Photovoltaics

Definition

Photovoltaic (or PV) systems convert light energy into electricity. The term "photo" is a stem from the Greek "phos," which means “light”.

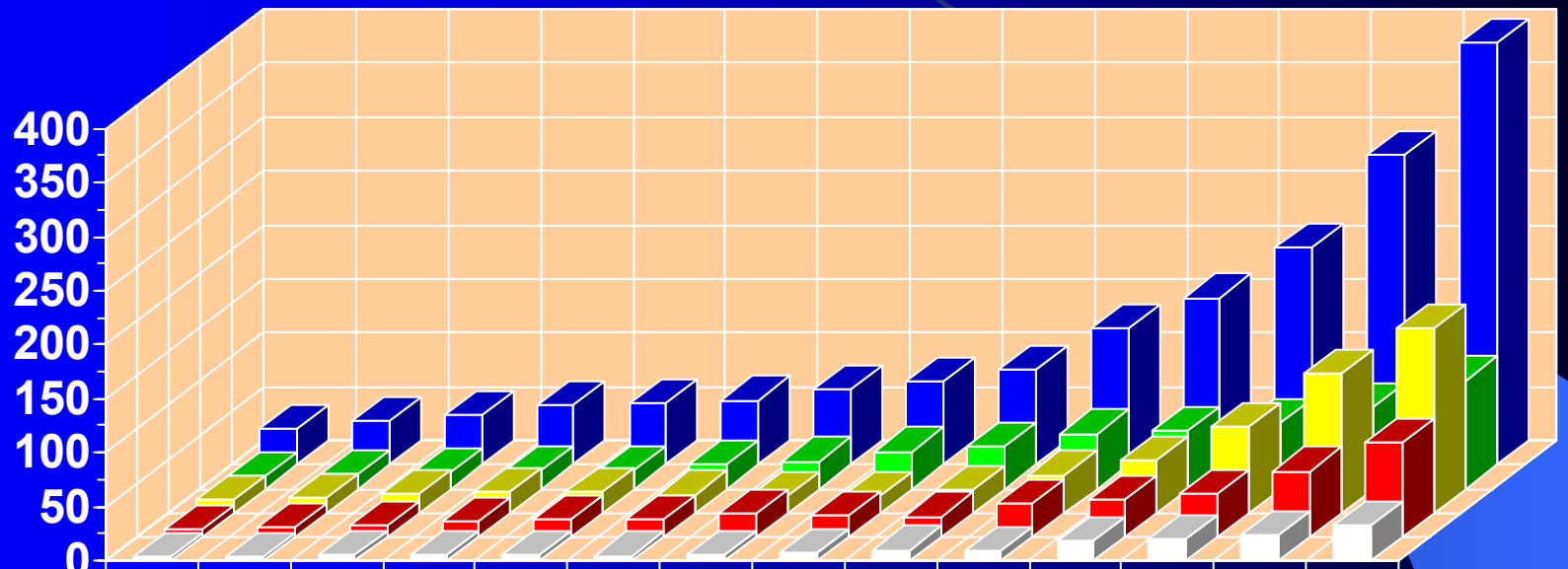
"Volt" is named for Alessandro Volta (1745-1827), a pioneer in the study of electricity.

"Photo-voltaics," then, could literally mean "light-electricity."

Topics To Be Covered

- PV System Components
  - Types
  - Configurations
  - Design Considerations
- Materials
- Applications
- The Business Case

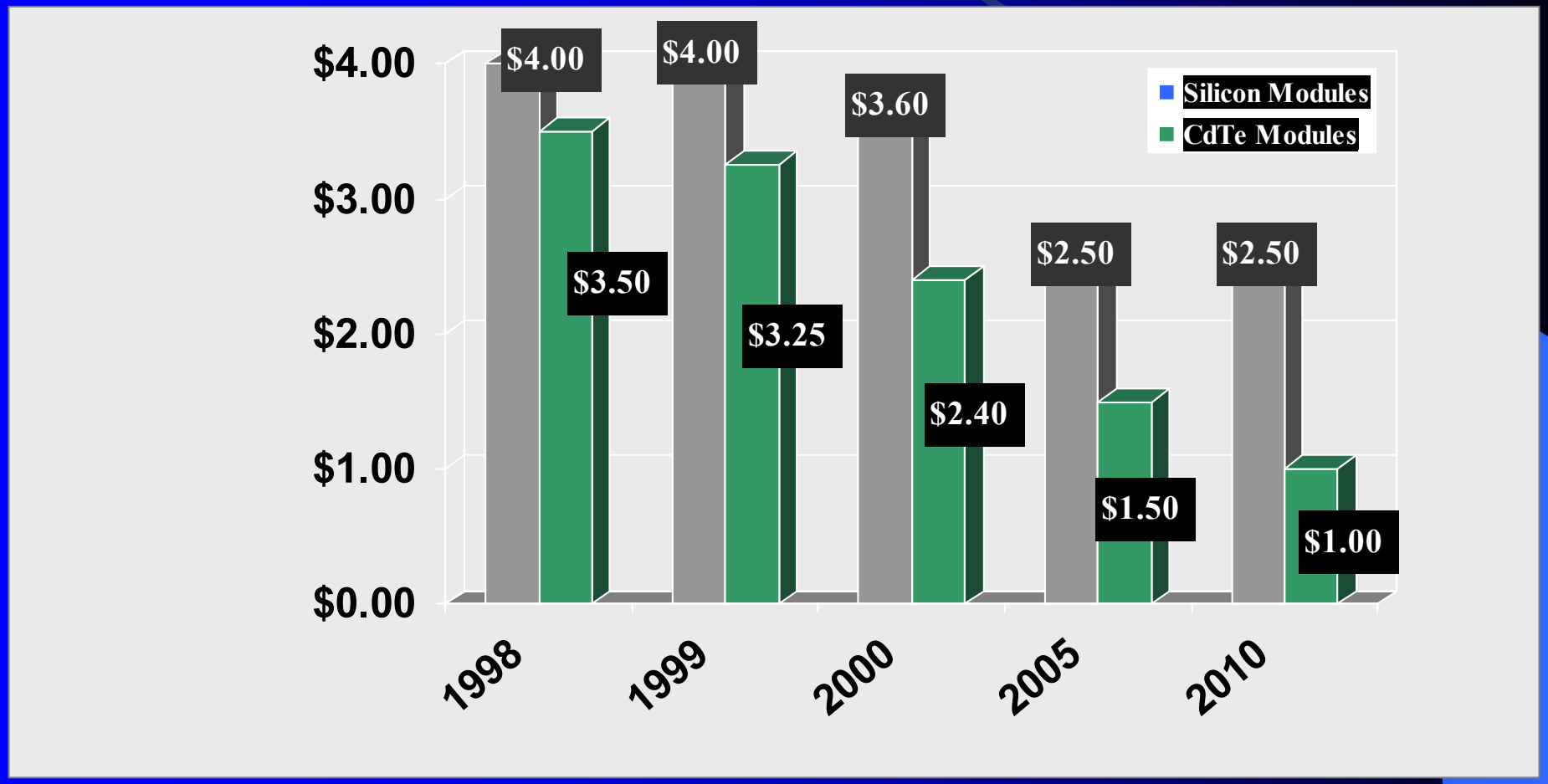
World PV Cell/Module Production (1988-2001) (in Megawatts)

