A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy


National Renewable Energy Laboratory

*Innovation for Our Energy Future*

# The Promise of Solar: Variables to Consider When Evaluating the Use of Solar

**Nancy Carlisle, AIA**
**National Renewable Energy Laboratory**

Presented at the 17th Annual Rocky Mountain Land-Use Institute (RMLUI) Land-Use Conference held March 6-7, 2008 in Denver, Colorado.

NREL/PR-670-42920

NREL is operated by Midwest Research Institute • Battelle

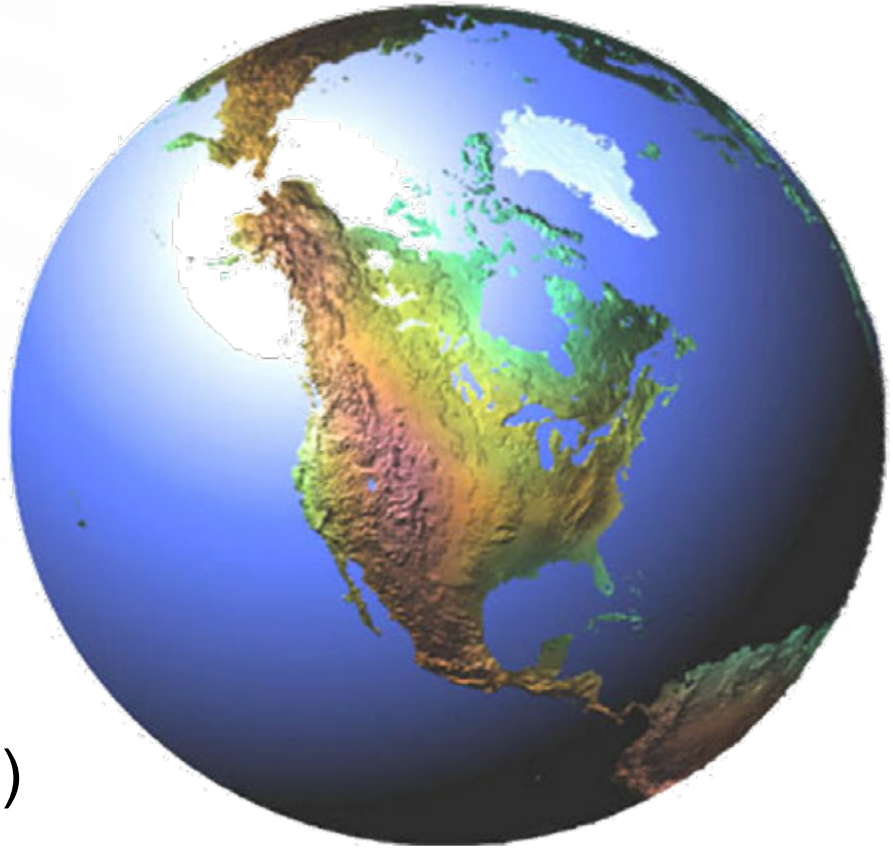
# Learning objectives

- What are the technologies?
- Variables - solar resource, land\roof area water requirements, cost and financial considerations
- Trade-offs - central versus distributed
- Future trends

# Humanity's Top Ten Problems

## Robert Smally, Nobel Laureate

- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism/War
- Disease
- Education
- Democracy
- Population (6.3 billion – 2003; 9-10 billion – 2050)



Humanity's problems are interconnected…

# Water required for various types of electrical energy production*

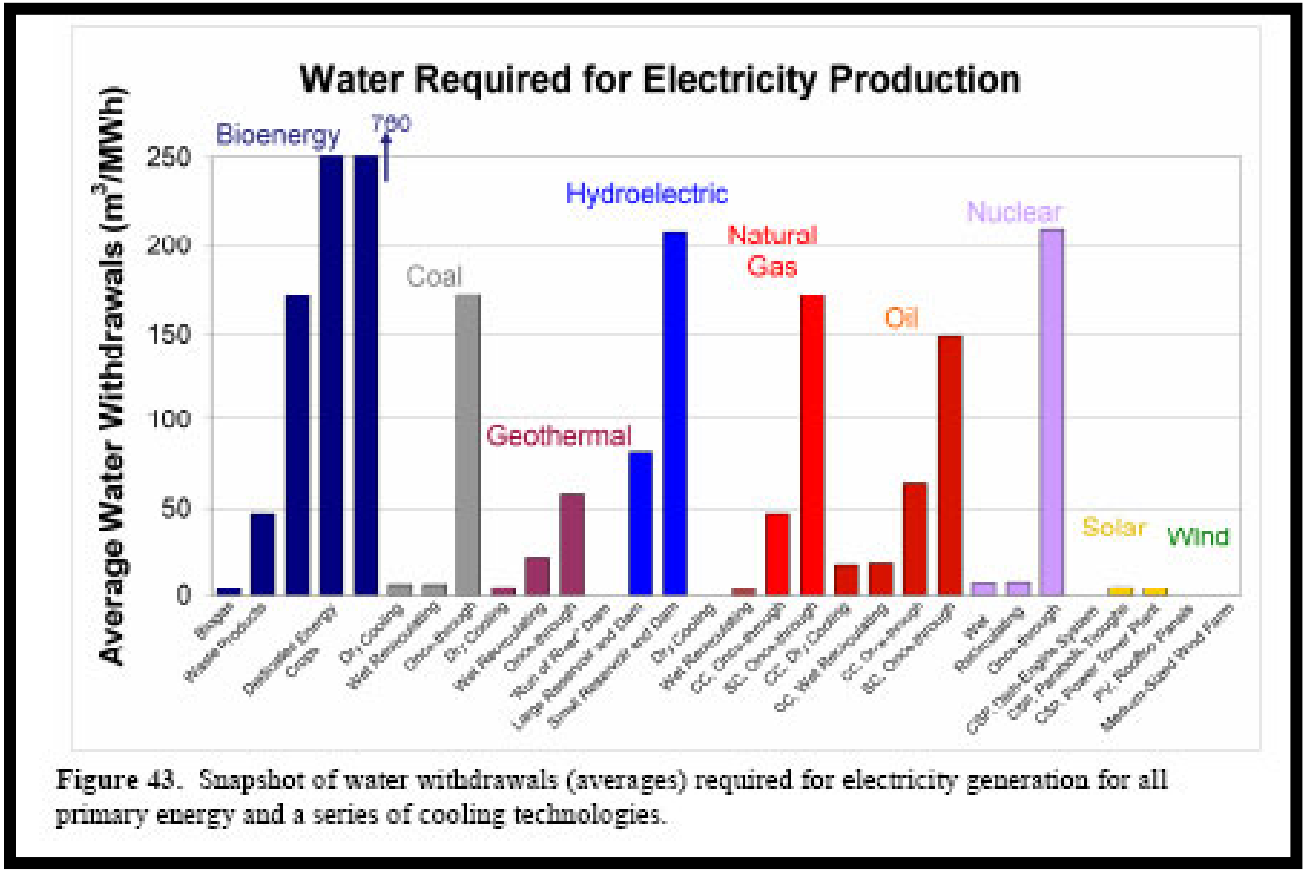
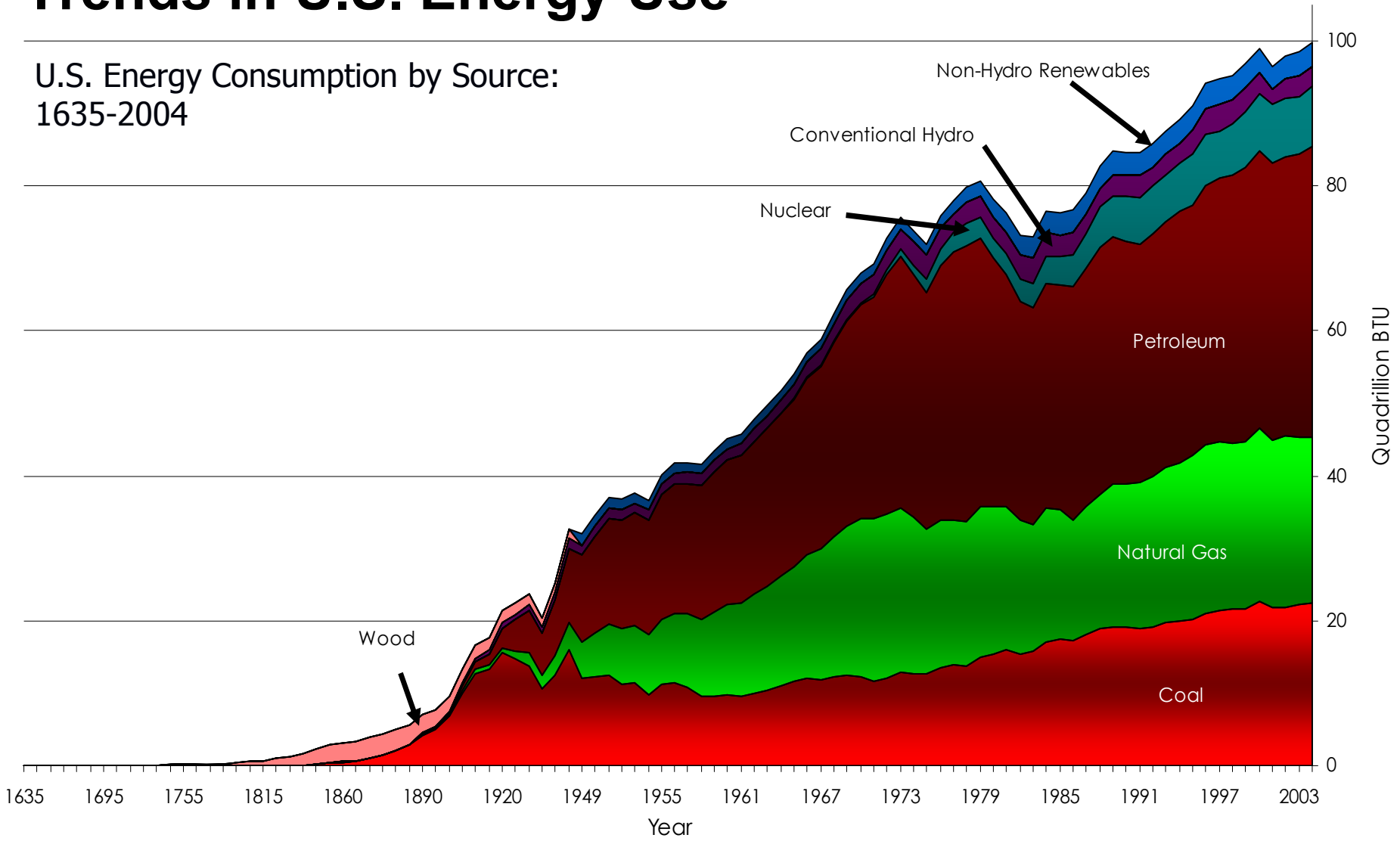



Figure 43. Snapshot of water withdrawals (averages) required for electricity generation for all primary energy and a series of cooling technologies.

