, AZ**

*Sandia National Laboratories*

**Upper Horse Flats, UT**

*Sandia National Laboratories*

*Sandia National Laboratories*

# Commercial Rooftops

**National Electric, Albuquerque, NM**

*National Electric*

**Environmental Protection Agency, Raleigh, NC**

*NREL/EPA*

# Commercial Rooftops

Convention Center, Orlando, FL

Georgia Tech Aquatic Center, Atlanta, GA

# Architectural Features

Georgia Tech Aquatic Center

# Highway Sign Lighting




# Billboards and Signs



# Specialty Applications

**SWH Circulation Pump**

*Commission on Economic Opportunity*

**U/V Water Disinfection**

*NREL/Byron Stafford*

**Irrigation Control**

*NREL/John Thorton*

# Agricultural Uses

**Fence Charging**


*NREL/DOE, Warren Gretz*

**Livestock Watering**

*NWRPPD, Jerry Anderson*

**Irrigation**

*Virgin Island Energy Office*

# Remote Residential

Private Home, U.S. Virgin Islands

# Schools

**Portable Classroom, Lakeland, FL**

**Electrical Training Center, Gainesville, FL**

**Mandarin H.S., Jacksonville, FL**

# Railroads and Utilities

**Aircraft Warning Beacon**

**Railway Signals**

# Area Lighting

FSEC


FSEC/Lakeland Electric

FSEC/National Park Service

Jim Dunlop

# Residential Grid-Connected

*FSEC/Lakeland Electric*

*New Smyrna Beach Utilities Commission*

# Residential Grid-Connected

FSEC/Lakeland Electric

Sharp Solar

# Utility-Scale PV Systems

**Kennedy Space Center, FL – 10 MW**

*Florida Power and Light*

**Carissa Plains, CA (c. 1985) – 6 MW**

*SolarWorld/ARCO*

**Alamosa, CO – 8.2 MW**

*NREL/Steve Wilcox*

# Flat-Plate PV Arrays

- **Flat-plate collectors utilize non-concentrated solar radiation.**
  - Most PV modules and arrays are flat-plate collectors.

**Fixed-Tilt Rack-Mount**

**Single-Axis Tracking Pole Mount**

# Concentrating PV Arrays

- Concentrating collectors focus the sun's power onto smaller areas, and must track the sun.