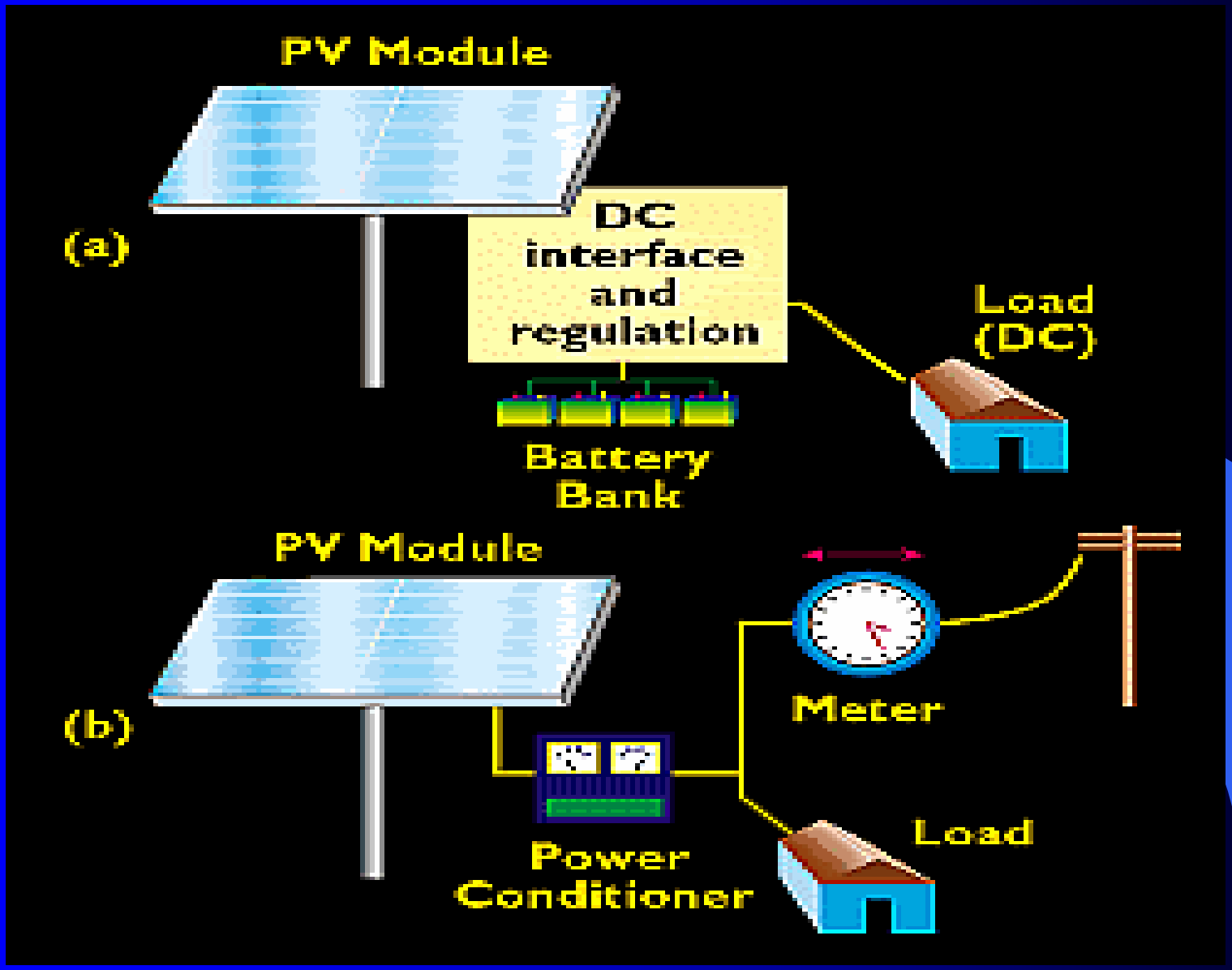


	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Rest of World	3	4	4.7	5	4.6	4.4	5.6	6.35	9.75	9.4	18.7	20.5	23.42	32.6
Europe	6.7	7.9	10.2	13.4	16.4	16.55	21.7	20.1	18.8	30.4	33.5	40	60.66	86.38
Japan	12.8	14.2	16.8	19.9	18.8	16.7	16.5	16.4	21.2	35	49	80	128.6	171.22
United States	11.1	14.1	14.8	17.1	18.1	22.44	25.64	34.75	38.85	51	53.7	60.8	74.97	100.3
Total	33.6	40.2	46.5	55.4	57.9	60.09	69.44	77.6	88.6	125.8	154.9	201.3	287.65	390.5

From PV News, Paul Maycock, editor; yearly February editions.

