Johns Manville

Solar Solutions for Commercial Roofing Systems

ECONOMICS

ENVIRONMENT

ENERGY

BURSI
THE BETTER UNDERSTANDING OF ROOFING SYSTEMS INSTITUTE

PV Basics & Components

JM E³co.
The JM Eco-leadership™ Company

Overview/Objectives

- Review Solar Electricity and Terminology
- Examine PV Systems and their Components
  - PV Modules (Crystalline and Thin Film)
  - Inverters
  - Racking/Mounting Systems
  - Balance of System
  - Monitoring Systems
- Overview PV System Performance Parameters
  - Module Orientation
  - Module Shading
  - Module Soiling

Solar Electricity and Terminology

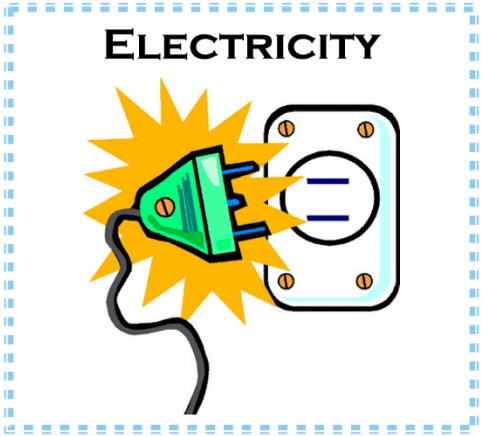
Solar Electricity

- Photovoltaic Effect

Photo = Light

Voltaic = produces voltage

Photovoltaic (PV) cell converts sunlight directly into electricity (using semi-conductor technology)



Solar PV Process

Cell

Wired
In
Series

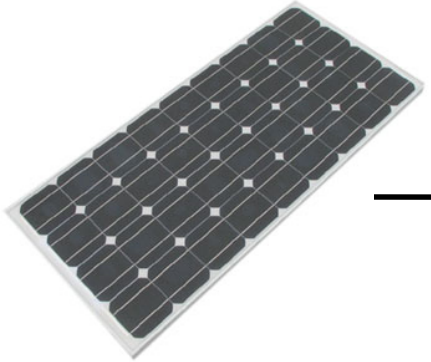
Module

Wired
In
Series

String/Array

DC to AC Conversion

Modules/Array/System



DC →

Inverter

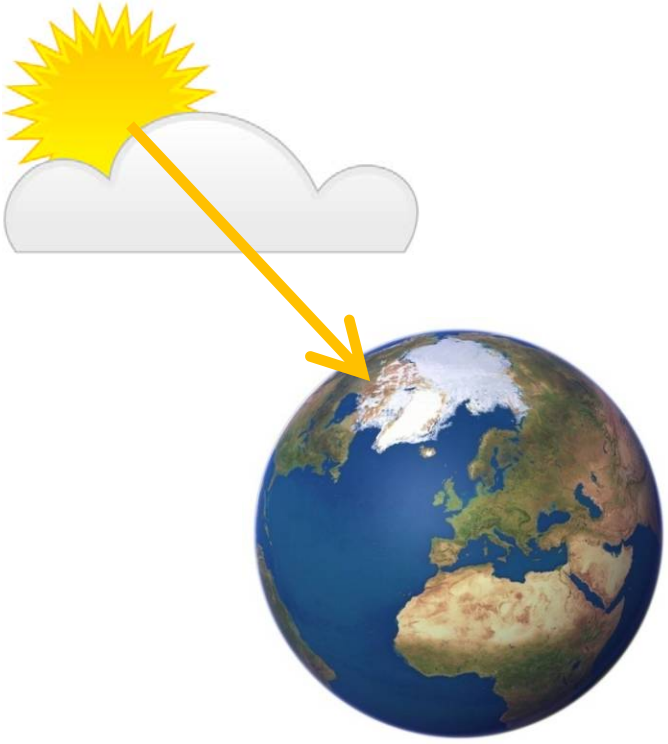
AC →

Usable Electricity

- Inverter changes the Direct Current (DC) electricity into Alternating Current (AC)
- Inverter also transforms AC electricity into a common voltage configuration

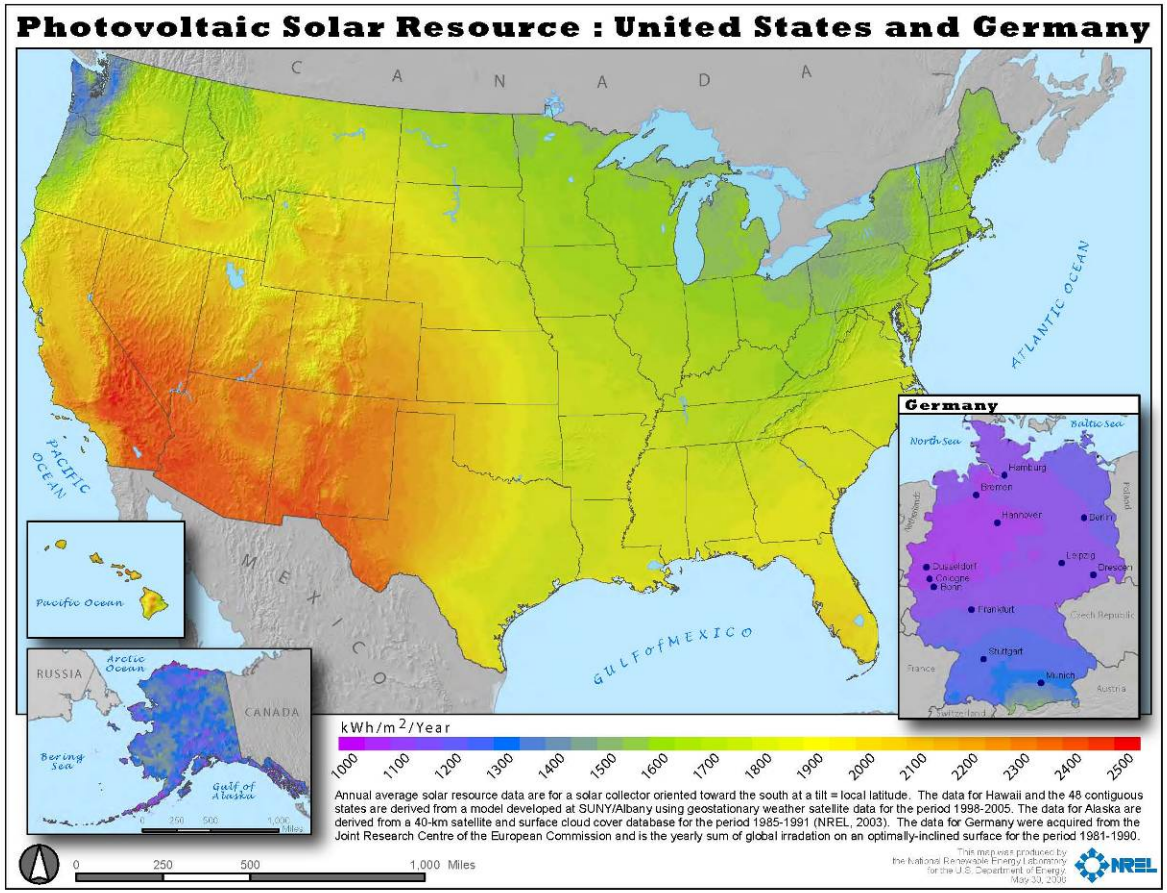
Solar Irradiance

- Radiant power of sunlight on a surface
- Units: Watts/m^2
- Peak Value = 1000 W/m^2
- Nominal Value = 800 W/m^2