**Line-Focus Two-Axis Tracking**

**Point-Focus Two-Axis Tracking**

# Concentrating Solar Thermal

## Dish Stirling

*NREL/DOE, Bill Timmerman*

## Parabolic Trough

*NREL/DOE, Warren Gretz*

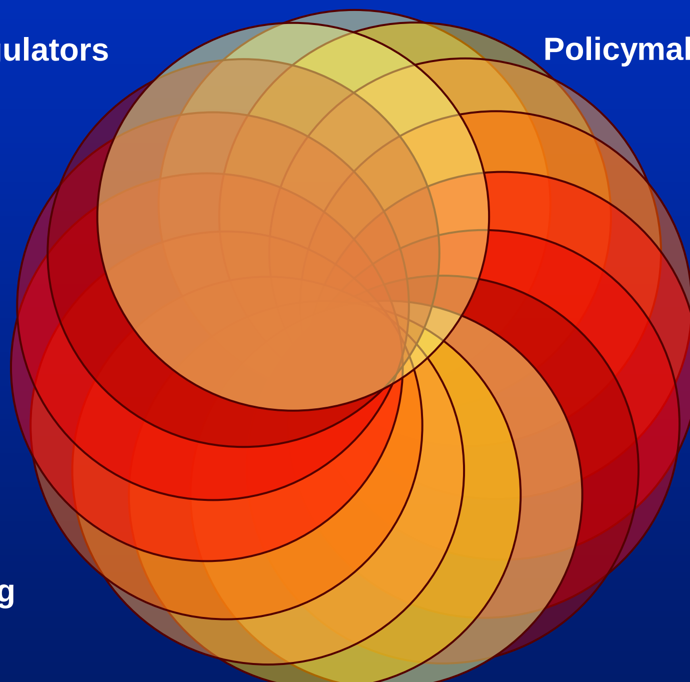
## Power Tower

*Sandia National Laboratories*

# The PV Industry: Yesterday and Today

| | c. 1990 | c. 2010 |
|---|---|---|
| | | |
| **Installed Capacity** | **< 50 MW/yr worldwide** | **> 10 GW/yr worldwide**<br>**> 500 MW/yr in U.S.** |
| **Product Listing and Certification** | **Infancy** | **All modules, inverters, controls and combiners listed to UL standards** |
| **Code Compliance** | **PV first introduced in 1984 NEC**<br>**Few systems permitted and inspected** | **All systems permitted and inspected by building officials** |
| **System Voltage** | **Residential ≤ 48 VDC** | **Residential up to 600 VDC**<br>**Commercial up to 1000 VDC** |
| **Predominant Markets** | **Stand-alone, off-grid** | **Grid-connected residential, commercial and utility-scale** |
| **Number of PV Companies** | **Hundreds** | **Tens of thousands** |
| **Maximum System Size** | **10 to 100 kW** | **1 to 20+ MW** |
| **Utility Interconnection** | **Few utilities permitted PV interconnections** | **All states and utilities permit interconnections from 2 to 20 MW** |
| **Licensing and Personal Certification** | **Nonexistent** | **State licensing and national certification programs emerging** |
| **Contractors and Installers** | **Small specialized companies, diversified in solar thermal and PV** | **Larger companies, electrical contractors and project developers** |
| **Global PV Industry Revenue** | **Tens of millions** | **Tens of billions** |

# PV Industry Sectors



- Research & Development
- Consumers & Owners
- Codes & Standards
- Building Officials & Regulators
- Policymakers & Government Agencies
- Contractors & Installers
- Product Manufacturers
- Architects & Engineers
- Marketing & Distribution
- Certification & Licensing
- Education & Training
- Financiers & Investors
- Project Developers & Integrators
- Insurers & Underwriters
- Energy Suppliers & Electric Utilities

# PV Industry Career Opportunities

- **Component Manufacturing**
  - engineers, designers, fabricators, assemblers
- **Sales and Marketing**
  - business and marketing professionals
- **Systems Engineering and Design**
  - professional engineers, architects and contractors
- **Procurement and Operations**
  - business and accounting professionals
- **Financing and Insurance**
  - lending institutions, legal professionals and underwriters
- **System Installation, Operations and Maintenance**
  - contractors, electricians and related trades
- **Inspection and Code Compliance**
  - regulators, utilities, electrical and building inspectors
- **Training and Education**
  - teachers and instructors
- **Product Research, Testing and Certification**
  - engineers, scientists, technicians

# Market Drivers

- Increasing costs and dependence on imported energy
- Environmental impacts from fossil fuel use
- Electric utility restructuring
- Net metering and interconnection rules
- Legislative mandates for renewable generation
- Financial incentives
- Increasing public awareness and interest

