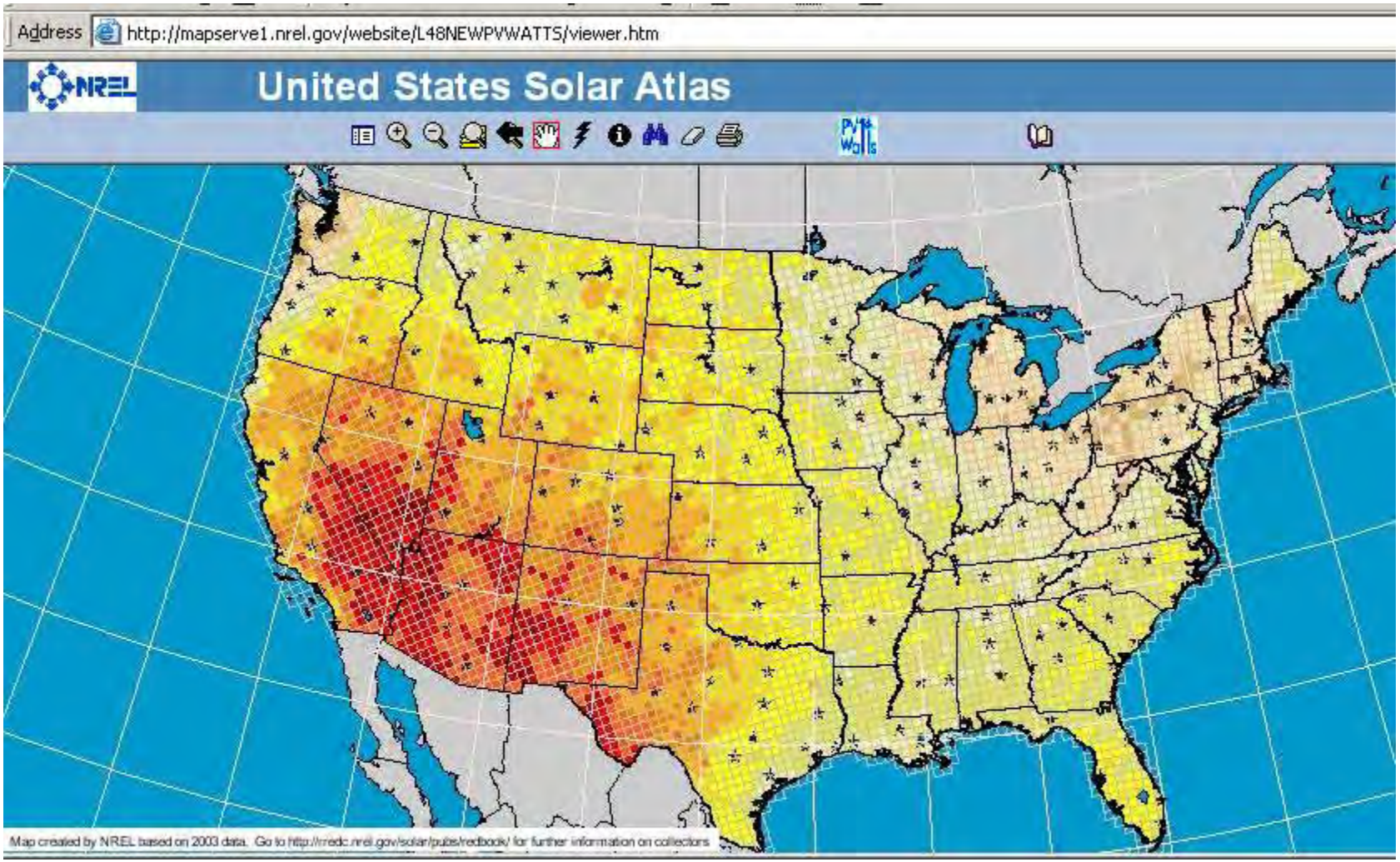
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Solar Energy – Capturing and Using Power and Heat from the Sun

Roger Taylor
Tribal Energy Program Manager

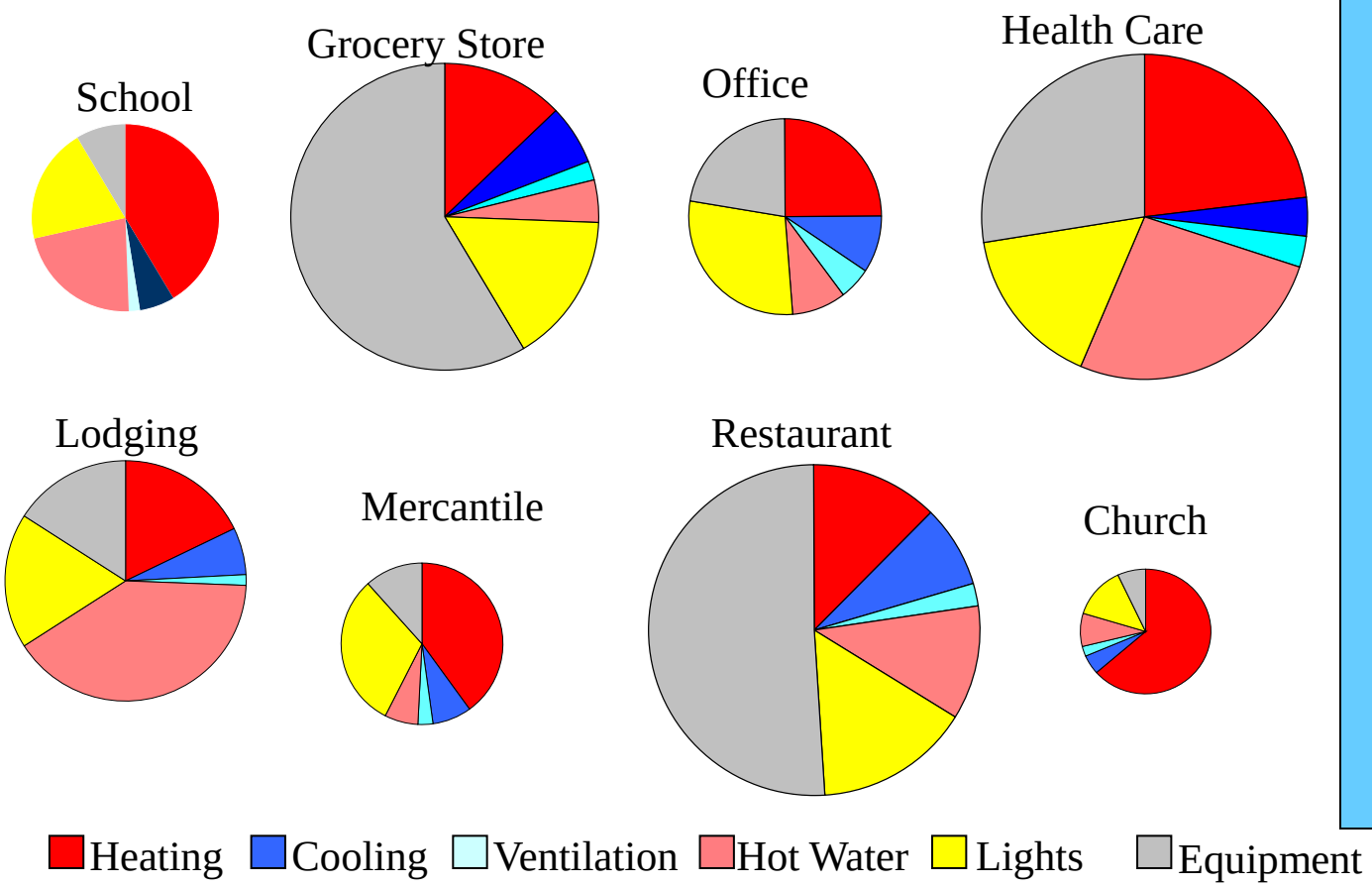
National Renewable Energy Laboratory

Golden, CO


Address
http://mapserve1.nrel.gov/website/L48NEWPVWATTS/viewer.htm
NREL
United States Solar Atlas
PV Watts
Map created by NREL based on 2003 data. Go to http://rredc.nrel.gov/solar/pubs/redbook/ for further information on collectors

Solar Thermal Technology & Applications

Building Hot Water Energy Use average 125 kbtu/sf/year



Energy for Water Heating kBtu/sf/year	
Office	8.7
Mercantile	5.1
Education	17.4
Health Care	63.0
Lodging	51.4
Pub Assembly	17.5
Food Service	27.5
Warehouse	2.0
Food sales	9.1
Public Safety	23.4
Other	15.3
All Buildings	13.8

Solar Water Heating Is Not New!

Before the advent of gas pipelines and electric utilities, the technology gained footholds in Florida and California before the 1920's

Over 1,000,000 systems are in use in American homes and business

The technology is in widespread use in:

- Caribbean basin
- China
- Israel
- Greece
- Japan
- Australia

Technical And Economic Viability Depends Upon

Amount of annual sunshine

Capital cost of the solar system

Prices of conventional fuels

Solar system annual O&M cost

Annual energy requirement and energy use profile

Temperature and amount of hot water (kWh produced)

Rate at which conventional fuels are escalating in price

Other (e.g. legislative mandates, tax credits)

Solar Thermal Applications

Low Temperature (> 30C)

- Swimming pool heating
- Ventilation air preheating

Medium Temperature (30C – 100C)

- Domestic water and space heating
- Commercial cafeterias, laundries, hotels
- Industrial process heating

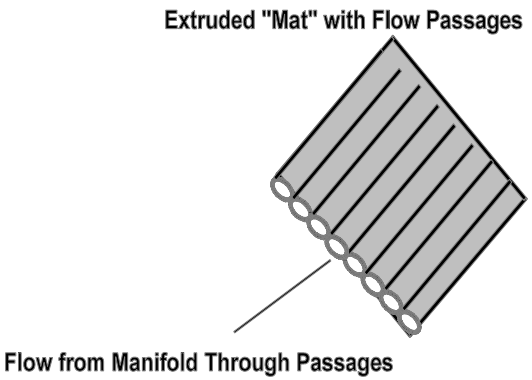
High Temperature (> 100C)

- Industrial process heating
- Electricity generation

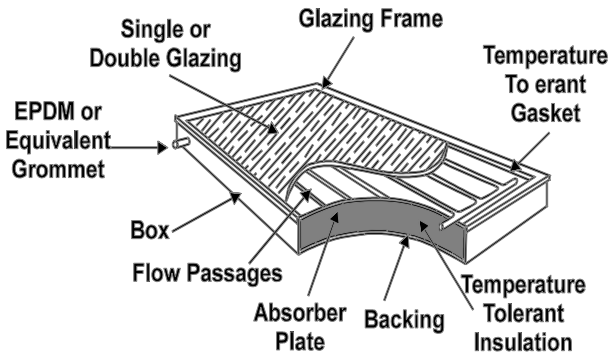
Solar thermal and photovoltaics working together

