Evaluation of Solar Power as an Energy Source

Systems Considerations in the Application of Solar

Clark College
20 January 2010
Paul Speer

Outline

- Solar Energy Primer
- Technology Alternatives
- Economics
- Local Case Study
- Technology Details
- Design Considerations
- Local Application & Regulation
- Scale Up Opportunities
- Q&A

Why Does Solar Matter?

- Size of Reserve
- “Green”
- Economics
- Energy independence
- Technology Advancement

Terminology

Electrical Units

- Volt (V)
- Amp (A)
- Watt (W)
- Kilowatt (kW)
- Kilowatt-hour (kWh)
- Megawatt (MW)

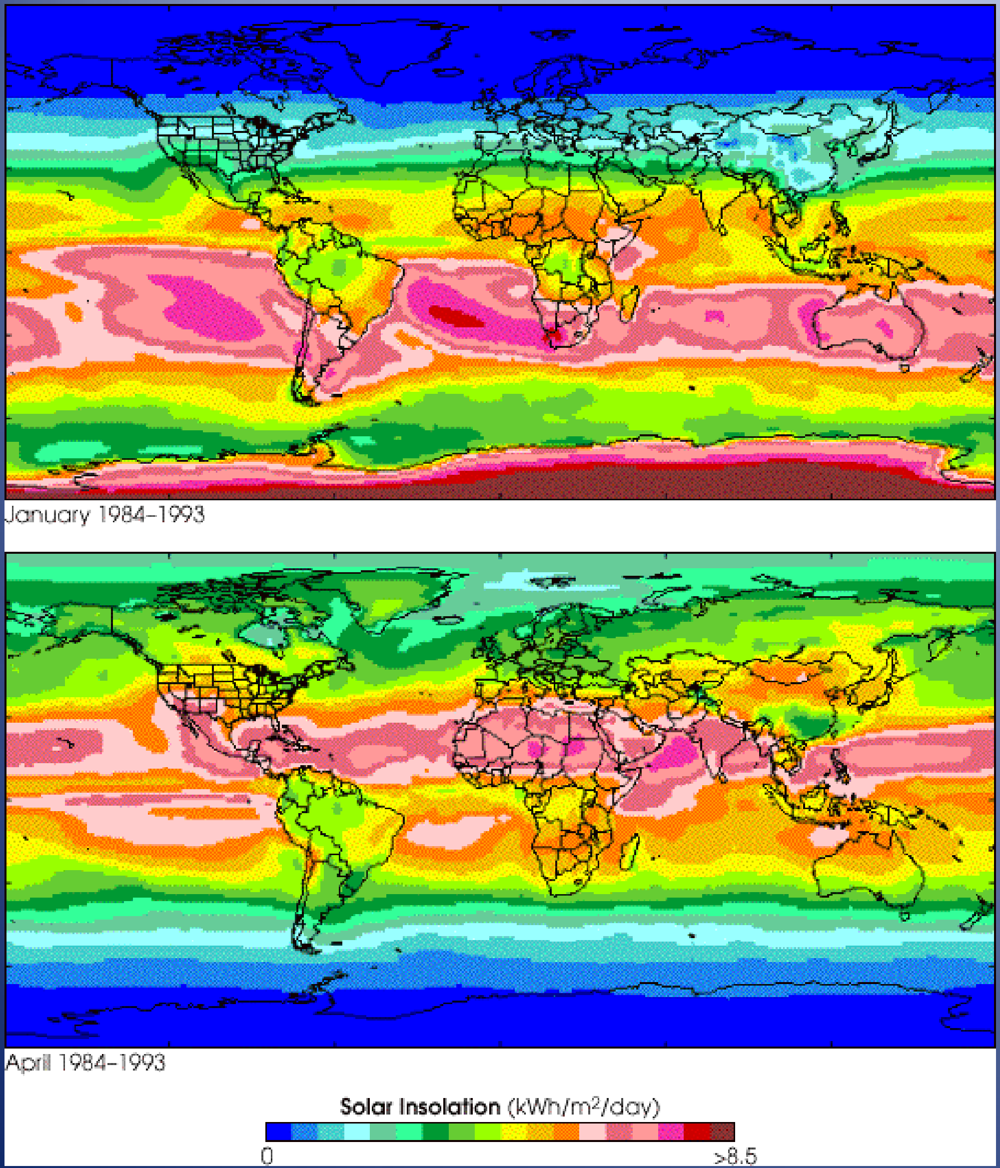
PV System Terms

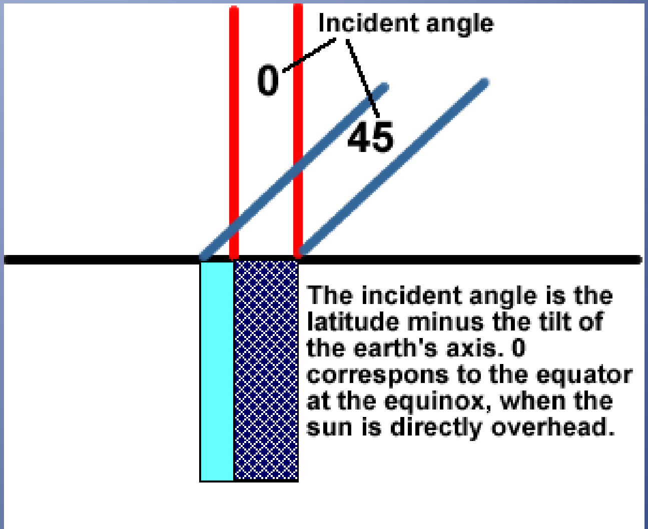
- Cell
- Panel
- String
- Array
- Inverter
- Battery Based
- Grid Tied

Solar Units

- Watt per meter squared (W/m^2) – Irradiance
- Kilowatt-hour per meter squared per day ($kWh/m^2/day$) – Insolation
- Azimuth (degrees)
- Elevation (degrees)