# Global PV Markets

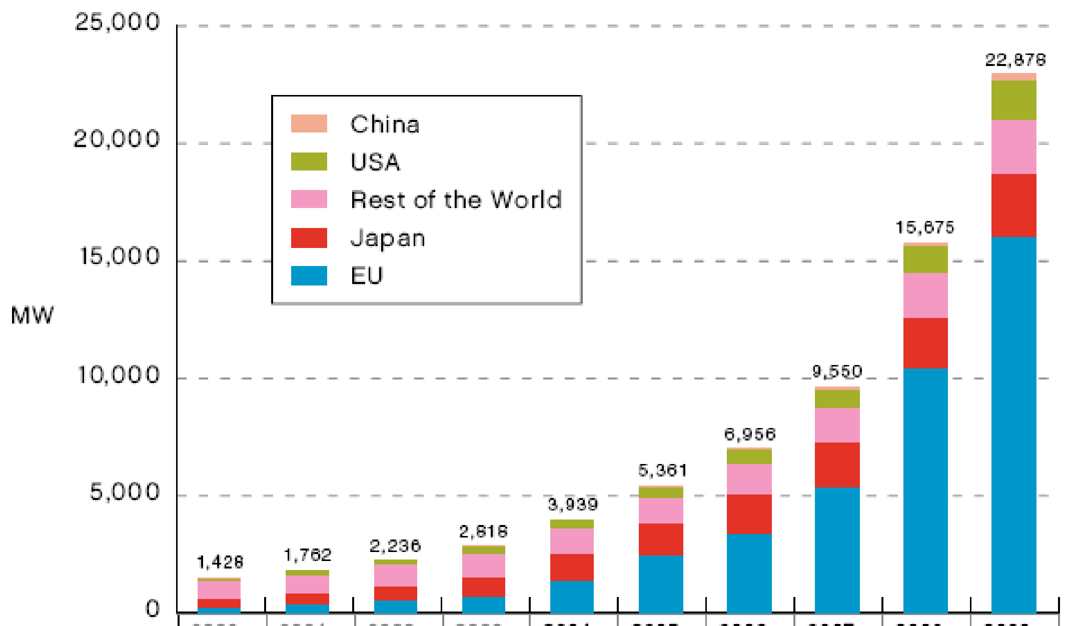
## 2005-2008 Annual PV Installations

| Country | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|
| US | 153 | 178 | 270 | 412 |
| Japan | 833 | 926 | 923 | 1,224 |
| Europe | 473 | 673 | 1,069 | 1,906 |
| ROW | 323 | 681 | 1,451 | 3,398 |
| **Total** | **1,782** | **2,459** | **3,714** | **6,941** |
| % Thin Film | 5 | 7 | 11 | 14 |

*Bradford/Maycock*

# Global PV Markets

## 2000-2009 Cumulative PV Installations

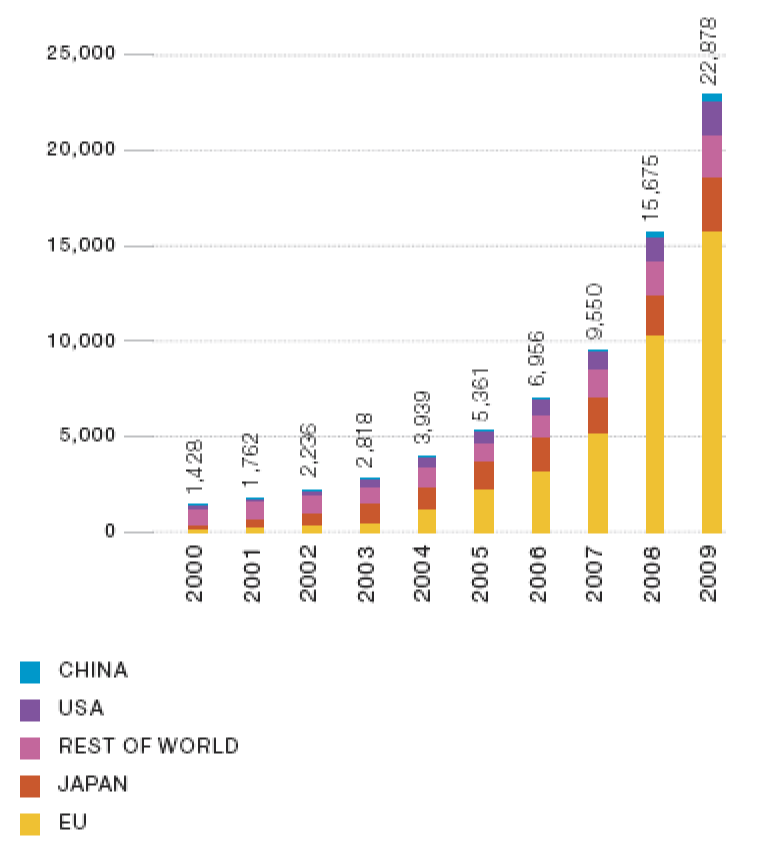



| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| China | 19 | 30 | 45 | 55 | 64 | 68 | 80 | 100 | 145 | 305 |
| USA | 139 | 168 | 212 | 275 | 365 | 479 | 624 | 831 | 1,173 | 1,650 |
| ROW | 763 | 825 | 913 | 1,000 | 1,044 | 1,051 | 1,235 | 1,422 | 1,870 | 2,347 |
| Japan | 318 | 452 | 637 | 860 | 1,132 | 1,422 | 1,708 | 1,919 | 2,149 | 2,633 |
| EU | 189 | 286 | 429 | 628 | 1,334 | 2,341 | 3,309 | 5,279 | 10,338 | 15,943 |
| Total | 1,428 | 1,762 | 2,236 | 2,818 | 3,939 | 5,361 | 6,956 | 9,550 | 15,675 | 22,878 |