Solar Irradiation

- Also called solar Insolation
- Radiant power of sunlight on a surface over time
- Units: kWh/m^2/day
- Irradiation = Irradiance x Time
- Denver =
- 2100kWh/m^2/year



Power vs. Energy

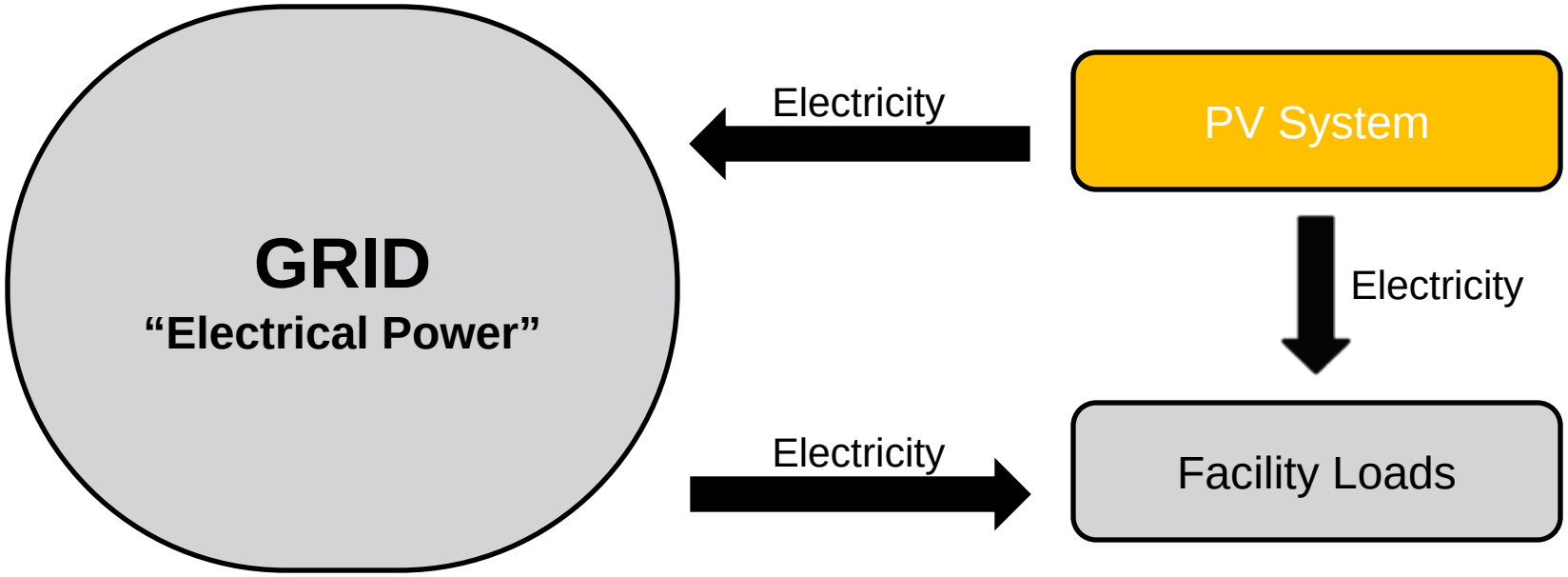
- Power
  - Power = Current x Voltage (P = I x V)
  - kilowatts (kW)
  - Demand
  - Solar PV System Size

1 kW (kilowatt) = 1000 W (watts)
1 MW (megawatt) = 1000 kW (kilowatts)

- Energy
  - Energy = Power x Time (E = P x T)
  - kilowatt-hours (kWh)
  - Consumption
  - Solar PV System Production

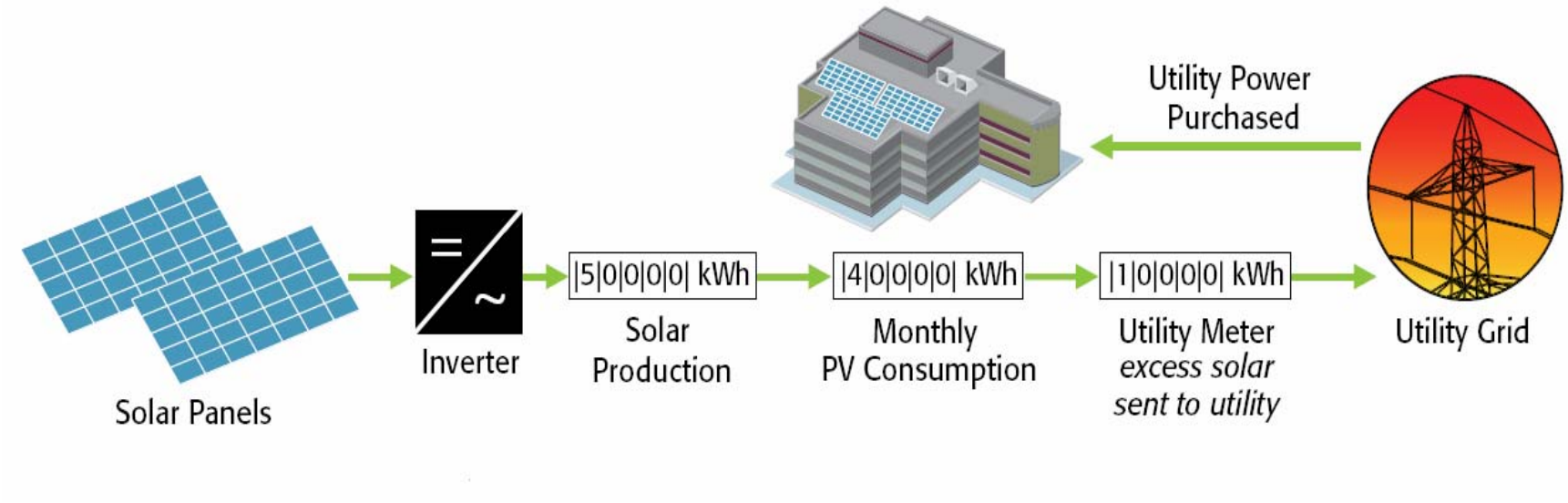
1 kWh (kilowatt-hour) = 1000 Wh (watt-hours)
1 MWh (megawatt-hour) = 1000 kWh (kilowatt-hours)