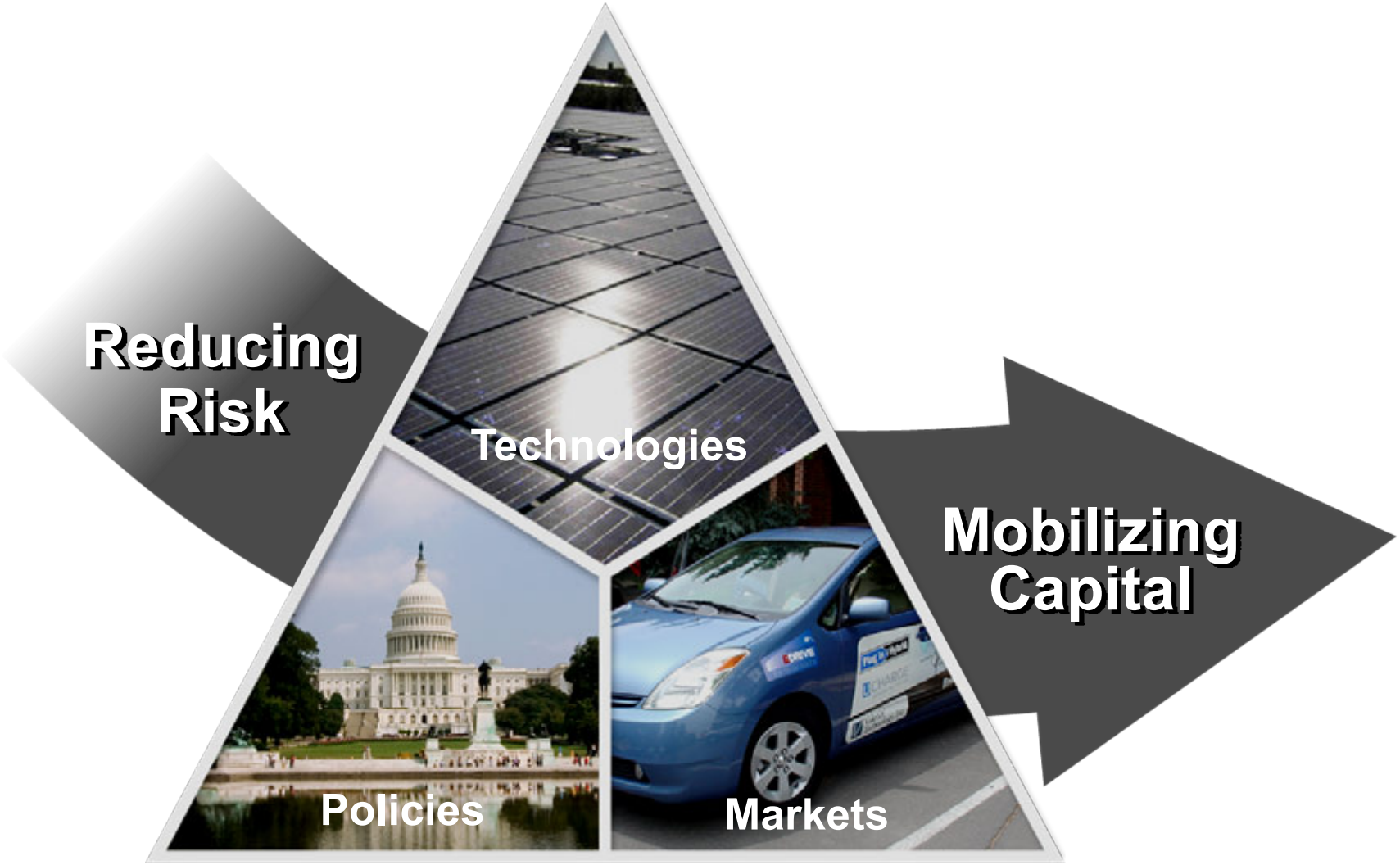
- In California. Source: D. Bren School of Environmental Science and Management. California's Energy-Water Nexus: Water Use in Electricity Generation. May 2007.

# Trends in U.S. Energy Use




Source: Annual energy review and long term historical data. Energy Information Administration. 2005.

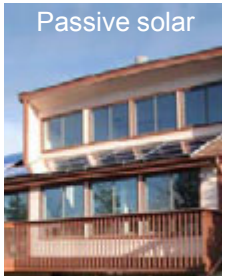
# Getting to "Significance" Involves….

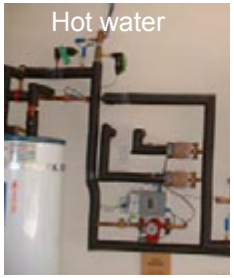



Source: NREL

# Applications of Solar

**Solar Thermal**




**Photovoltaics (PV)**

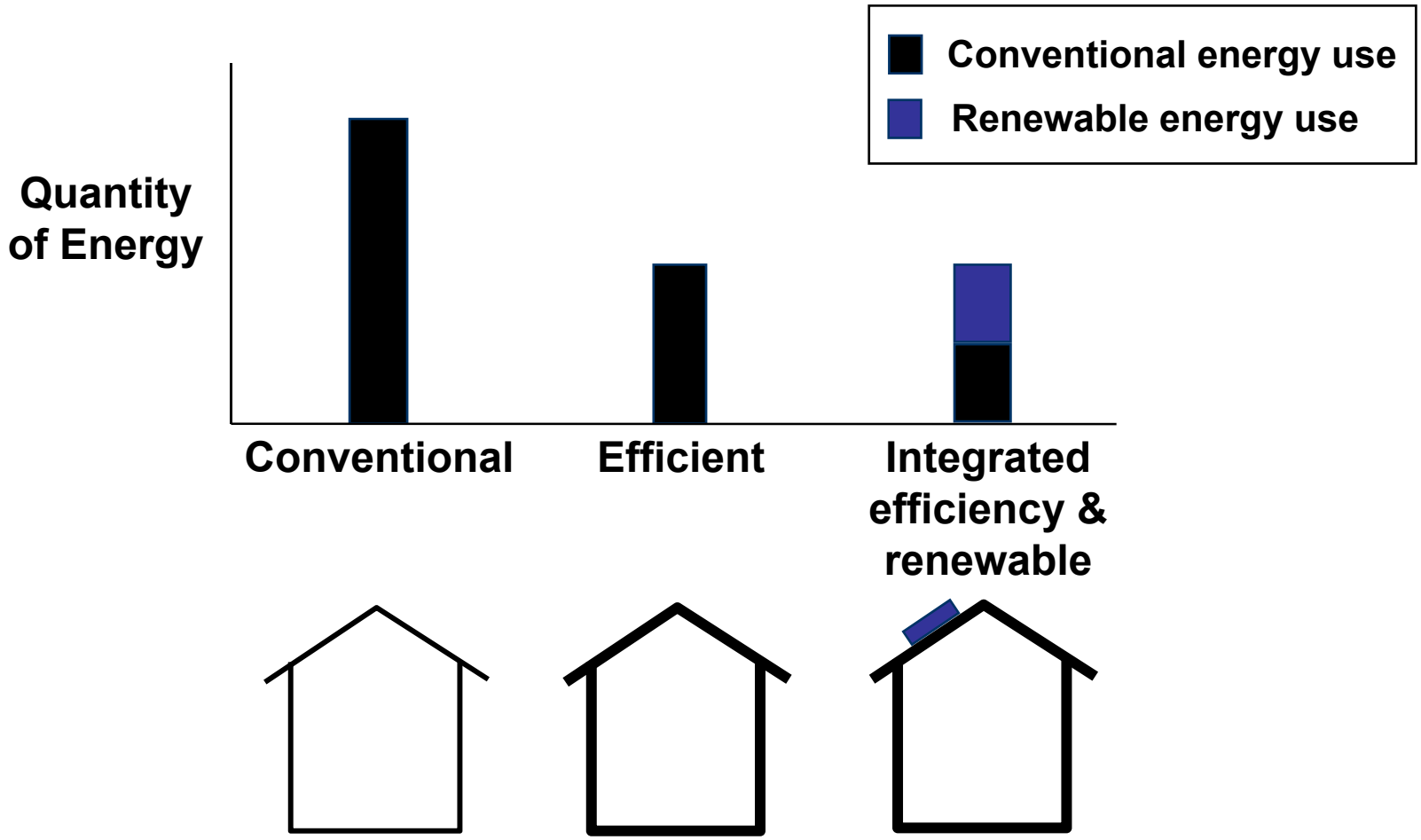
**Concentrating Solar Power (CSP)**

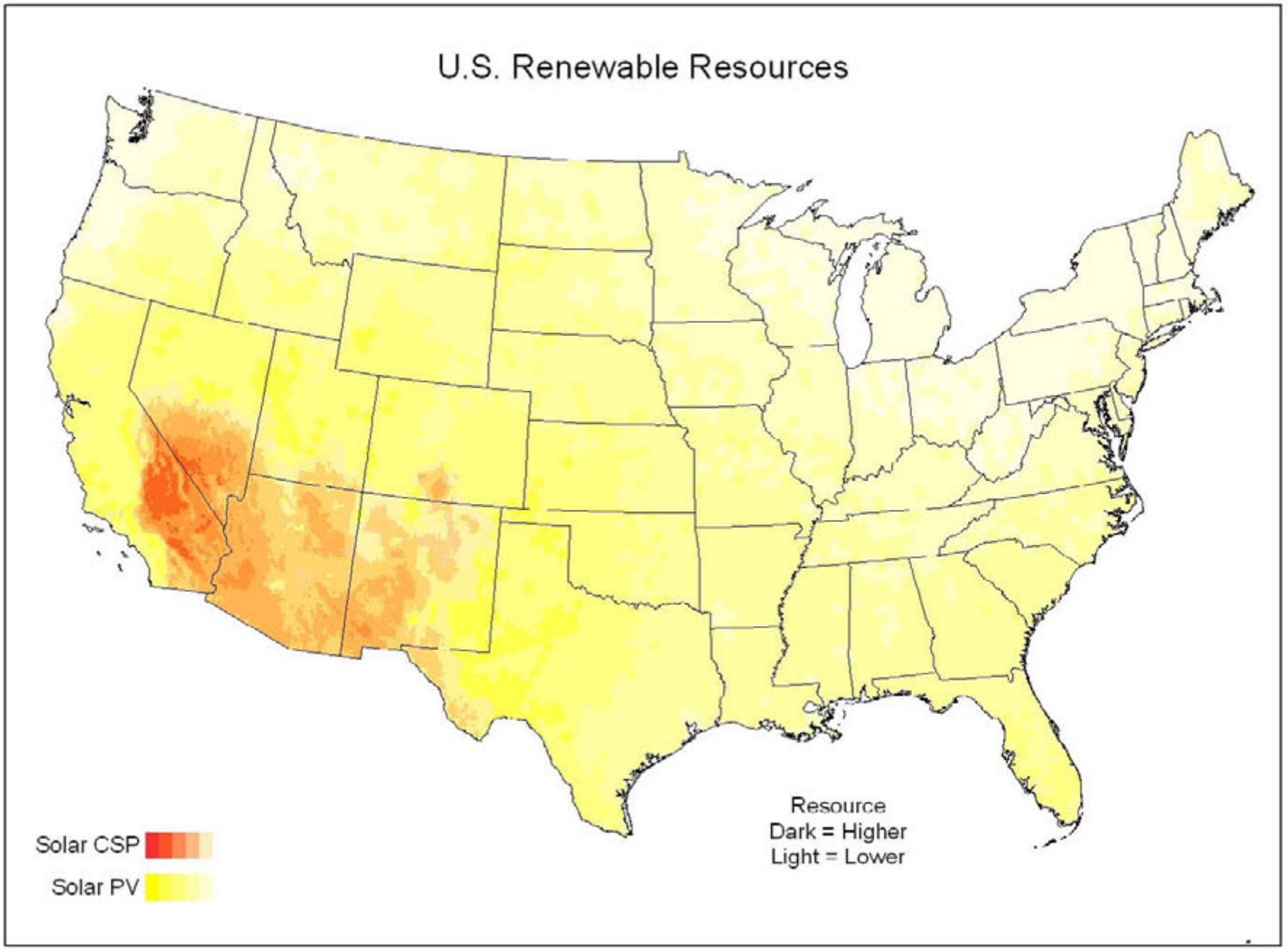
Distributed Generation, on-site or near point of use