Collector Types

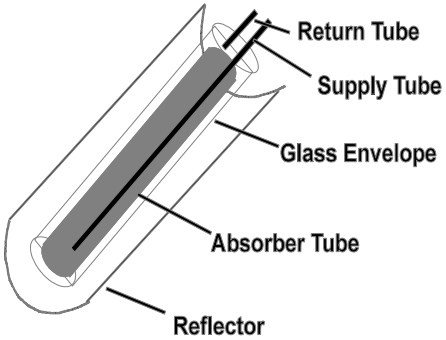
Unglazed EPDM Collector



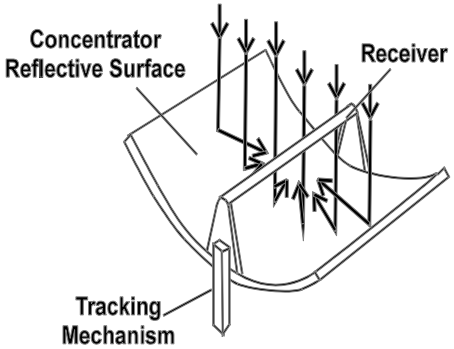
Flat Plate



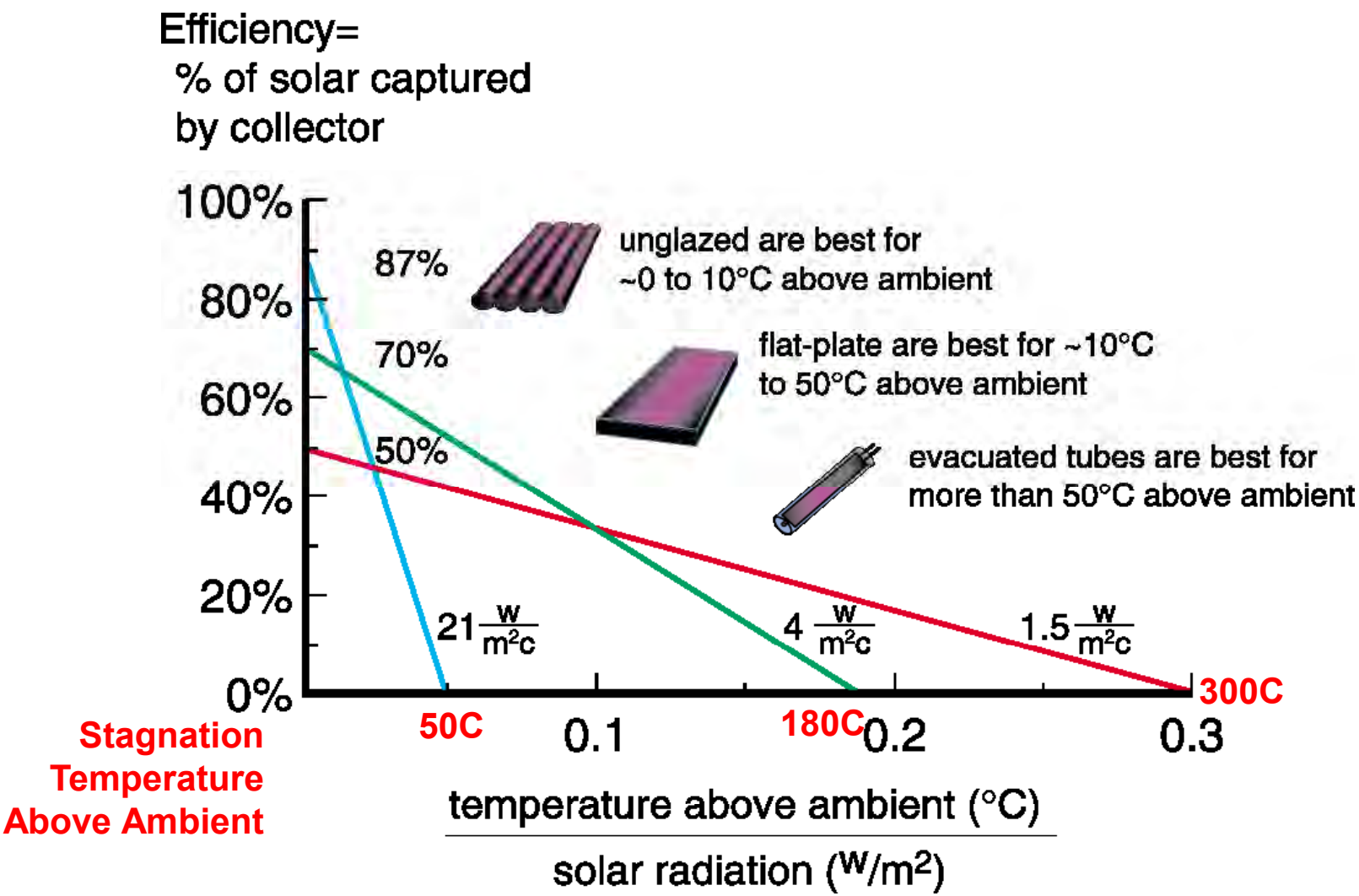
Evacuated Tubes



Parabolic Trough



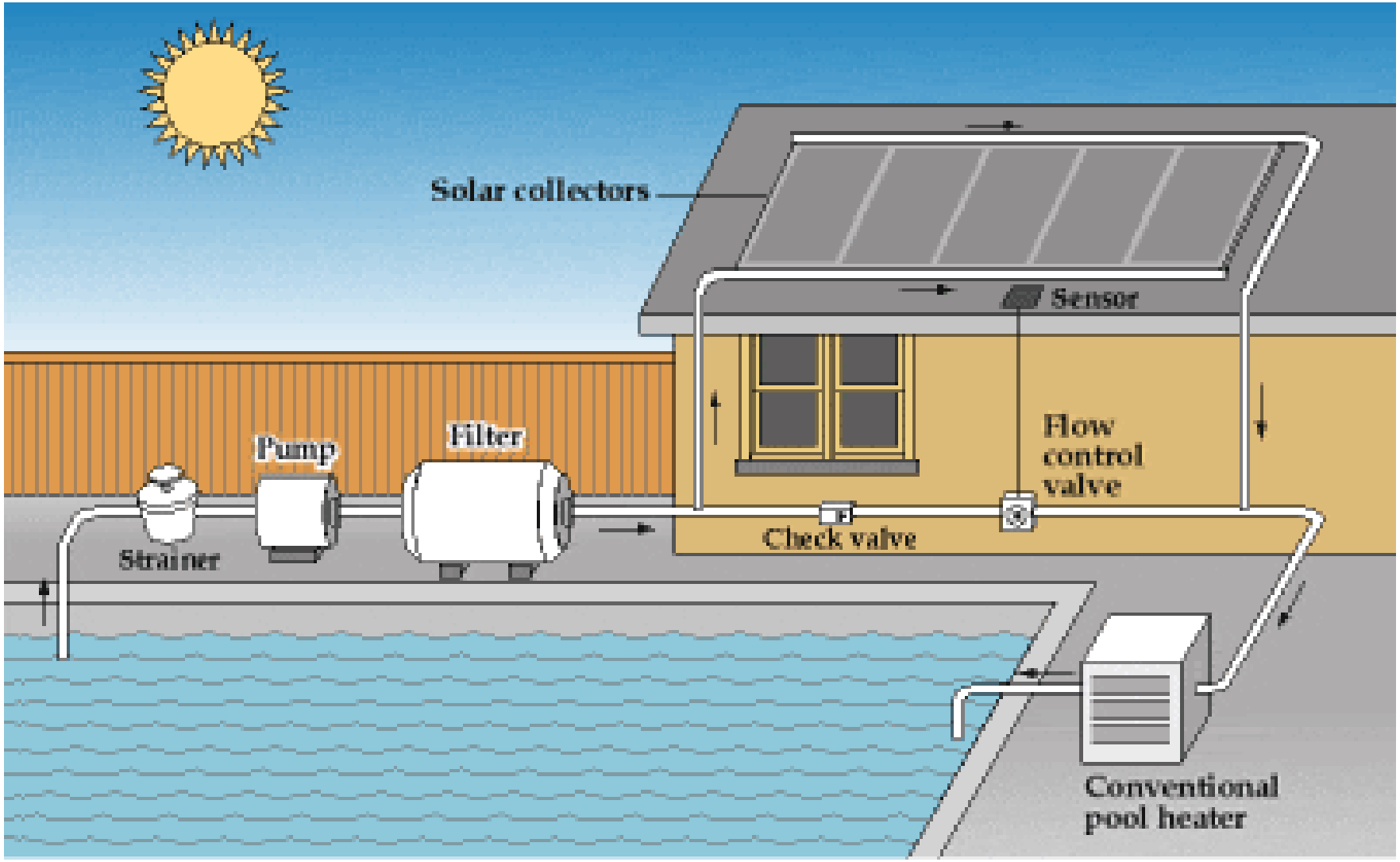
Which collector is best depends on the temperature...

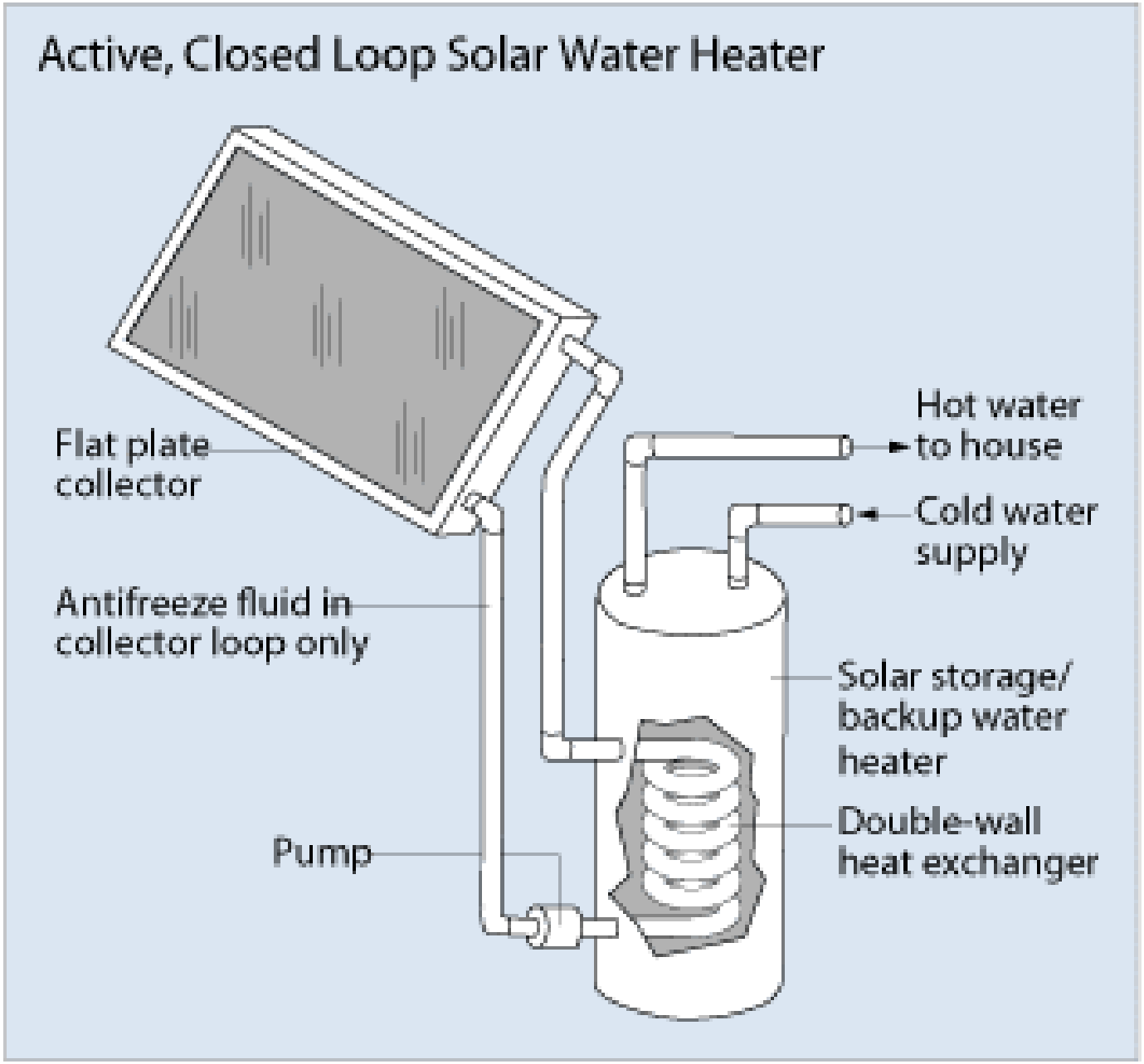


Solar Rating and Certification Corp.

Contact information
Solar Rating and Certification Corporation
c/o FSEC, 1679 Clearlake Road
Cocoa, FL 32922-5703
Voice (321)638-1537
Fax (321)638-1010
E-mail: srcc@fsec.ucf.edu

- An independent nonprofit organization that tests performance and certifies almost every solar heater on the market today.
- Reports efficiency and annual performance for different climates and temperature uses.