Cost Comparison
Silicon vs Thin Film



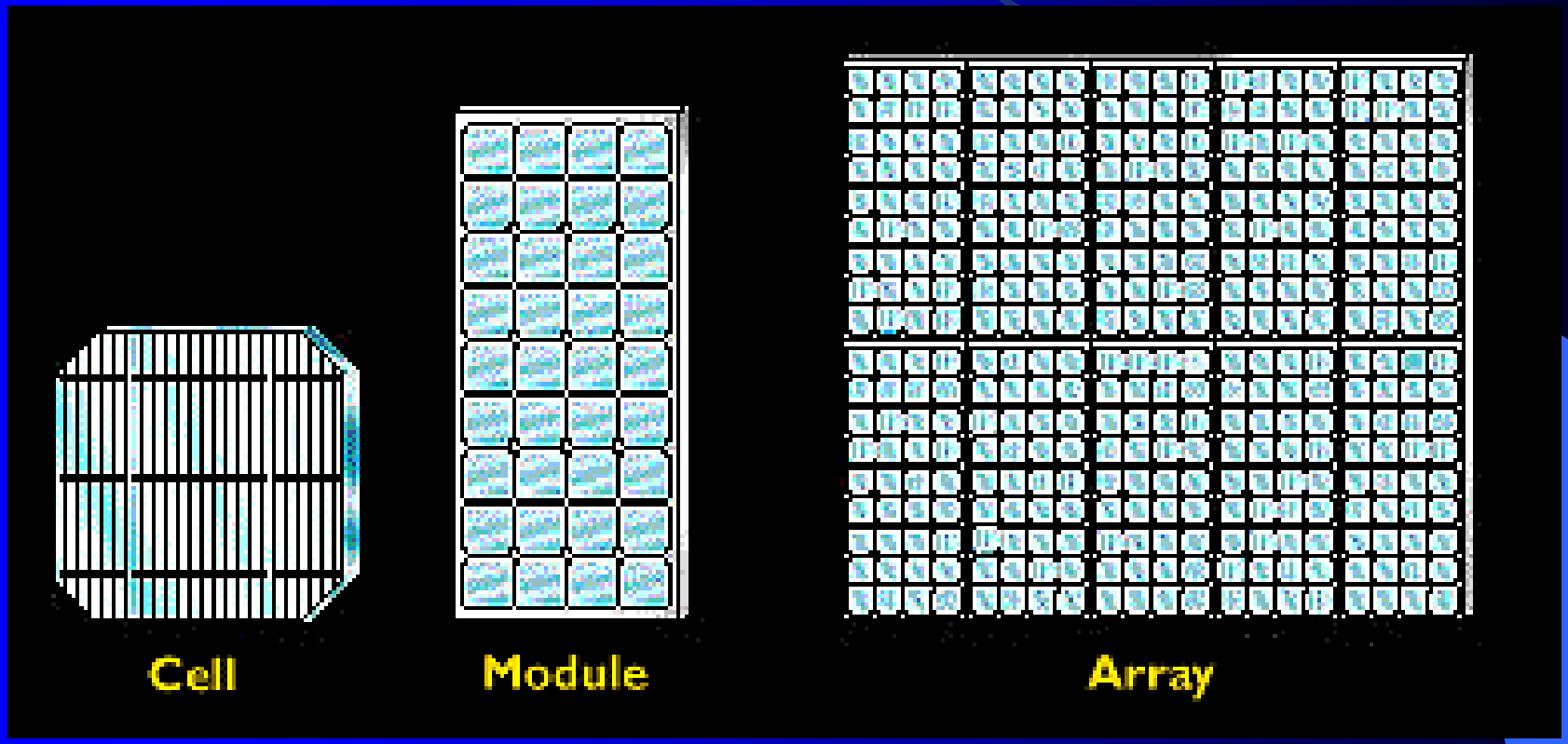

PV Module
(a)
DC interface and regulation
Load (DC)
Battery Bank
PV Module
(b)
Meter
Power Conditioner
Load

Components

The PV cell is the basic unit in a PV system

An individual PV cell typically produces between 1 and 2 watts

Components



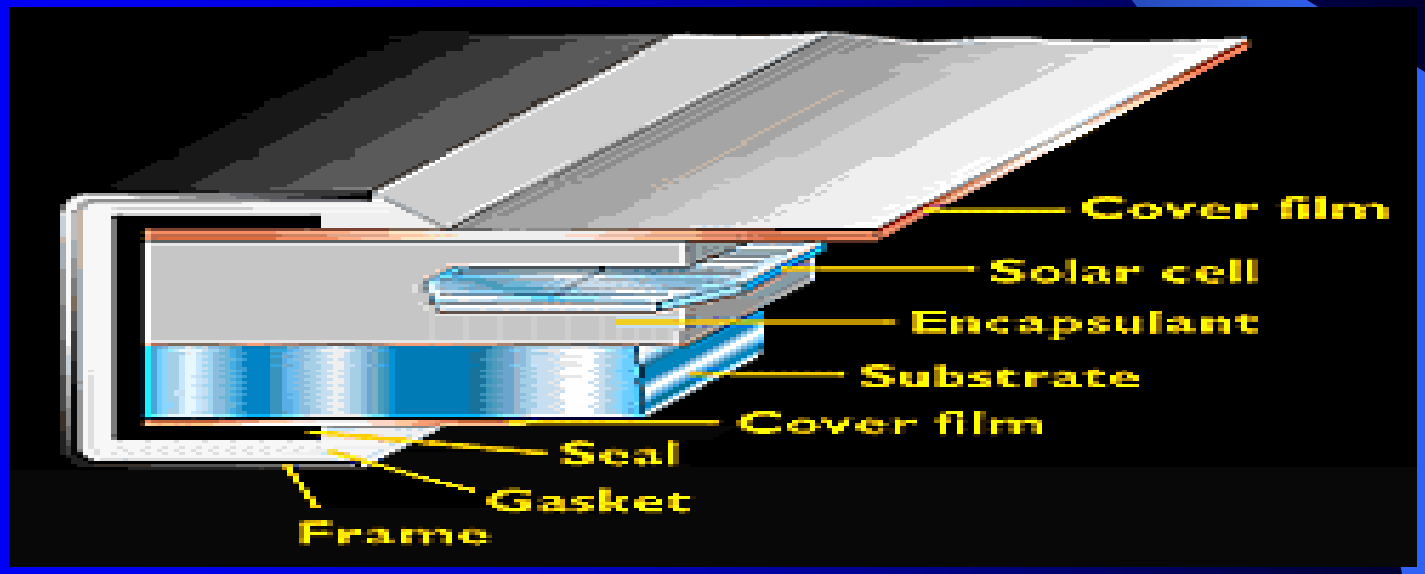
Components
Balance of System

Cells, Modules or arrays, by themselves, do not constitute a PV system. Also needed are the balance of system (BOS) components which include