*European Photovoltaic Industry Association*

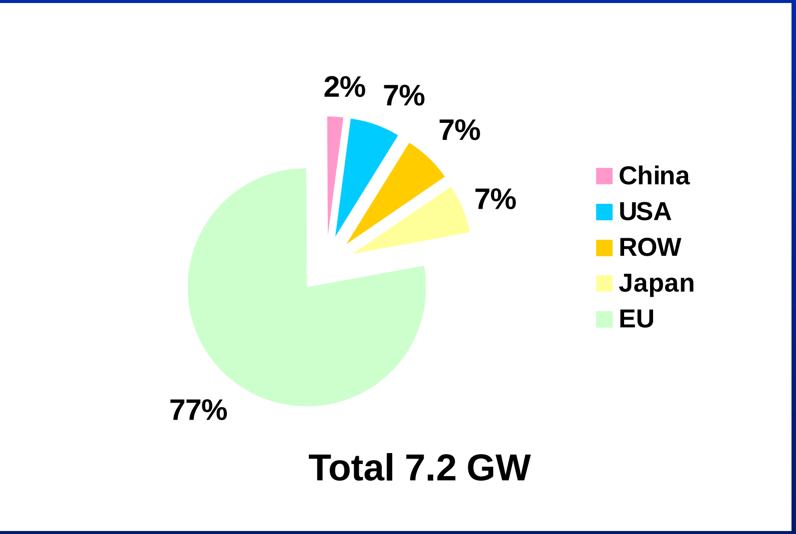
# Global PV Markets

Cumulative Global PV Capacity




*European Photovoltaic Industry Association*

2009 Global PV Installations

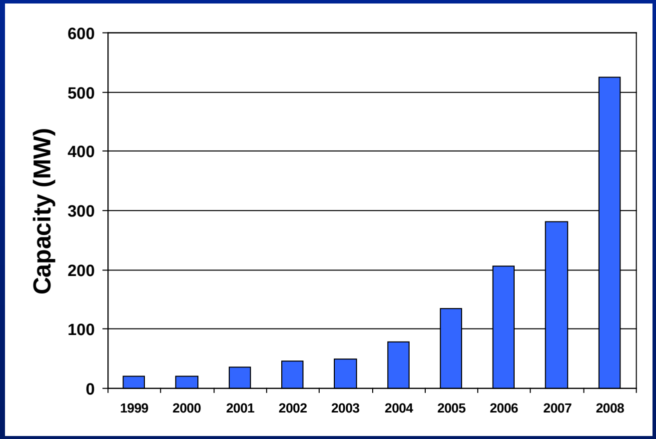



*European Photovoltaic Industry Association*

# U.S. PV Markets

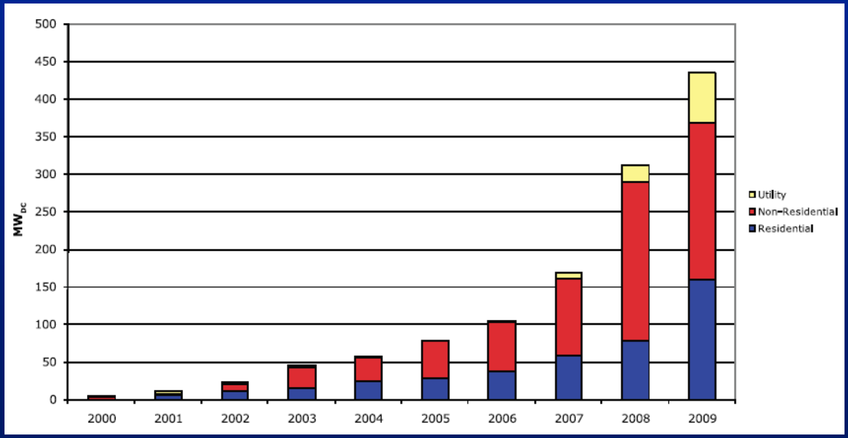
- U.S. PV shipments and installed capacity are growing over 50% per year, reaching approximately 500 MW per year in 2010.
- The majority of PV capacity is installed in the commercial and utility sectors, while the residential sector has more total installations.

**Total Domestic Shipments**




*DOE/Energy Information Agency*

**Grid-Connected Installations**




*Interstate Renewable Energy Council /Larry Sherwood*

# Financial Incentives

- Rebates
- Tax credits and exemptions
- Production incentives
- Grants and loans

# Database of State Incentives for Renewable Energy (DSIRE)

- **National resource for PV project developers and consumers:**
  - www.dsireusa.org
- **Contains information on rules, regulations and policies for renewable energy and energy efficiency programs in all states, including:**
  - Financial incentives
  - Net metering and interconnection rules
  - Licensing, permitting and building codes
  - Legislative actions