Solar Power and the Grid



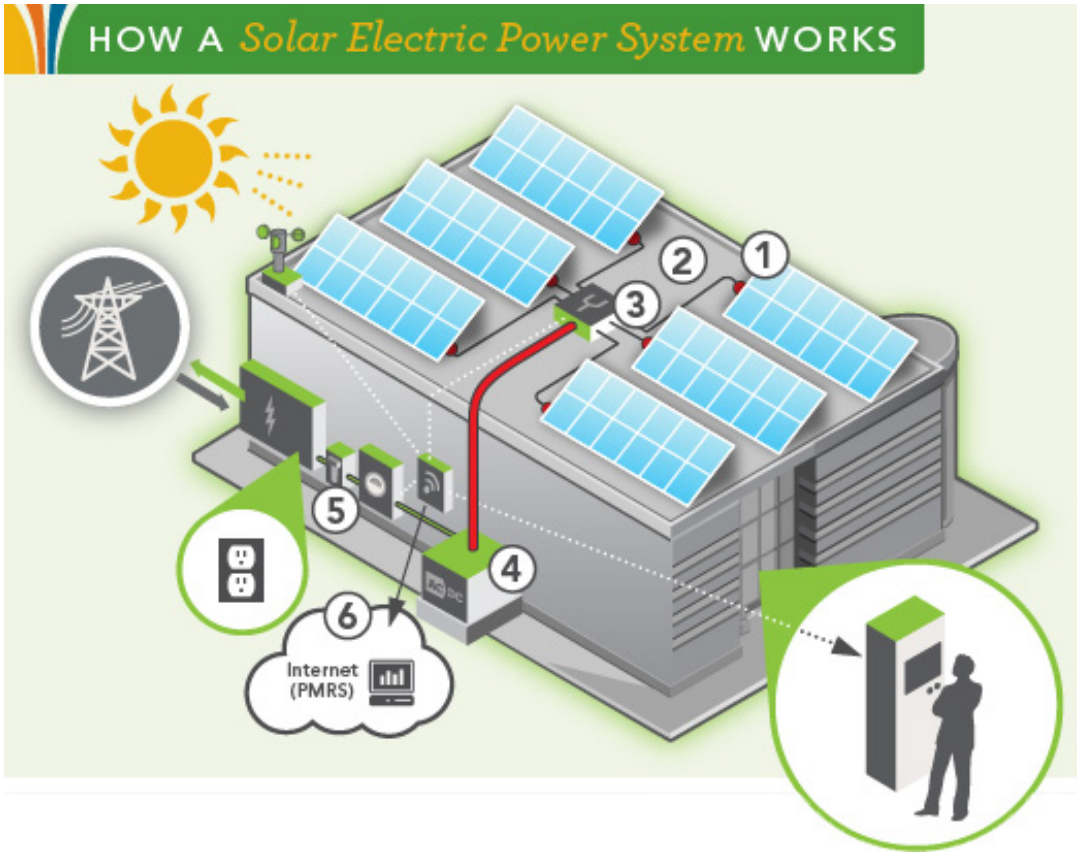
- PV electricity feeds power to facility loads
- Excess PV electricity feeds power to the grid
- One way or another, facility loads get needed electricity

Net Metering



- Utility installs a Bi-Directional meter (Net meter) at PV facility
- Net meter measures the net electricity used
- Utilities credit excess electricity to monthly bill

PV System Overview



1. PV Modules
2. Racking/Mounting System
3. DC Combiner Boxes
4. DC to AC Inverter
5. Power Meter/Disconnect/ Distribution Panel
6. Monitoring System

PV System Components

- PV Modules (50% of system cost)
- Inverter (7.5% of system cost)
- Racking/Mounting System (12.5% of system cost)
- Installation & Balance of System (20% of system cost)
  - Combiner Boxes
  - Wiring
  - Conduit
  - Disconnects/Breakers
- Monitoring System (< 1% of system cost)
- Others (10% of system cost)

PV Modules

Module Ratings

STC (Standard Test Conditions)

PTC, CEC (PV USA Test Conditions/California Energy Commission)

The PTC rating, which is lower than the STC rating, is generally recognized as a more realistic measure of PV output because the test conditions better reflect "real-world" solar and climatic conditions, compared to the STC rating. All ratings in the list are DC (direct current) watts

Crystalline Silicon (c-Si)

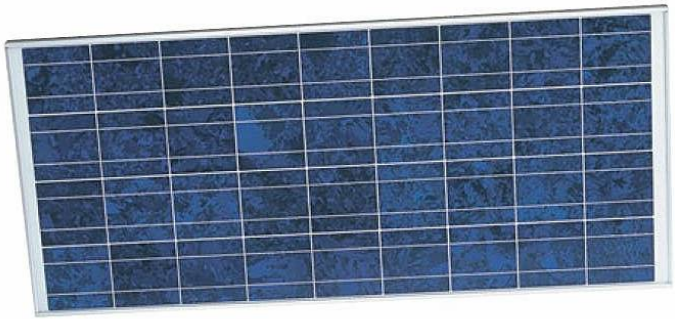
- Cells are manufactured from Wafer-Based crystalline silicon
- Two Primary Types:

Monocrystalline

- Single Crystal Lattice Structure
- No defects or impurities
- More efficient
- More expensive to manufacture

Polycrystalline

- Multiple Crystal Lattice Structures
- Recognized by visible grain
- Less efficient
- Less expensive manufacture



Crystalline Characteristics

STC Rated Power:	150 W – 250 W
Module Area:	14 SF – 18 SF
Module Dimensions:	roughly 3'x5.5'
Module Weight:	2.5 – 3.5 lbs/SF
Conversion Efficiency:	12% - 20%
Power Density:	11 W/SF – 19 W/SF
Temperature Dependence:	0.5%/^{o}C
Degradation:	0.5% - 1% per year
Warranty:	20 – 25 year production

Typical Applications

Roof Mount

- Incorporated with racking systems (penetrating or ballasted)
- Works best with flat, low slope roofs, and standing seam metal roofs
- Incorporates module tilts for increased system performance
- Some incorporate membranes for integrated solutions

Crystalline Example

Sharp NU-U235F1

- Monocrystalline
- Rated Power: 235 W STC
- Tested Power: 211.7 W PTC (CEC)
- Module Area: 17.5 SF
- Dimensions: 64.6” x 39.1”
- Weight: 44 lbs (2.5 lbs/SF)
- Conversion Efficiency: 14.4%
- Power Density: 13.2 W/SF
- Temperature Dependence: -.50%/ ^{o}C

Crystalline Pros and Cons

Advantages

- Highest efficiencies
- Highest power densities (more power per SF)
- Incorporates module tilts = increased performance (tilted systems require more installation area)
- Large number of module manufacturers and choices

Disadvantages

- Poor performance in high temperatures
- Poor performance when shaded
- Poor performance in ambient/diffuse lights
- Weigh roughly 2.5 lb/SF

Thin Film

- Manufactured by depositing minimal amounts of semiconductor material onto glass, metal, plastic, etc.
- Multiple Types:
  - Amorphous Silicon (a-Si)
  - Cadmium Telluride (Cd-Te)
  - Copper Indium/Gallium Diselenide
  - (CIGS)

- Thin Films:
  - Possibility of being flexible
  - Good for Building Integrated PV (BIPV)
  - Low efficiency
  - Low manufacturing cost