Global Solar Insolation

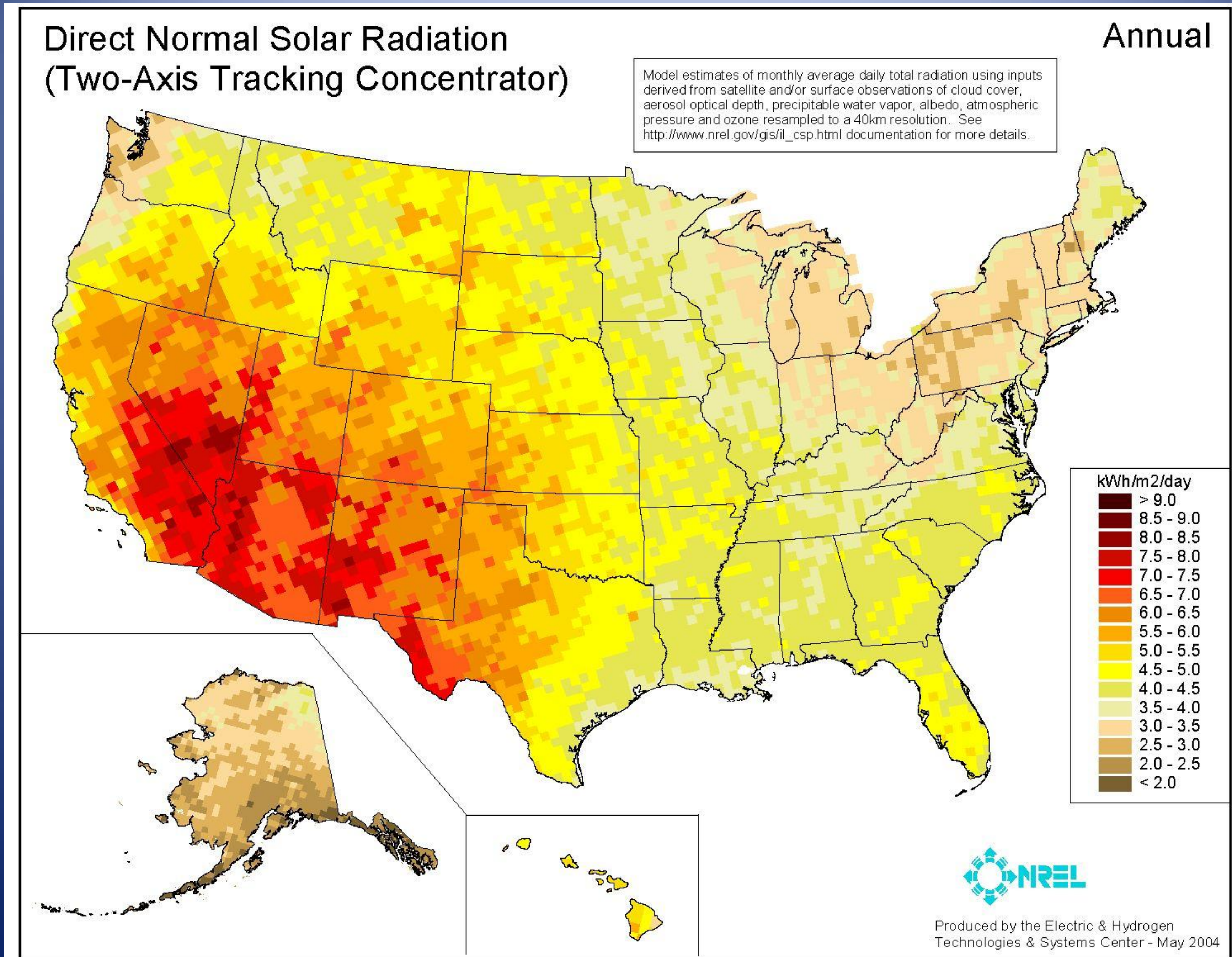




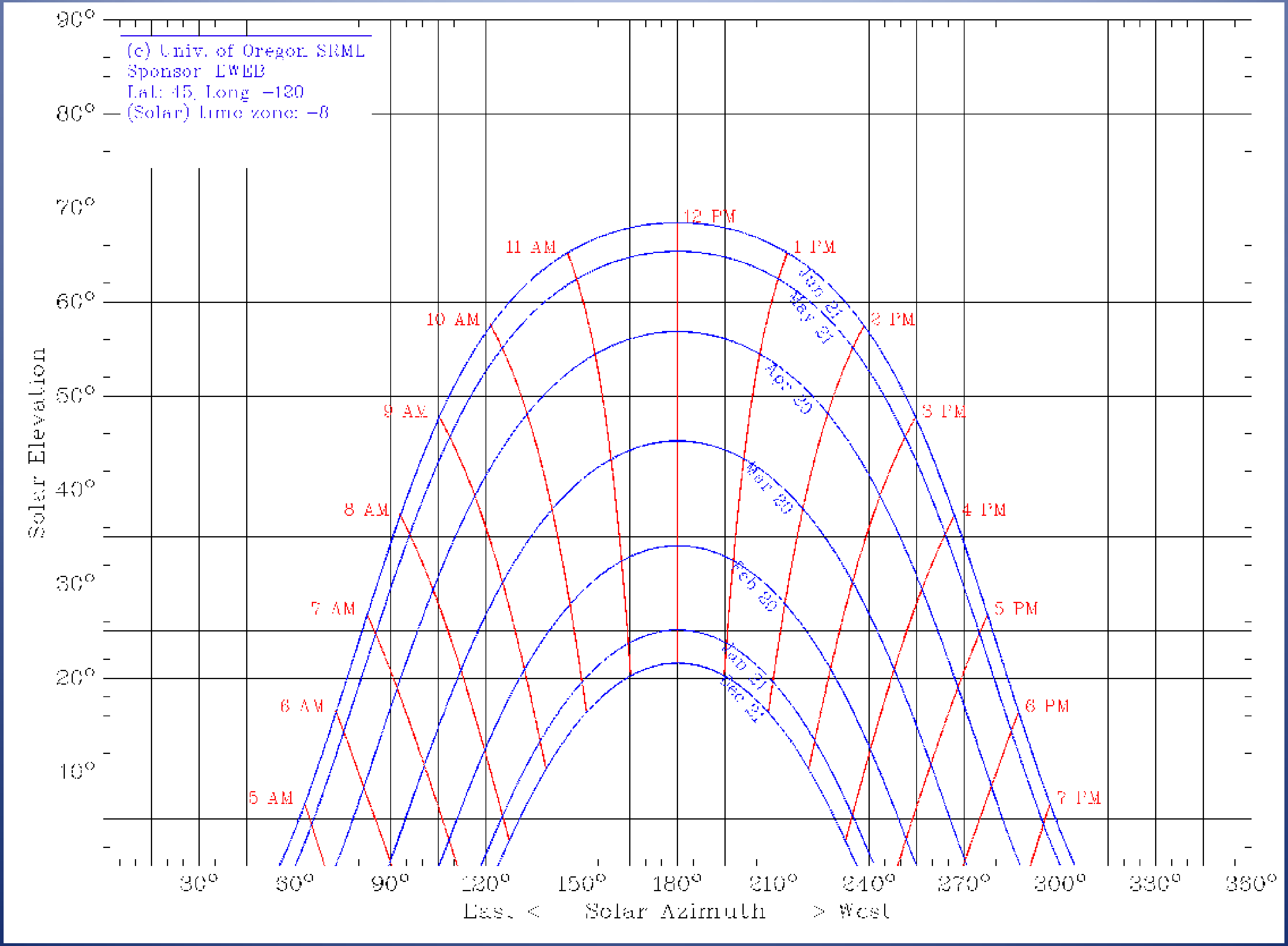
Earth is tilted ~23.5 degrees to its orbital plane.

Vancouver is at 45.6 degrees N. latitude.

Source: http://oceanography.earthednet.org/Mini_Studies/Seasonal_Variations/Seasonal_variations.html

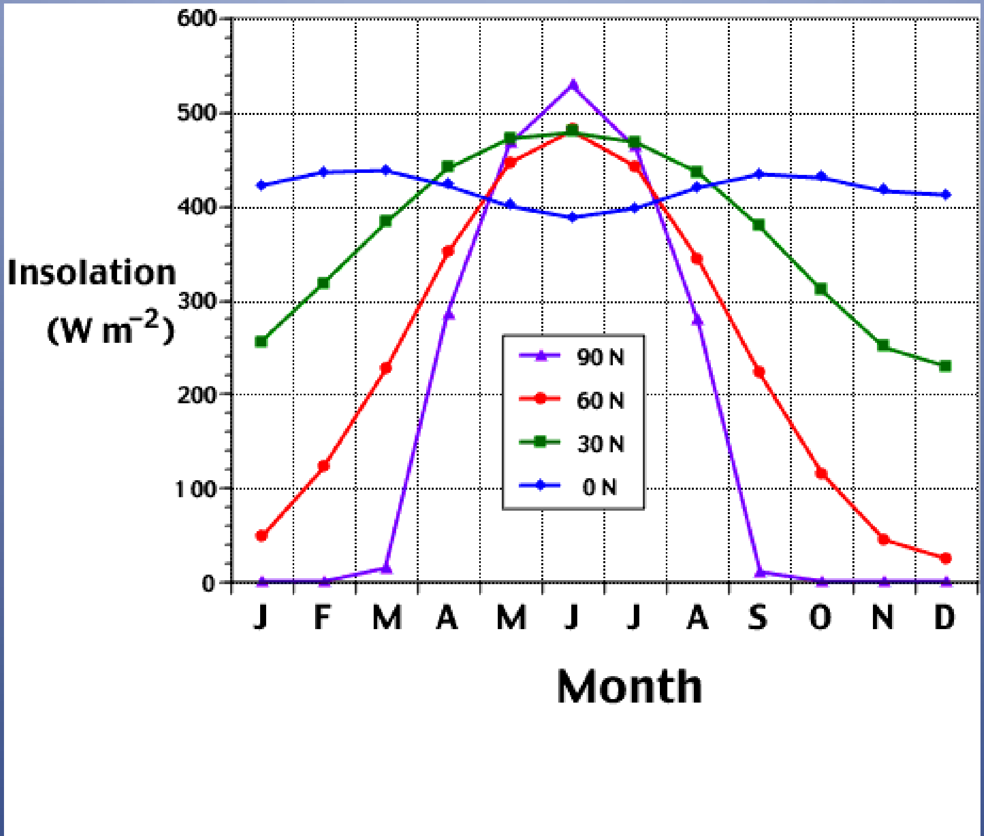

Direct Normal Solar Radiation
(Two-Axis Tracking Concentrator)
Annual
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_csp.html documentation for more details.
kWh/m2/day
> 9.0
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2.0
NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

Sun Charts



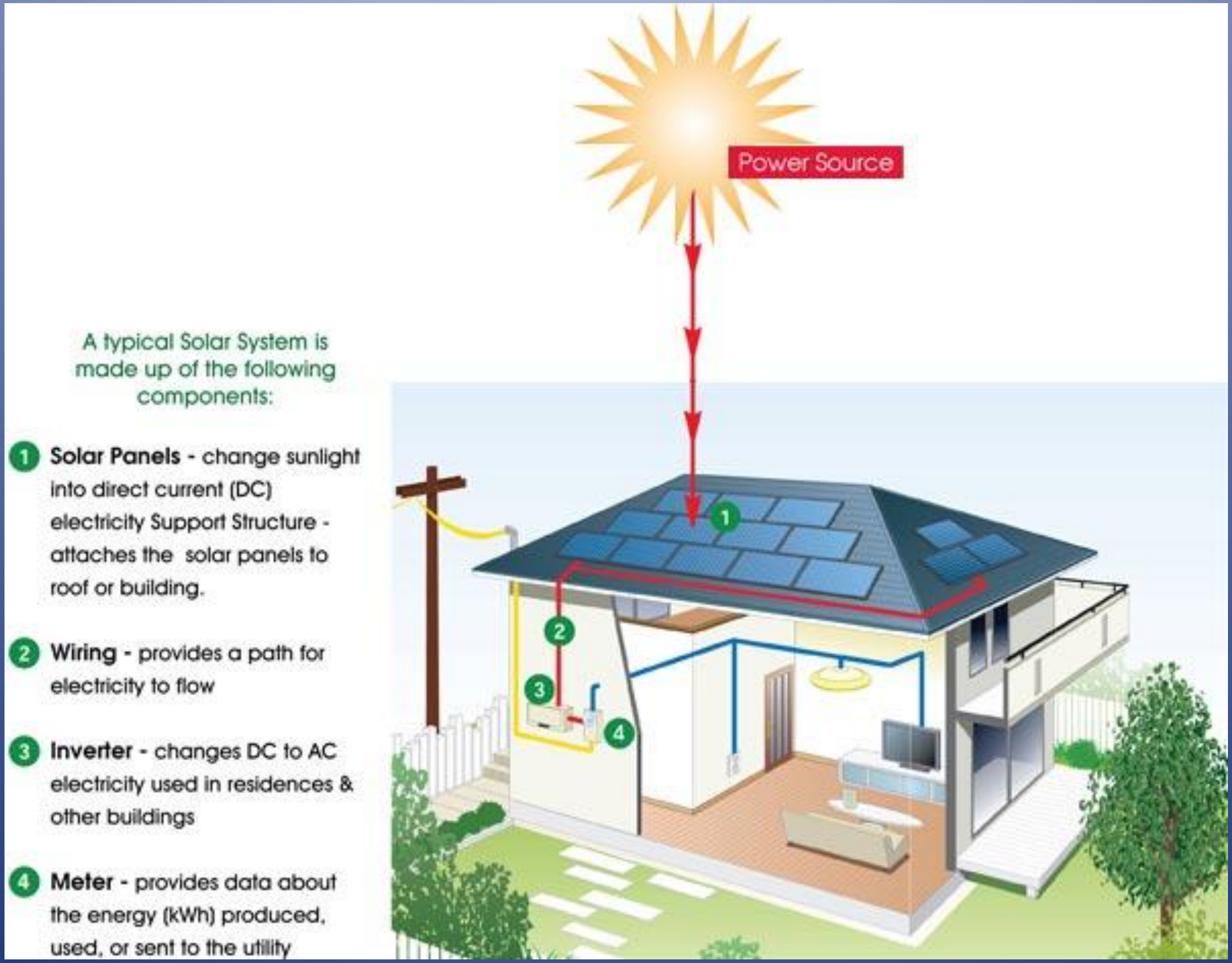
Source: http://solardat.uoregon.edu/SunChartProgram.html

Seasonal & Latitude Effects



Source:
http://oceanography.earthednet.org/Mini_Studies/Seasonal_Variations/Seasonal_variations_files/insolationchart.gif