Solar collectors
Sensor
Flow control valve
Check valve
Filter
Pump
Strainer
Conventional pool heater


Active, Closed Loop Solar Water Heater
Flat plate collector
Antifreeze fluid in collector loop only
Pump
Hot water to house
Cold water supply
Solar storage/ backup water heater
Double-wall heat exchanger

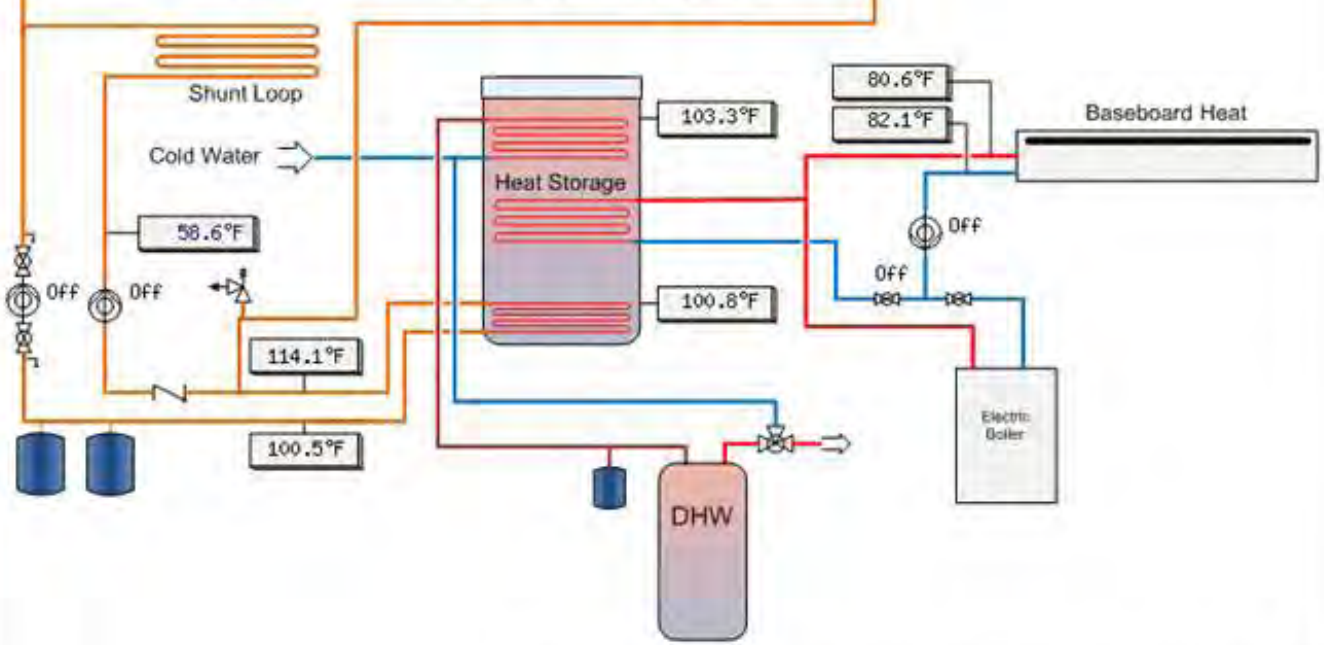
system.png

MOHICAN NATION STOCKBRIDGE-MUNSEE BAND

LIFETIME SOLAR

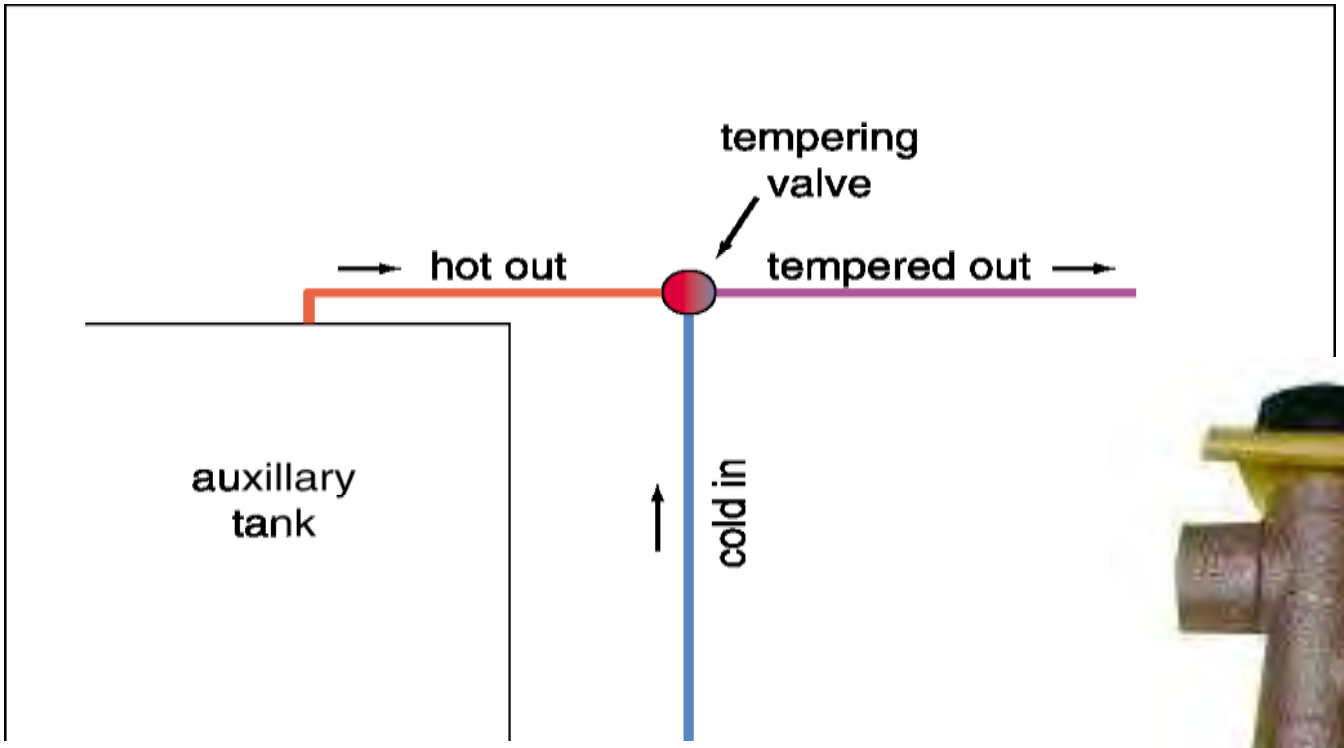
(5) SunMaxx 25 EVT Evacuated Tube Collectors

Time: 15:55:18 CST	Date: 03/08/2011	
Solar Return	114.1°F	VPump Off
Solar Supply	100.5°F	Shunt Off
Solar Irradiance	182.5 W/m2	
Shunt Loop	58.6°F	
Tank Top	103.3°F	
Tank Bottom	100.8°F	
Outside Temp	38.0°F	
Basement Temp	60.5°F	
Boiler Supply	80.6°F	Pump Off
Boiler Return	82.1°F	
Solar Pump	2.10	Run Hours
Shunt Loop Pump	0.00	Run Hours
Boiler Pump	2.80	Run Hours
Boiler Valve	0.00	Run Hours



Sponsored By The Department of Energy, Renewable Energy labs, Golden CO

Tempering Valve to Prevent Scalding: Extremely Important for Safety!



Mid-Temperature Example:

Chickasaw National Recreation Area, OK

Small Comfort Stations

- 195 square feet of flat plate collectors
- 500 gallon strorage volume
- Cost $7,804
- Delivers 9,394 kWh/year
- Saves $867 / year

Large Comfort Stations

- 484 square feet of flat plate collectors
- 1000 gallon strorage volume
- Cost $16,100
- Delivers 18,194 kWh/year
- Saves $1,789 / year

Requirements for Success

- Appropriate Application (Provide a Reasonable Payback)
- Proven Design
- Freeze Protection
- Properly Sized (undersized, not oversized)
- Require No Manual Intervention
- Operational Indicators or Monitoring
- Conservation First
- Verify Load
- Performance Guarantee
- Require Operations and Maintenance Manual and Training
- Acceptance Test

Resources and References

American Society of Heating, Air Conditioning and Refrigeration Engineers, Inc.

- ASHRAE 90003 -- Active Solar Heating Design Manual
- ASHRAE 90336 -- Guidance for Preparing Active Solar Heating Systems Operation and Maintenance Manuals
- ASHRAE 90346 -- Active Solar Heating Systems Installation Manual

Solar Rating and Certification Corporation

- SRCC-OG-300-91 -- Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems

My Tribal Energy Champion is:

My Green Energy Team Includes:

Tribal Energy Objectives:

Building Weatherization Needs:

Tribal Strategic Energy Planning

Tribal Energy Vision Statement:

Solar Heat Opportunities (Buildings & Hot Water)

Key Tribal Buildings	Annual Energy Use	Energy/sq.ft
Other Key loads:		
# Homes:		
New Loads:		

Solar Electric Opportunities:

The next steps I will take when I get home are:

Wind Power Opportunities:

Biomass Heat Opportunities:

Geothermal Heat Opportunities:

Current Energy Suppliers:

Electricity:

Gas/Propane:

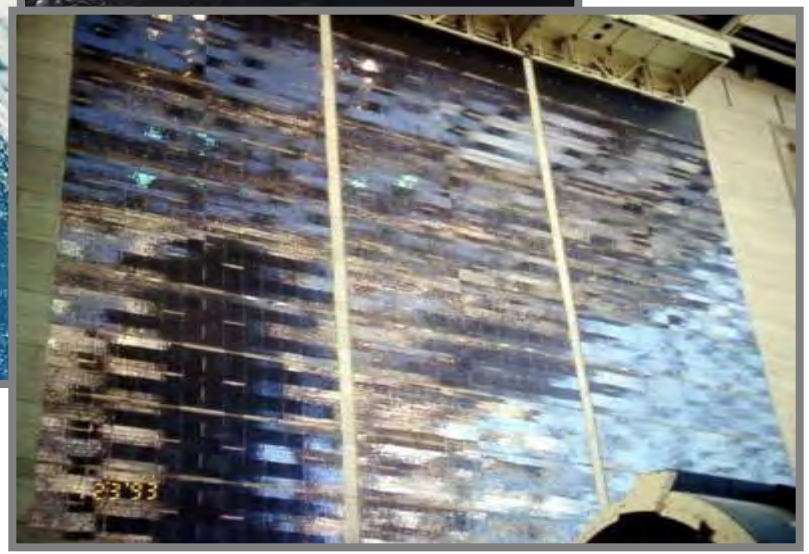
Hydropower Opportunities:

Biomass Power Opportunities:

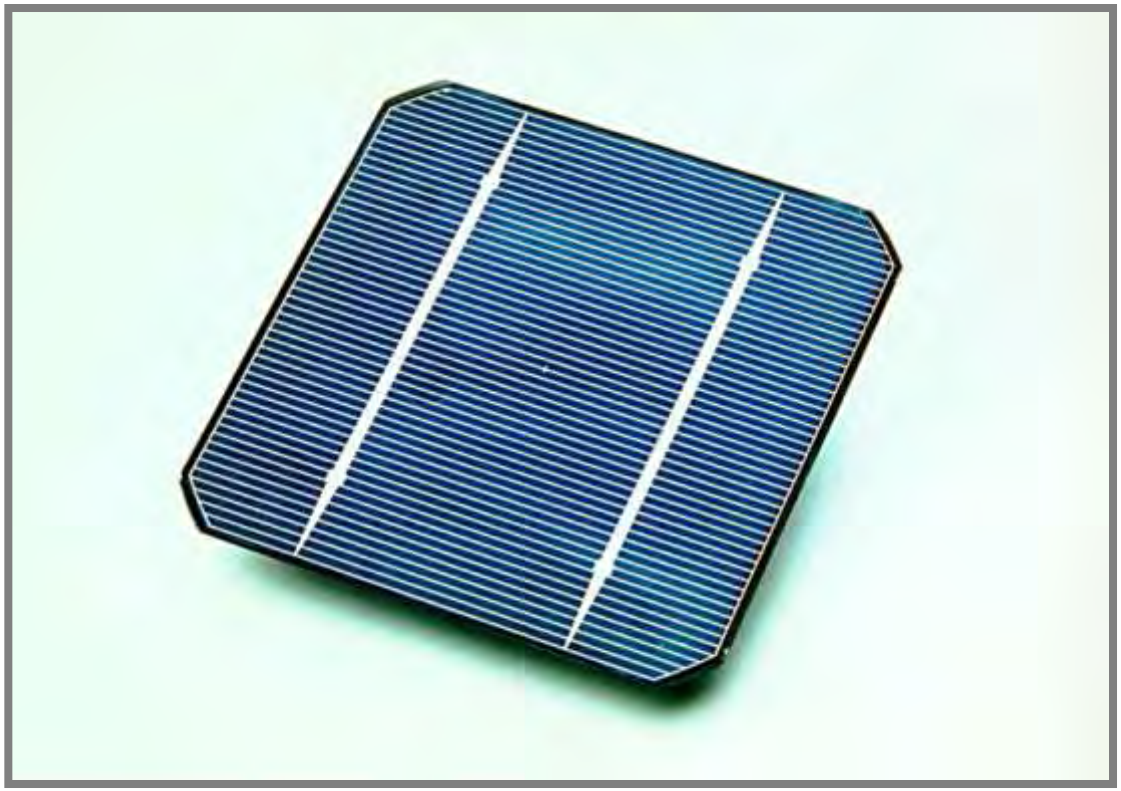
Geothermal Power Opportunities:

Cultural & Environmental Constraints:

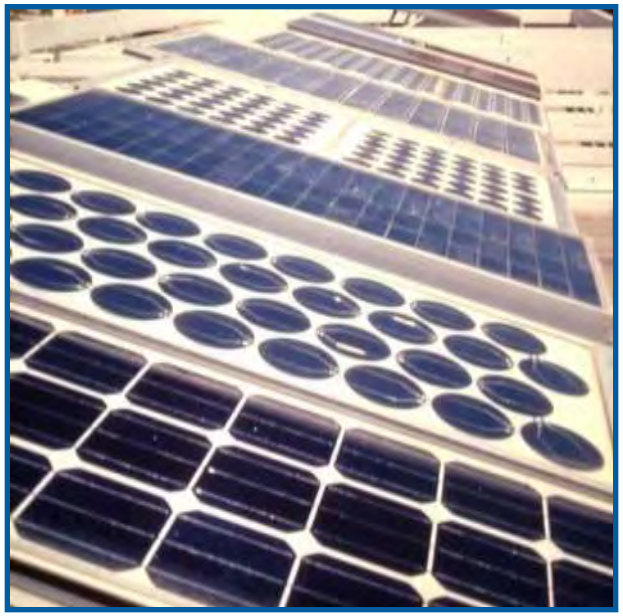
U.S.A.



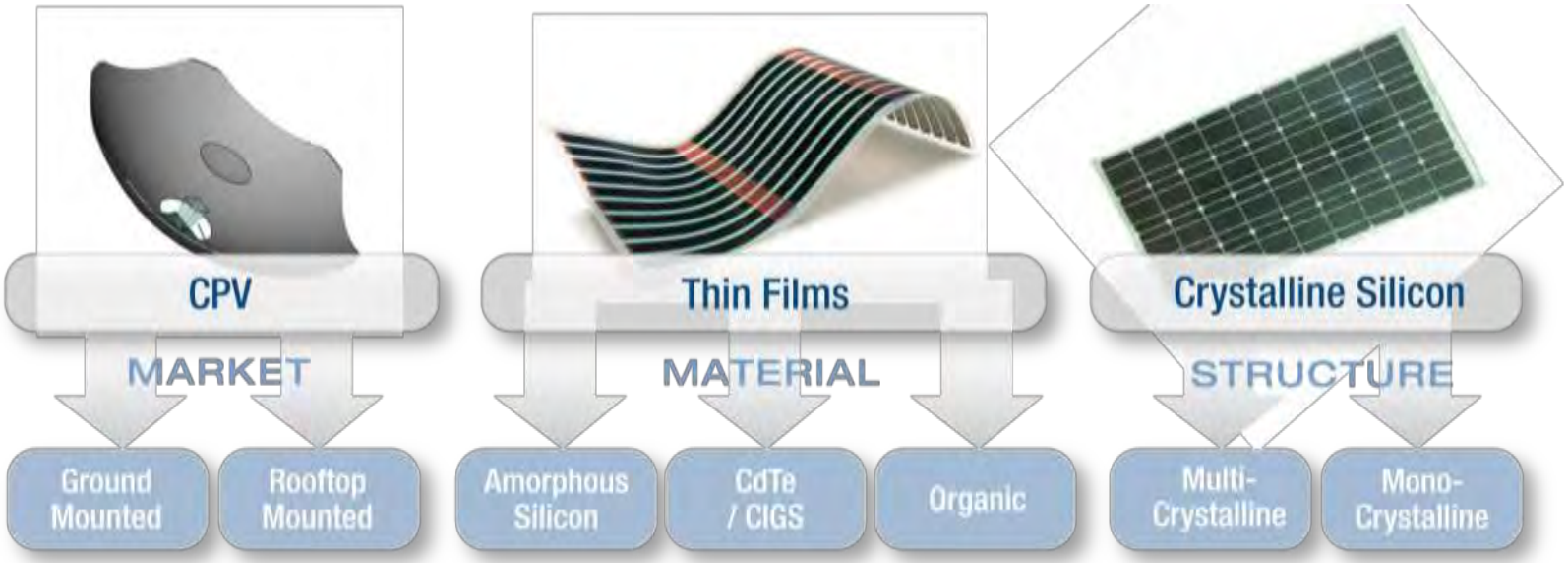
A typical solar cell (10cm x 10cm) generates about 1W at about 0.5V.



Individual cells are connected in series (increases the voltage) and in parallel (increases the current) into a module.