Thin Film Characteristics

STC Rated Power:	50 W – 150 W
Module Area:	10 SF – 24 SF
Module Dimensions:	1.25'x18'
Module Weight:	< 1 lb/SF
Conversion Efficiency:	6% - 11%
Power Density:	5 W/SF – 10 W/SF
Temperature dependence:	0.20% per ^{o}C
Degradation:	0.5% - 1% per year
Warranty:	20 – 25 year production

Typical Applications

Roof Mount

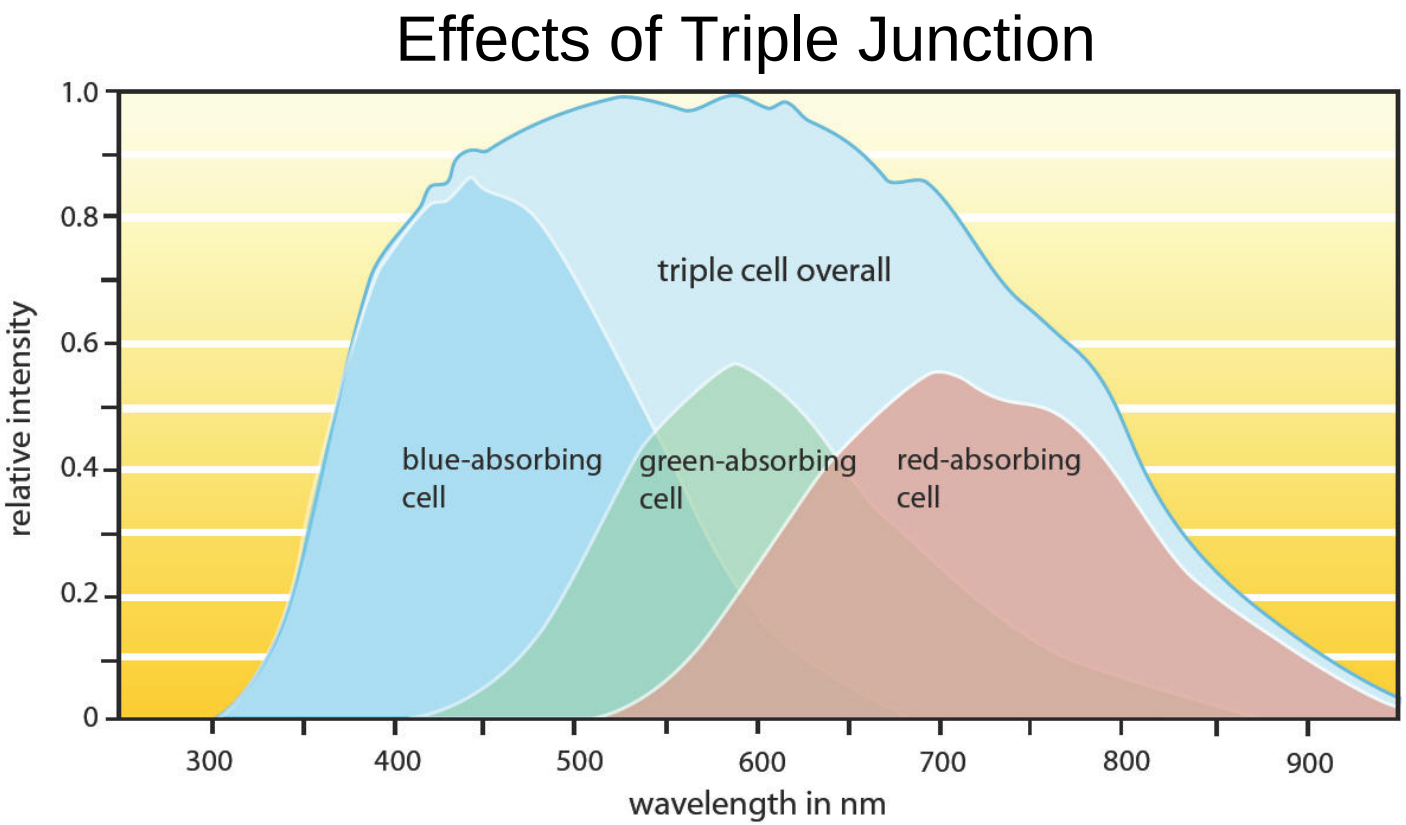
- Directly adhered to flat, low slope, and some steep slope roofs
- Works best with single ply membranes or metal roofing
- No racking systems, penetrations or ballast blocks
- Some incorporate sacrificial membranes for integrated solutions, recoverability and roof integrity

Thin Film Example

Unisolar PVL-144

- A-Si, triple junction, laminate
- Rated Power: 144 W STC
- Tested Power: 136.4 W PTC (CEC)
- Module Area: 23.25 SF
- Dimensions: 216” x 15.5”
- Weight: 17 lbs (.7 lbs/SF)
- Conversion Efficiency: 6.7%
- Power Density: 6.2 W/SF
- Temperature Dependence: -.21%/ ^{o}C