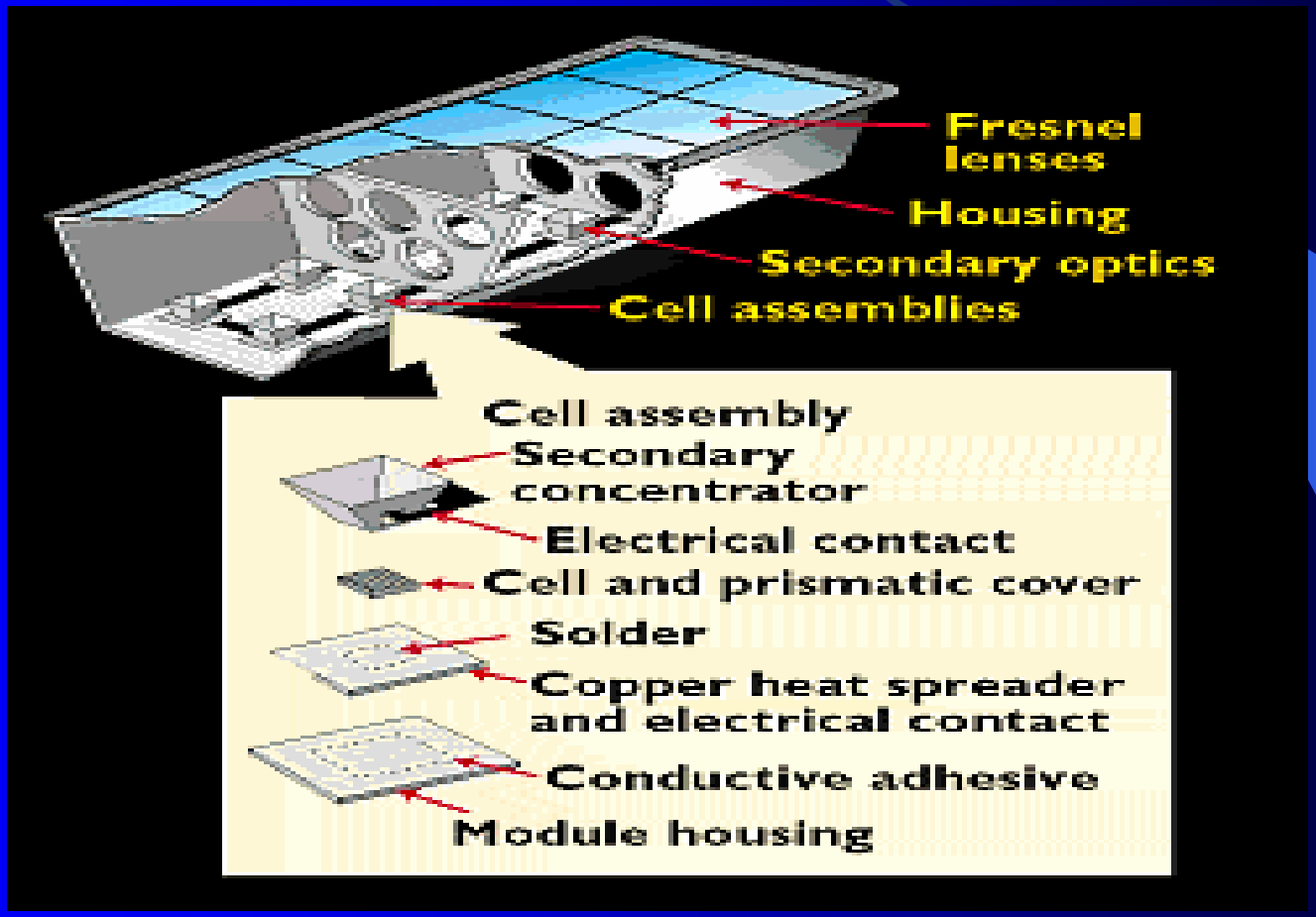
- Mounting structures on which to mount and orient them to the sun
- Conversion of AC to DC

System Types
Flat Plate Collectors

Typical modules have a substrate, encapsulant and a transparent cover.



System Types
Concentrator



System Types - Advantages

Flat-plate –

- They are simpler to design and fabricate.
- Use all the sunlight that strikes them

Concentrator

- Decreases the area needed
- Uses relatively inexpensive materials (plastic lenses and metal housing)

Design - Irradiance

- The amount of solar power striking a surface
- Measured in watts per sq meter
- Clear sunny day = 1000 watts per sq meter

Design - PV Power Ratings

- Maximum power (measured at STC)
- 1000 w/sq m irradiance
- 25 deg. C

NREL's Solar Energy Research Facility (SERF)

Design - Insolation

- The amount of solar energy striking a surface
- Typically measured in kWh per sq meter per day

True Or False?

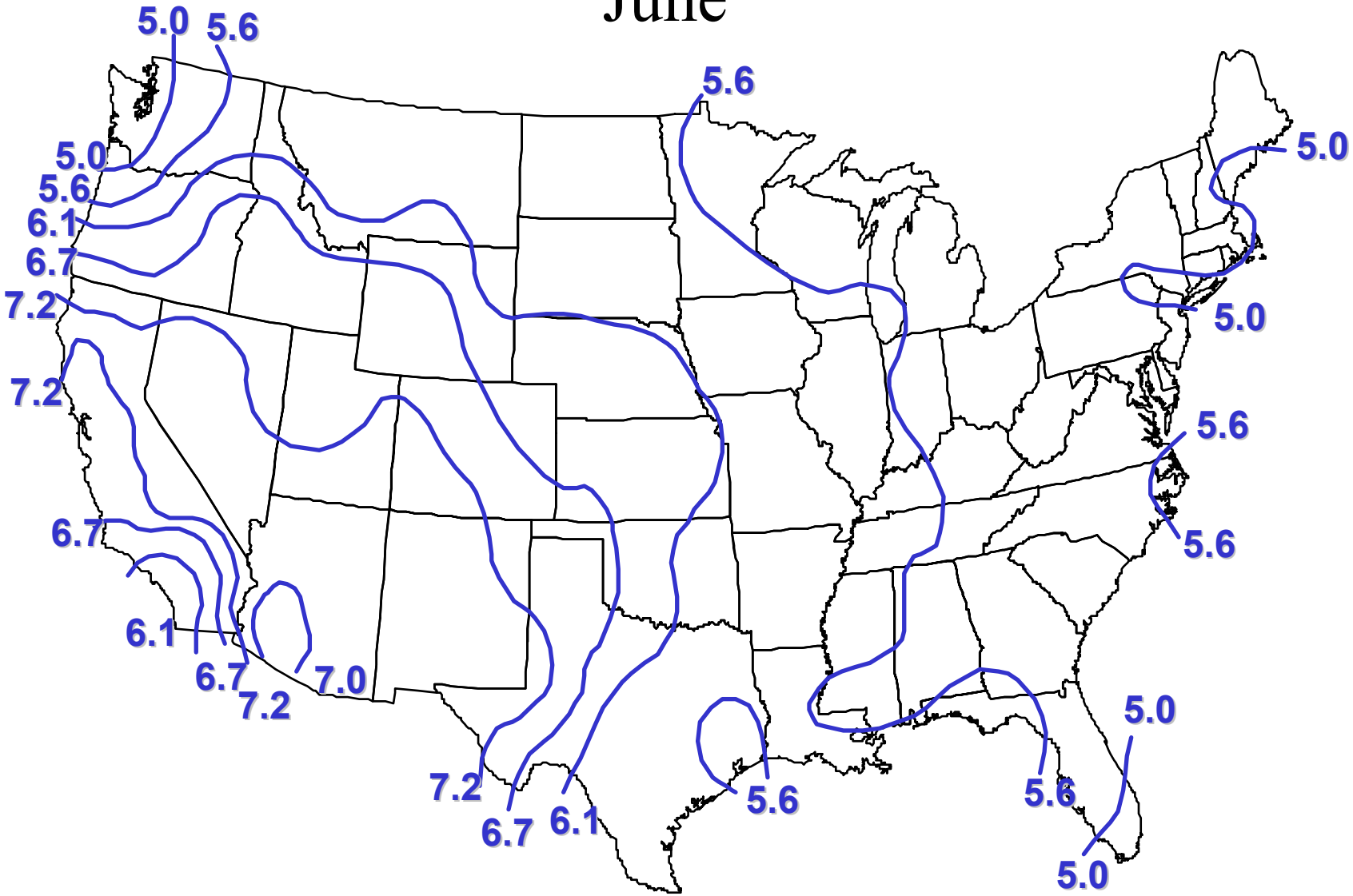
Eugene, OR gets more insolation than Miami, FL