Centralized Generation, large users or utilities

- Transportation
- Residential & Commercial Buildings
- Industrial

# Integrated solutions: Renewables go hand-in-hand with Energy Efficiency




U.S. Renewable Resources
Solar CSP
Solar PV
Resource
Dark = Higher
Light = Lower

# Photovoltaics and Concentrating Solar Power

## Status in U.S.

**PV**
- 526 MW
- Cost 18-23¢/kWh

**CSP**
- 355 MW
- Cost 12¢/kWh

## Potential:

**PV**
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

**CSP**
8.5 ¢/kWh by 2010
6 ¢/kWh by 2015

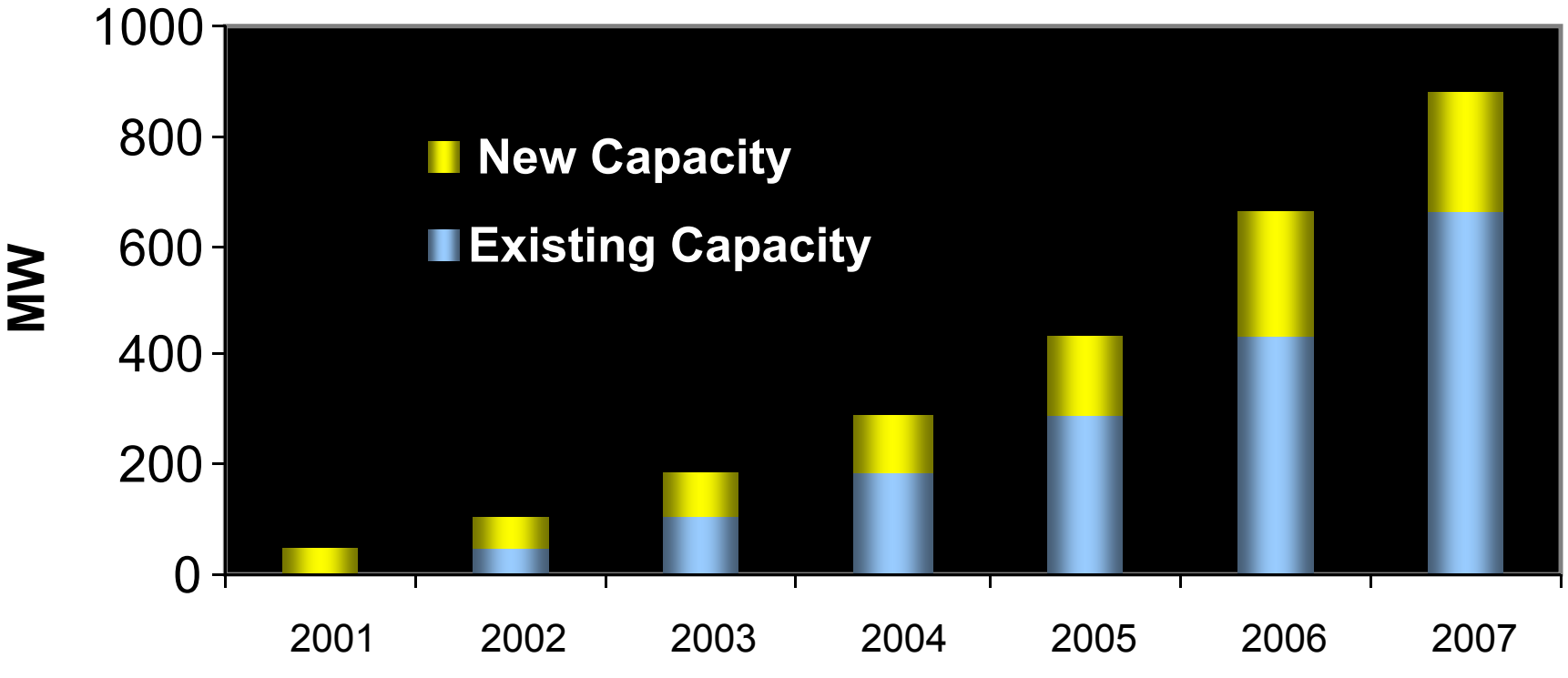
Source: U.S. Department of Energy, IEA
Updated November 8, 2006

## NREL Research Thrusts:

**PV**
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

**CSP**
- Next generation solar collectors
- High performance storage

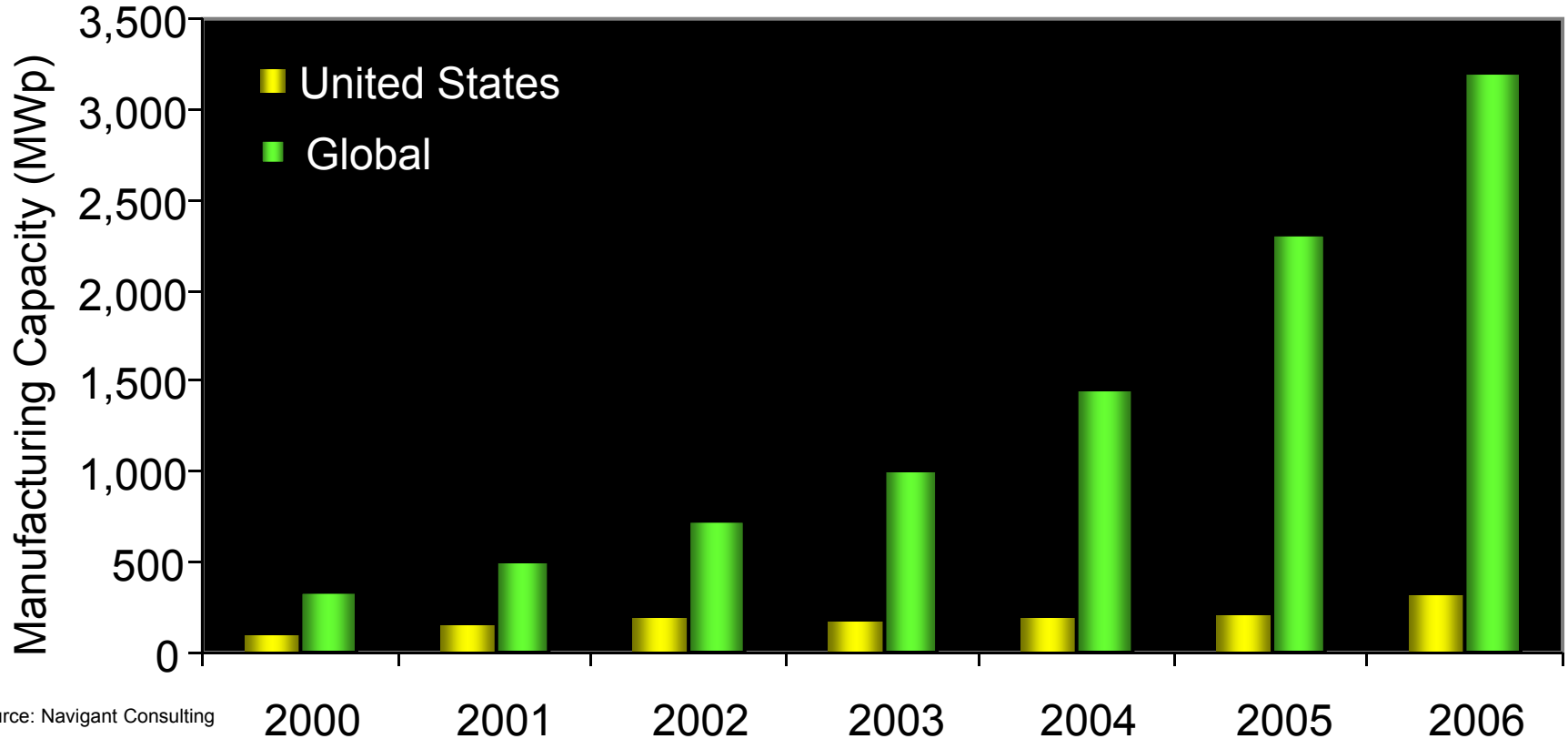
# U.S. Solar Photovoltaic Capacity Growth




| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007* |
|---|---|---|---|---|---|---|---|
| **Annual growth (%)** | n/a | 134% | 72% | 57% | 48% | 52% | 34% |
| **Total capacity (MW)** | 46 | 108 | 186 | 291 | 432 | 658 | 883 |