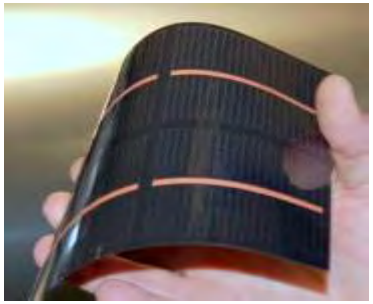


Photovoltaic (PV) technologies



20x-100x

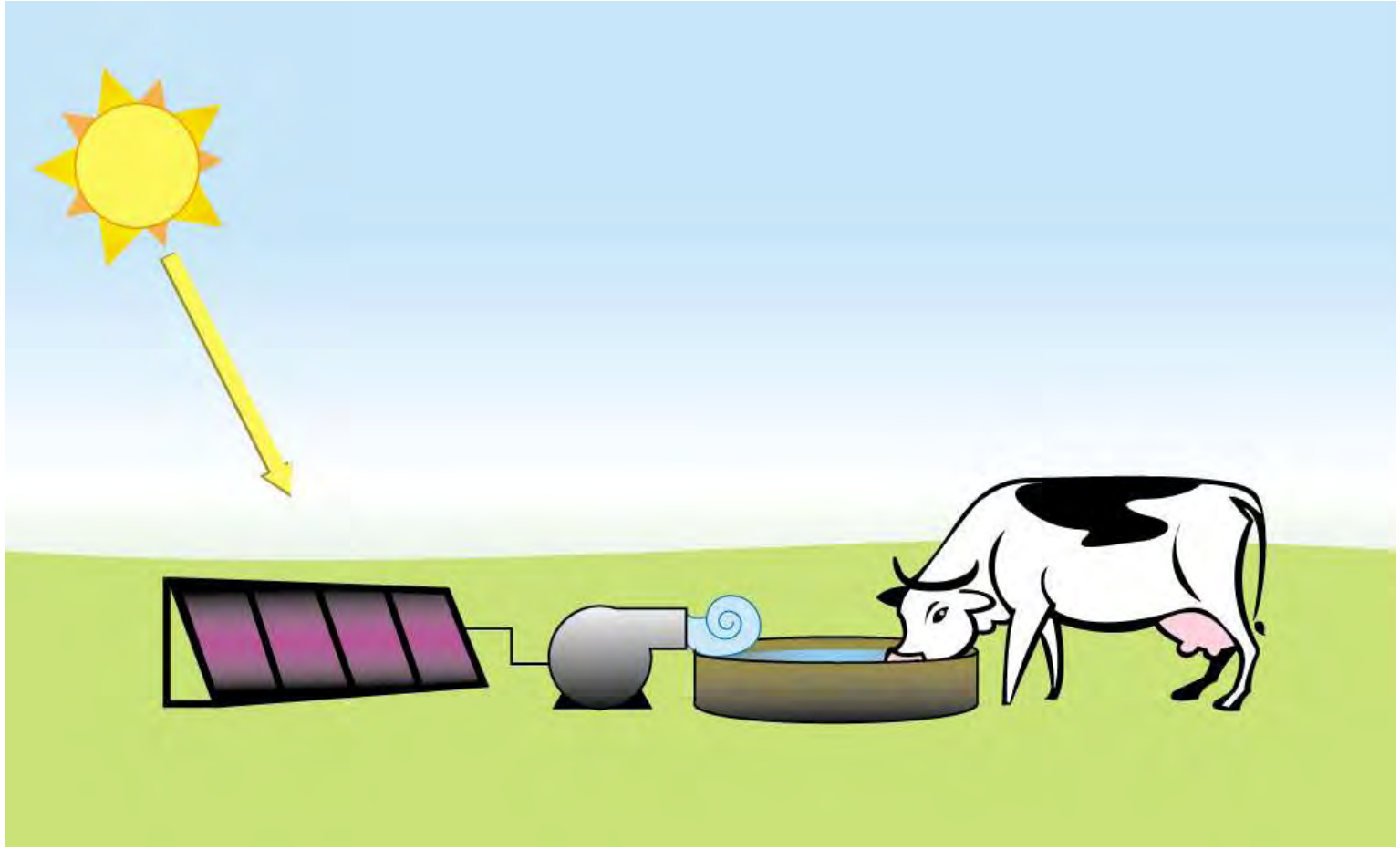
500x



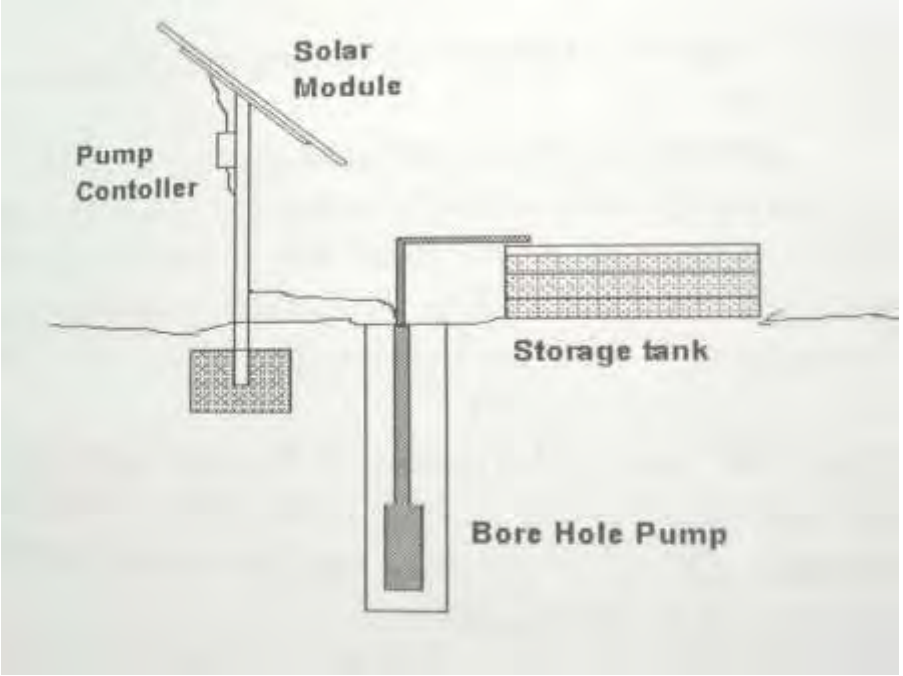
$Cu(In,Ga)Se_2$ ~ 1-2 um

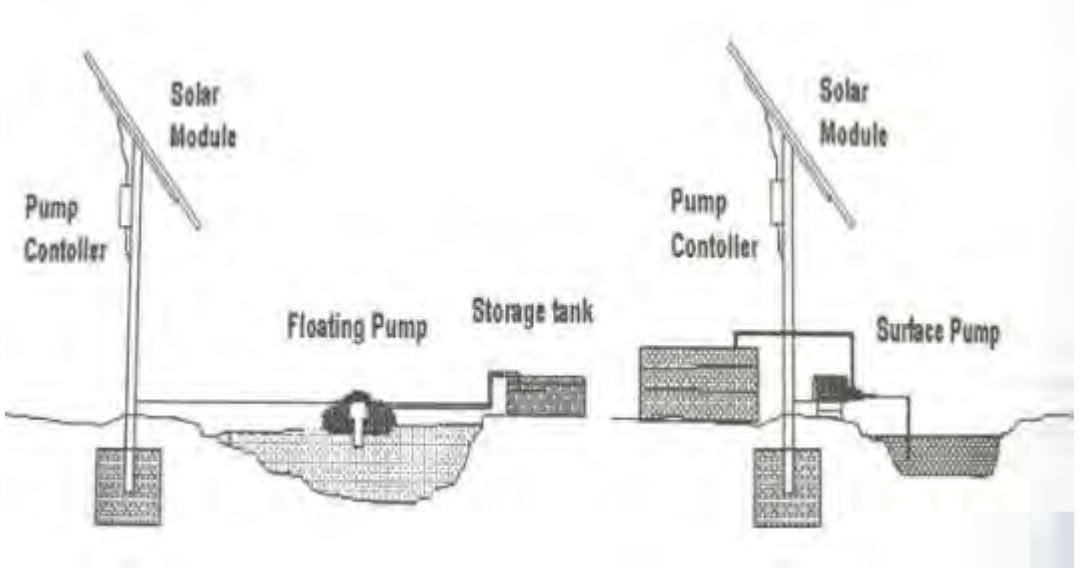
c-Si ~ 180 um

Simple Direct Drive PV System



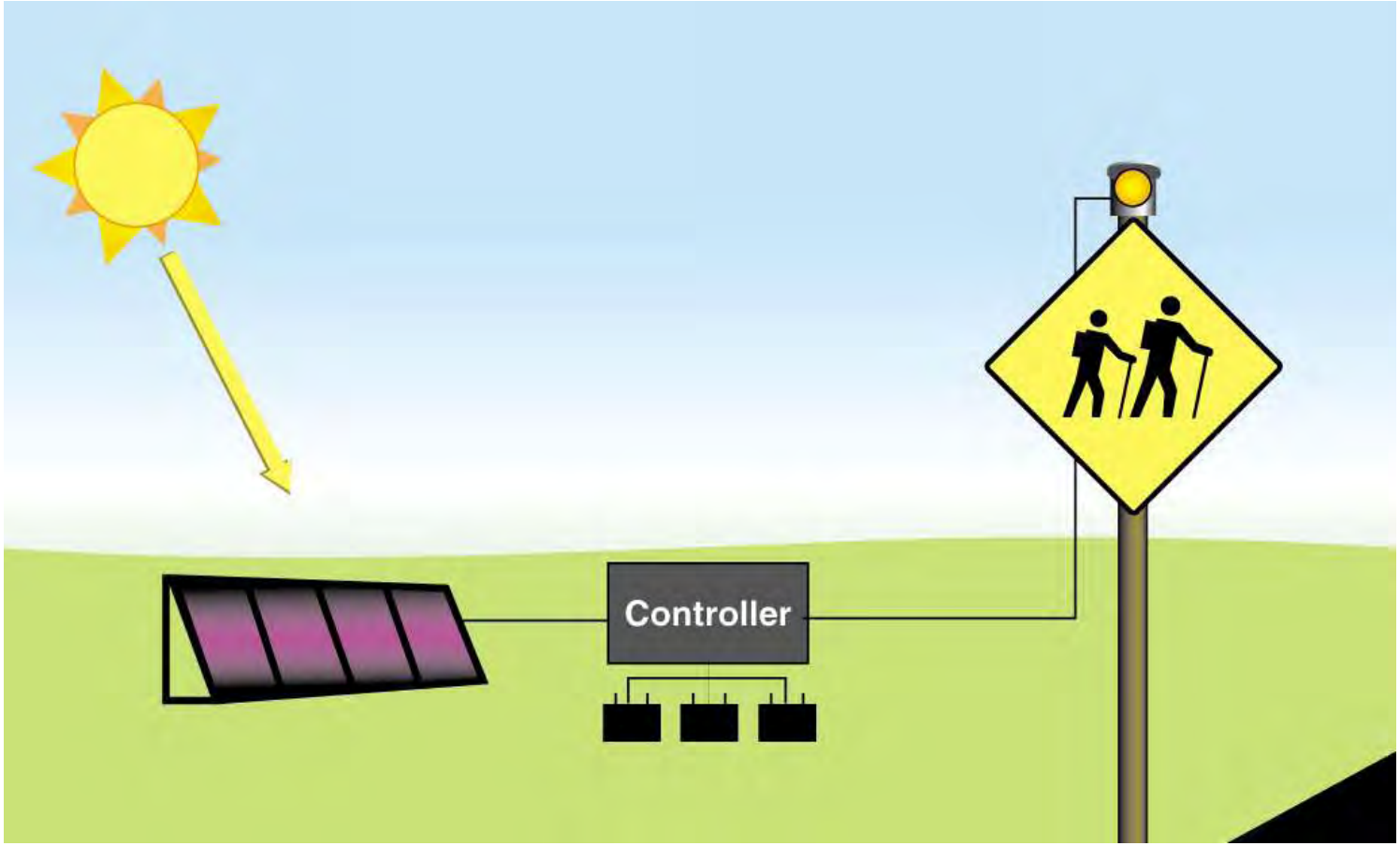
Water Pumping Designs

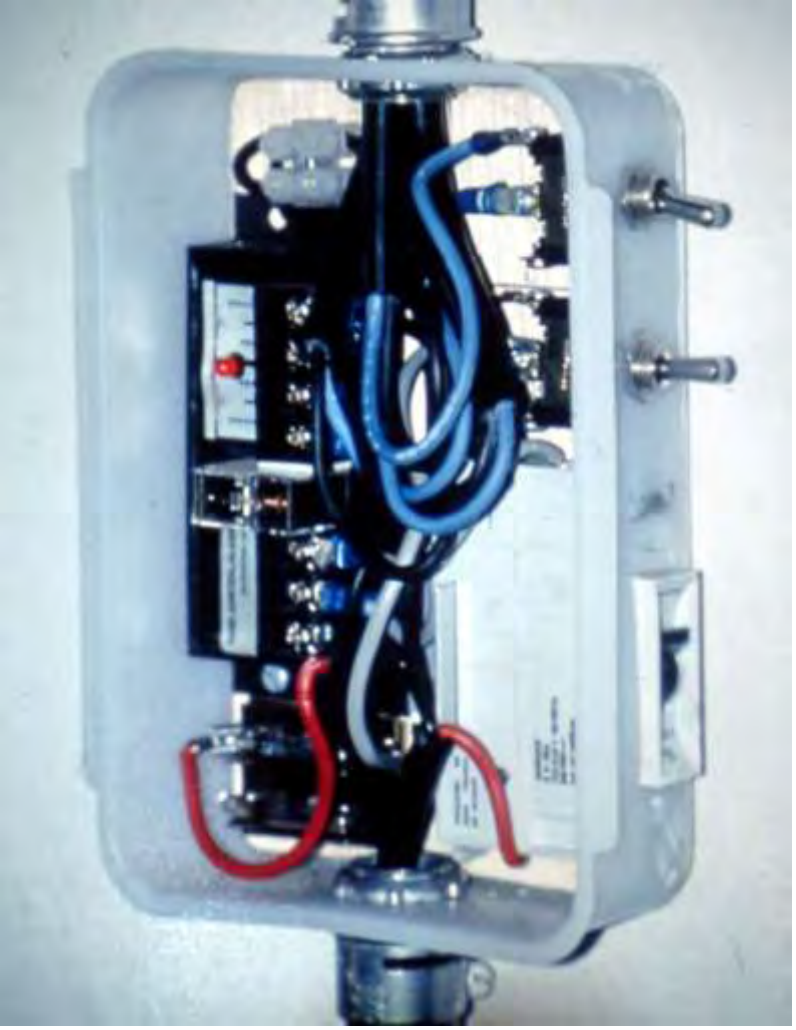




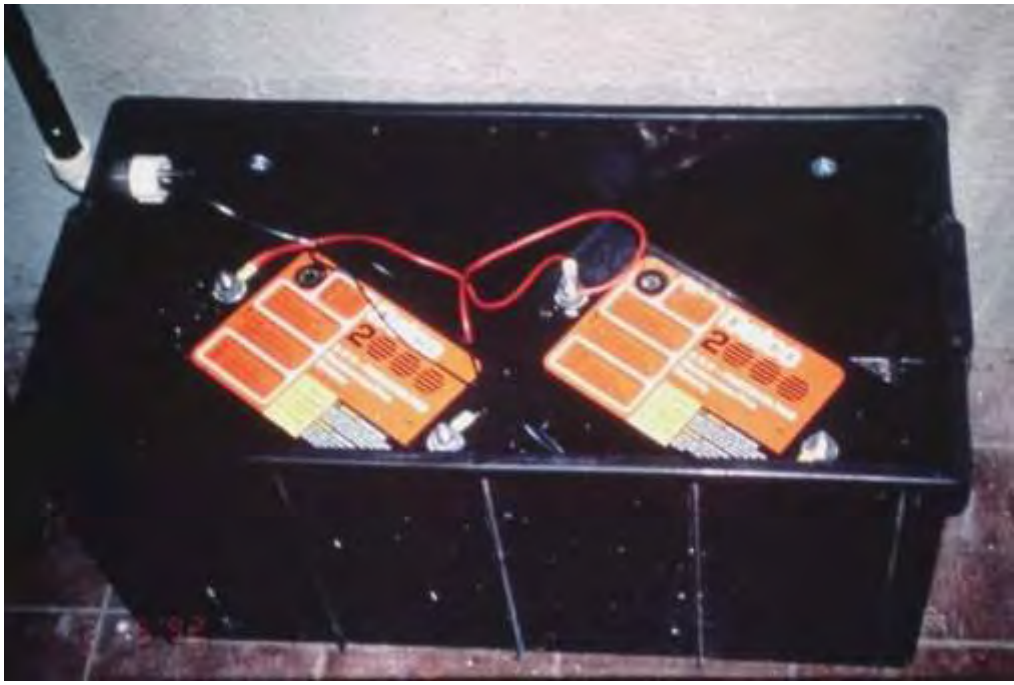
Solar Water Pumping Inadequate Wind & High Maintenance Costs

Simple DC PV System with Battery Storage





Charge Controller protects the Batteries From: Overcharge, Over-Discharge



Energy Storage

- Deep cycle storage batteries are common
- Batteries require a temperature moderated enclosure and maintenance
- Storage size tied to electrical usage
- Technical issues are temperature & temperature
- Most systems with batteries use a charge control device