Insolation kWh/sq m/day

	June 21	Dec 21
• Anaheim, CA	6.1	4.0
• Boston, MA	5.0	2.2
• Denver, CO	6.7	4.4
• Eugene, OR	6.1	1.7
• Miami, FL	5.0	3.9
• San Jose, CA	7.0	3.3

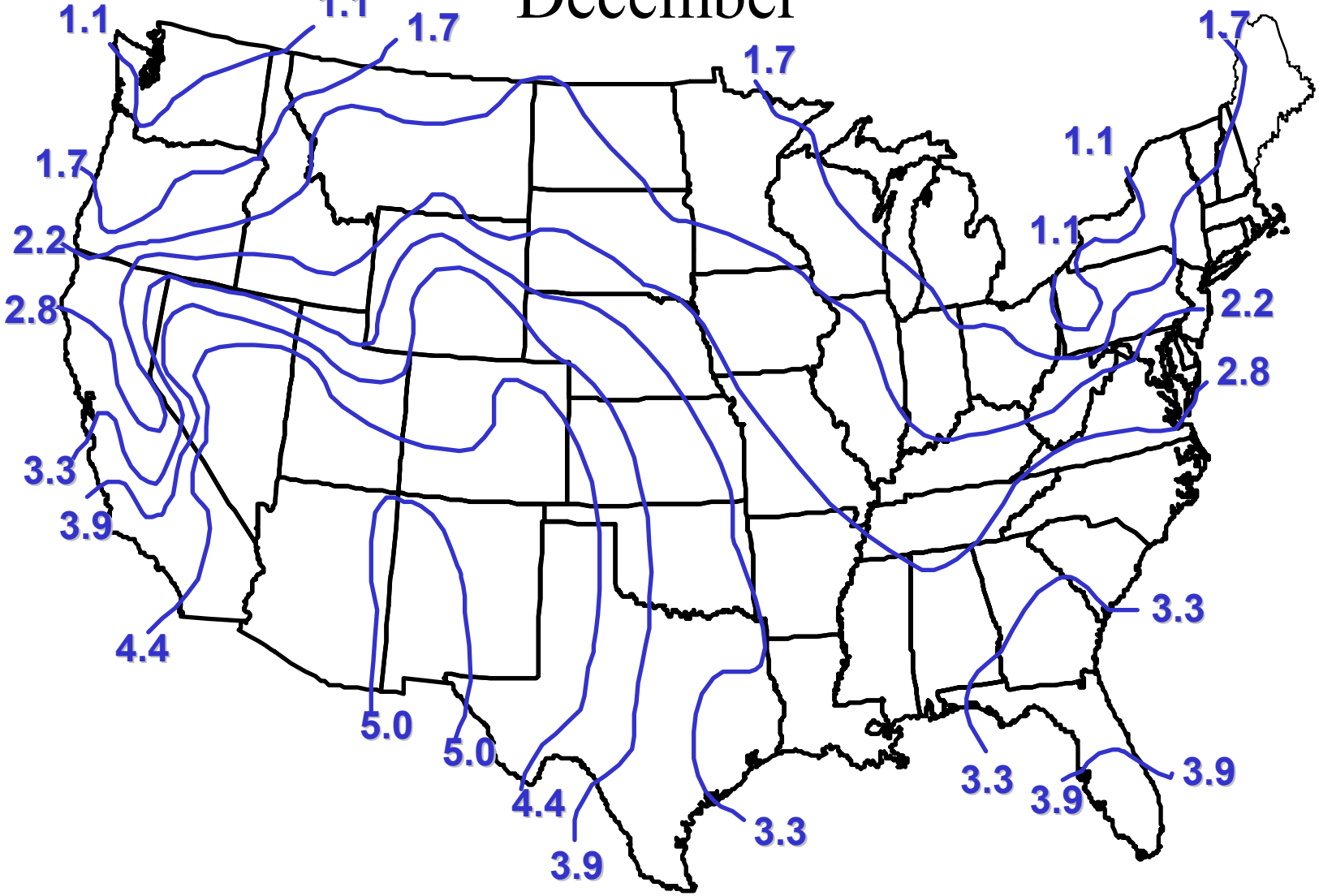
Radiance and Time

June



Radiance and Time

December



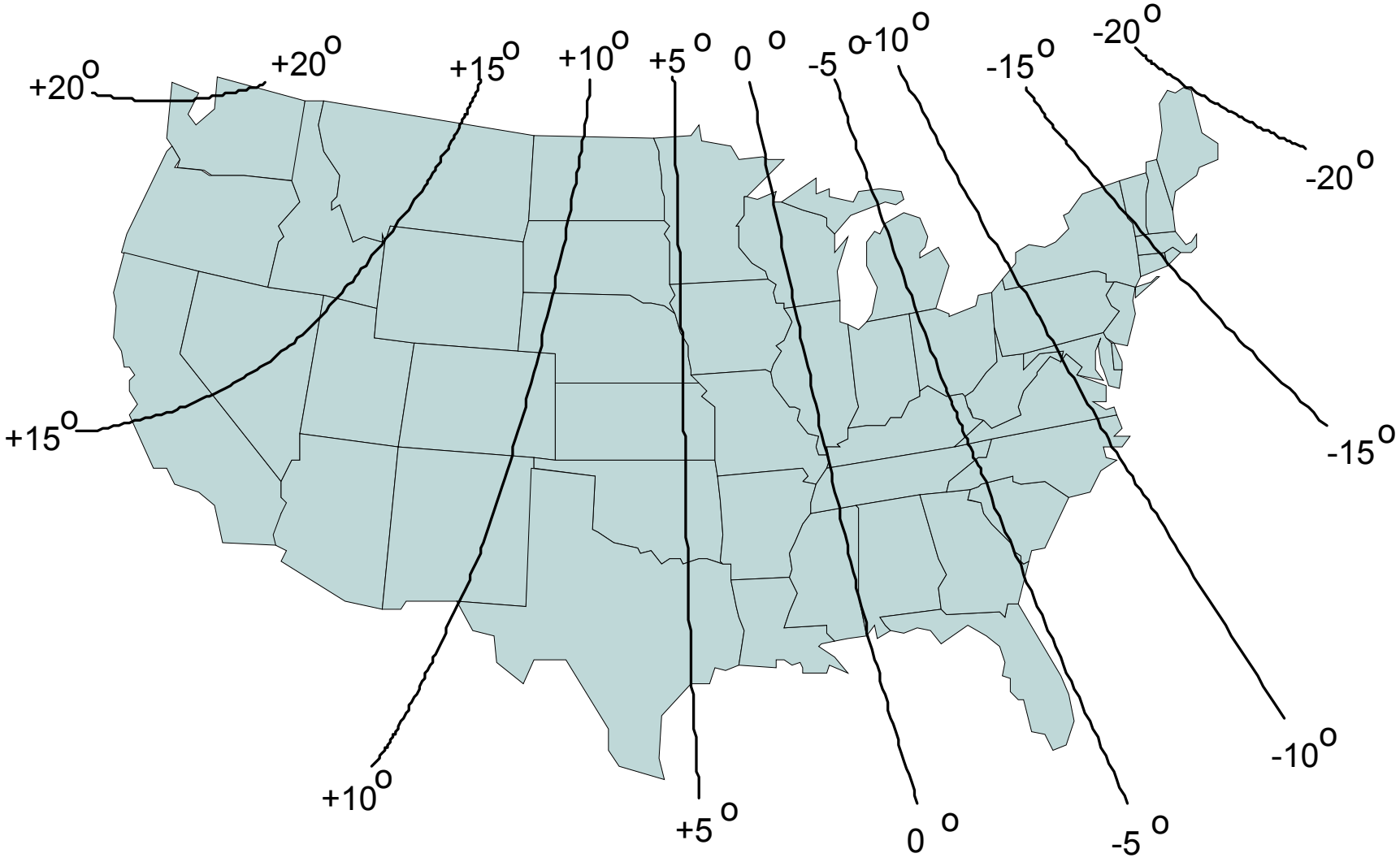
Maximizing The Solar Harvest

- Tilt and orient array properly towards true south
- Prevent shading
- Minimize array soiling
- Tracking

Array Orientation

- Use a compass to find true South
- Adjust for magnetic declination which varies with geography

Magnetic Declination Map



Array Tilt Angle

The number of degrees that the array is tilted up from horizontal

Tilt Angle Adjustment

Advantages

- Daily adjustments increases output by 15-20%
- Quarterly adjustments increase output by 5 %

Disadvantages

- Adds complexity to the system
- Adds costs

Solar Tracker Types

- Single Axis