Source: Navigant Consulting/Piper Jaffray

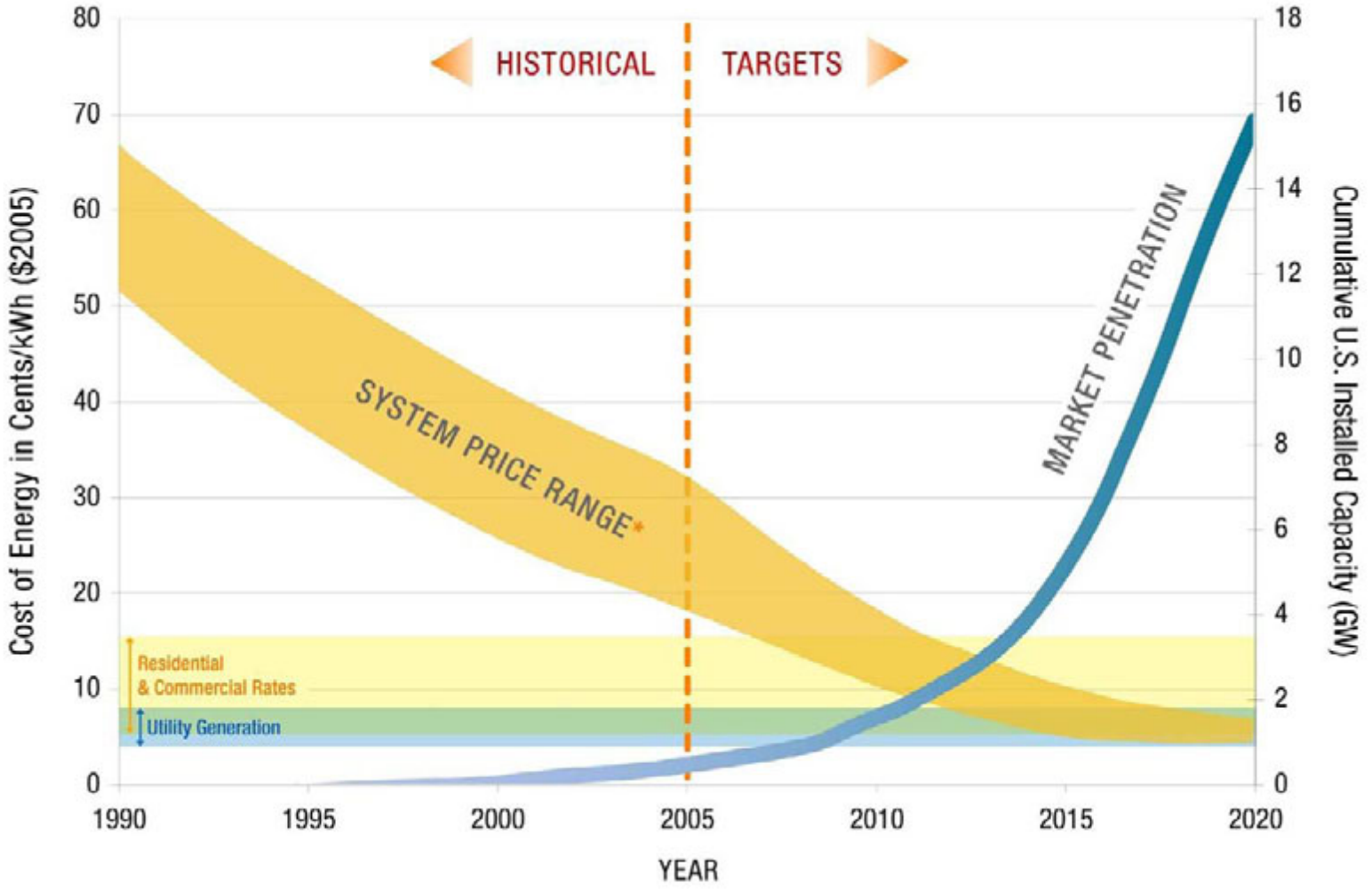
# Solar Manufacturing Capacity




Source: Navigant Consulting

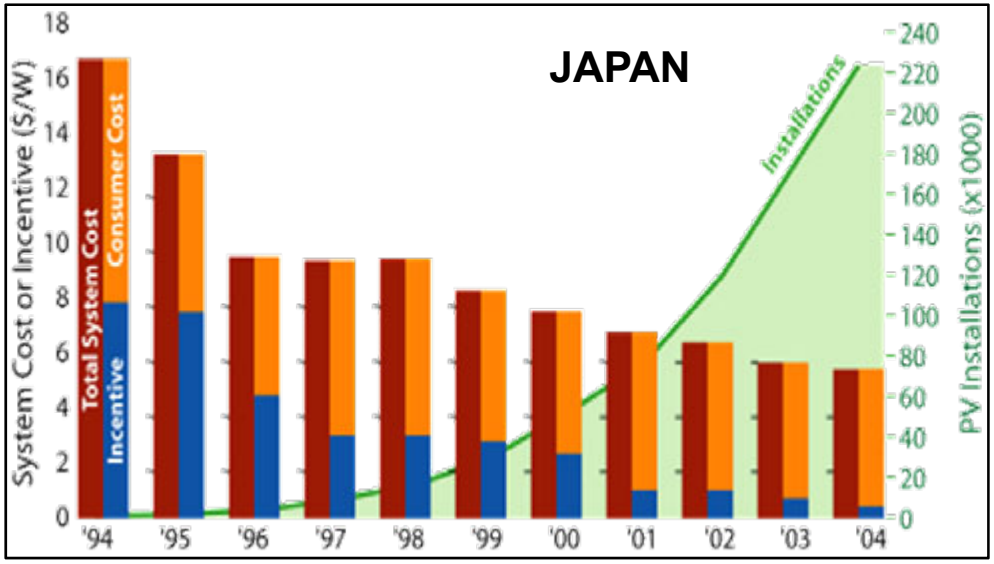
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|
| **Total Global Manufacturing Capacity (MWp)** | 225 | 328 | 504 | 728 | 1,002 | 1,460 | 2,303 |
| **Annual Global Growth** | 28% | 54% | 45% | 38% | 46% | 58% | 39% |
| **Total U.S. Manufacturing Capacity (MWp)** | 90 | 143 | 179 | 170 | 186 | 212 | 314 |
| **Annual U.S. Growth** | 14% | 58% | 26% | -5% | 9% | 14% | 48% |

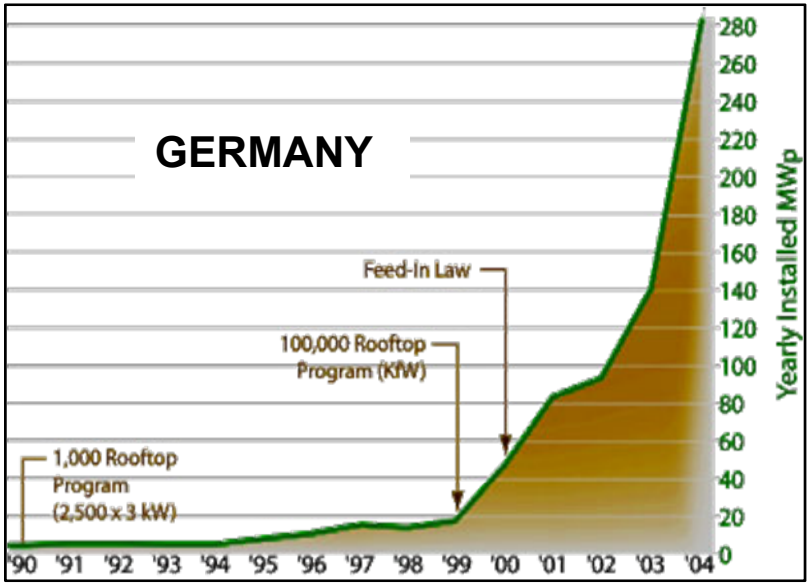
# PV Cost and Market Penetration Targets

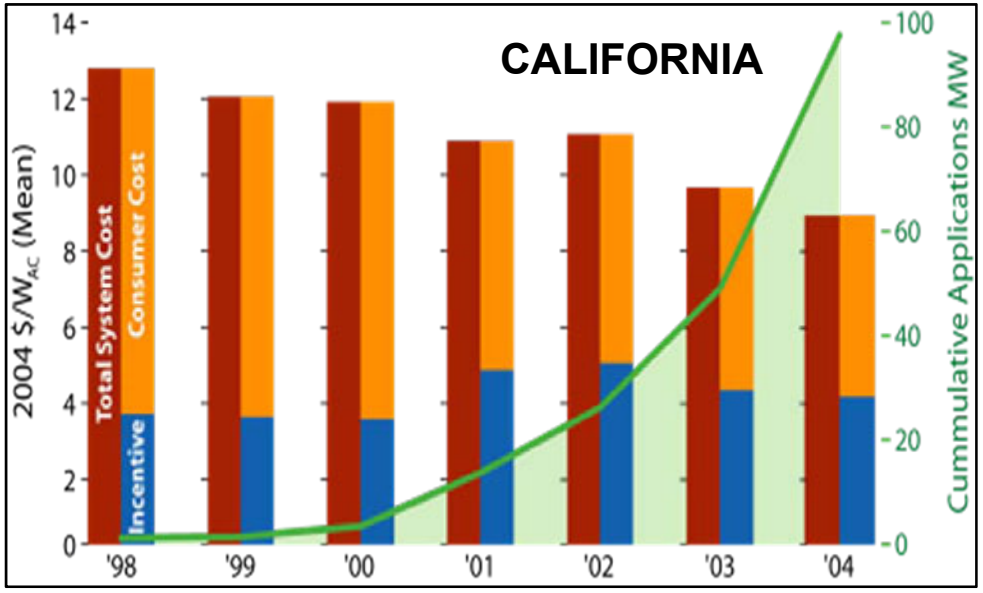


# Solar PV Example

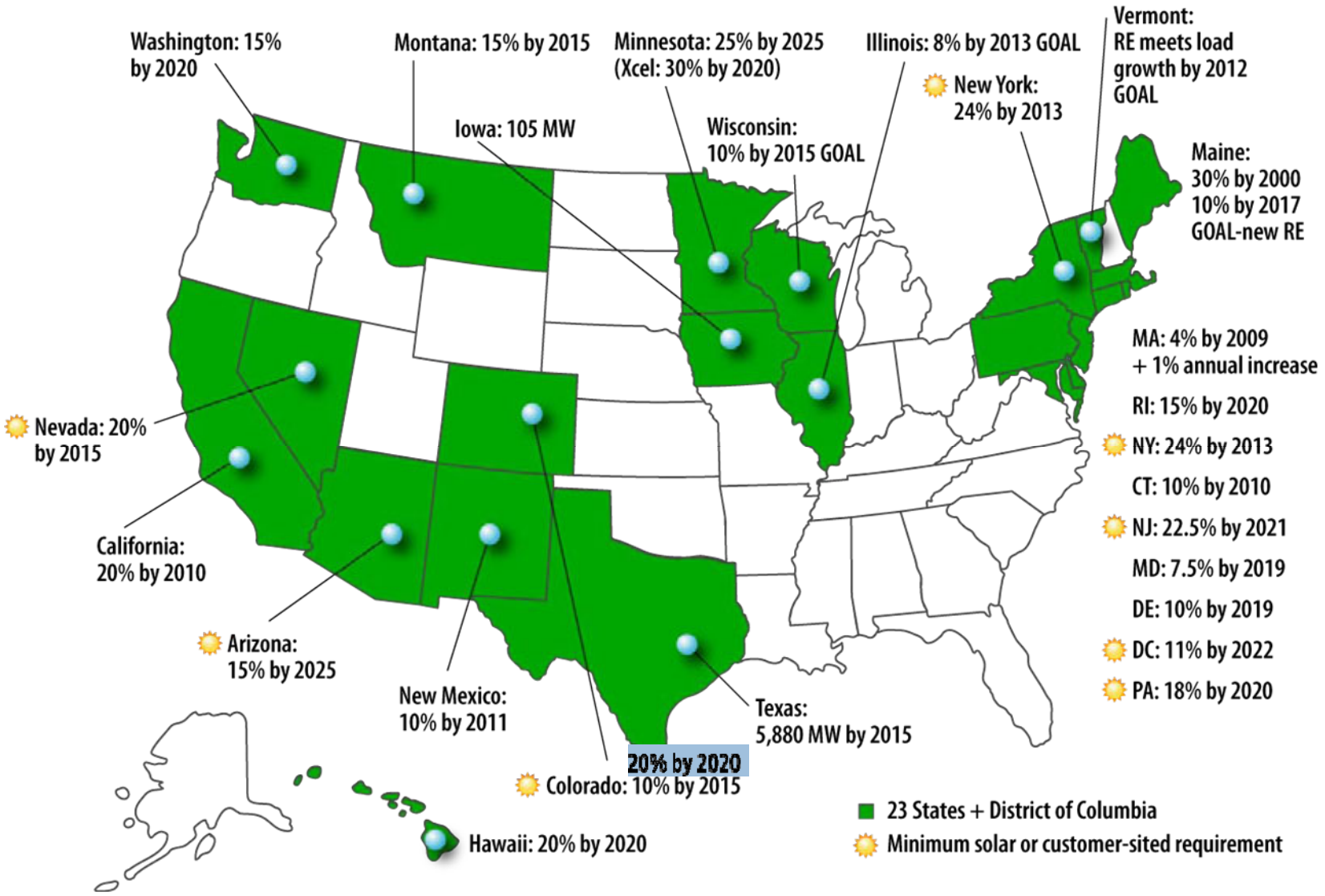
## Market Growth is Enabled by Progressive Public Policy