Typical PV - Battery Systems

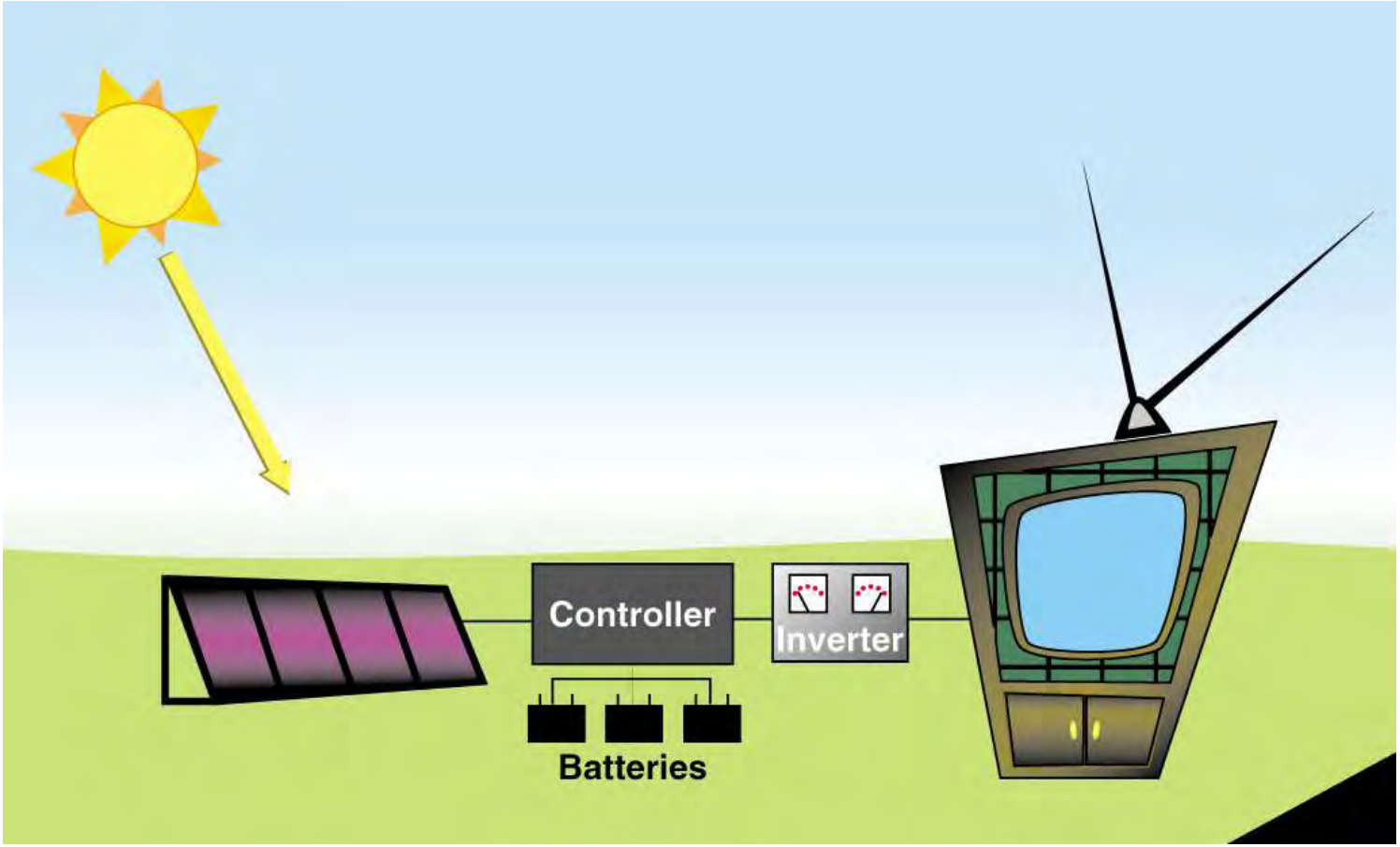
Department of Interior

National Park Service

USDA Forest Service

Military Field Applications

AC PV System with Inverter

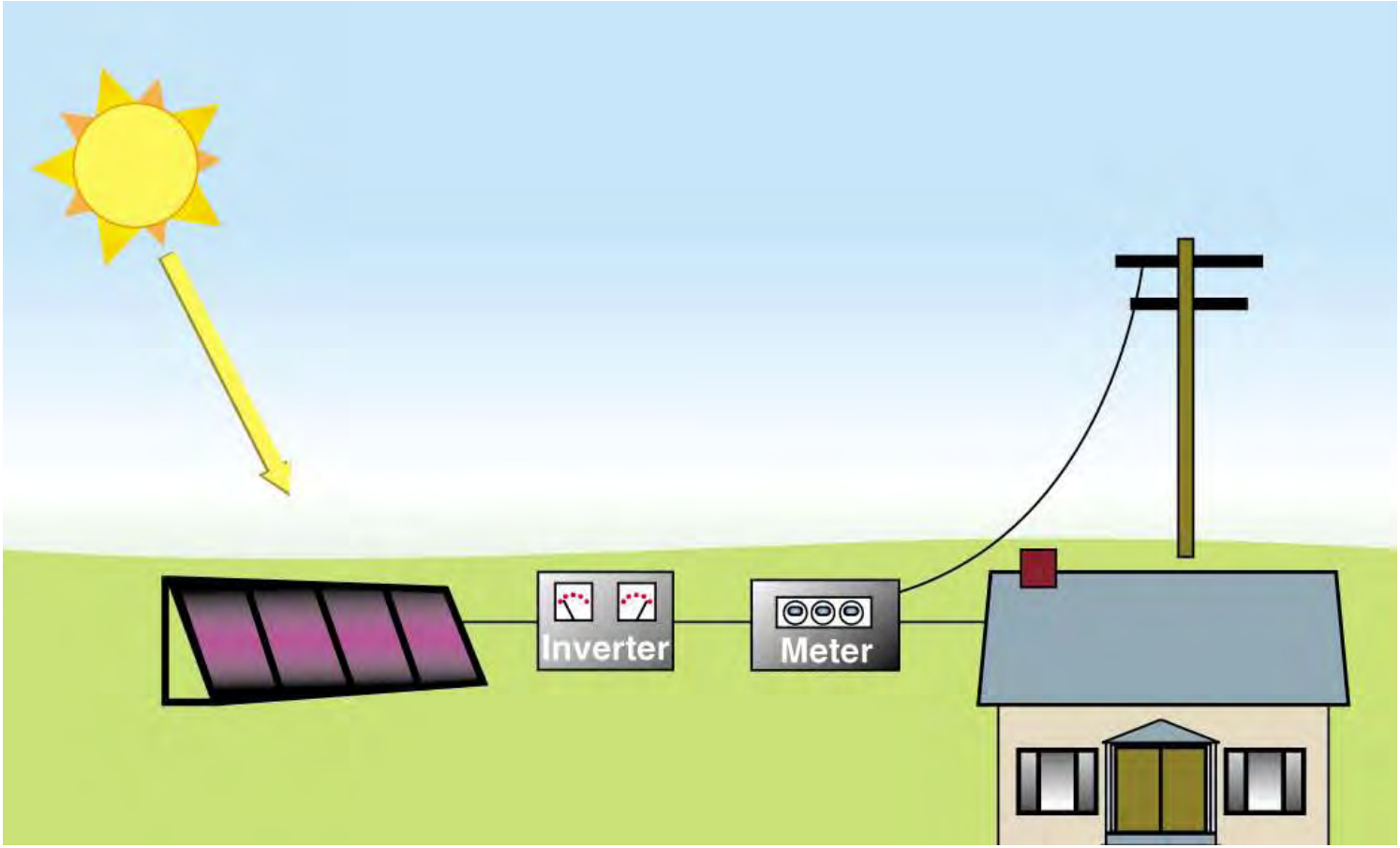


Inverter - 5kW

Converts Direct Current (DC) to Alternating Current (AC)

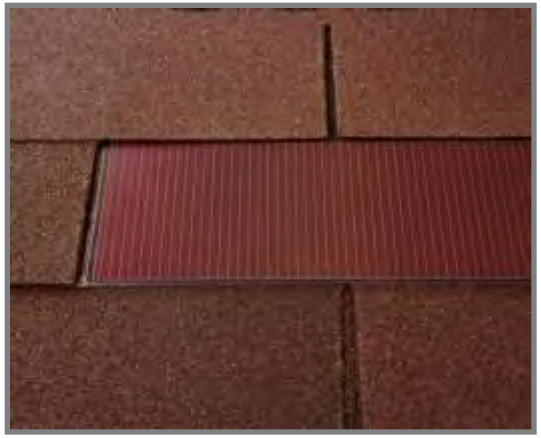
50 kW Inverter

Utility-Connected (Line-Tie PV System)

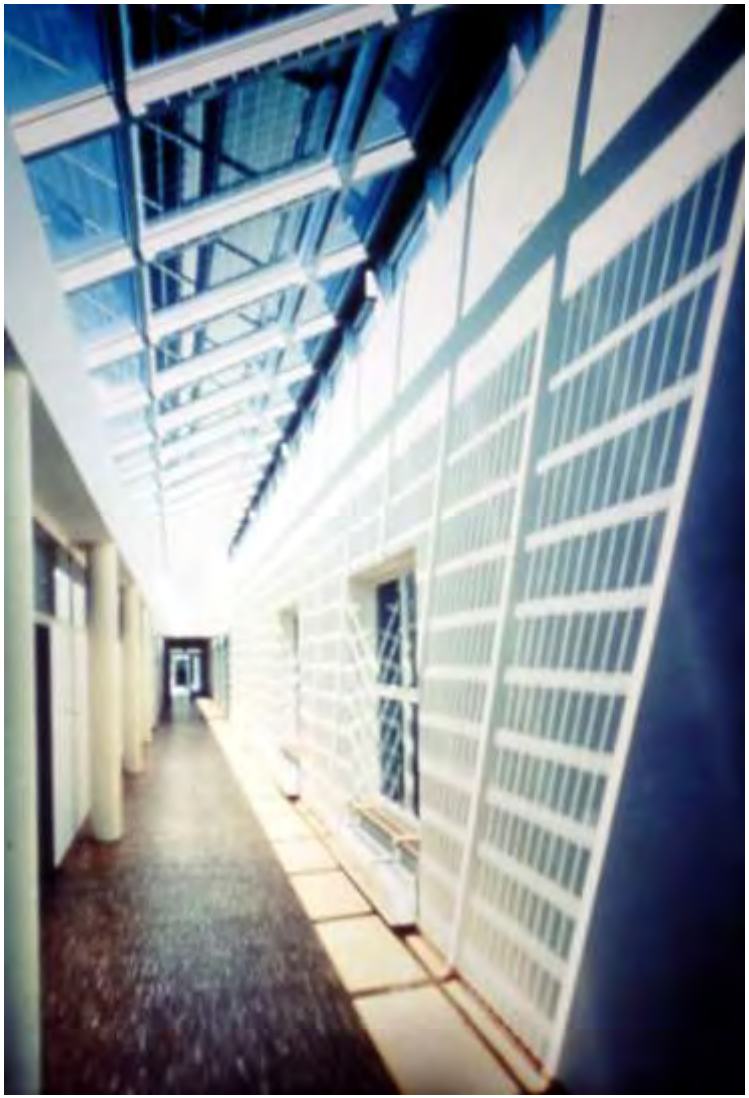


Jicarilla, Apache, NM
2.4 kW Grid Connected
Dulce High School

Building-Integrated PV (BIPV)