Thin Film Light Performance



Thin Film Pros and Cons

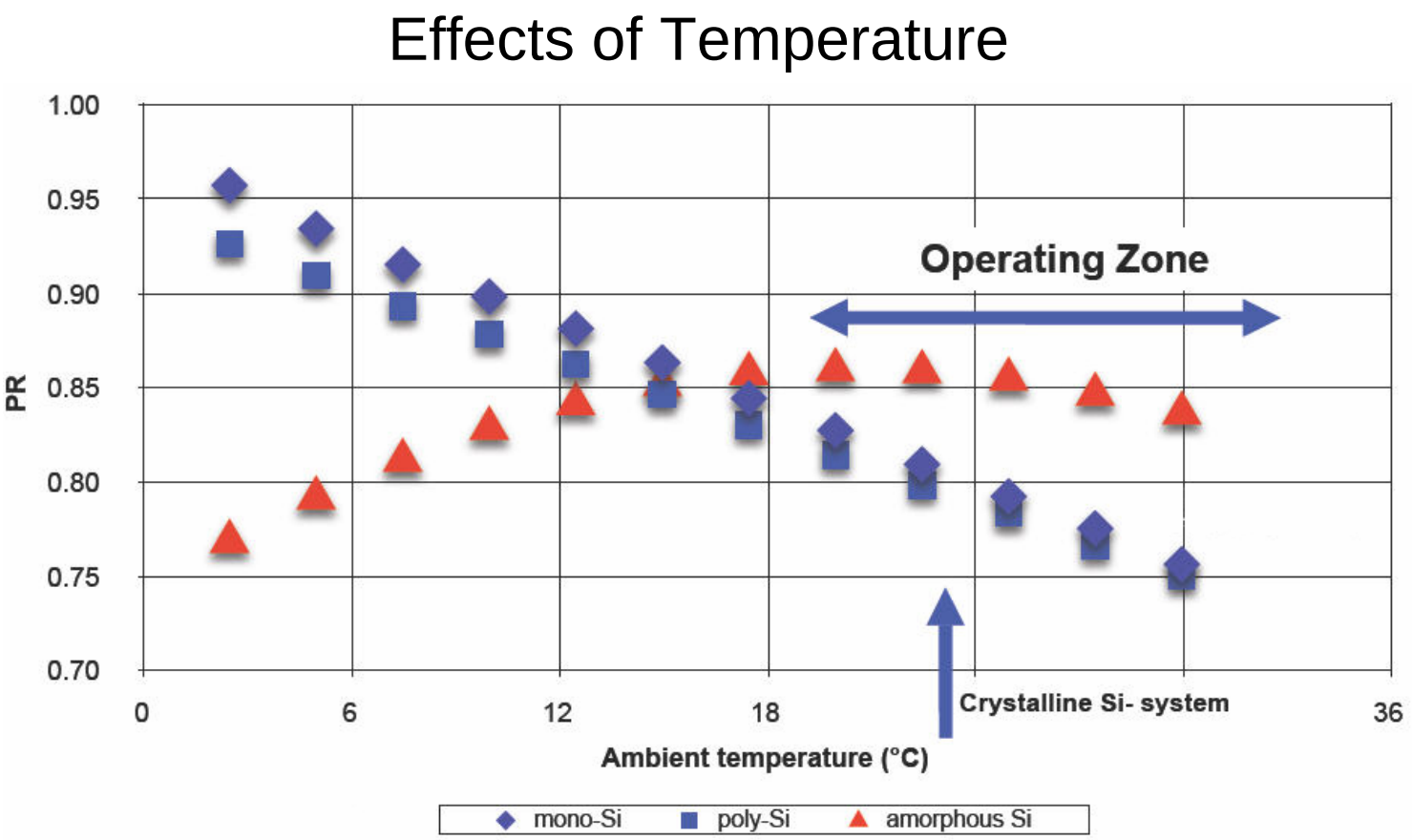
Advantages

- Good performance in high temperatures
- Good performance when shaded
- Good performance in ambient/diffuse lights
- Requires no racking system, penetrations or ballast
- Weigh less than 1 lb/SF

Disadvantages

- Lowest efficiencies
- Lowest power densities (Less power per SF)
- Small number of module manufacturers and choices

Temperature Performance



Inverters

Inverters

String Inverters

- Used mainly for Residential Applications
- Used in some Commercial Applications
  - CAN connect to 3-phase configurations
- Sizes from 1 kW – 10 kW AC
- 95% - 96% CEC Efficiencies
- Weigh 35 – 150 lbs
- Wall Mounted (1.5 – 3 SF)
- Outdoor Rated Enclosures
- Integrated Disconnects
- Communication Capabilities
- 10 – 20 year warranties

Inverters Cont.

Central Inverters

- Used for Commercial Applications
- Sizes from 30kW – 1000kW
- 95% - 97.5% CEC Efficiencies
- Weigh 1,000 – 12,000 lbs
- Pad Mounted
- Outdoor Rated Enclosures
- Integrated Disconnects
- Communication Capabilities
- 5 – 20 year warranties

Satcon®

PV Inverters | PowerGate® Plus

Inverters Cont.

Micro Inverters

- Used for Residential/Commercial Applications
- Sizes from 175W to 200W
- 94.5% - 95% CEC Efficiencies
- Weigh 5 lbs
- 5.5” x 10.5” x 1.5”
- Mounted to back of module
- Outdoor Rated Enclosures
- Communication Capabilities
- 15 year warranty

Mounting Systems

Roof Mounted Racking, Penetrations

- Structurally fixed to building structure
- Requires lengthy structural analysis on existing structure and new solar structure
- Typically 2.5 – 3 lbs/SF with modules
- Mount modules with a large tilt, wind loading is less of an issue
- Penetrations are expensive, use least amount as structurally possible
- Most expensive method of installing a roof mounted solar array

Roof Penetrations

Roof Mounted Racking, Ballasted

Ballast Gravel Tray

Wind Shield

- Fixed to roof by system weight (no penetrations)
- Ballast gravel or blocks required to hold system down
- Anchors are sometimes used to hold system in place
- Requires lengthy structural analysis on existing building structure
- Typically 5 – 10 lbs/SF with modules
- Modules mounted with lower tilts, and wind shields, wind is a large issue

BIPV (Building Integrated PV)

- Does not require a separate mounting/racking system
- Very roofing friendly – secured via heat welding or with adhesives
- Thin Film mounted flat
- Rigid Crystalline mounted with low tilts
- Requires little to no structural analysis on existing structure
- Multipurpose PV system serves as a power plant and building skin

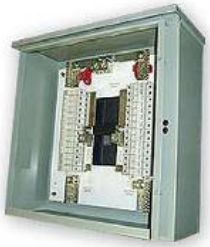
Balance of System Components

- Grounding Lugs – Allow for modules to be connected to equipment grounding

- Wiring – Transfer power

- Conduit – Protects wiring

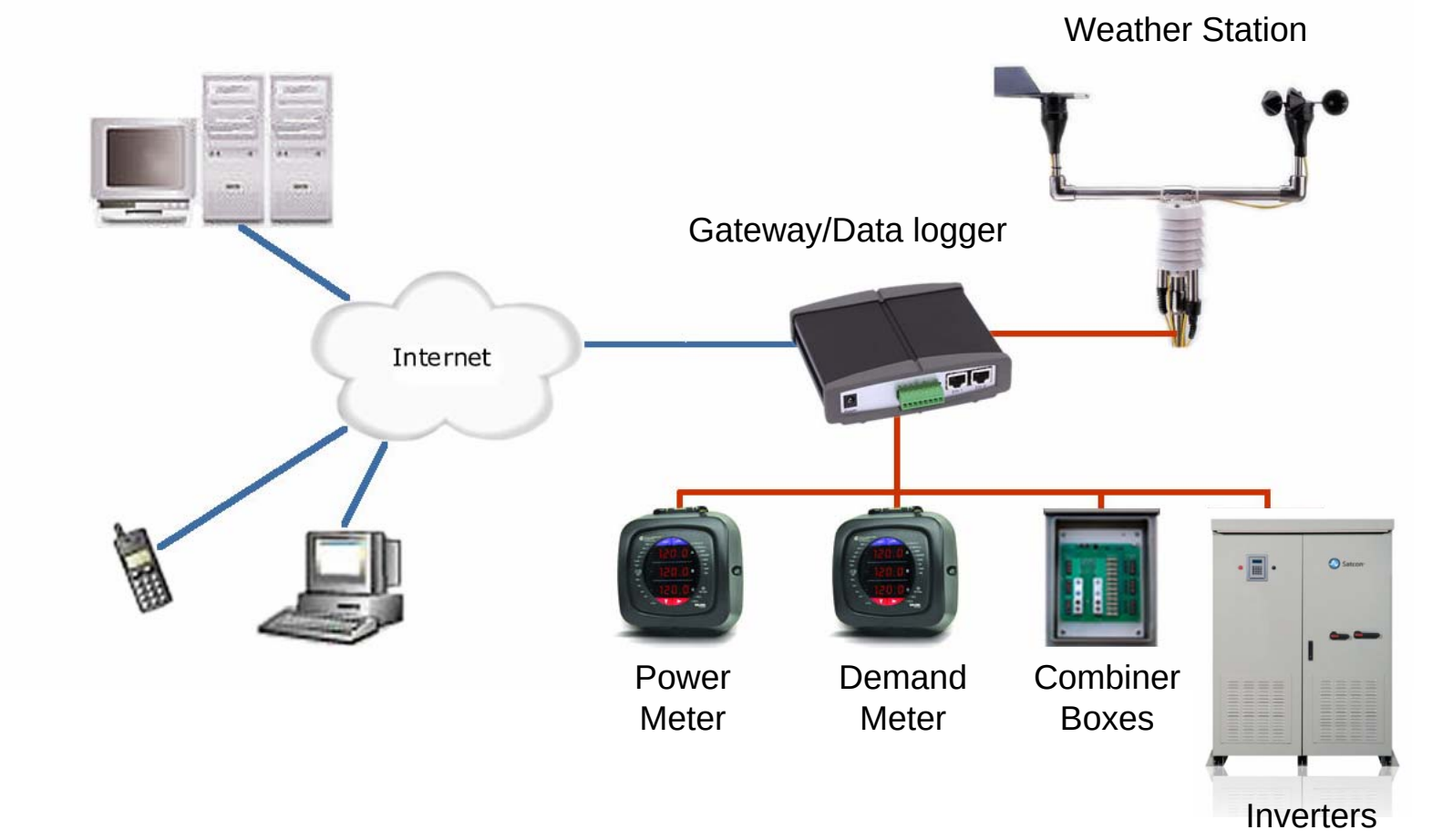
- Combiner Boxes – Consolidate/Simplify system wiring