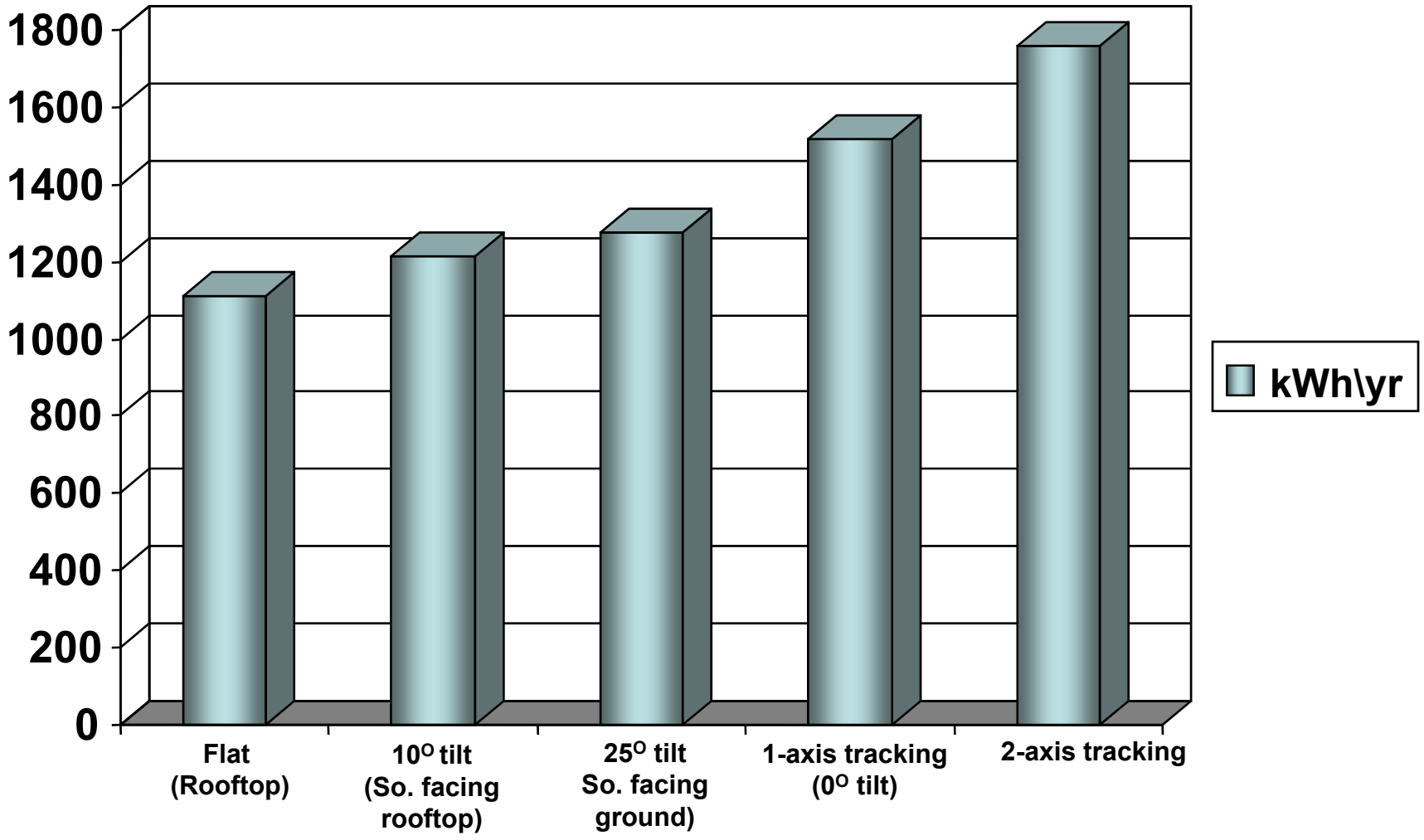



# State Policy Framework
## Renewable Electricity Standards

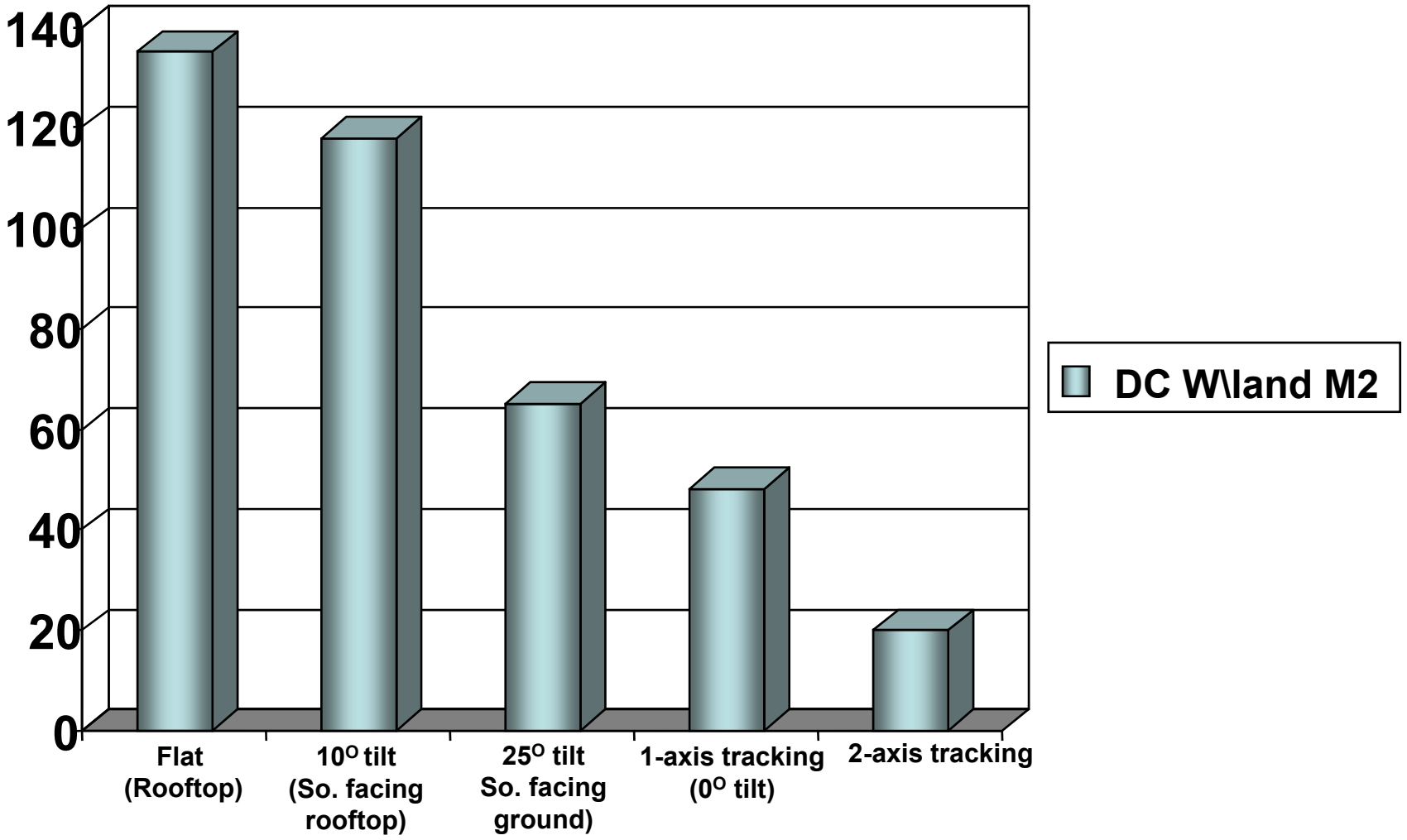



Source: DSIRE database, March 2007

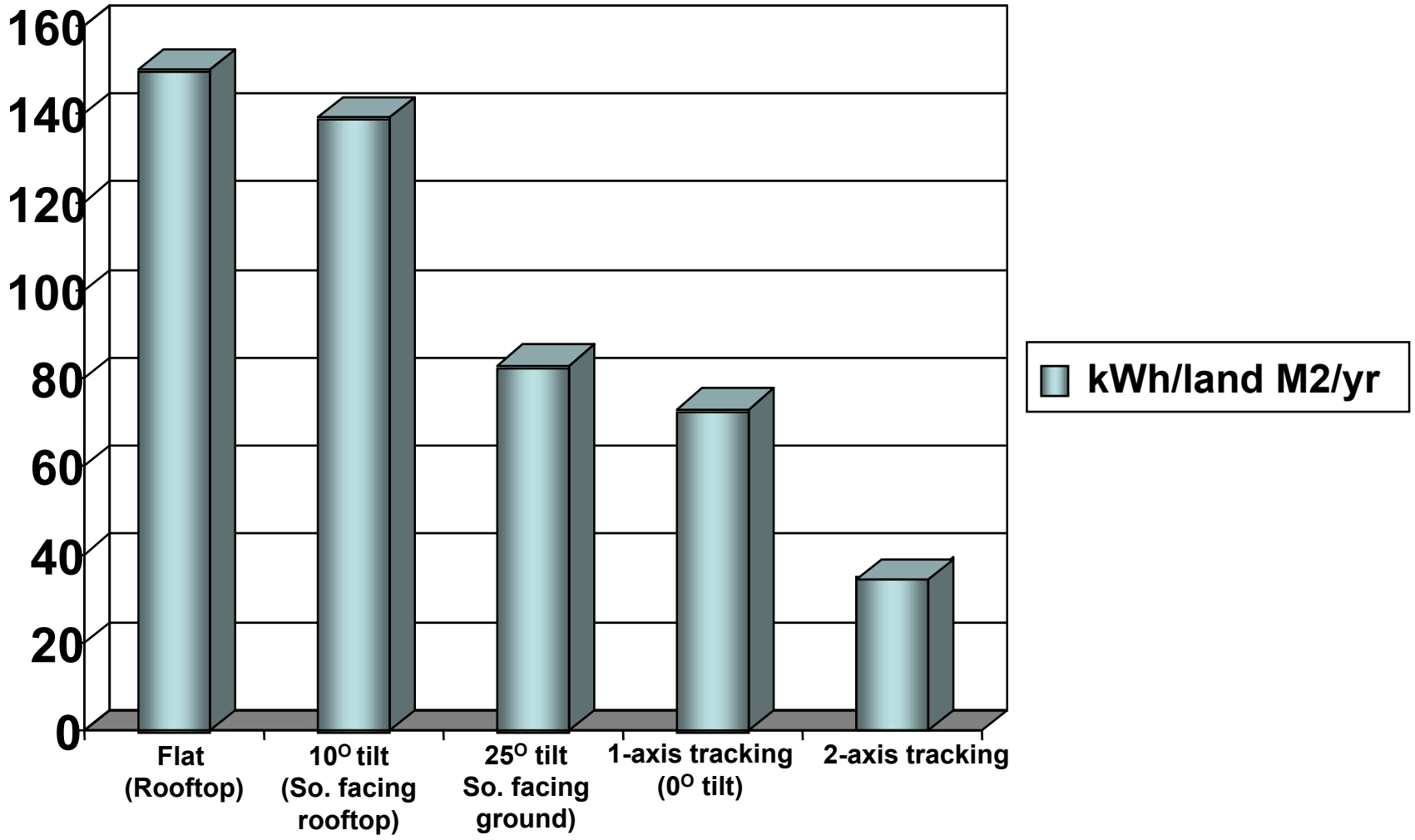
# PV System Performance:
# Output from a 1 KW (DC) system