- Double Axis
- Passive
- Active

Single Axis Tracking

Tracker Pluses and Minuses

- (+) Maximizes solar output
- (-) Adds expense and complexity
- (-) Wind > 25 mph can be a problem
- (-) Avoid in remote locations

Shading

- Avoid shading from buildings, trees, and other obstacles
- Cut back vegetation as it grows
- Place array far enough off the ground to allow snow shedding
- Periodically wash arrays
- Consider using diodes

Band Gap Energy

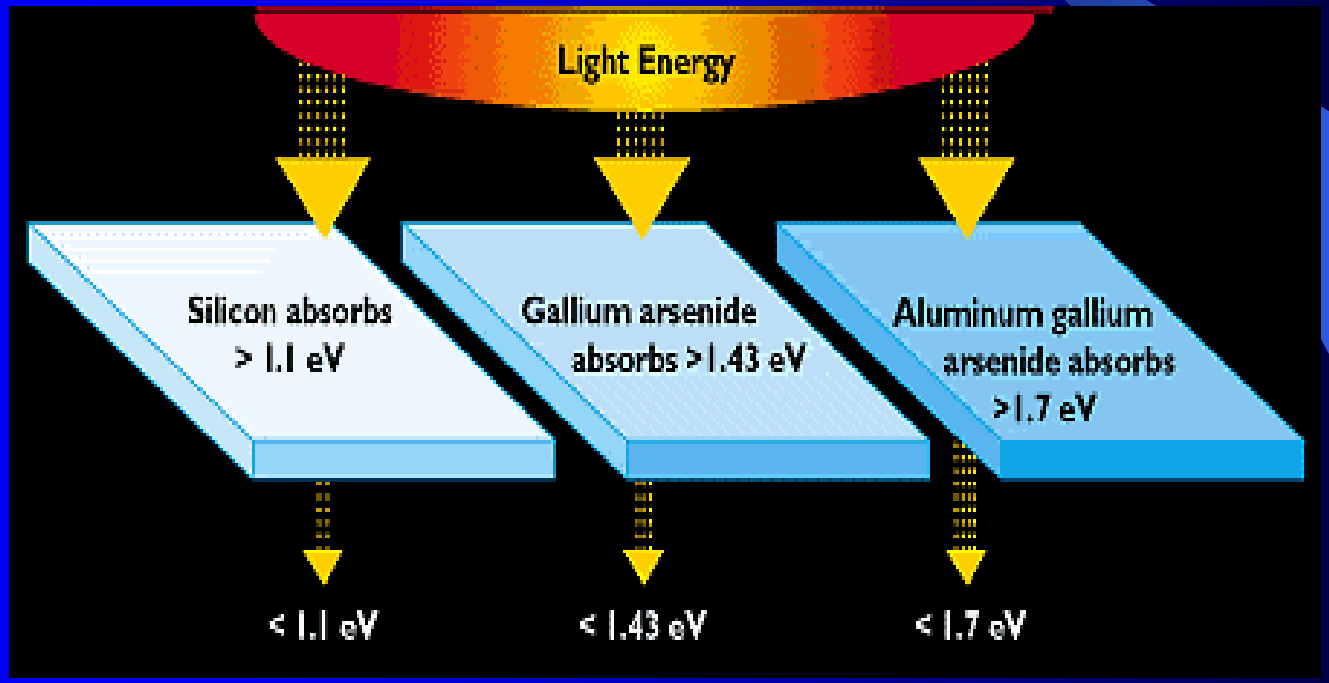
The level of energy that frees electrons from their atomic bonds to produce an electric current

Coefficient of Temperature

- Heat impacts cell performance
- Polycrystalline modules lose performance at increased temperature.
- Amorphous silicon increases performance at higher temperature

Band-Gap Energies

Effective PV semiconductors have band-gap energies ranging from 1.0 to 1.6 electron-volts (eV).