Typical Residential Grid Tied Solar PV Installation

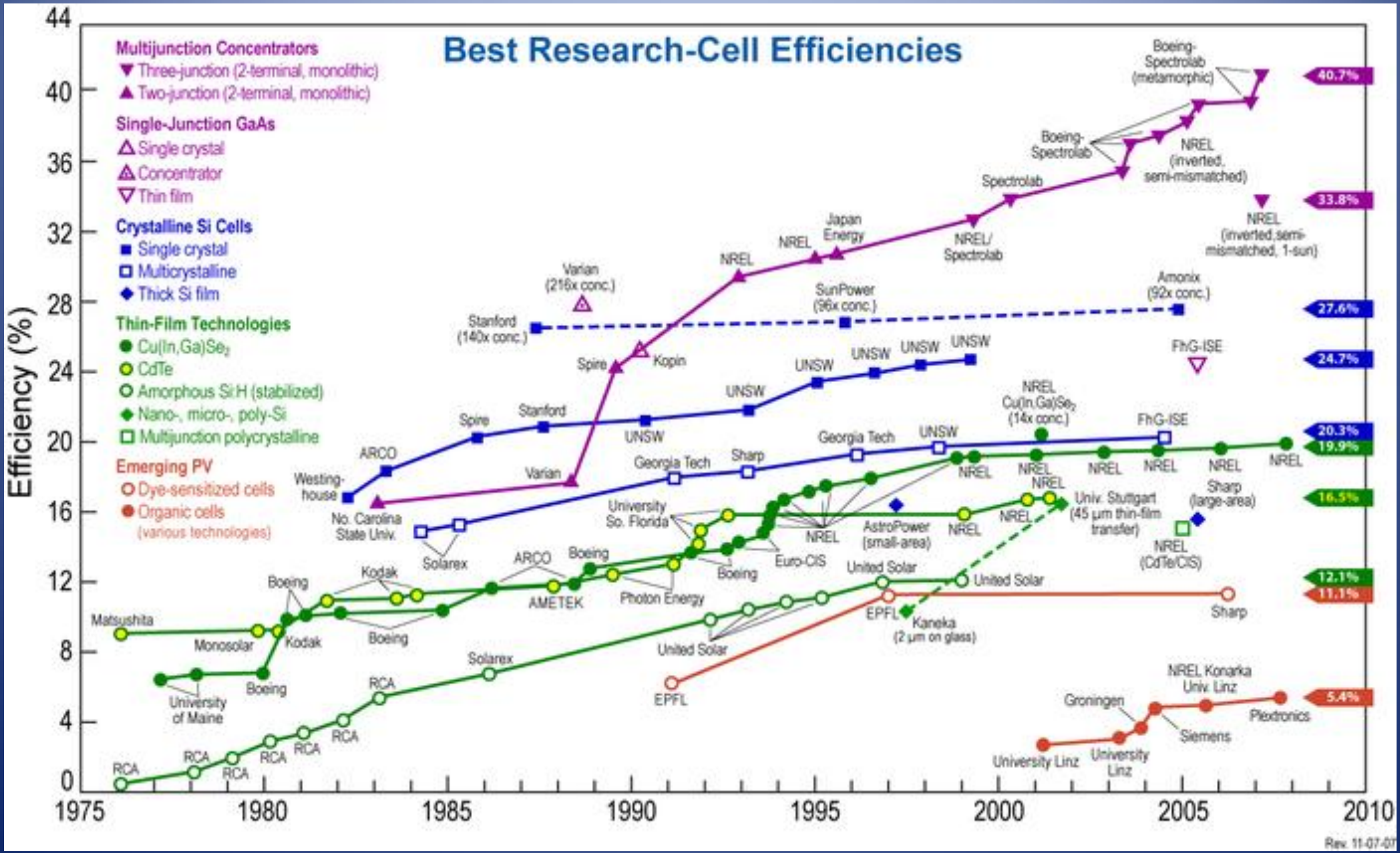


Source: http://us.sanyo.com/Solar/How-Solar-Works

Technologies

- Passive solar and conservation
- Solar hot water
- PV Panels
  - Silicon (Various architectures including spectral filtering)
  - Thin Film & Organic
  - Nano technology
- Solar Concentrators:
  - to fluid
  - to PV
  - to Stirling Engine & Generator
- Control Systems – Sun trackers
- Inverters
- Grid tied vs. Battery
- Monitoring

Fun Facts: First observation of PV effect was in 1839 by a French physicist. First solar cell constructed in 1883. Einstein explained in 1905. Modern solar cell patented in 1946.



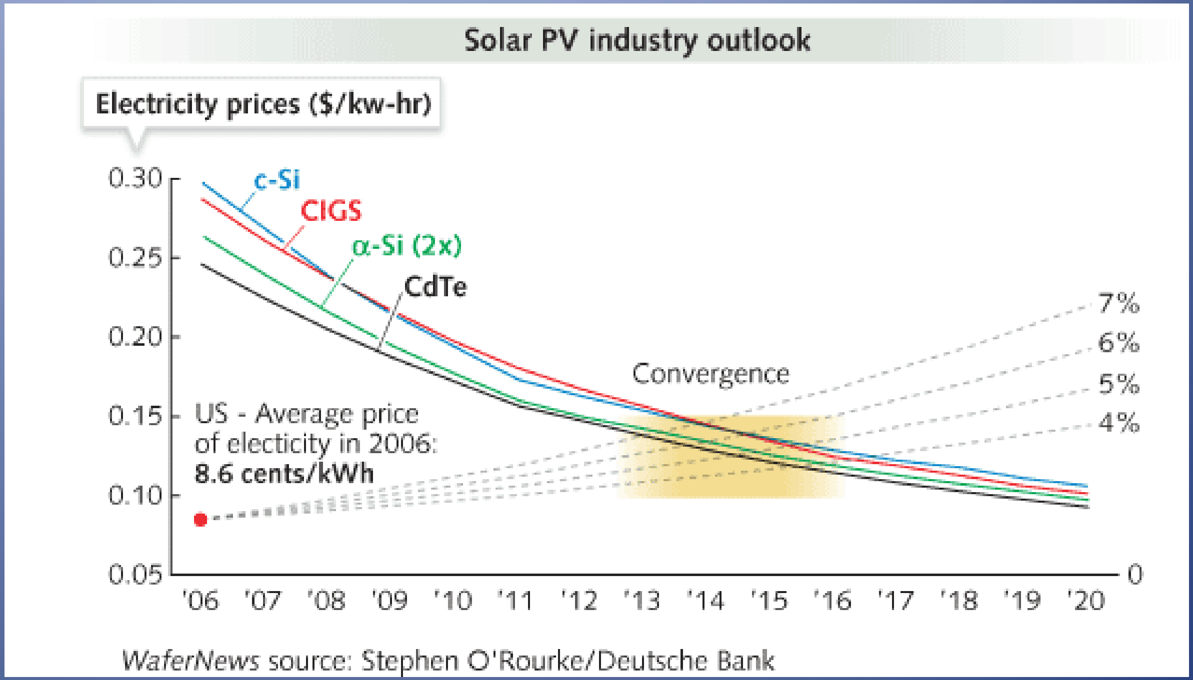
Souce: http://en.wikipedia.org/wiki/Solar_cell

Economic Drivers

- Technology Learning Curves & Demand
- Cost of Energy Alternatives
- Environmental Considerations
- Federal Tax Credits
- State Credits
- PUD Offsets

Residential Cost per kWh

	Cents/kWh
• Germany[2]	30.66
• Hawaii[1]	26.45
• Connecticut[1]	20.78
• UK [2]	18.59
• CA [1]	14.08
• US (avg)[1]	11.76
• OR (avg) [1]	8.95
• WA (avg) [1]	7.87
• **Clark County[3]**	**7.65**
• Canada[2]	6.18



Source: 1. http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html (Oct '09)
2. http://en.wikipedia.org/wiki/Electricity_tariff#Price_comparision ('09)
3. Clark PUD (Jan '10)

Case Study: Array Configuration

Primary Array: 54 Sanyo^{TM} HIT210 panels (11,340 W total) 180° Azimuth, 30° Elevation

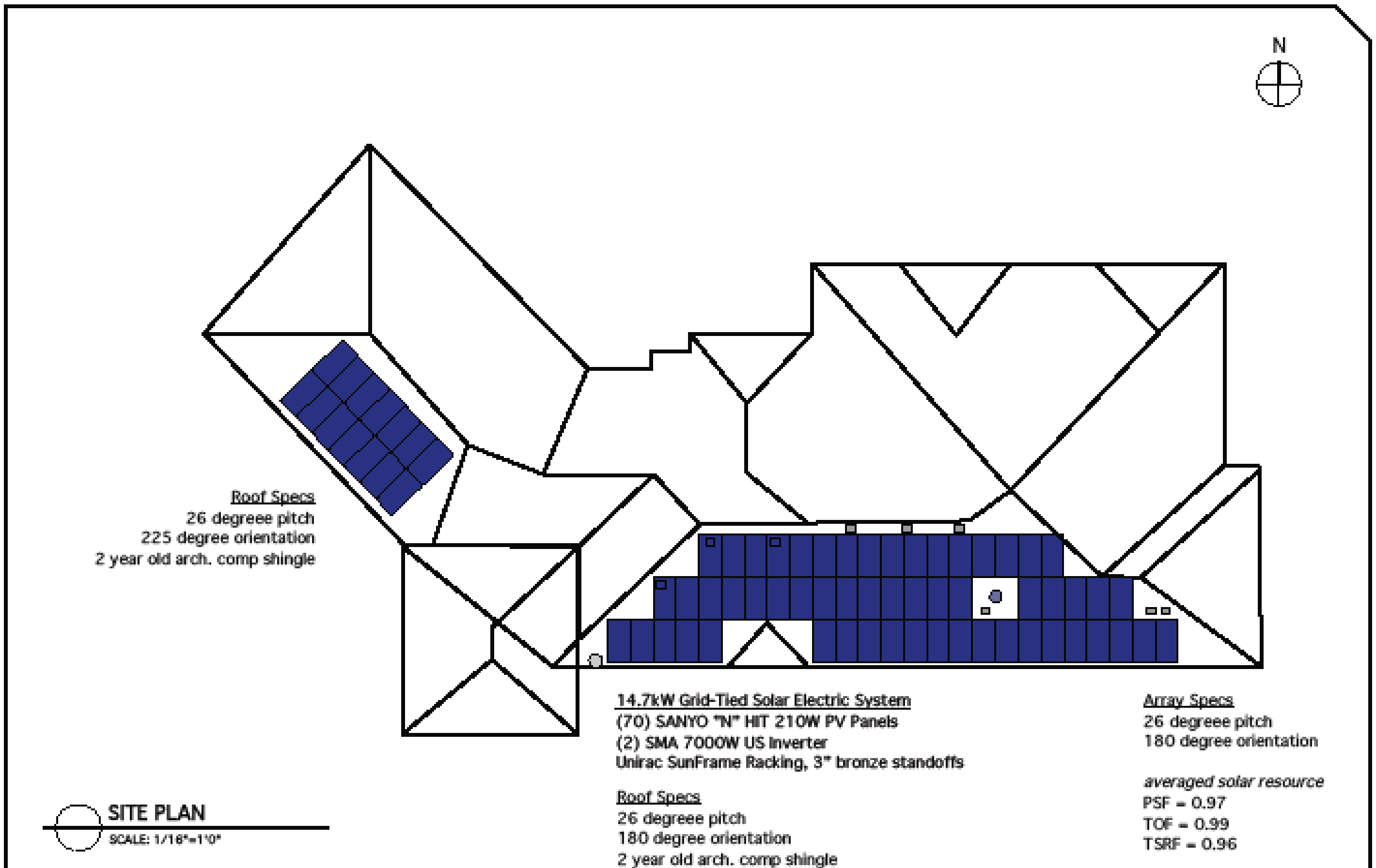
Secondary Array: 14 Sanyo^{TM} HIT210 panels (2,940 W total) 225° Azimuth, 30° Elevation