# PV System Performance Characteristics: PV Array Power Density



# PV System Performance Characteristics: System Energy Density



# Pros and cons of central versus distributed approach to community-based renewable generation

***Distributed or Rooftop PV Systems***

| Pro | Con |
|---|---|
| • Consumers in homes with PV tend to conserve more<br>• No line losses<br>• For new construction, the cost of the home's PV can be included in the homes construction cost and therefore in the mortgage | • Individual maintenance<br>• Home layouts need to consider orientation for PV |

***Central Systems Serving Community***

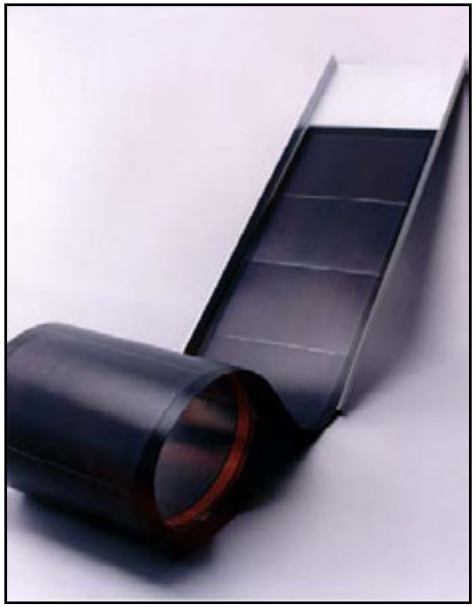
| Pro | Con |
|---|---|
| • Lower cost than distributed PV<br>• Can be 1-axis tracking PV which produces 30% more energy than fixed PV<br>• Could be wind, biomass, etc. based<br>• Central O&M and performance monitoring<br>• Can double as an amenity (such as shading a parking structure)<br>• Maintained by technology experts | • Transmission and distribution losses<br>• May require land (unless installed on top of parking or other structure)<br>• Metering to credit individual homes can be more difficult<br>• A community based power system with a micro-grid is a non-traditional approach to power delivery. |

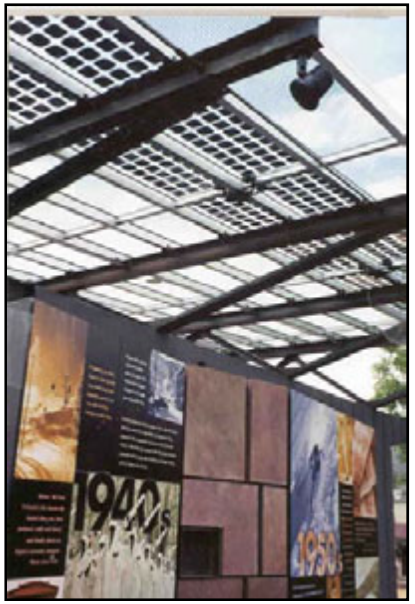
# Large-scale Applications of PV

**WorldWater & Power and Alternity Power Atlantic County Wastewater Treatment Plant, 8 MW solar-wind hybrid, NJ**

# Distributed Applications of PV

# Examples of integrated solar roofing products





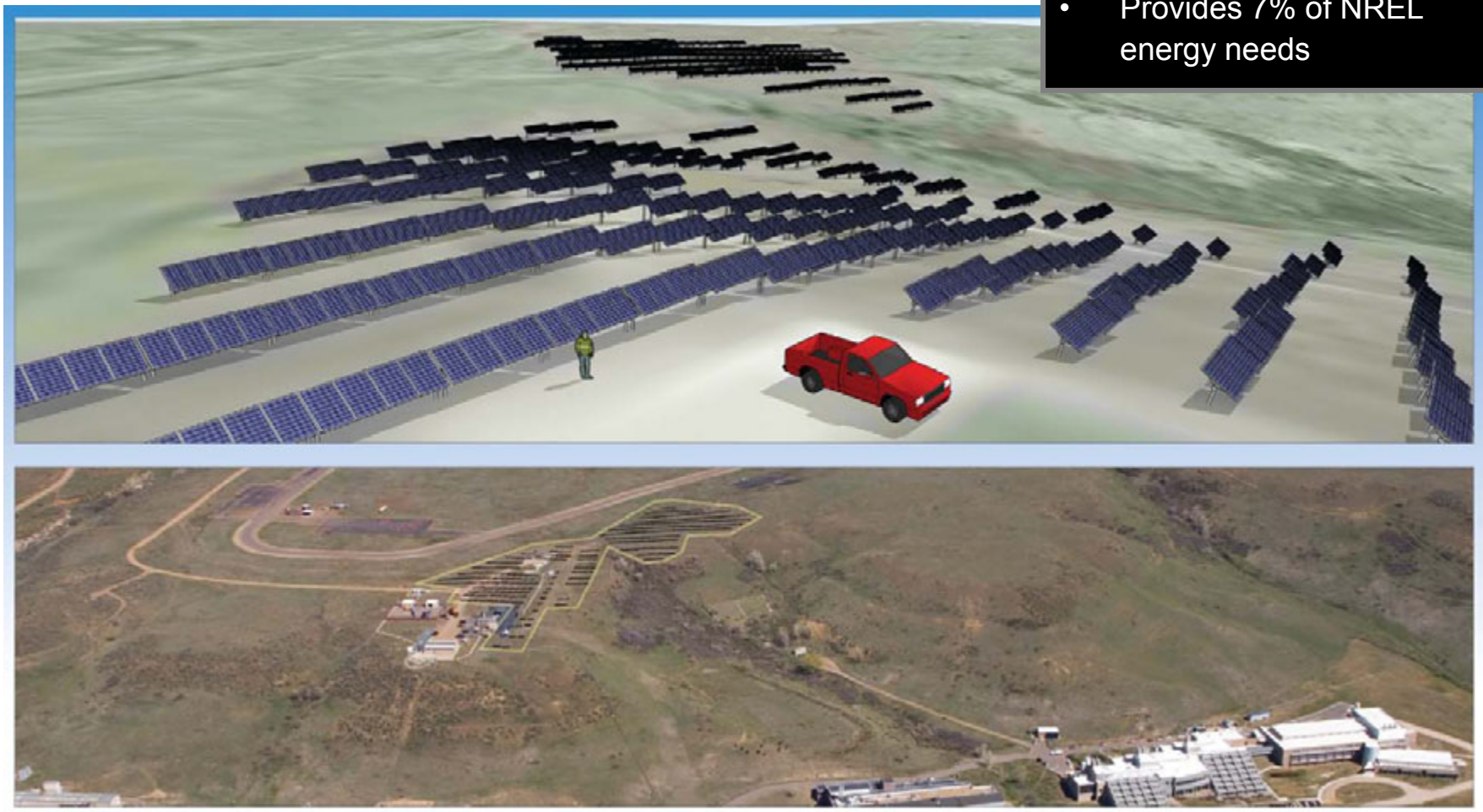

# Many new large applications in Colorado

- This PV system is expected to generate 1,667,000 kWh\year (10% of the DFC campus peak electrical load)
- Collectors at 20 degree fixed tilt
- Requires 6 acres of land
- First cost was $6.9 Million
- Incentives
- $6.9M ($5.8\Watt)
- REC = 1,525 MWH

*GSA Denver Federal Center (1.19 MWdc)*

# NREL's Mesa Top PV Project

- **750 kWdc (1,200,000 kWh) single-axis tracking PV system**
- Located on South Table Mountain on 5-6 acres
- Grid connected (NREL "side of the meter")
- Provides 7% of NREL energy needs