*Interstate Renewable Energy Council / North Carolina Solar Center*

# Quality Measures for PV Systems

Equipment Standards
Component Testing
Performance Ratings
Product Certification

↓

Quality Components →

Documented Systems
Design Review & Approval

↓

Quality System Designs →

Education & Training
Licensing & Certification
System Testing & Inspection

↓

Quality Installations

↓

Warranties & Service Contracts
Product Assurance
Satisfied Customers
Successful Industry

# Quality PV System Installations

- **PV designers and installers require knowledge, skills and experience in working with electrical systems and equipment.**

- **Elements of a quality PV installation include:**
  - System design is appropriate for the site and application, and sized to meet performance expectations.
  - System uses listed, quality components with proper ratings.
  - Installation is completed in a workmanlike manner and complies with all applicable building and electrical codes.
  - System is commissioned, inspected and approved by utility and building code officials.
  - Owners/operators are trained on safety and operations.

# Practitioner Certification

- North American Board of Certified Energy Practitioners (NABCEP)
- Underwriters Laboratory UL University
- Electronics Technicians Association – ETA International
- Manufacturer and distributor programs

# North American Board of Certified Energy Practitioners

- **NABCEP PV Entry-Level Program**
  - Associated with entry-level educational programs and continuing education providers; students may take entry-level examination from registered providers.

- **NABCEP PV Installer Certification**
  - Voluntary credential for PV professionals; not a contractor's license.
  - The job task analysis for PV installers is the basis for the certification program and examination content.

- **See: www.nabcep.org**

# UL University PV Installer Certification Program

- **PV System Installer Certification Program**
  - A credential focused on the critical knowledge and skills of the occupation; open only to licensed electrical professionals. Examination is based on key job duties for the PV installer.
- **Photovoltaic (PV) System Installation Training**
  - A five-day, instructor-led and hands-on course intended for licensed electricians who will be tasked with the end-to-end installation of residential and/or commercial photovoltaic systems.
- **See: www.uluniversity.us**

# PV System Documentation

- **A complete documentation package for PV system installations should include:**
  - System design and equipment specifications
  - Owner/operator manuals for the system and major components
  - Electrical and mechanical drawings
  - Site layout and equipment locations
  - Installation and commissioning procedures
  - Operating and maintenance procedures

# PV Project Development

- **PV installation projects involve the following steps:**
  - Marketing, sales and customer development
  - Site survey and preplanning
  - Pursue financing and incentives
  - System design and engineering
  - Equipment specification and procurement
  - Plan review and permitting
  - Interconnection application and approval
  - Contracting and installation
  - Commissioning, inspection and approval
  - Operations, maintenance and performance monitoring

# Utility-Scale

**Desoto Next Generation Energy Center, Arcadia, FL – 20 MW**

*Florida Power and Light*

# Military Bases

**Nellis AFB, Las Vegas, NV – 14 MW**

*SunPower/Bombard Electric*

# High-Tech Centers

**Google, Mountain View, CA – 1.6 MW**

# Commercial Roofs

**Habilitation Center, Portland, OR**

# Airports

Dennis Whalen

# Resources

- **Know what incentives are available and the process to apply:**
  - www.dsireusa.org

- **Participate in industry associations, attend trade shows, develop industry partnerships:**
  - www.seia.org
  - www.sepa.org
  - www.ases.org

- **Subscribe to trade journals:**
  - www.solarprofessional.com
  - www.photon-magazine.com
  - www.homepower.com
  - www.magazine.iaei.org

# Suggested References


- Photovoltaic Systems, Jim Dunlop. ISBN 978-0-8269-1287-9, National Joint Apprenticeship and Training Committee and American Technical Publishers: www.jimdunlopsolar.com
- National Electrical Code, National Fire Protection Association. www.nfpa.com
- OSHA Safety Standards for the Construction Industry, www.osha.gov
- Photovoltaic Systems Engineering, 3rd Edition, by Roger Messenger and Jerry Ventre. ISBN 0-8493-1793-2, CRC Press LLC: www.crcpress.com
- Solar America Board for Codes and Standards: www.solarabcs.org
- National Renewable Energy Laboratory Website: www.nrel.gov
- Sandia National Laboratories Photovoltaics Website: www.photovoltaics.sandia.gov/
- Southwest Technology Development Institute, PV Codes and Standards Website by John Wiles: www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html

# Summary

- The value of PV systems includes high-reliability, long-life and a free and abundant fuel source – sunlight.
- PV applications include stand-alone and interactive systems for a variety of end-uses.
- Markets for PV systems are increasing at extraordinary rates.
- Achieving quality PV systems involves using good equipment, designs and installation practices.

# Questions and Discussion