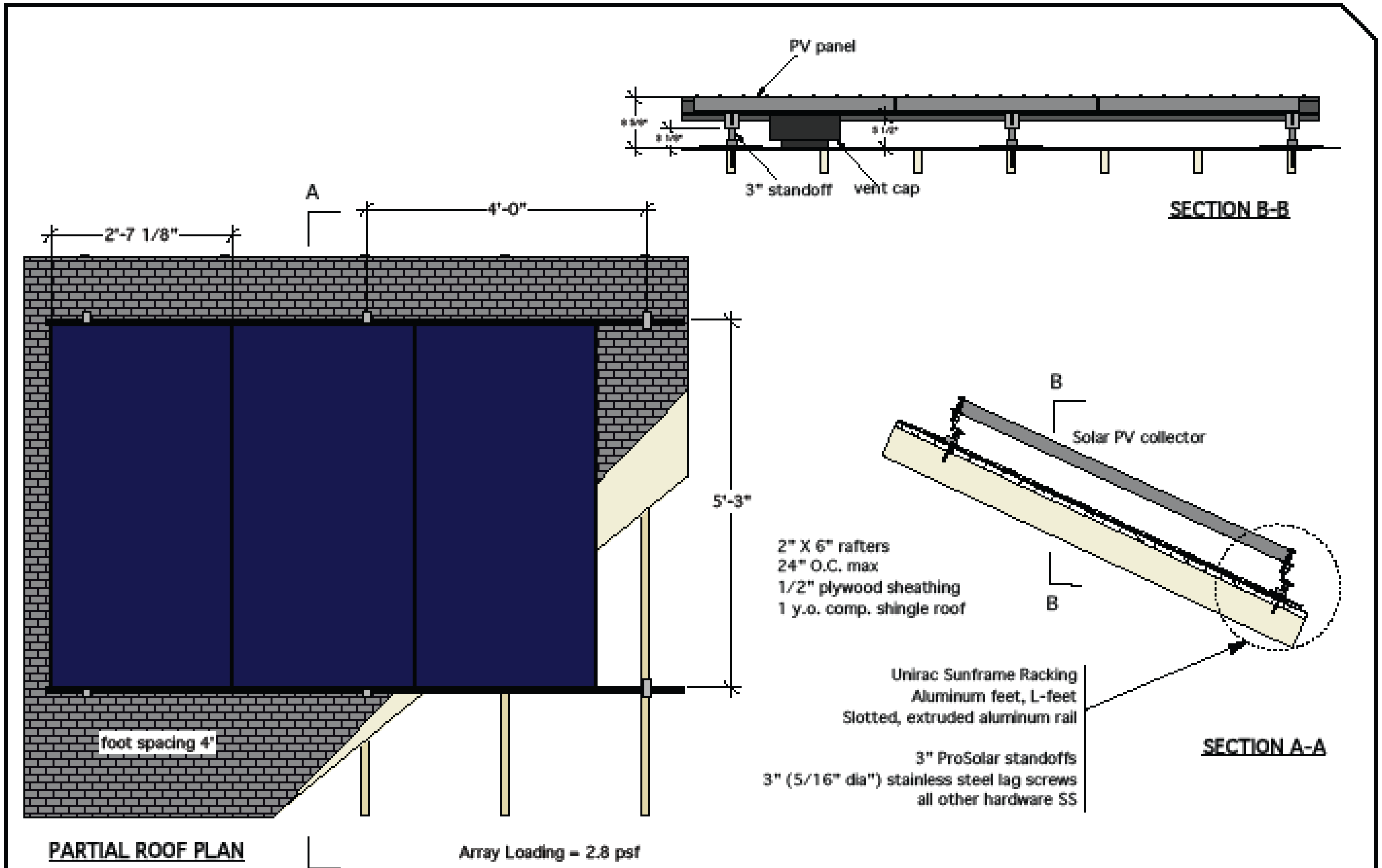
Grid Tie and Monitoring System

Projected average yield: 14,280 kWh per year

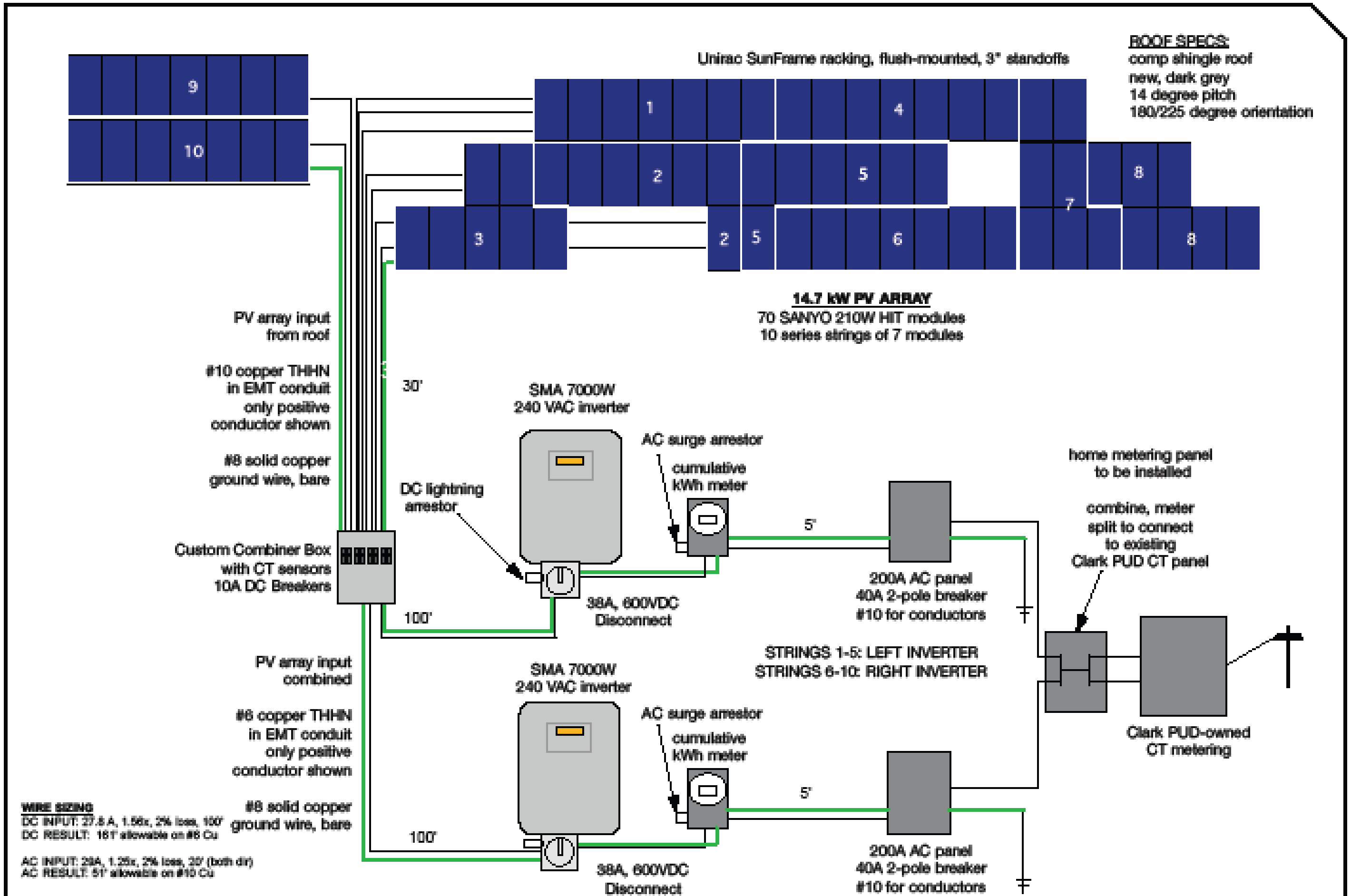
Inverters: SMA™ 7000US, Internet via Obvius Aquisuite™ and DECK™ Monitoring

Production Meters (2) and PUD net meter

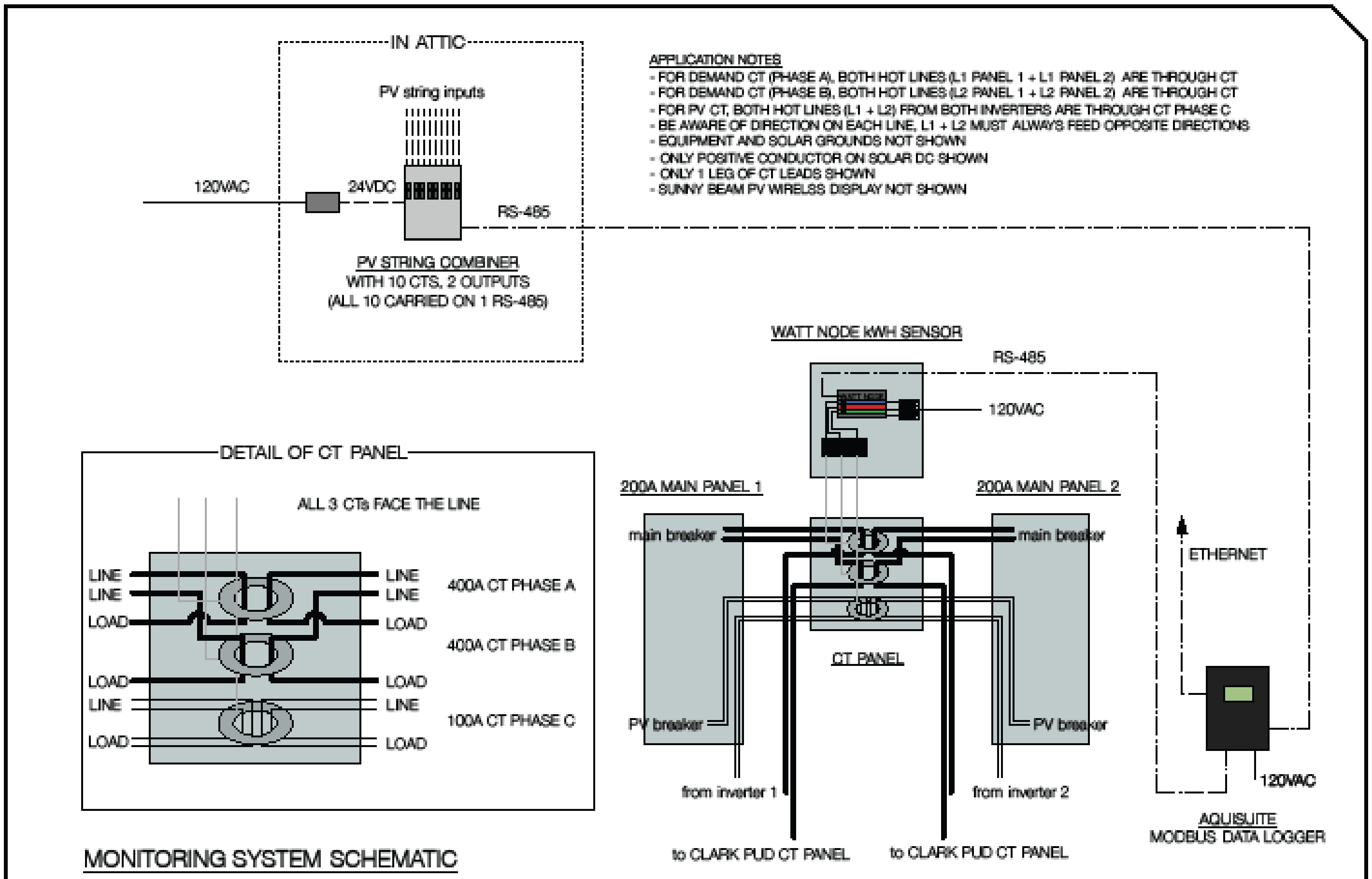

N
Roof Specs
26 degreee pitch
225 degree orientation
2 year old arch. comp shingle
14.7kW Grid-Tied Solar Electric System
(70) SANYO "N" HIT 210W PV Panels
(2) SMA 7000W US Inverter
Unirac SunFrame Racking, 3" bronze standoffs
Roof Specs
26 degreee pitch
180 degree orientation
2 year old arch. comp shingle
Array Specs
26 degreee pitch
180 degree orientation
averaged solar resource
PSF = 0.97
TOF = 0.99
TSRF = 0.96
SITE PLAN
SCALE: 1/16"=1'0"