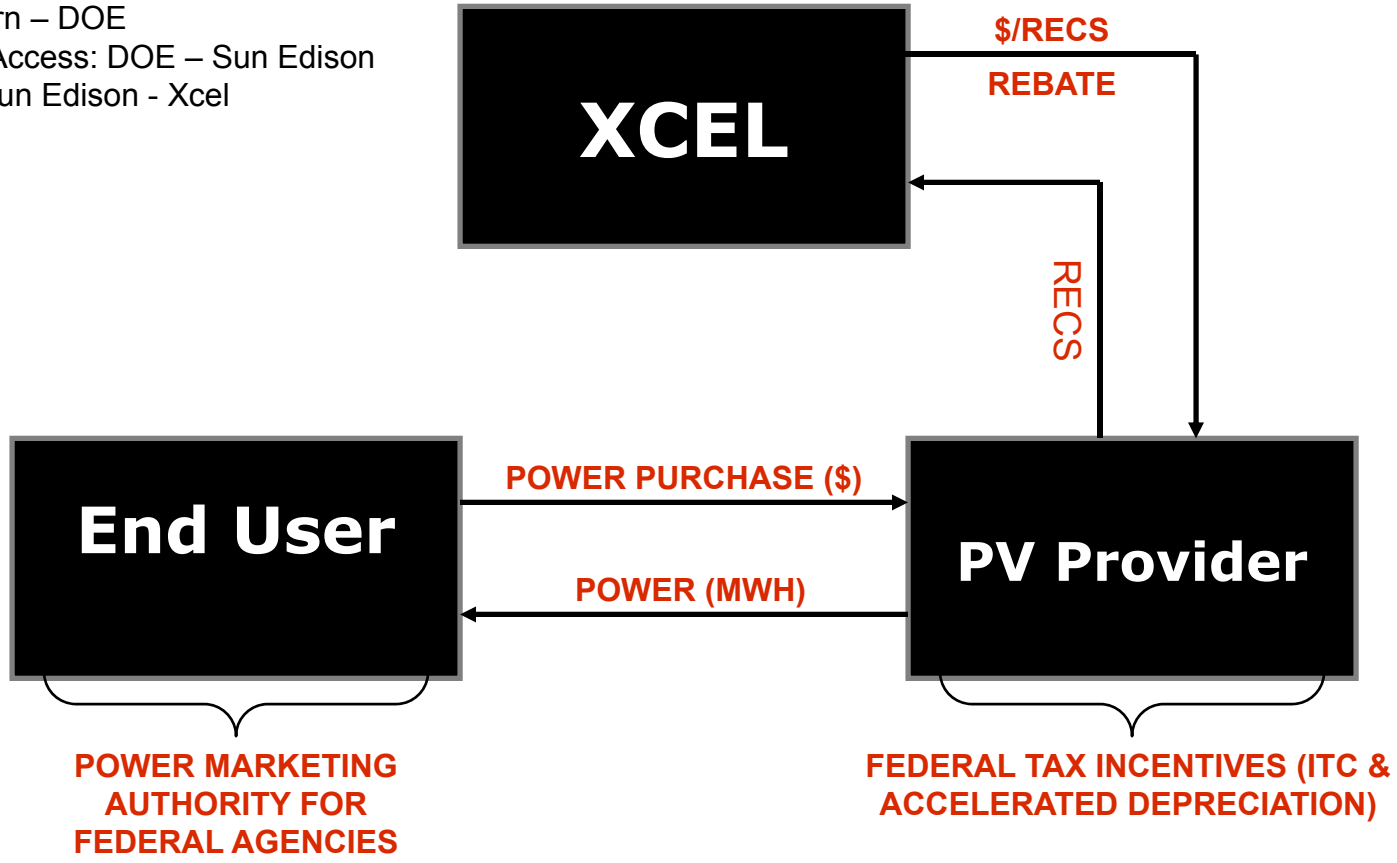
# Xcel Solar*Rewards Program

- CO statute requires solar resource acquisitions from 2006 – 2020 (20% renewables by 2020)
- Acquisitions made through RFP process
- SO-REC* Purchase Contract (100kW-2MW tier)
  - Rebate: $2/watt up to $200K
  - SO-RECs: bidders compete based on SO-REC price offering over 20 year term
- Current RFP response due April 2008
  - Two RFPs completed (oversubscribed)

*Solar Energy and Customer-Sited Renewable Energy Credits ($/MWH)

# Power Purchase Agreement "Wiring Diagram"

Agreements for NREL
PPA: Western/DOE - Sun Edison
IAA: Western – DOE
Easement/Access: DOE – Sun Edison
SO-REC: Sun Edison - Xcel



# What's In It for the Parties?

## Xcel

- Secures RECs to meet State statute/Public Utilities Commission requirement (Amendment 37) renewable energy use requirements
- Cost recovery
- Corporate benefits of using renewable energy

## Third Party Developers (profitable business)

- Federal tax incentives
- Xcel Rebate and REC revenues
- Sale of electricity

## User

- Purchase of power at ≤ utility electric price (or greater)
- Lease/easement considerations?
- End of term ownership/early "buyout"
- Supports use of renewable energy without capital investment

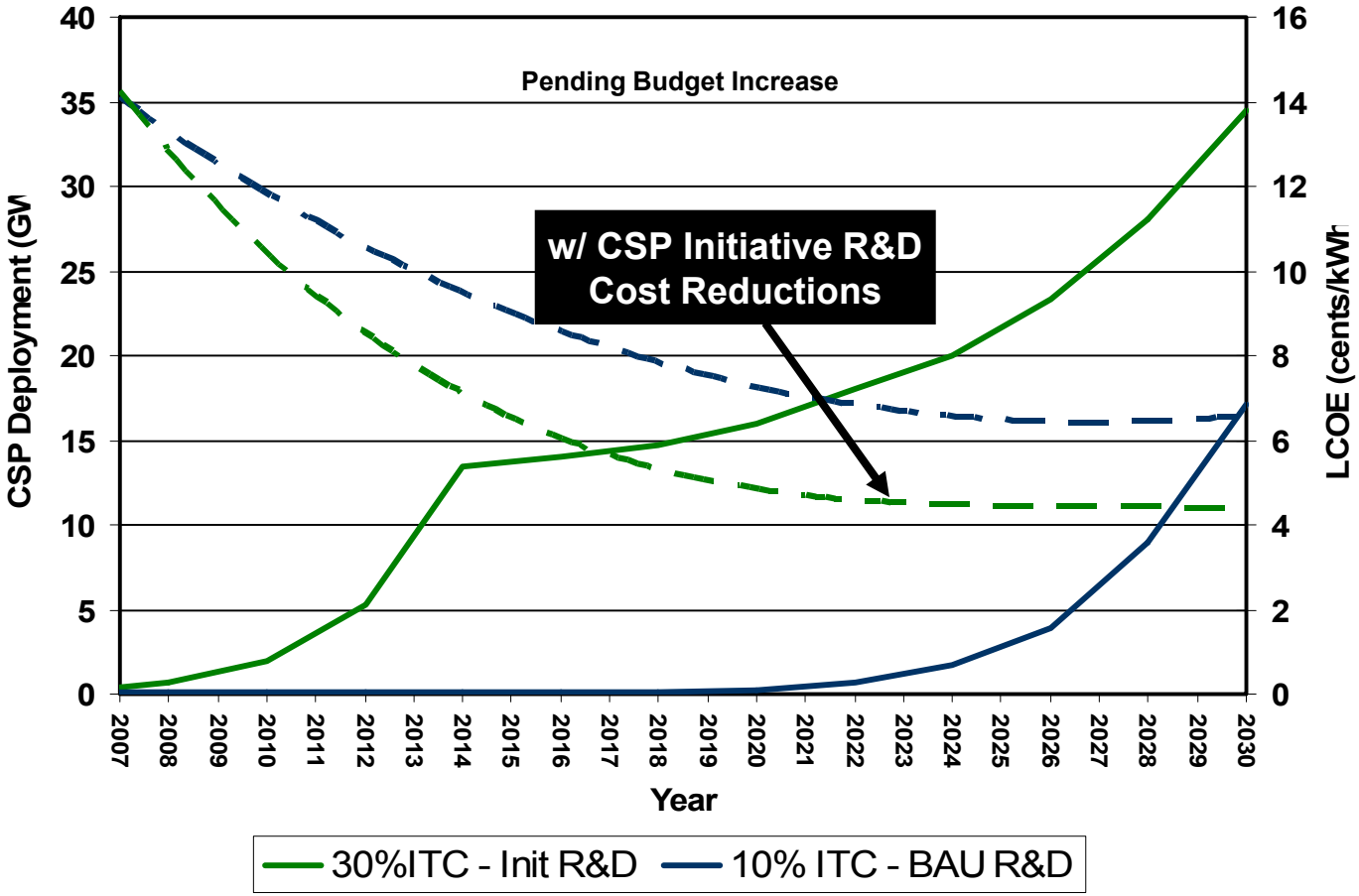
# Concentrated solar

- Generates electricity for utility grid applications
- Also can be used to heat water
- Utility applications requires approximately 10 acres\MW of power
- Land needs less than 2% slope
- CPC only use the direct beam radiation therefore applications are limited to locations in the SW US

Kramer Junction CPC (1991)

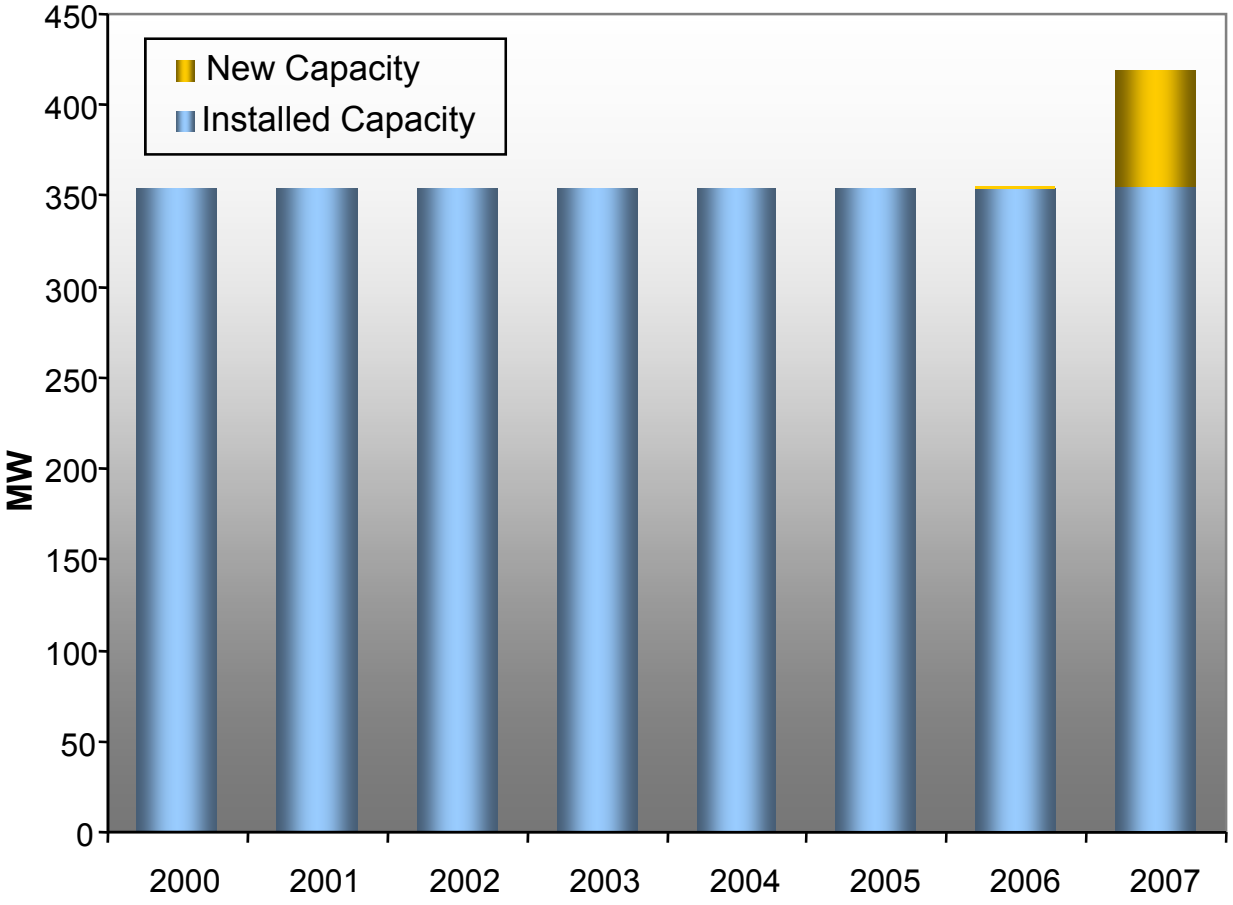
FCI Phoenix

# CSP Cost and Market Penetration Targets




**Targeting CSP plants at GW-scale with baseload-equivalent price/dispatchability.**

# U.S. Concentrating Solar Power Capacity Growth




| | Annual growth (%) | Total capacity (MW) |
|---|---|---|
| **2000** | 0% | 354 |
| **2001** | 0% | 354 |
| **2002** | 0% | 354 |
| **2003** | 0% | 354 |
| **2004** | 0% | 354 |
| **2005** | 0% | 354 |
| **2006** | 0.3% | 355 |
| **2007** | 18% | 419 |