- Disconnects/ Breakers – System shutdown and maintenance

- Fuses – Over current protection

Web Based Monitoring



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SOLRENVIEW

SOLECTRIA RENEWABLES

Johns Manville Technical Center

[Refresh in 14:36]

System Info

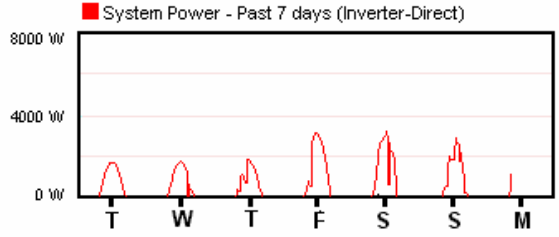
Location 10100 W. Ute Ave. Littleton, CO 80127

Monitoring Started Fri Aug 7, 2009

Installer JM E3co. The JM Eco-leadership™ Company

Inverter Models	Inverter WAC	Qty.	Total Capacity (WAC)
Solectria PVI 4000	4000	2	8000

Panel Modules	Module WDC	Qty.	Total Capacity (WDC)
UniSolar 144	144	24	3456
SunTech 220	220	12	2640



System Status Now [2009-11-09 08:29:54 MST]

Online [*last update:* **2009-11-09 08:21:42 MST**]

System Status, Inverter-Direct:	Active	
Energy generated today:	0.6	kWh
Lifetime energy generated:	2210.3	kWh
Lifetime CO_2 emission offset:	2763	lbs
System AC power now:	1283.0	W

View Inverter-Direct

PV System Performance Parameters

System Performance Factors

Uncontrollable

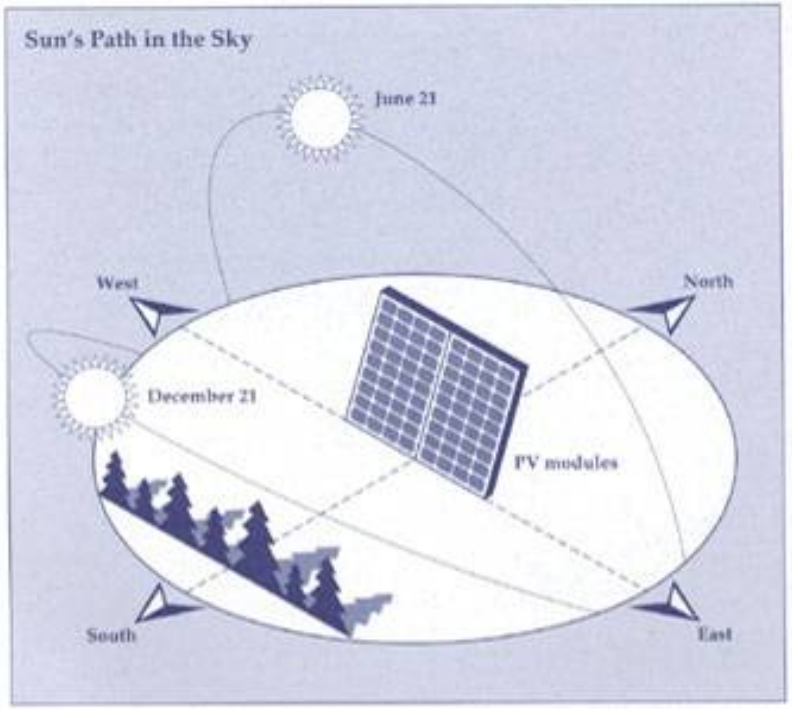
- Weather (Solar Irradiation)

Controllable

- Module Performance
- Module Orientation
- Inverter Efficiency
- System Shading
- System Soiling
- Wiring Losses
- Others