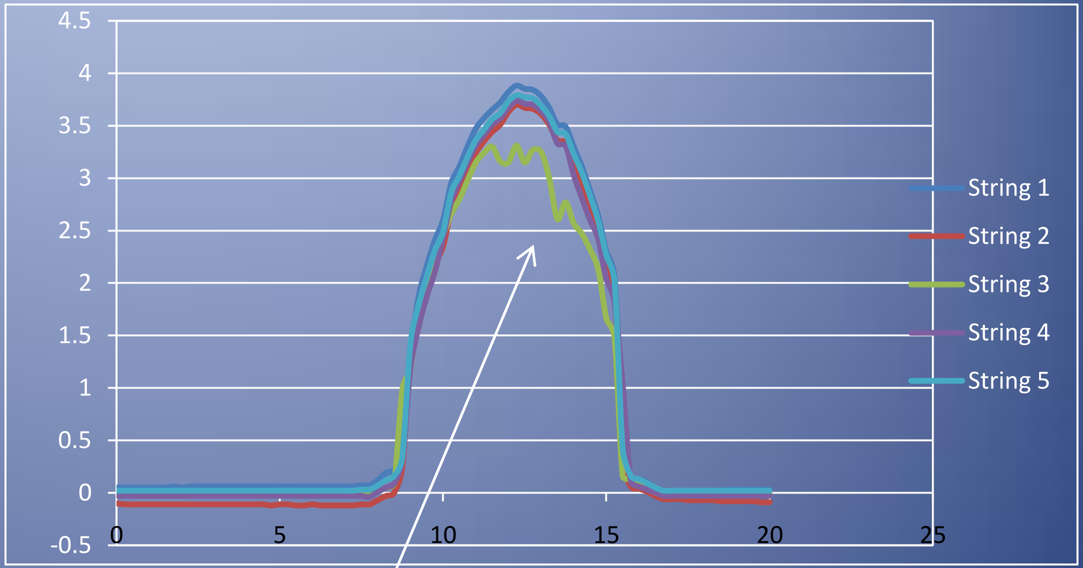
PV panel
3" standoff
vent cap
SECTION B-B
A
2'-7 1/8"
4'-0"
5'-3"
foot spacing 4'
PARTIAL ROOF PLAN
Array Loading = 2.8 psf
B
Solar PV collector
2" X 6" rafters
24" O.C. max
1/2" plywood sheathing
1 y.o. comp. shingle roof
B
Unirac Sunframe Racking
Aluminum feet, L-feet
Slotted, extruded aluminum rail
3" ProSolar standoffs
3" (5/16" dia") stainless steel lag screws
all other hardware SS
SECTION A-A



ROOF SPECS:
comp shingle roof
new, dark grey
14 degree pitch
180/225 degree orientation
Unirac SunFrame racking, flush-mounted, 3" standoffs
9
10
1
4
2
5
7
8
3
2
5
6
8
14.7 kW PV ARRAY
70 SANYO 210W HIT modules
10 series strings of 7 modules
PV array input from roof
#10 copper THHN in EMT conduit only positive conductor shown
#8 solid copper ground wire, bare
30'
SMA 7000W 240 VAC inverter
AC surge arrestor
cumulative kWh meter
DC lightning arrestor
home metering panel to be installed
combine, meter split to connect to existing Clark PUD CT panel
5'
Custom Combiner Box with CT sensors 10A DC Breakers
100'
38A, 600VDC Disconnect
200A AC panel
40A 2-pole breaker
#10 for conductors
STRINGS 1-5: LEFT INVERTER
STRINGS 6-10: RIGHT INVERTER
PV array input combined
#6 copper THHN in EMT conduit only positive conductor shown
SMA 7000W 240 VAC inverter
AC surge arrestor
cumulative kWh meter
Clark PUD-owned CT metering
5'
#8 solid copper ground wire, bare
WIRE SIZING
DC INPUT: 27.8 A, 1.56x, 2% loss, 100'
DC RESULT: 161' allowable on #6 Cu
AC INPUT: 29A, 1.25x, 2% loss, 20' (both dir)
AC RESULT: 51' allowable on #10 Cu
100'
38A, 600VDC Disconnect
200A AC panel
40A 2-pole breaker
#10 for conductors

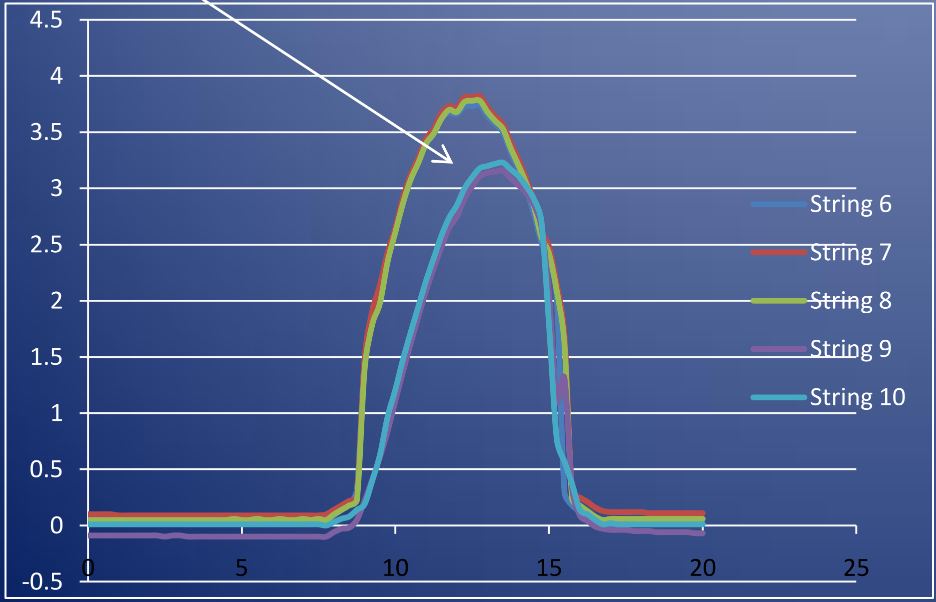

IN ATTIC
PV string inputs
120VAC
24VDC
RS-485
PV STRING COMBINER
WITH 10 CTS, 2 OUTPUTS
(ALL 10 CARRIED ON 1 RS-485)
APPLICATION NOTES
- FOR DEMAND CT (PHASE A), BOTH HOT LINES (L1 PANEL 1 + L1 PANEL 2) ARE THROUGH CT
- FOR DEMAND CT (PHASE B), BOTH HOT LINES (L2 PANEL 1 + L2 PANEL 2) ARE THROUGH CT
- FOR PV CT, BOTH HOT LINES (L1 + L2) FROM BOTH INVERTERS ARE THROUGH CT PHASE C
- BE AWARE OF DIRECTION ON EACH LINE, L1 + L2 MUST ALWAYS FEED OPPOSITE DIRECTIONS
- EQUIPMENT AND SOLAR GROUNDS NOT SHOWN
- ONLY POSITIVE CONDUCTOR ON SOLAR DC SHOWN
- ONLY 1 LEG OF CT LEADS SHOWN
- SUNNY BEAM PV WIRELSS DISPLAY NOT SHOWN
WATT NODE kWH SENSOR
RS-485
120VAC
DETAIL OF CT PANEL
ALL 3 CTs FACE THE LINE
LINE
LINE
LOAD
LINE
LINE
LOAD
400A CT PHASE A
400A CT PHASE B
LOAD
LINE
LOAD
LOAD
LINE
LOAD
100A CT PHASE C
200A MAIN PANEL 1
200A MAIN PANEL 2
main breaker
main breaker
ETHERNET
CT PANEL
PV breaker
PV breaker
from inverter 1
from inverter 2
120VAC
AQUISUITE
MODBUS DATA LOGGER
to CLARK PUD CT PANEL
to CLARK PUD CT PANEL
MONITORING SYSTEM SCHEMATIC

Typical String Level Data (DC Amps)