# CSP Industry is Still Taking Shape

## Thermal Storage R&D

- Enabling solar generated power to be delivered to grid any time needed by utilities

## Transition to High Volume Manufacturing

- Reduce costs and increase supply base for critical components

## Advanced Concepts

- Explore new technologies that could significantly reduce system and/or component cost

# The Vision

Vehicles and Fuels

Energy Smart Buildings

Renewables

**A Renewable Energy Community**

# It starts with sustainable land use planning……

*Planned community where homes have solar access*

**Guiding principles**

- All development & building should occur in the context that all resources are limited
- Communities and buildings can be resource providers not just resource users
- Land is a stewardship role for future generations
- It is less expensive short and long term to build in harmony with the environment
- Communities are planned for people and technologies are to be supportive not dominant
- Environmental education is an essential "first step" in the rediscovery of our intuitive sense of integrating with the environment

* Images courtesy of Wonderland Hills (http://www.whdc.com)

** Text courtesy of Dewees Island principles (http://www.deweesisland.com/)

# Buildings – Efficiency coupled with passive and active solar



*"The NAHB Research Center predicts that zero energy homes could be moving into the mainstream of the nations housing markets as early as 2012 and hold the potential for reducing the energy consumption of all single family homes by 19% by 2050 even as more than a million new homes are added annually".*

# Vehicles Can Be Part of the Home Package

Toyota Dream House PAPI

*Plug-in vehicle in a Japanese Home*

*Net Zero Energy Canadian Home*

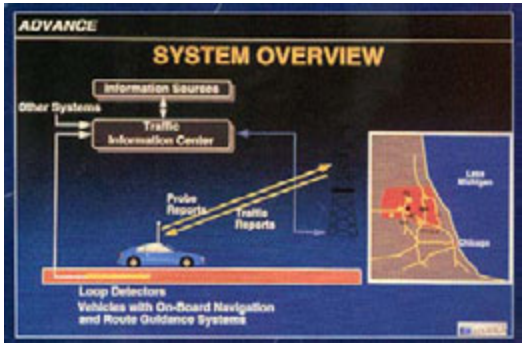
E-vehicles are also part of the green program at Terramor Village. (Photo courtesy of EDAW.)

Terramor Village homes will include a 110-volt electric outlet for charging Neighborhood Electrical Vehicles (NEVs).

Notice the latest generation of solar panels on one of the Terramor homes. (Photo courtesy of Shea Homes.)

# What types of vehicles are in a Renewable Community?

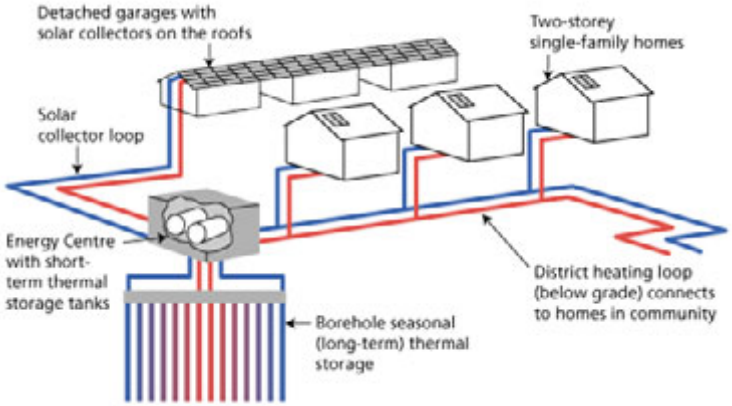
- Electric Vehicles + Bi-directional plug-in
- Hybrid Electric Vehicles + Plug-in
- Fuel Cell Vehicles + Plug-in
- CNG/LNG Vehicles + home refueling
- Clean Diesel / biodiesel
- Car share program
- Others…

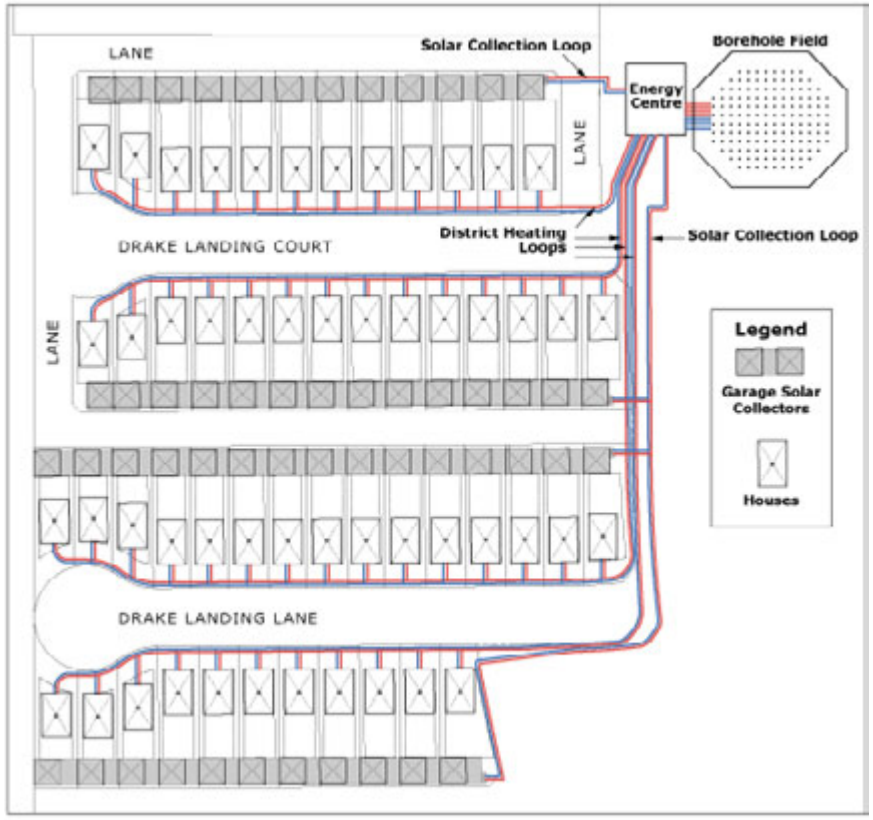




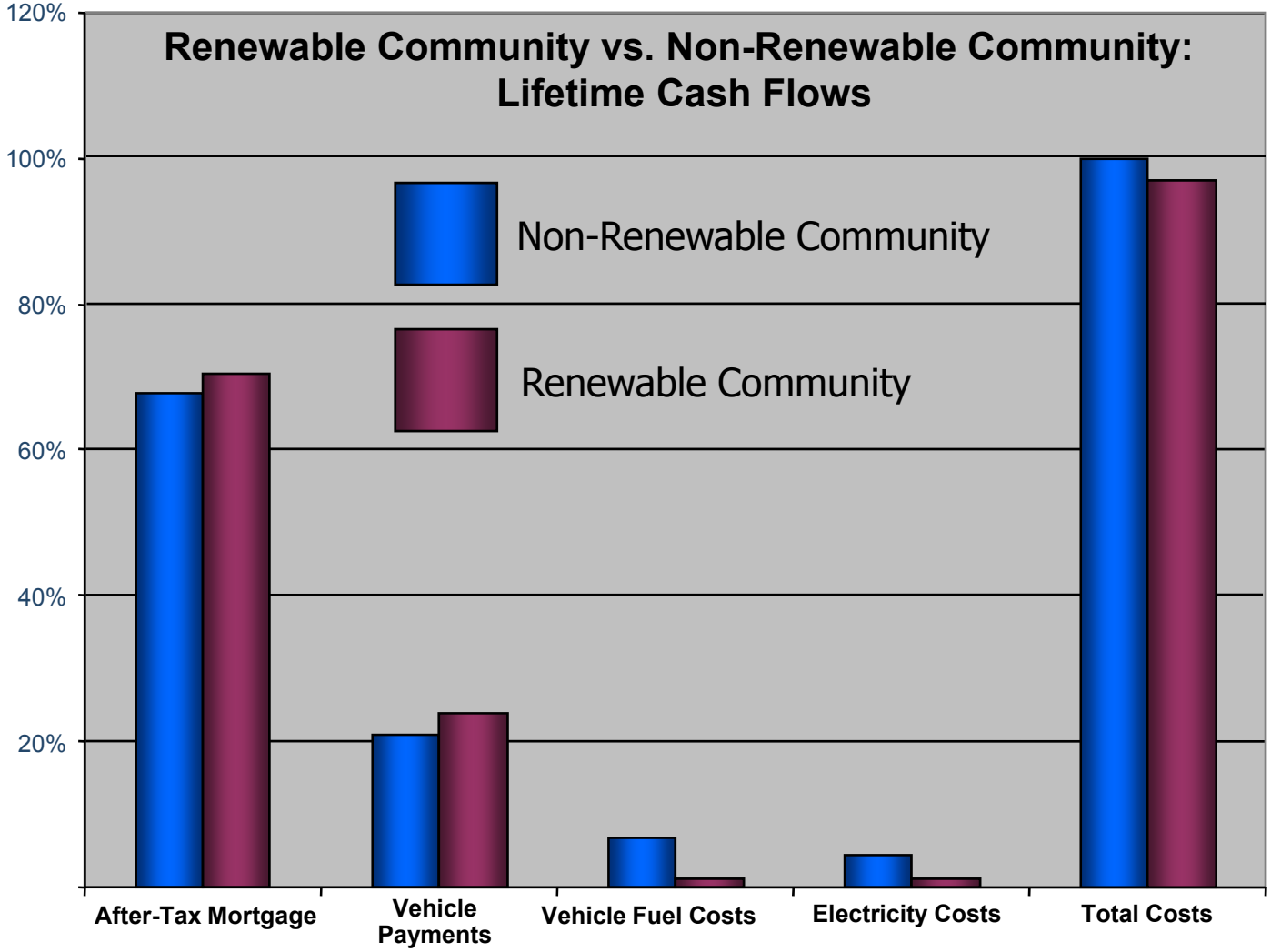
# Drake Landing, Canada

## Community with microgrid, using GSHP and Solar



# From a Consumer's Point of View: A Renewable Community Can Cost Less Than a Non-renewable Community!



# The time is now to….

- develop an integrated approach to clean energy on a community level
- plan for a deeper transformation to a nearly carbon-neutral urban economy