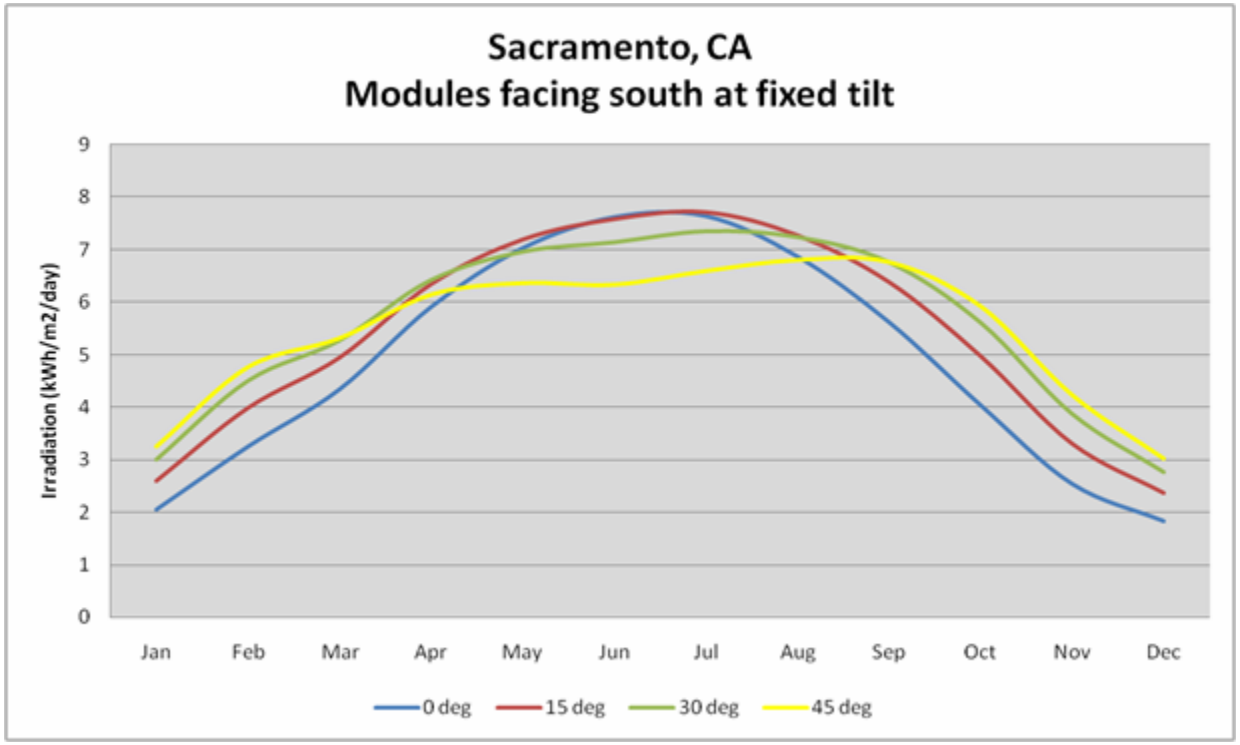
Module Orientation

Ideally, modules work best with direct sunlight
⟶ should face towards the sun as much as possible



- Orientation: Compass bearing (South is optimal)
- Module Tilt: Elevation angle (0° - 30° is optimal)

Module Tilts



Average/Year

0 deg = 4.9

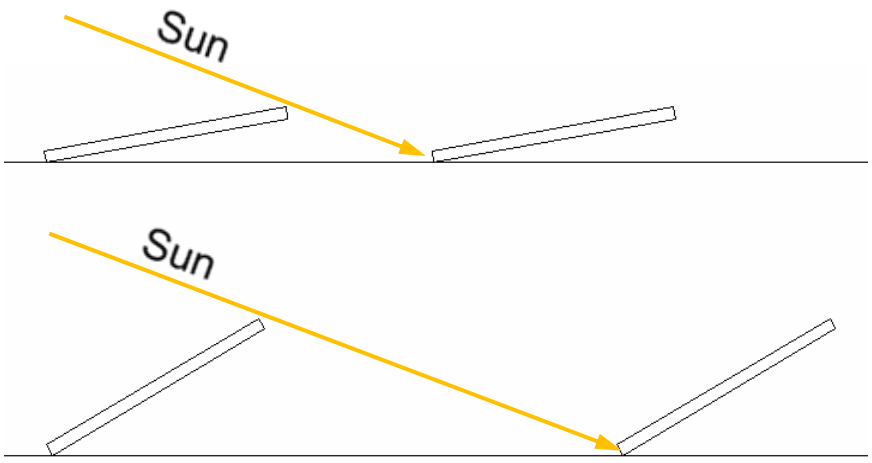
15 deg = 5.4

30 deg = 5.58

45 deg = 5.46

Module tilt of 30º is ideal for annual performance in the continental U.S.

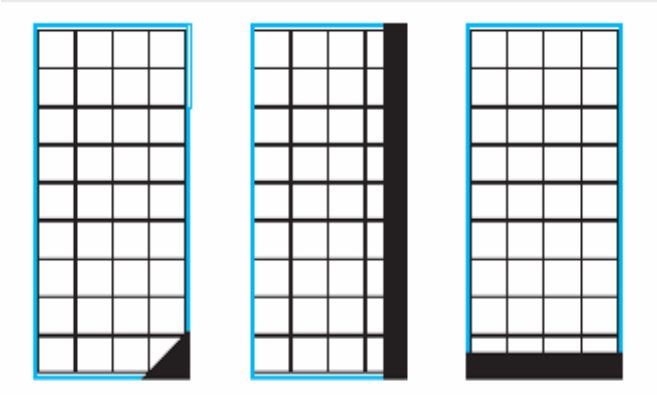
Module Tilt Inter-Row Shading



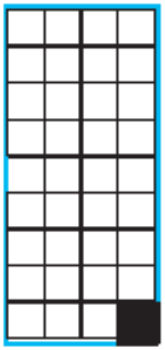
Higher tilt creates more shade → Higher tilt requires more available area

Module Shading

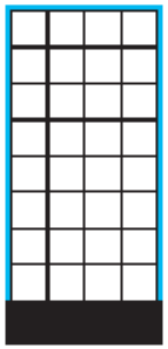
- When objects or obstructions prevent PV modules from receiving sunlight
- Best system performance with 6 hours of un-shaded operation throughout the entire year
- Crystalline modules are generally more susceptible to shading losses than thin film



50% loss of power output

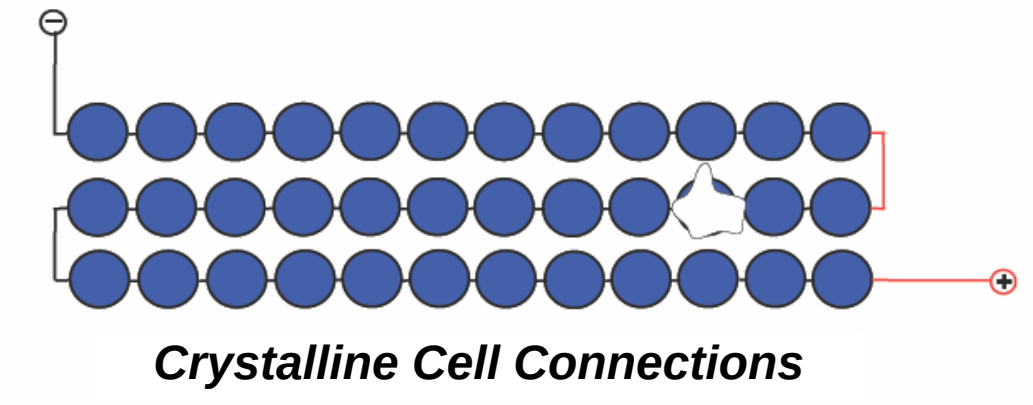


50% loss of power output



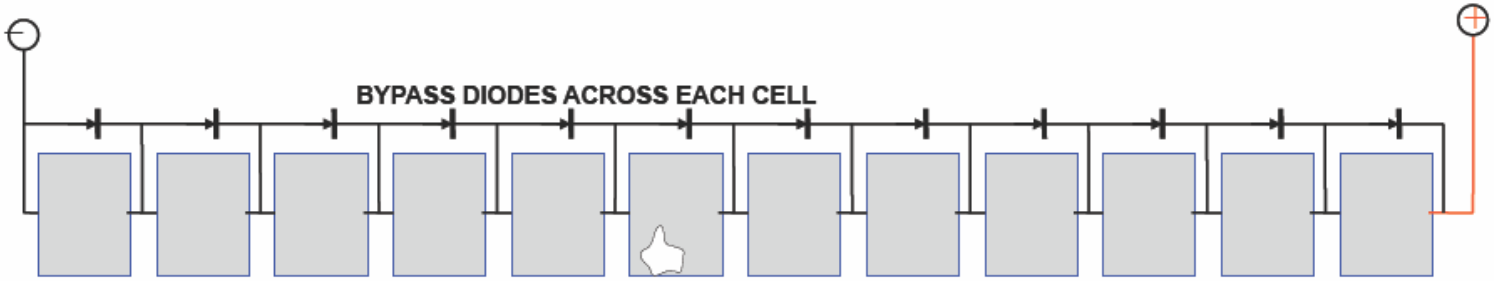
100% loss of power output

Shading Performance



Crystalline Cell Connections

Shade any one cell = Output loss of 50%
Cell Area = 4” x 4”