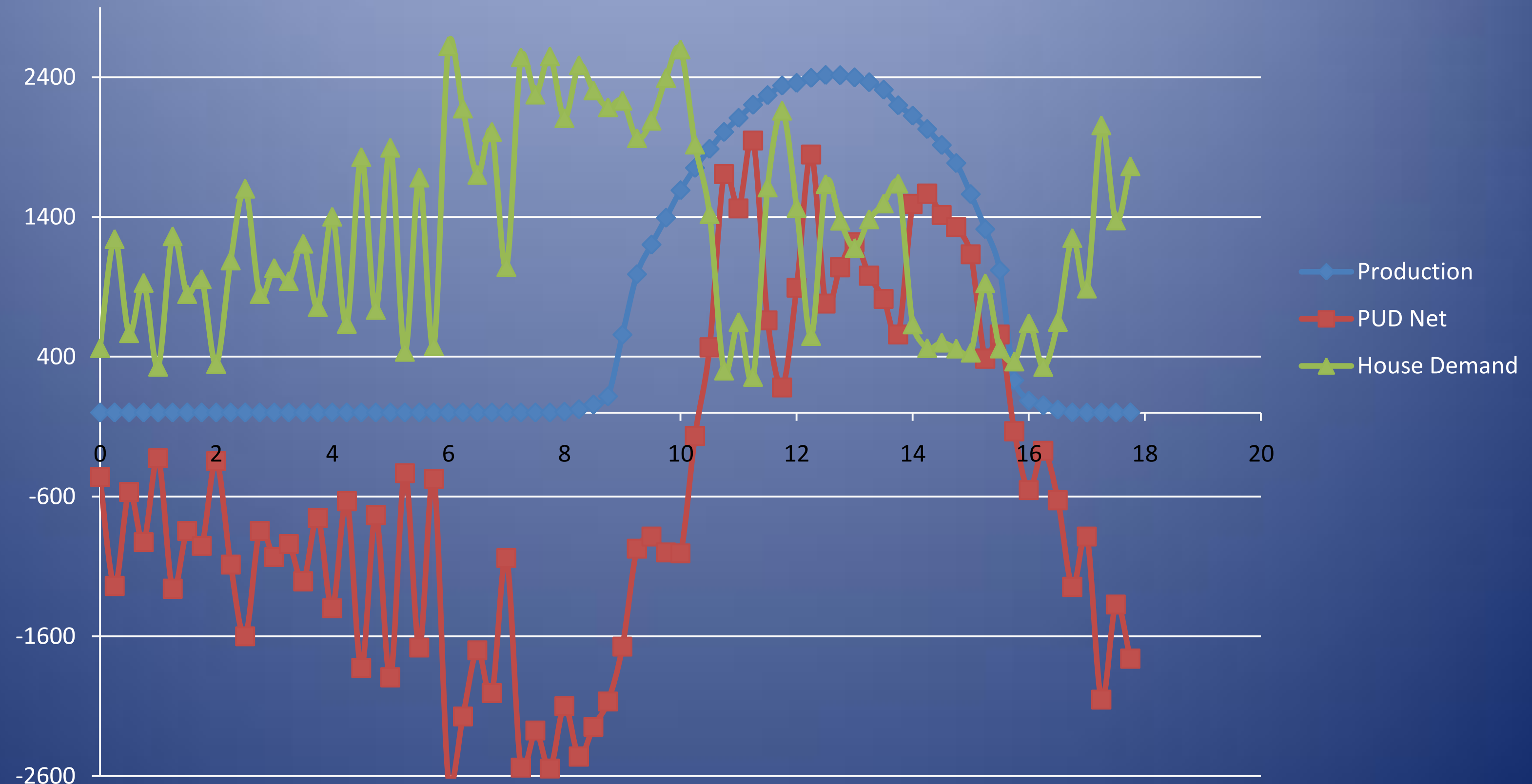


Note lower output from shaded panel

Note delayed output from SW pointing panels

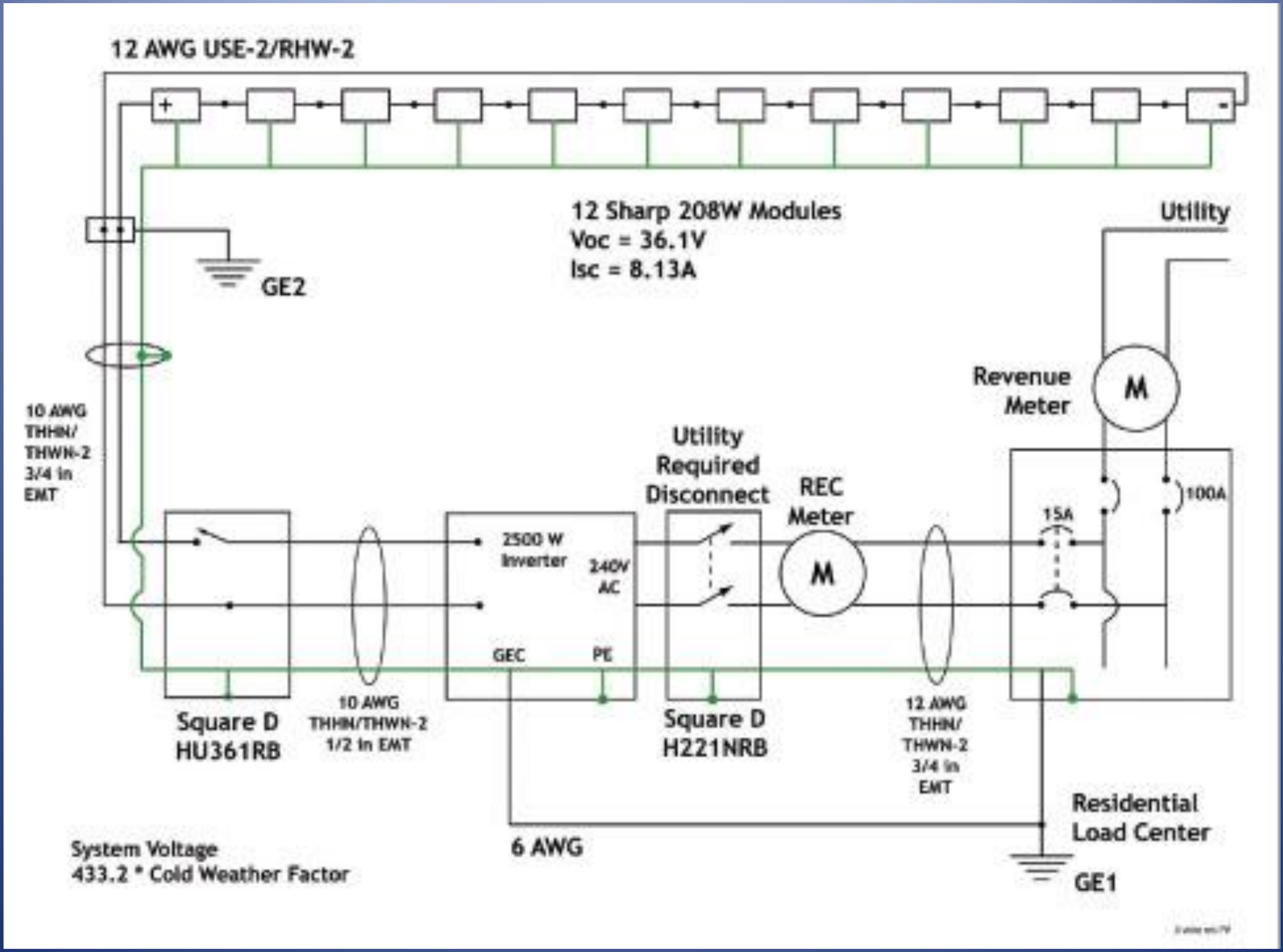


Typical Line Level Data (AC kWh)

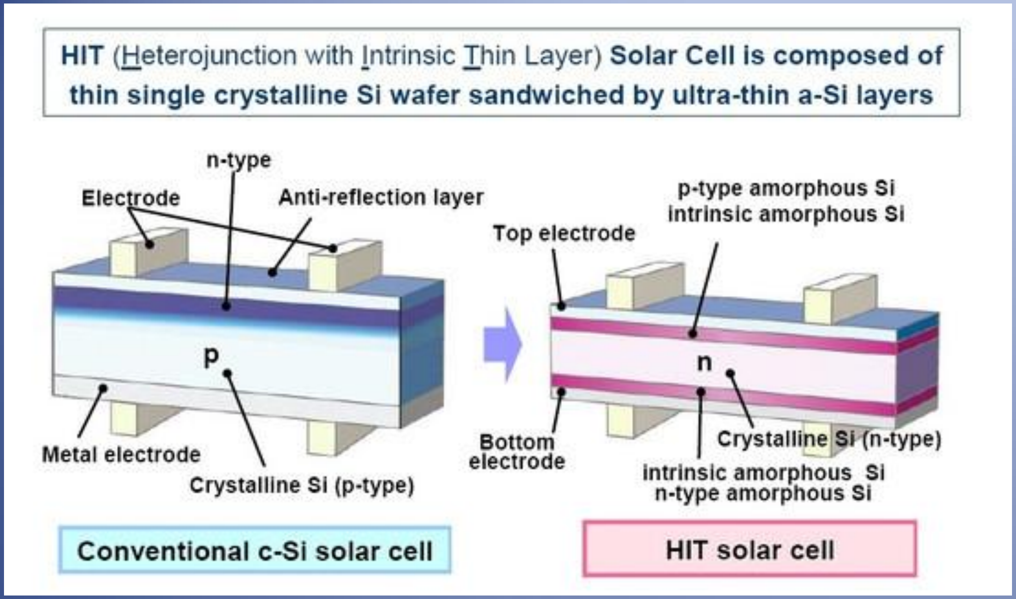


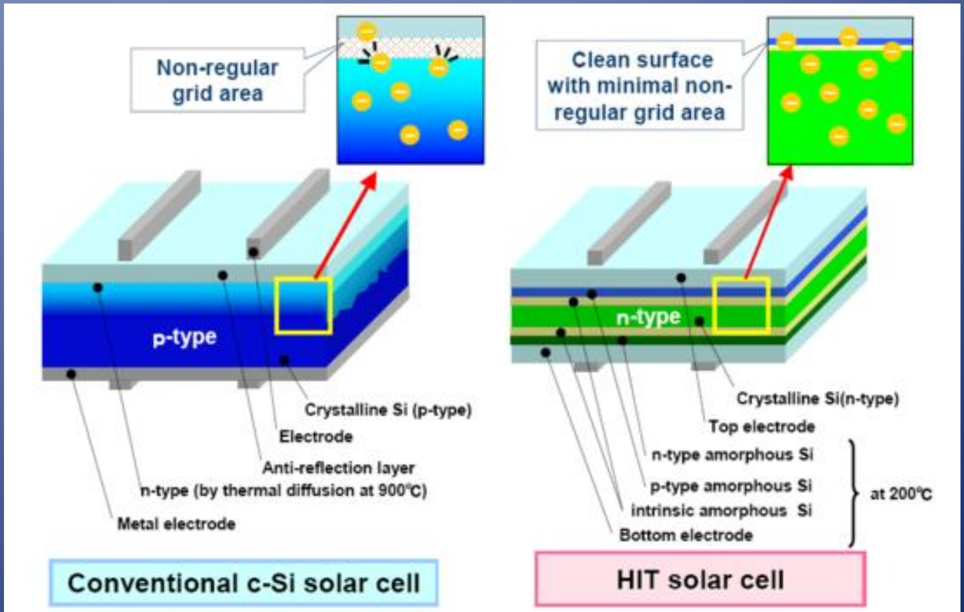
Energy Transfer & Loss Considerations

- Sun to Panel Exchange
  - Weather
  - Season
  - Shading
  - Latitude
- Panels
  - Technology efficiency
  - Heat
  - Age
- String configuration
  - Panels per string & number of strings (voltage sag vs inverter operation range)
- Panel to Inverter
  - Line losses
- Inverter
  - Conversion losses
- Inverter to Grid
  - Line losses

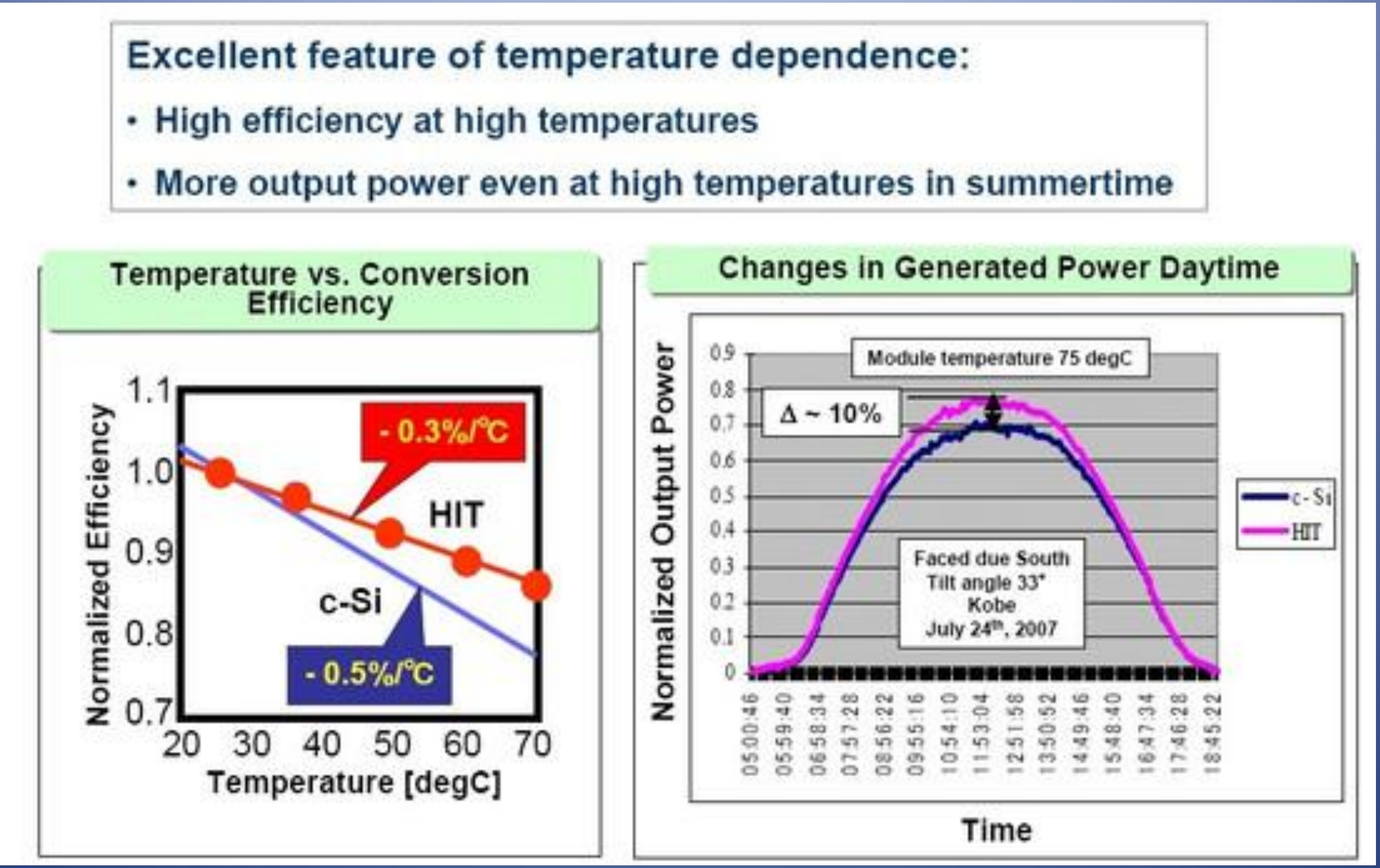


http://www.iaei.org/magazine/wp-content/uploads/2009/05/07dwiles_figure1_118979159.jpg