Materials - Silicon

- Most popular solar-cell material for commercial applications
- Abundant (in the Earth's crust-second only to Oxygen)

Materials – Silicon Photovoltaic Technologies

- *Single-crystal silicon*
- *Semicrystalline silicon*
- *Amorphous silicon*

Single-Crystal Silicon

Has a uniform molecular structure - the entire structure is grown from the same or a "single" crystal.

Single-Crystal Silicon

Advantages

- Mature technology
- Highly efficient
- Proven reliability in the field

Disadvantages

- High manufacturing cost
- Requires electronic grade silicon

Polycrystalline Silicon

- Consists of several smaller crystals or grains, which introduce "boundaries."
- Grain boundaries impede the flow of electrons and reduce the power output of the cell.

Polycrystalline Silicon

Advantages

- Uses lower cost silicon
- Mature technology
- Proven reliability in the field

Disadvantages

- High manufacturing cost
- Lower efficiency than single-crystal silicon

Amorphous Silicon (aSi)

- Are non-crystalline structures
- Contain large numbers of structural and bonding defects.

Amorphous Silicon

Advantages

- Less costly to manufacture
- Can be “stacked” to capture more of the solar spectrum
- Can be deposited on flexible substrates

Disadvantages

- Performance degradation in sunlight

Non-Silicon Technologies (Polycrystalline)

- **Cadmium Telluride (CdTe)**
- **Copper Indium Diselenide**

Cadmium Telluride (CdTe)

Advantages

- Low cost manufacturing
- Ideal band gap
- Abundant raw semi-conductor materials

Disadvantages

- Immature technology
- Cadmium environmental issues
- Lower efficiency than polycrystal silicon

Copper Indium Diselenide (CIS)

Advantages

- Low cost manufacturing
- Ideal band gap
- No environmental issues

Disadvantages

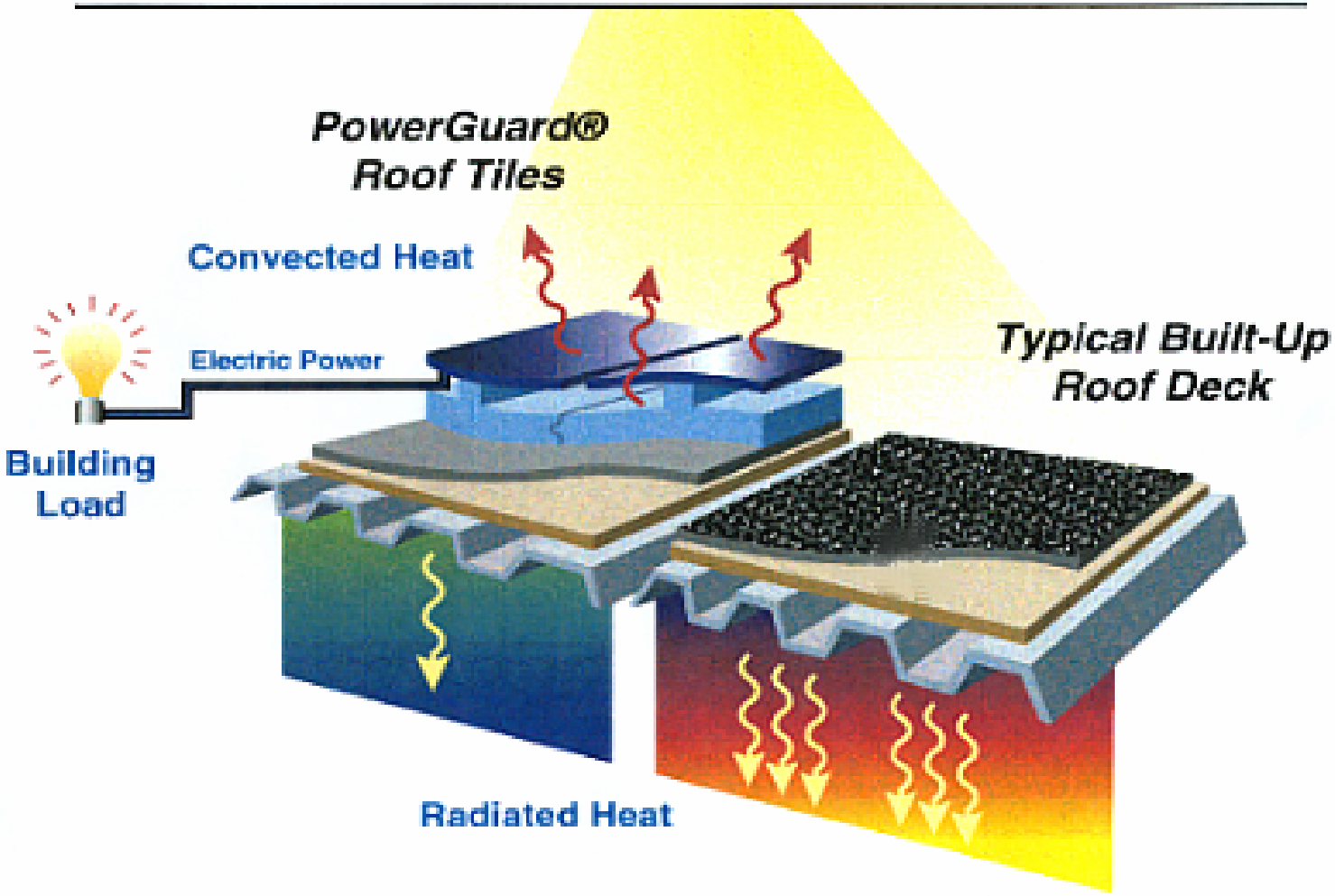
- Immature technology
- Raw material issues

Commercial Applications

Electric Vehicle Recharging

Building Integrated PV System

PowerGuard® - Power Generation & HVAC Savings



Skylighting

Residential Photovoltaic Products

Why Residential?