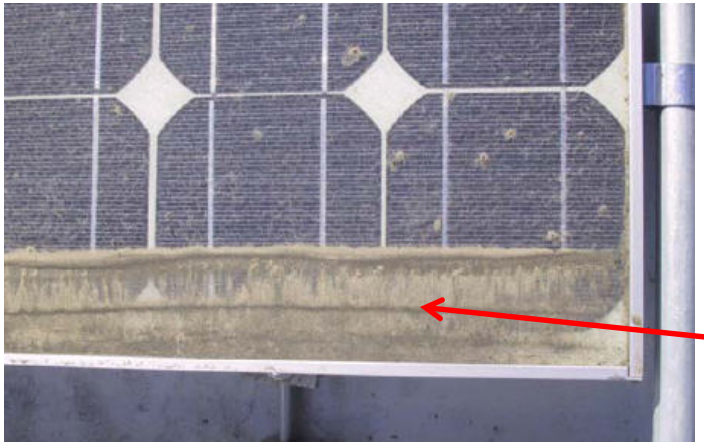
Thin Film Cell Connections

Shade any one cell = Output loss of < 4.5%
Cell Area = 14” x 9”

What Not To Do!

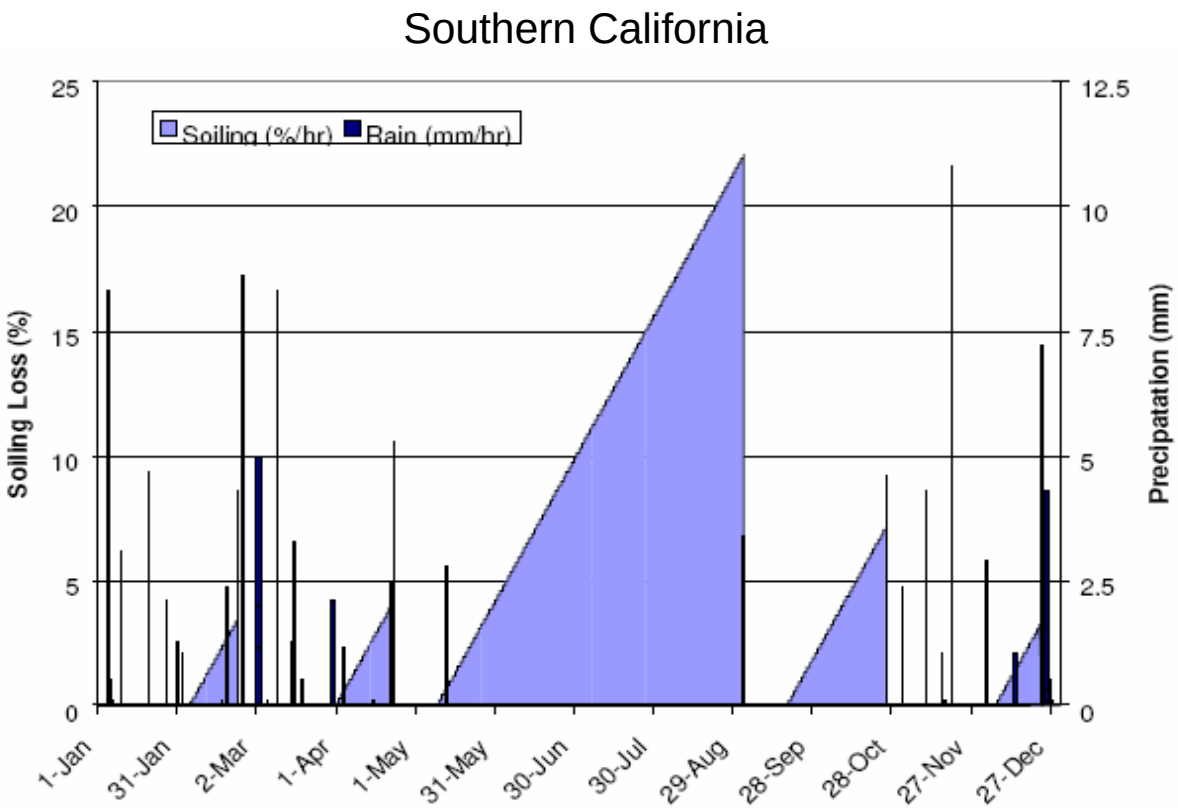
Module Soiling

- The impact of dust, dirt, bird droppings and other debris on PV modules
- Has a moderate impact on PV system performance
- Installing the modules with a moderate to high tilt (15° - 30°) will help prevent some soiling
- Dry climates are affected by soiling the most



Dirt/Mud Buildup

Module Soiling cont.



- Average annual loses due to soiling are 1.5% - 6.2% depending on site location
- One thorough cleaning in the middle of summer is typically the best/most cost effective way to reduce soiling loses

Snow Coverage

Light snow

- Causes negligible energy loss
- Light snow is melted from the temperature of the modules (typically 50° C)

Heavy snow (> 6in)

- Same effect as hard source shading
- Causes noticeable energy losses
- Modules should be cleared/swept clean of snow to prevent losses
- High module tilt helps prevent snow build-up (15° – 30°)

Estimating PV System Performance

PVWatts

A Performance Calculator for Grid-Connected PV Systems

PV WATTS V1:

http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

PV WATTS V2:

http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version2/

Resources/References

- Solar irradiation maps

  http://www.nrel.gov/gis/solar.html
- PV System overview diagram

  http://www.tiogaenergy.com/how-solar-works.php
- Net metering diagram

  http://www.californiasolarcenter.org/pdfs/ppa/Rahus_SPPACustomersGuide_v20081005LR.pdf
- Sharp

  http://sharpusa.com/SolarElectricity.aspx
- Unisolar

  http://www.uni-solar.com/

  http://solarcostarica.com/pdf/Brochures/Uni-Solar%20vs%20Crystal%20Tech%20-%202%20Sided%20-%202.08.pdf

Resources/References, cont.

- Satcon
  http://www.satcon.com/
- Solectria
  http://www.solren.com/
- Unisolar, effects of shading
  http://solarcostarica.com/pdf/Brochures/Uni-Solar%20vs%20Crystal%20Tech%20-%202%20Sided%20-%202.08.pdf
- Powerlight, effects of soiling study
  http://www.5thgenerationsolar.com/pdf/Solar%20Soiling%20Effect%20Study%20-%205BV_1_12.pdf

QUESTIONS?