Skylights

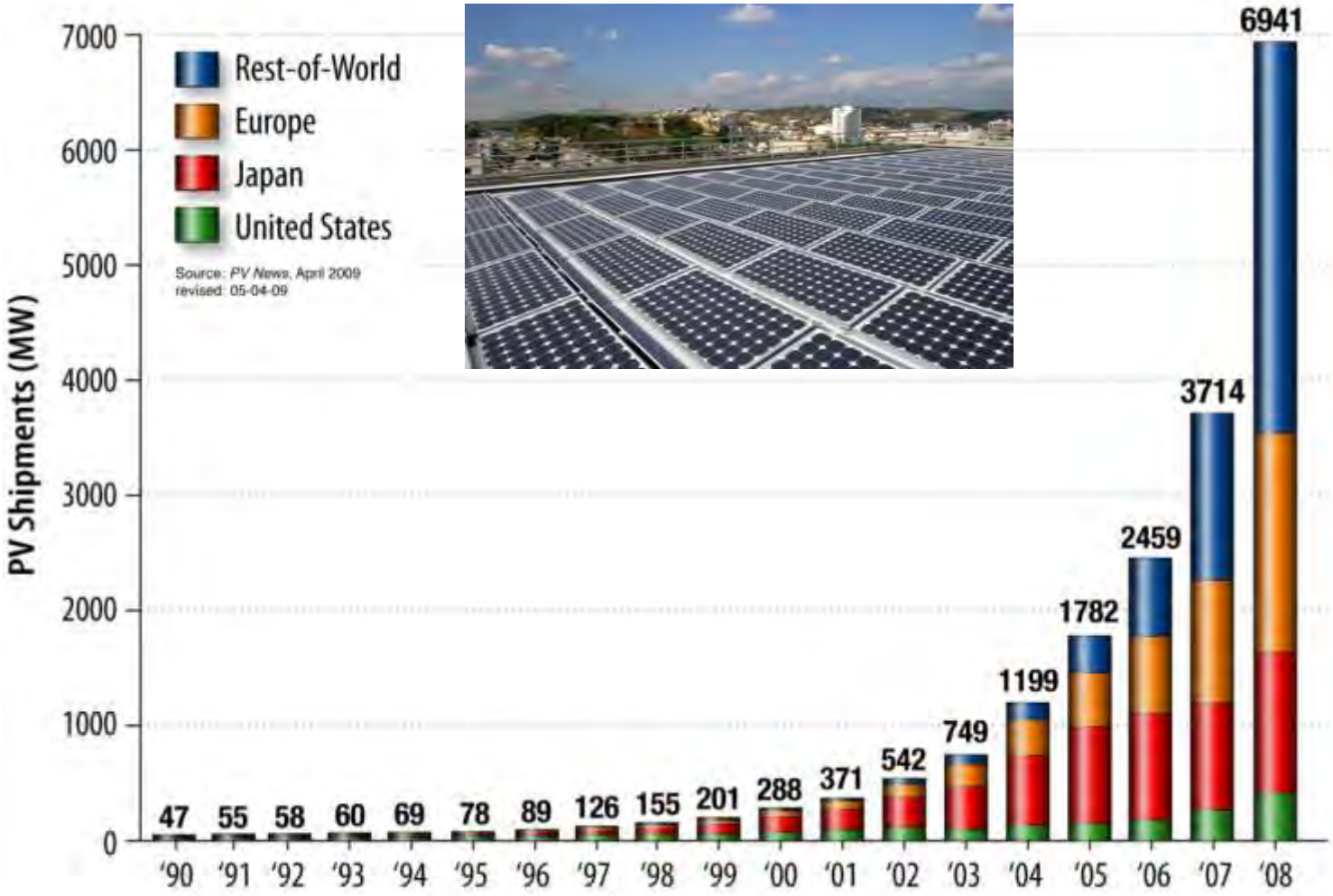


Window Shading

Parking Lot Covers

SunEdison 8MW, San Louis Valley, CO

Growth of Global PV Industry



0.01%-0.1% of electricity now comes from PV - extrapolates to > 5% in 2020

competitive with conventional electricity for 0.1% - 1% of market; more in future

Challenges for Photovoltaics

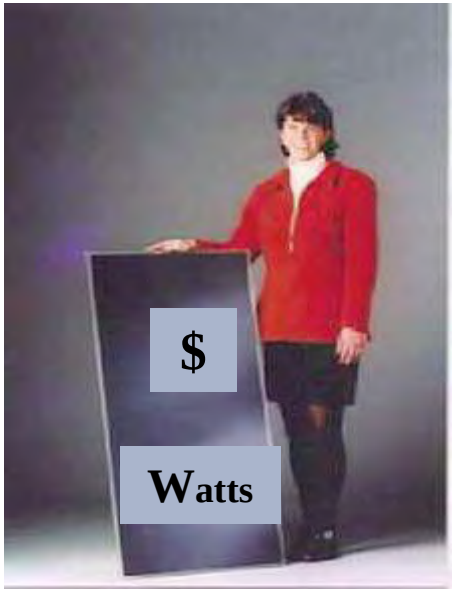
Continue to drive down costs and develop sufficient product diversity to address and maximize all market segments

Ensure adequate supply chain for a large and rapidly growing industry

Continue to provide reliable products with 30 yr lifetimes (both actual and perceived)

Fundamental Targets Leading to U.S. PV Deployment Success

Module



System

Electric Power Source

$ 1/Wp

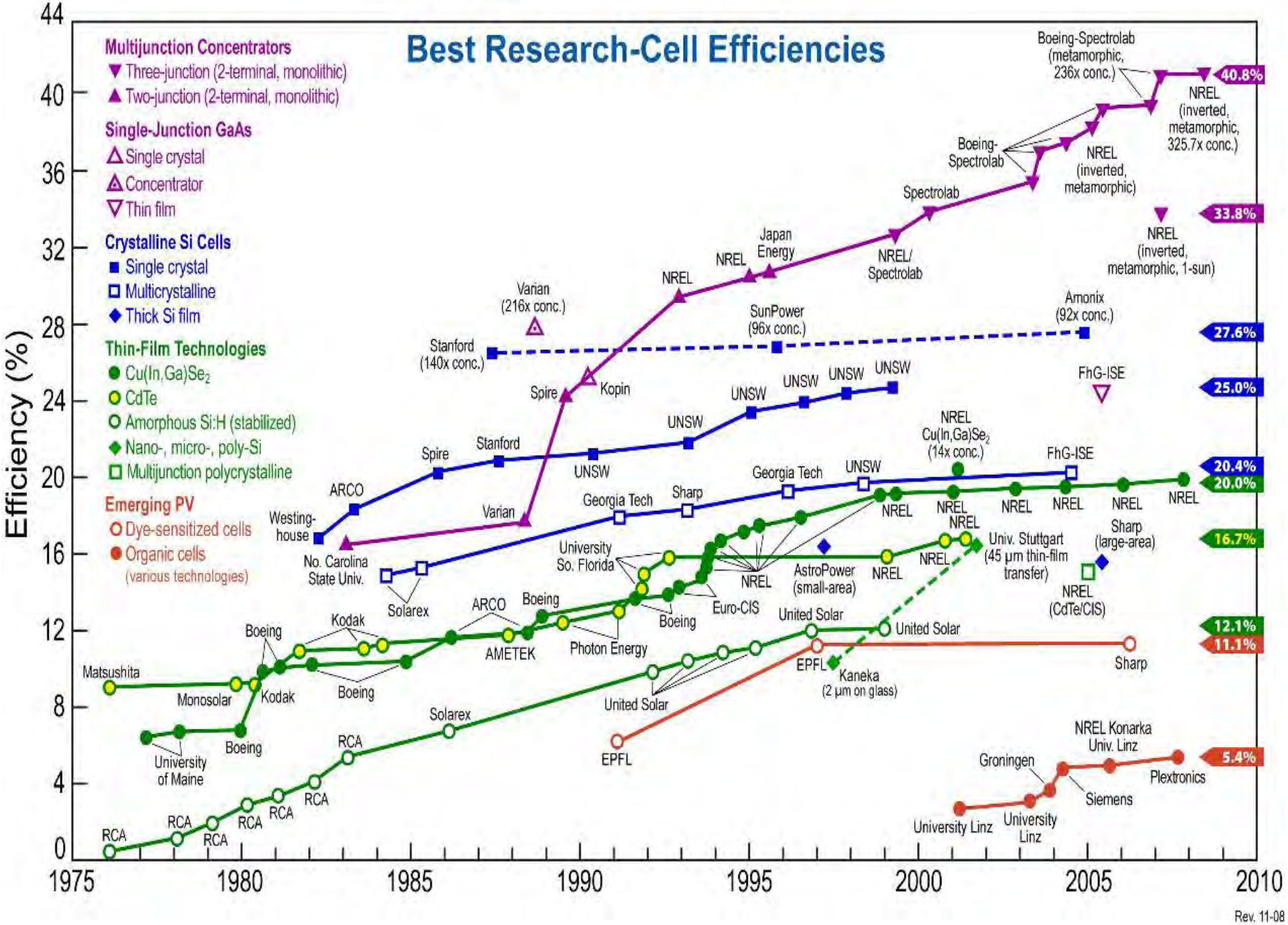
$ 2 to 3/Wp

Manufacturing Scale Up

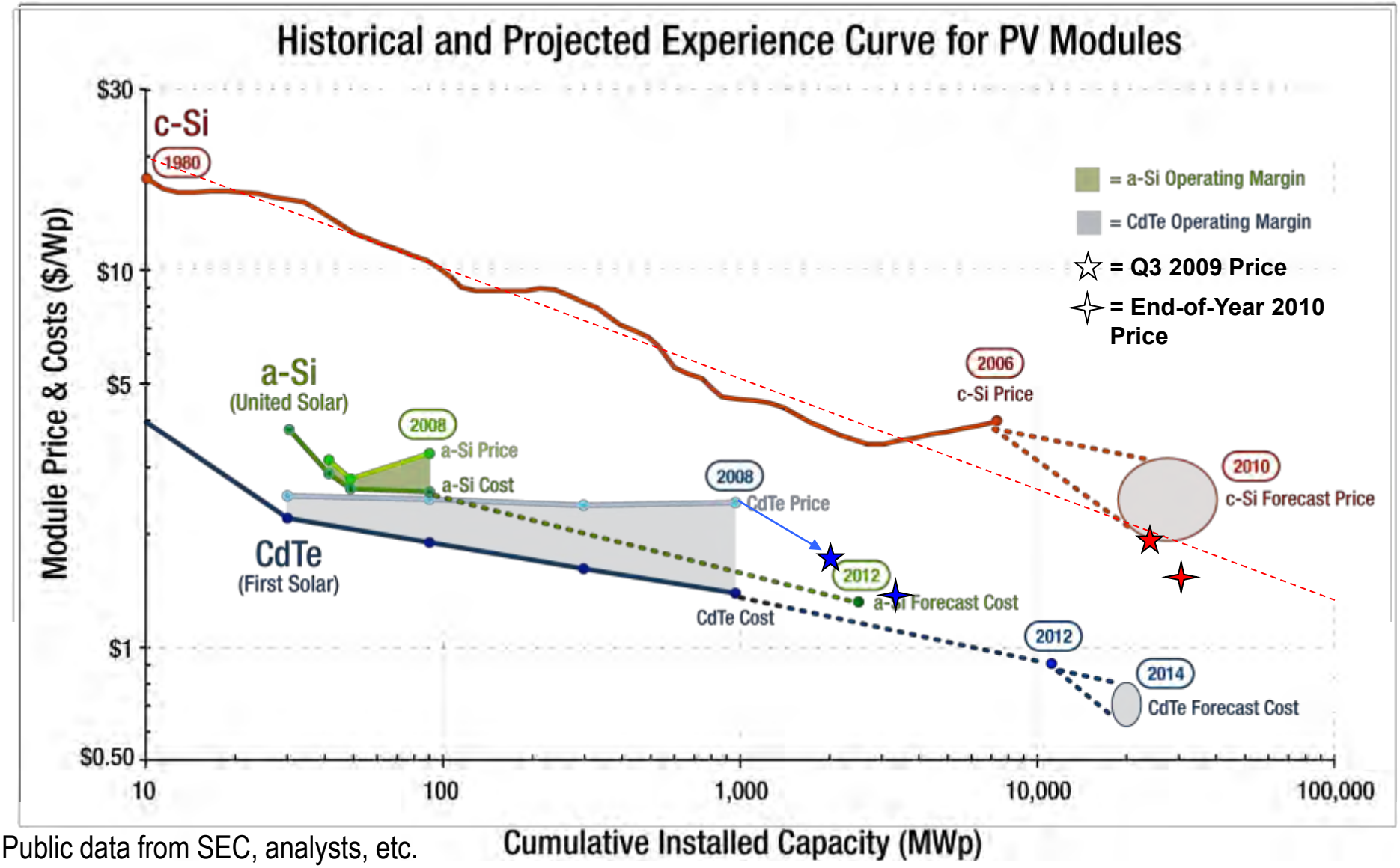
- ❑Supply Chain (gigawatt scale).
- ❑Meeting efficiency & $/m^2 cost targets.
- ❑Maintain Performance/Quality.
- ❑Energy Payback & Environmental .