- Environmentally-friendly power
- Back-up power during utility outages
- Remote power for “off-grid” living
- Reliability - Contains no moving parts
- Requires no fuel
- Has a lifetime in excess of 30 years

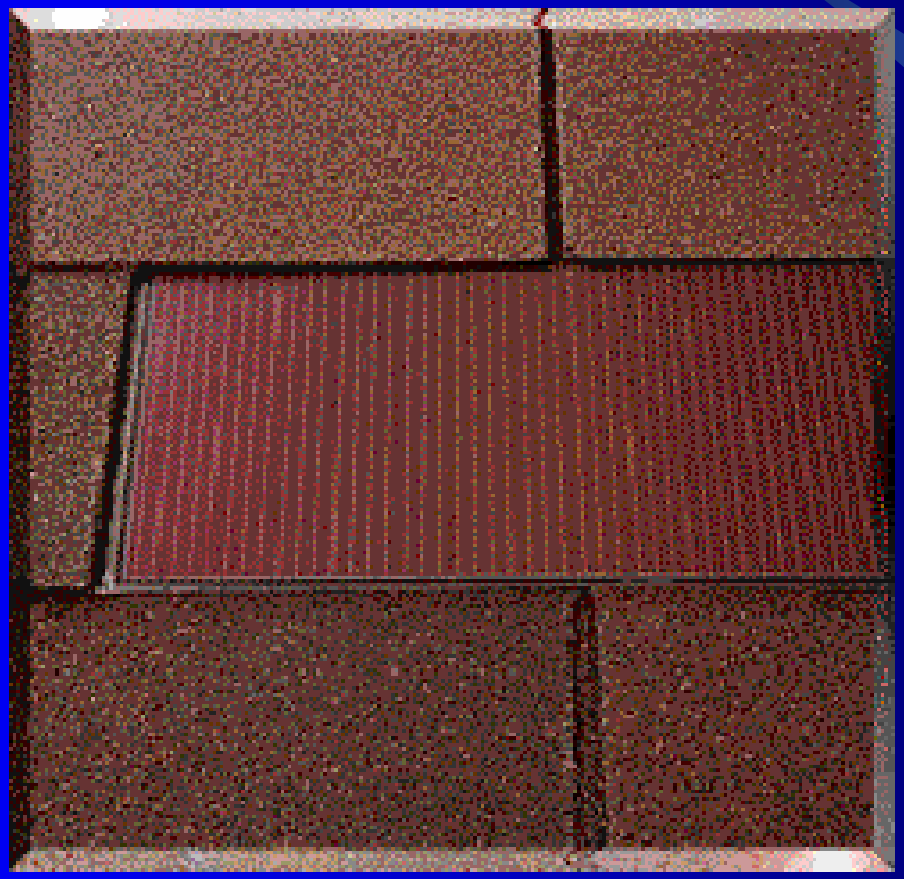
Grid Tied Systems

Residential Grid Tied
Two Options

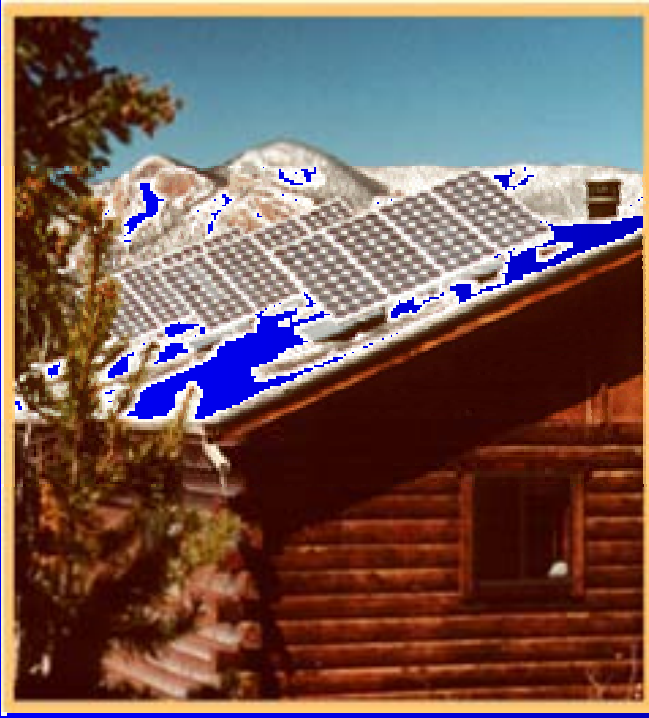
- Utility Connected
  - Only components are PV & inverter
- Utility Connected with Emergency Back-up Capabilities
  - Battery bank back-up for critical circuits

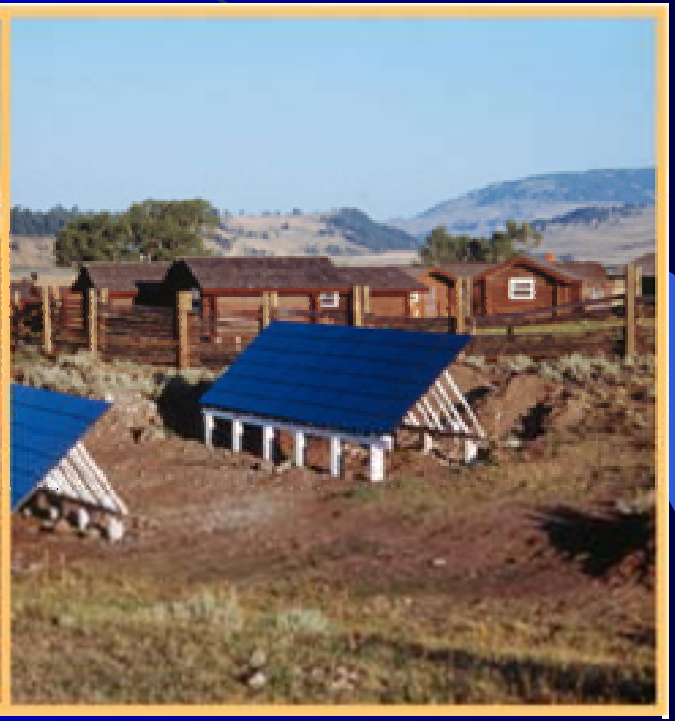
Residential – Net Metered

Photovoltaic Shingles



Remote Residential





Packaged Systems

- PV is the primary electricity source
- Combined with Propane
- Battery bank back-up
- Generator for supplemental battery charging
- Future fuel cell hybrid

Specialized Off-Grid

Mt. Evans Observatory

Specialized Off-Grid

- Telecommunications
- Oil & gas industry
- Remote monitoring equipment

Summary

- State what has been learned
- Define ways to apply training
- Request feedback of training session