Source: http://us.sanyo.com/Solar/SANYO-HIT-Technology



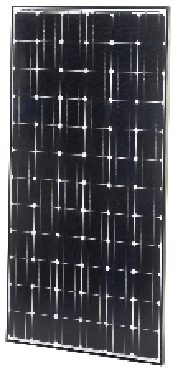
Soruce: http://us.sanyo.com/Solar/SANYO-HIT-Technology

Think GAIA
For Life and the Earth

SANYO

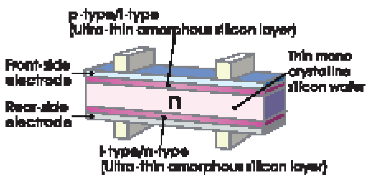
HIT Photovoltaic Module

HIT Power 210N
Photovoltaic Module



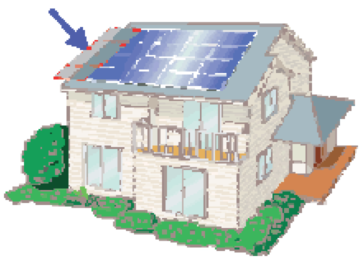
Module Efficiency: 16.7%
Cell Efficiency: 18.9%
Power Output - 210 Watts

SANYO HIT® Solar Cell Structure



SANYO'S Proprietary Technology
HIT solar cells are hybrids of mono crystalline silicon surrounded by ultra-thin amorphous silicon layers, and are available solely from SANYO.

Unnecessary Section When Using SANYO



High Efficiency
HIT® Power solar panels are leaders in sunlight conversion efficiency. Obtain maximum power within a fixed amount of space. Save money using fewer system attachments and racking materials, and reduce costs by spending less time installing per watt. HIT Power models are ideal for grid-connected solar systems, areas with performance based incentives, and renewable energy credits.

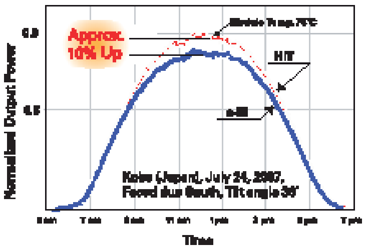
Power Guarantee
SANYO's power ratings for HIT Power panels guarantee customers receive 100% of the nameplate rated power (or more) at the time of purchase, enabling owners to generate more kWh per rated watt, quicken investments returns, and help realize complete customer satisfaction.

Temperature Performance
As temperatures rise, HIT Power solar panels produce 10% or more electricity (kWh) than conventional crystalline silicon solar panels at the same temperature.

Valuable Features
The packing density of the panels reduces transportation, fuel, and storage costs per installed watt.

Quality Products Made in USA
SANYO silicon wafers located inside HIT solar panels are made in California and Oregon (from October 2009), and the panels are assembled in an ISO 9001 (quality), 14001 (environment), and 18001 (safety) certified factory. Unique eco-packing minimizes cardboard waste at the job site. The panels have a Limited 20-Year Power Output and 5-Year Product Workmanship Warranty.

Increased Performance with SANYO



Source: http://us.sanyo.com/dynamic/product/Downloads/Solar%20Sales%20Sheets%20210N-23881117.pdf

HIT Power 210N

Electrical Specifications

Model	HIT Power 210N or HIP-210NKHA5
Rated Power (Pmax)[1]	210 W
Maximum Power Voltage (Vpm)	41.3 V
Maximum Power Current (Ipm)	5.09 A
Open Circuit Voltage (Voc)	50.9 V
Short Circuit Current (Isc)	5.57 A
Temperature Coefficient (Pmax)	-0.336%/ °C
Temperature Coefficient (Voc)	-0.142 V/ °C
Temperature Coefficient (Isc)	1.95 mA/ °C
NOCT	114.8°F (46°C)
CEC PTC Rating	194.8 W
Cell Efficiency	18.9%
Module Efficiency	16.7%
Watts per Ft.²	15.48 W
Maximum System Voltage	600 V
Series Fuse Rating	15 A
Warranted Tolerance (-/+)	-0% / +10%

Mechanical Specifications

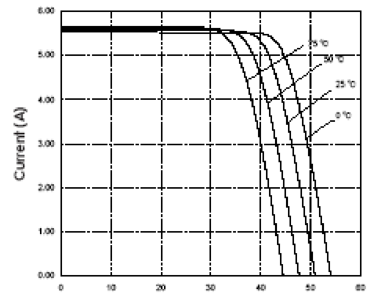
Internal Bypass Diodes	3 Bypass Diodes
Module Area	13.96 Ft² (1.26m²)
Weight	35.3 Lbs. (16kg)
Dimensions LxWxH	62.2x31.4x1.8 in. (1580x798x46 mm)
Cable Length +Male/-Female	40.55/34.6 in. (1030/880 mm)
Cable Size / Connector Type	No. 12 AWG / MC4™ Locking Connectors
Static Wind / Snow Load	60PSF (2880Pa) / 39PSF (1867Pa)
Pallet Dimensions LxWxH	63.2x32x72.8 in. (1607x815x1850 mm)
Quantity per Pallet / Pallet Weight	34 pcs./1234.5 Lbs (560 kg)
Quantity per 53' Trailer	952 pcs.

Operating Conditions & Safety Ratings

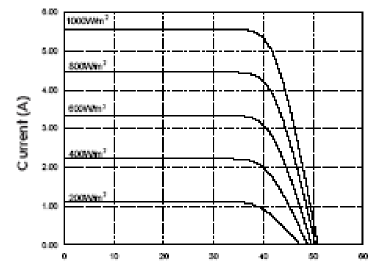
Ambient Operating Temperature	-4°F to 115°F (-20°C to 46°C)[2]
Hail Safety Impact Velocity	1" hailstone (25mm) at 52 mph (23m/s)
Fire Safety Classification	Class C
Safety & Rating Certifications	UL 1703, cUL, CEC
Limited Warranty	5 Years Workmanship, 20 Years Power Output

[1]STC: Cell temp. 25°C, AM1.5, 1000W/m² [2]Monthly average low and high of the installation site.
Note: Specifications and information above may change without notice.

Dependence on Temperature

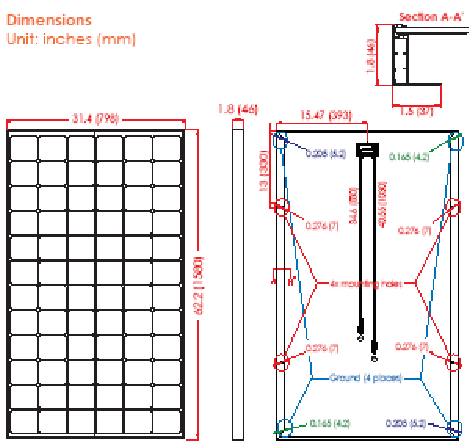


Dependence on Irradiance



Dimensions

Unit: inches (mm)

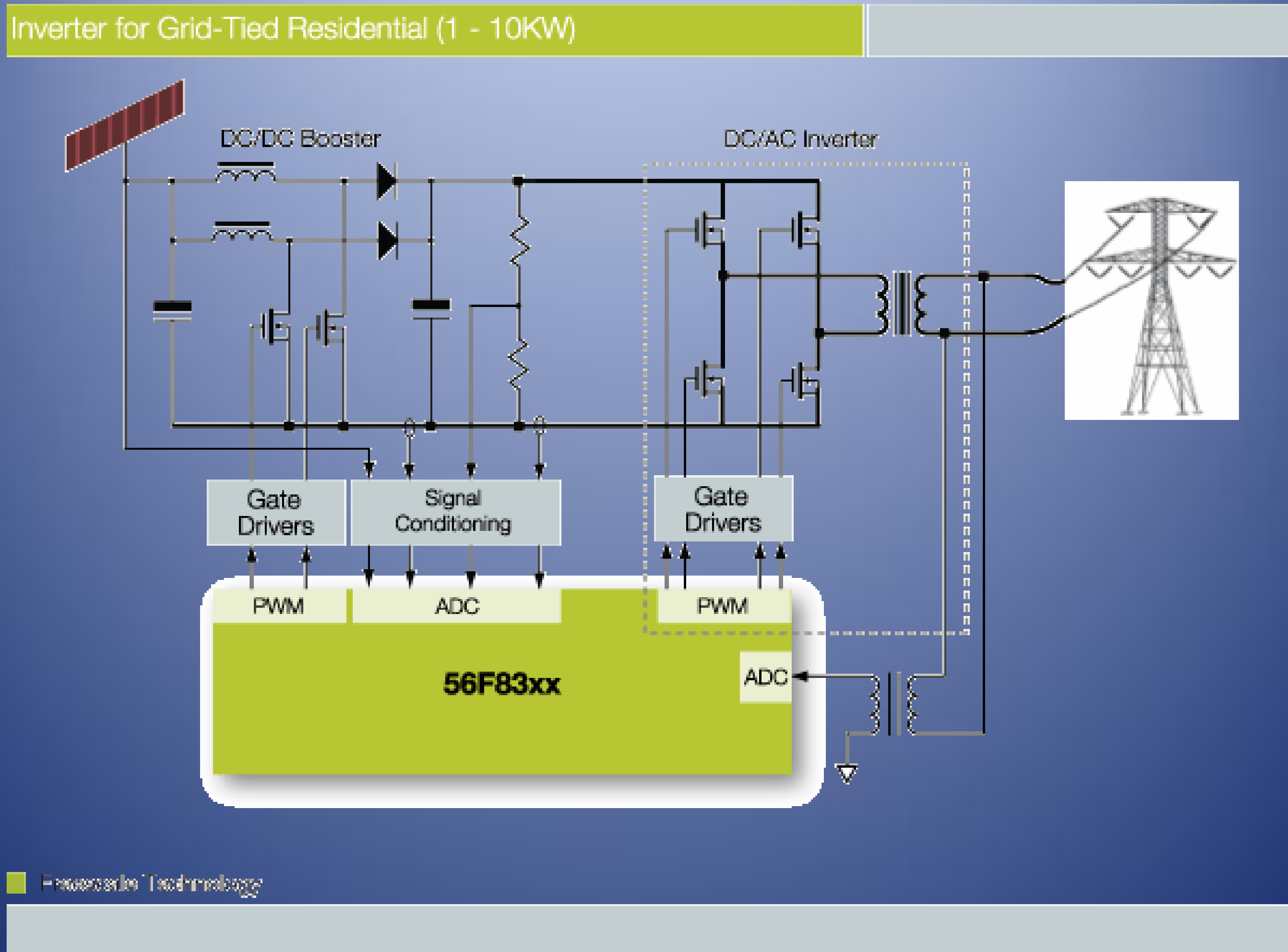


CAUTION!

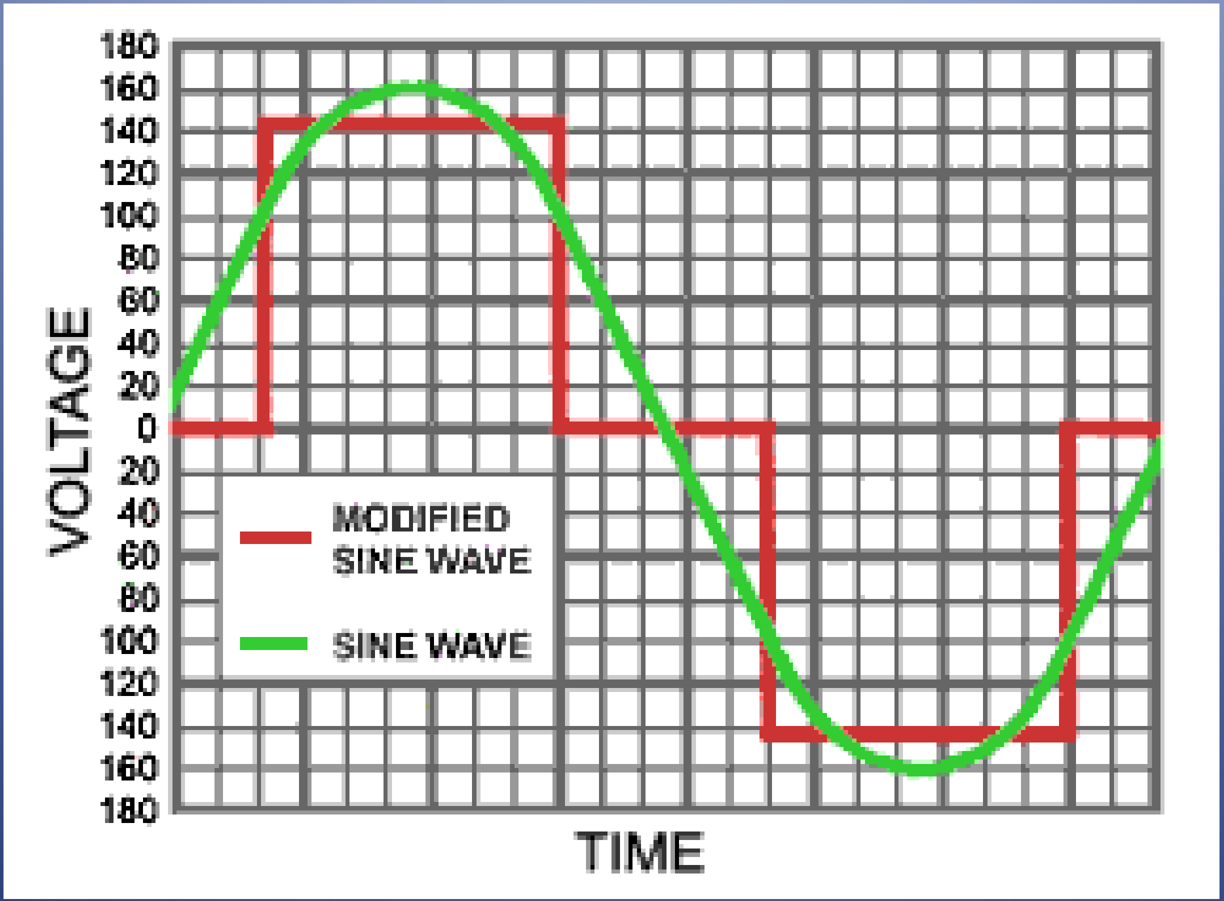
SANYO

SANYO Energy (U.S.A.) Corp.
Solar Division

Source:
http://us.sanyo.com/dynamic/product/Downloads/Solar%20Sales%20Sheets%20210N-23881117.pdf



http://www.electro-tech-online.com/attachments/alternative-energy/29058d1241912600-grid-tie
schematic-pvengsol_1_10kw_bd.gif

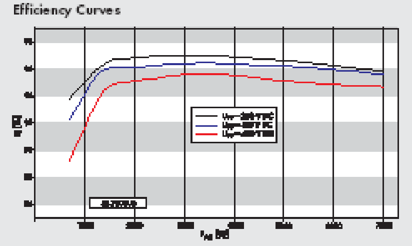


http://www.absak.com/images/waveforms.gif

Technical Data

	SB 5000US	SB 6000US	SB 7000US	SB 8000US
Recommended Maximum PV Power (Module STC)	6250 W	7500 W	8750 W	10000 W
DC Maximum Voltage	600 V	600 V	600 V	600 V
Peak Power Tracking Voltage	250–480 V	250–480 V	250–480 V	300–480 V
DC Maximum Input Current	21 A	25 A	30 A	30 A
Number of Fused String Inputs	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)
PV Start Voltage	300 V	300 V	300 V	365 V
AC Nominal Power	5000 W	6000 W	7000 W	8000 W
AC Maximum Output Power	5000 W	6000 W	7000 W	8000 W
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 21 A, 18 A	29 A, 25 A, 22 A	34 A, 29 A, 25 A	N/A, 32 A, 29 A
AC Nominal Voltage Range	183 - 229 V @ 208 V 211 - 264 V @ 240 V 244 - 305 V @ 277 V	183 - 229 V @ 208 V 211 - 264 V @ 240 V 244 - 305 V @ 277 V	183 - 229 V @ 208 V 211 - 264 V @ 240 V 244 - 305 V @ 277 V	N/A @ 208 V 211 - 264 V @ 240 V 244 - 305 V @ 277 V
AC Frequency: nominal / range	60 Hz / 59.3 - 60.5 Hz	60 Hz / 59.3 - 60.5 Hz	60 Hz / 59.3 - 60.5 Hz	60 Hz / 59.3 - 60.5 Hz
Power Factor (Nominal)	0.99	0.99	0.99	0.99
Peak Inverter Efficiency	96.8%	97.0%	97.1%	96.5%
CEC Weighted Efficiency	95.5% @ 208 V 95.5% @ 240 V 95.5% @ 277 V	95.5% @ 208 V 95.5% @ 240 V 96.0% @ 277 V	95.5% @ 208 V 96.0% @ 240 V 96.0% @ 277 V	N/A @ 208 V 96.0% @ 240 V 96.0% @ 277 V
Dimensions: W x H x D in inches	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5
Weight / Shipping Weight	141 lbs / 148 lbs	141 lbs / 148 lbs	141 lbs / 148 lbs	148 lbs / 152 lbs
Ambient Temperature Range	−13 to 113 °F	−13 to 113 °F	−13 to 113 °F	−13 to 113 °F
Power consumption at night	0.1 W	0.1 W	0.1 W	0.1 W
Topology	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave
Cooling Concept	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling
Mounting Location: indoor / outdoor (NEMA 3R)	●/●	●/●	●/●	●/●
LCD Display	●	●	●	●
Communication: RS485 / wireless	○/○	○/○	○/○	○/○
Warranty: 10 years / 15 years / 20 years	●/○/○	●/○/○	●/○/○	●/○/○
Compliance: IEEE-929, IEEE-1547, UL 1741, UL 1998, FCC Part 15 A & B	●	●	●	●
Specifications for nominal conditions	● Included ○ Optional			
NOTE: US inverters ship with grey lids.				

Efficiency Curves



Tel. +1 916 625 0870
Toll Free +1 888 4 SMA USA
www.SMA-America.com

SMA America, LLC

Source: http://download.sma.de/smaprosa/dateien/4752/SUNNYBOY5678-DUS094221.pdf

TABLE 12-2. Construction and Resistances of Standard Class B Concentric Conductors.

Conductor Size		Class B Stranding			Nominal dc Resistance ohms/1000 ft at 25 °C	
Area in Circular Mils	Gauge, AWG Size	Number of Wires	Diameter of wires (mils)	Conductor Diameter (inches)	Bare	Alloy Coated or Tinned
2 000 000		127	125.5	1.632	0.00539	0.00555
1 500 000		91	128.4	1.412	0.00719	0.00740
1 250 000		91	117.2	1.289	0.00863	0.00883
1 000 000		61	128.0	1.152	0.0108	0.0111
750 000		61	110.9	0.998	0.0144	0.0148
600 000		61	99.2	0.893	0.0180	0.0187
500 000		37	116.2	0.813	0.0216	0.0222
400 000		37	104.0	0.728	0.0270	0.0278
350 000		37	97.3	0.681	0.0308	0.0320
300 000		37	90.0	0.630	0.0360	0.0374
250 000		37	82.2	0.573	0.0431	0.0449
211 600	0000	19	105.5	0.528	0.0510	0.0525
167 800	000	19	94.0	0.470	0.0643	0.0669
133 100	00	19	83.7	0.418	0.0811	0.0843
105 600	0	19	74.5	0.373	0.102	0.106
83 690	1	19	66.4	0.332	0.129	0.134
66 360	2	7	97.4	0.292	0.163	0.169
52 620	3	7	86.7	0.260	0.205	0.213
41 740	4	7	77.2	0.232	0.258	0.269
33 090	5	7	68.8	0.206	0.326	0.339
26 240	6	7	61.2	0.184	0.411	0.427
20 820	7	7	54.5	0.164	0.518	0.539
16 510	8	7	48.6	0.146	0.653	0.679
10 380	10	7	38.5	0.116	1.04	1.08
6 530	12	7	30.5	0.092	1.65	1.72
4 110	14	7	24.2	0.073	2.63	2.73
2 580	16	7	19.2	0.058	4.18	4.44
1 620	18	7	15.2	0.046	6.64	7.05
1 020	20	7	12.1	0.036	9.97	10.6
643	22	7	10.0	0.030	16.1	16.7

Source: http://www.claytonengineering.com/Training/myweb6/MElect/FM%2055-509-1%20Chptr%2012%20Electrical%20Conductors.htm

Regulatory Considerations

- Federal
  - Solar Resource
  - Roof Age
- County
  - Mechanical integrity (lift & load)
  - Fire Safety (clear spaces)
- State
  - Worker Safety
  - Approved Electrical Components & Methods (UL)
- PUD
  - Grid Continuity (community obligation)
  - Safety – "Islanding" (Phase & voltage)
  - Economic (preserving revenue stream)
  - Equipment Standardization (cost, service, maintenance)

Other Considerations

- Roof area & orientation
- Esthetics
- Shading
- CC&R’s
- Budget & ROI (Time horizon and assumptions)

Local Solar Base

- "…. 39 installations, of which 17 are residential. Most are solar, there are a few wind generators, a couple hydro and three hybrid wind & solar sites. Total installed capacity is 300 kW" (Clark PUD, Jan 5, 2010)
- Portland Metro Area (Oregon) 457 solar installations, 3.2 MW (oregon.cleanenergymap.com, Jan 20, 2010)

Scale Up

Lieberose Photovoltaic Park: 53 (MW) solar PV power plant in Brandenburg, Germany. 700,000 solar panels. On line 10/2009. Supplies 15,000 households a year. $238M investment.

Source: http://en.wikipedia.org/wiki/Lieberose_Photovoltaic_Park

For More Information

- **Clark PUD:** *www.**clark**publicutilities.com*
- **Oregon Energy Trust:** www.***energytrust***.*org*
- **Database of state incentives**: *www.dsireusa.org*
- **Solar Oregon:** http://www.solaroregon.org
- **Oregon clean energy map: h**ttp://oregon.cleanenergymap.com
- **Home Power Magazine:** w*ww.**homepower**.com*

Questions?