$cents/kWhr

- ❑System Installation Costs
- ❑Grid Integration
- ❑20 to 30 yr. lifetime/reliability
- ❑1 to 2% Degradation
- ❑ Low Operating Costs


Best Research-Cell Efficiencies
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
Efficiency (%)
Boeing-Spectrolab (metamorphic, 236x conc.)
NREL (inverted, metamorphic, 325.7x conc.)
Boeing-Spectrolab
NREL (inverted, metamorphic)
Spectrolab
NREL (inverted, metamorphic, 1-sun)
NREL/ Spectrolab
Japan Energy
NREL
Varian (216x conc.)
SunPower (96x conc.)
Amonix (92x conc.)
Stanford (140x conc.)
Spire
Kopin
UNSW
FhG-ISE
NREL Cu(In,Ga)Se2 (14x conc.)
Spire
Stanford
ARCO
Westing-house
Varian
Georgia Tech
Sharp
No. Carolina State Univ.
Solarex
University So. Florida
Univ. Stuttgart (45 µm thin-film transfer)
Sharp (large-area)
AstroPower (small-area)
NREL (CdTe/CIS)
Euro-CIS
Boeing
Kodak
ARCO
AMETEK
Photon Energy
United Solar
Matsushita
Monosolar
University of Maine
EPFL
Kaneka (2 µm on glass)
Sharp
RCA
NREL Konarka Univ. Linz
Groningen
Plextronics
Siemens
University Linz
40.8%
33.8%
27.6%
25.0%
20.4%
20.0%
16.7%
12.1%
11.1%
5.4%
Rev. 11-08

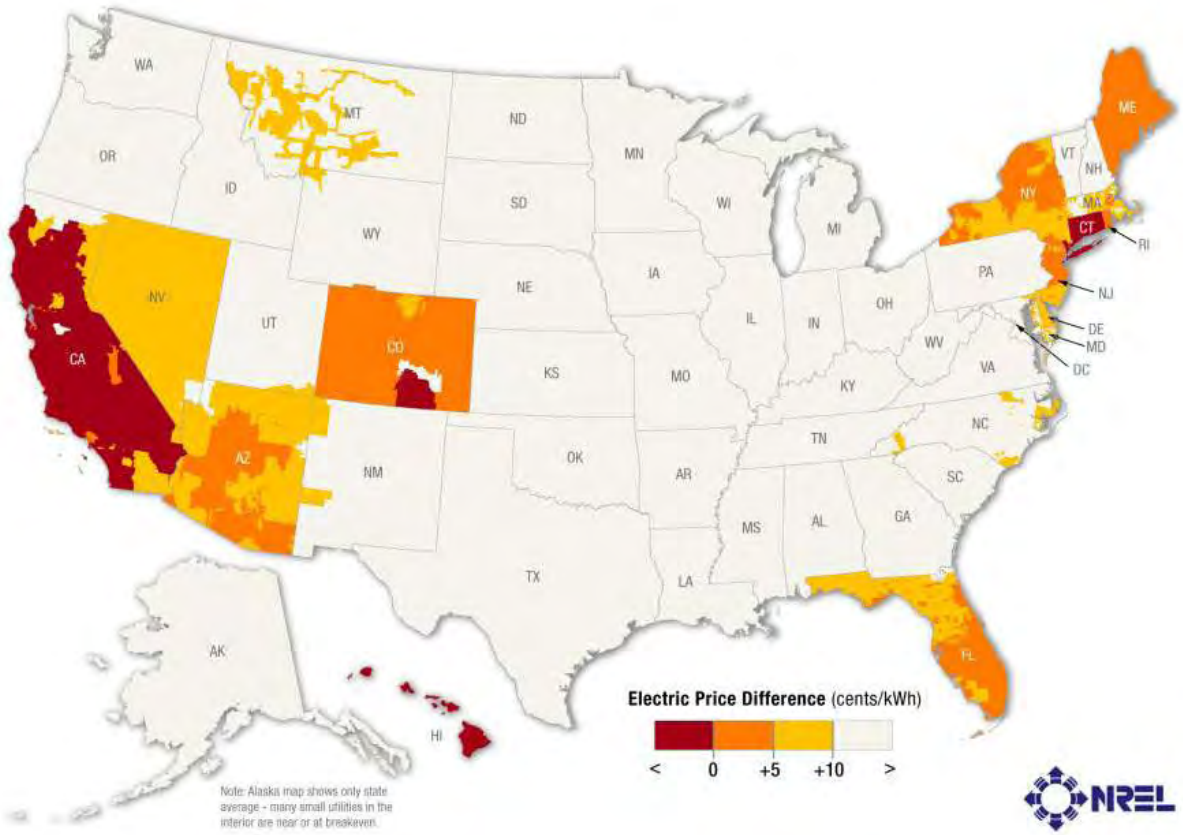
Costs have been dramatically reduced across vastly different technologies



Public data from SEC, analysts, etc.

Market penetration begins - 2007 residential PV and electricity price differences with existing incentives

Currently PV is financially competitive where there is some combination of high electricity prices, excellent irradiance and/or state/local incentives.

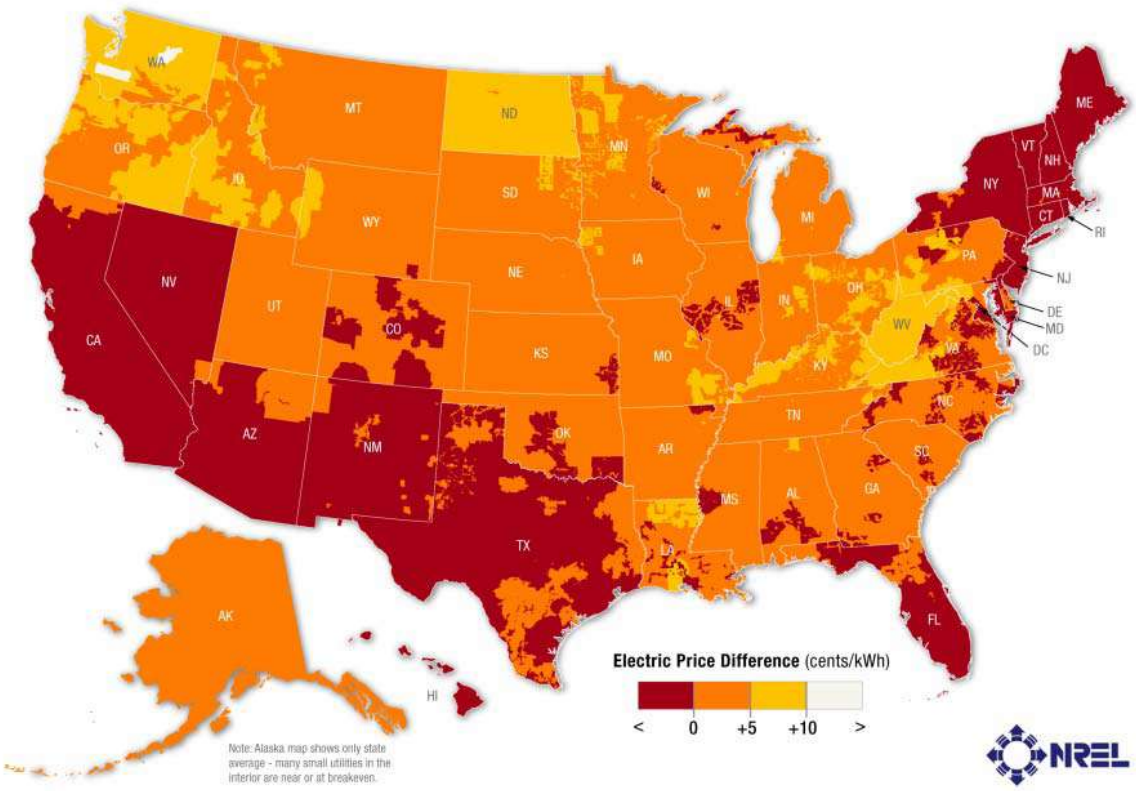


Assumptions: For the price of electricity, the average electricity price for the 1000 largest utilities in the U.S. based on EIA data for 2006 (except CA, where existing tiered rates structures were used). **The installed system price is set at $8.5/Wp** in the current case and is assumed to be financed with a home equity loan (i.e., interest is tax deductible), with a 10% down payment, 6% interest rate, with the owner in the 28% tax bracket, and a 30 year loan/30 year evaluation period. Incentives included are the Federal ITC worth $500/kW due to $2000 cap and individual state incentives as of December 2007.

The conservative forecast - 2015 residential without incentives and moderate (1.5% PA) increase in real electricity prices

PV is less expensive in 250 of 1,000 largest utilities, which provide ~37% of U.S. residential electricity sales

85% of sales (in nearly 870 utilities) are projected to have a price difference of less than 5¢/kWh between PV and grid electricity

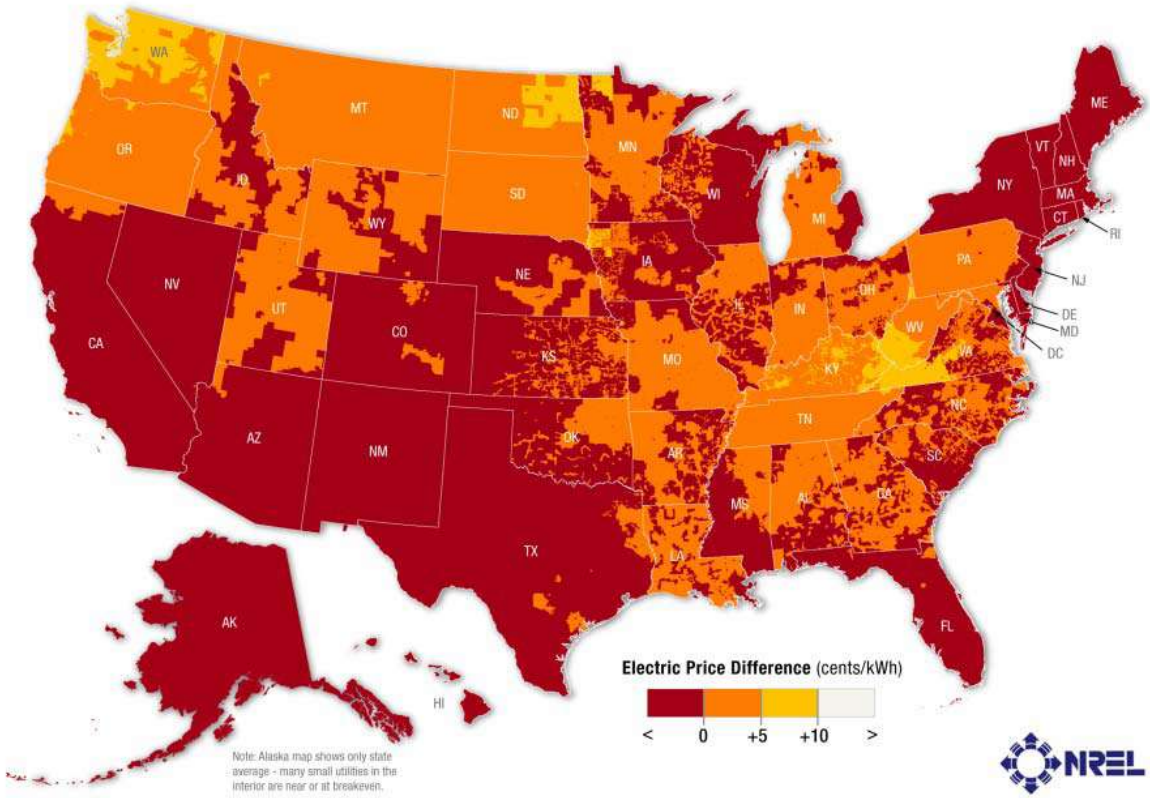


Notes: **The installed system price is set at $3.3/Wp.**

The realistic forecast - 2015 residential installations without incentives and aggressive (2.5% PA) increases in real electricity prices

PV is less expensive in 450 of the 1,000 largest utilities, which provide ~50% of U.S. residential electricity sales

91% of sales (in nearly 950 utilities) have a price difference of less than 5¢/kWh between PV and grid electricity



Notes: **The installed system price is set at $3.3/Wp**.

My Tribal Energy Champion is:

My Green Energy Team Includes:

Tribal Energy Objectives:

Building Weatherization Needs:

Tribal Strategic Energy Planning

Tribal Energy Vision Statement:

Solar Heat Opportunities (Buildings & Hot Water)

Key Tribal Buildings	Annual Energy Use	Energy/sq.ft
Other Key loads:		
# Homes:		
New Loads:		

Solar Electric Opportunities:

The next steps I will take when I get home are:

Wind Power Opportunities:

Biomass Heat Opportunities:

Geothermal Heat Opportunities:

Current Energy Suppliers:

Electricity:

Gas/Propane:

Hydropower Opportunities:

Biomass Power Opportunities:

Geothermal Power Opportunities:

Cultural & Environmental Constraints: