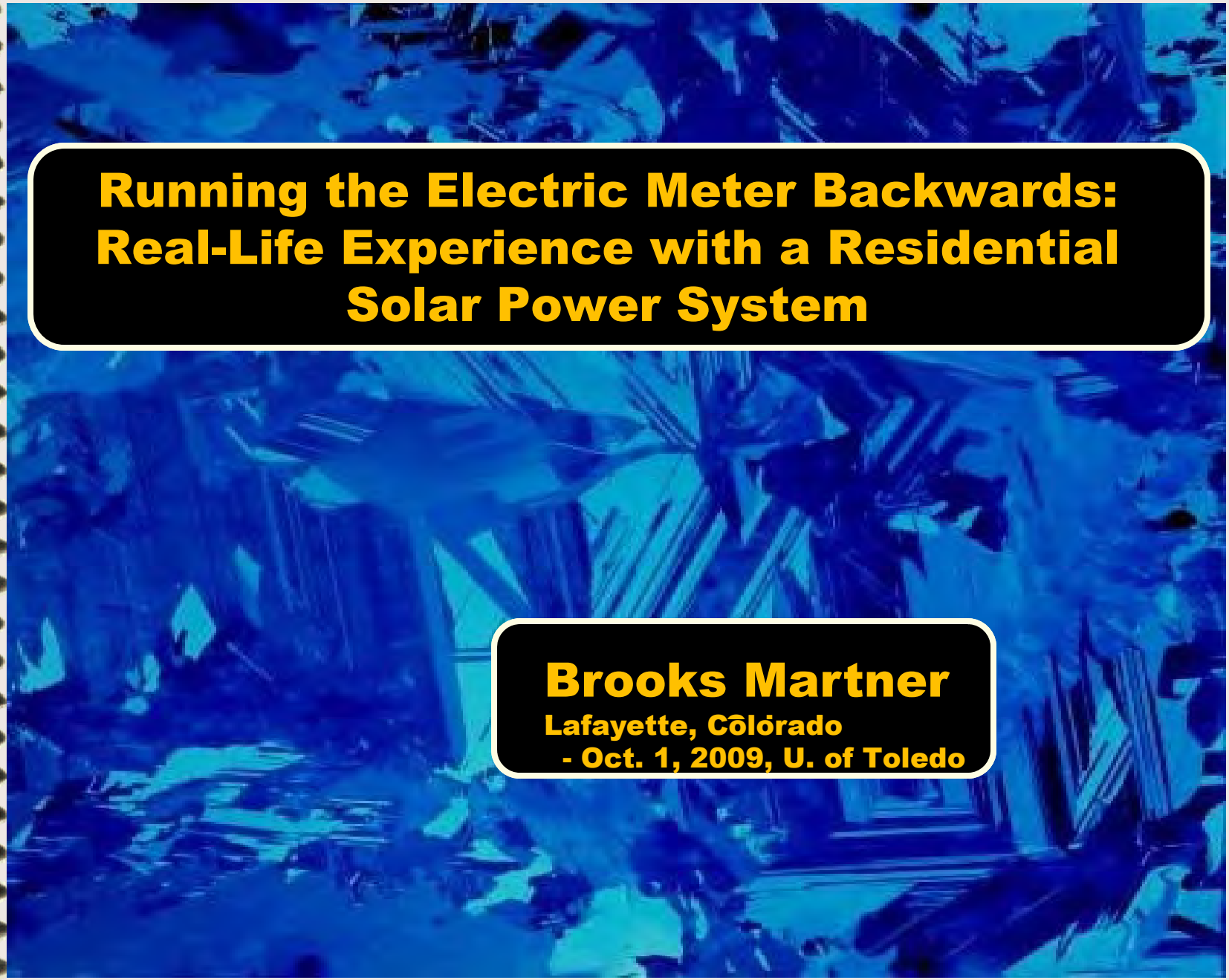

Running the Electric Meter Backwards:
Real-Life Experience with a Residential
Solar Power System
Brooks Martner
Lafayette, Cô lo rado
- Oct. 1, 2009, U. of Toledo

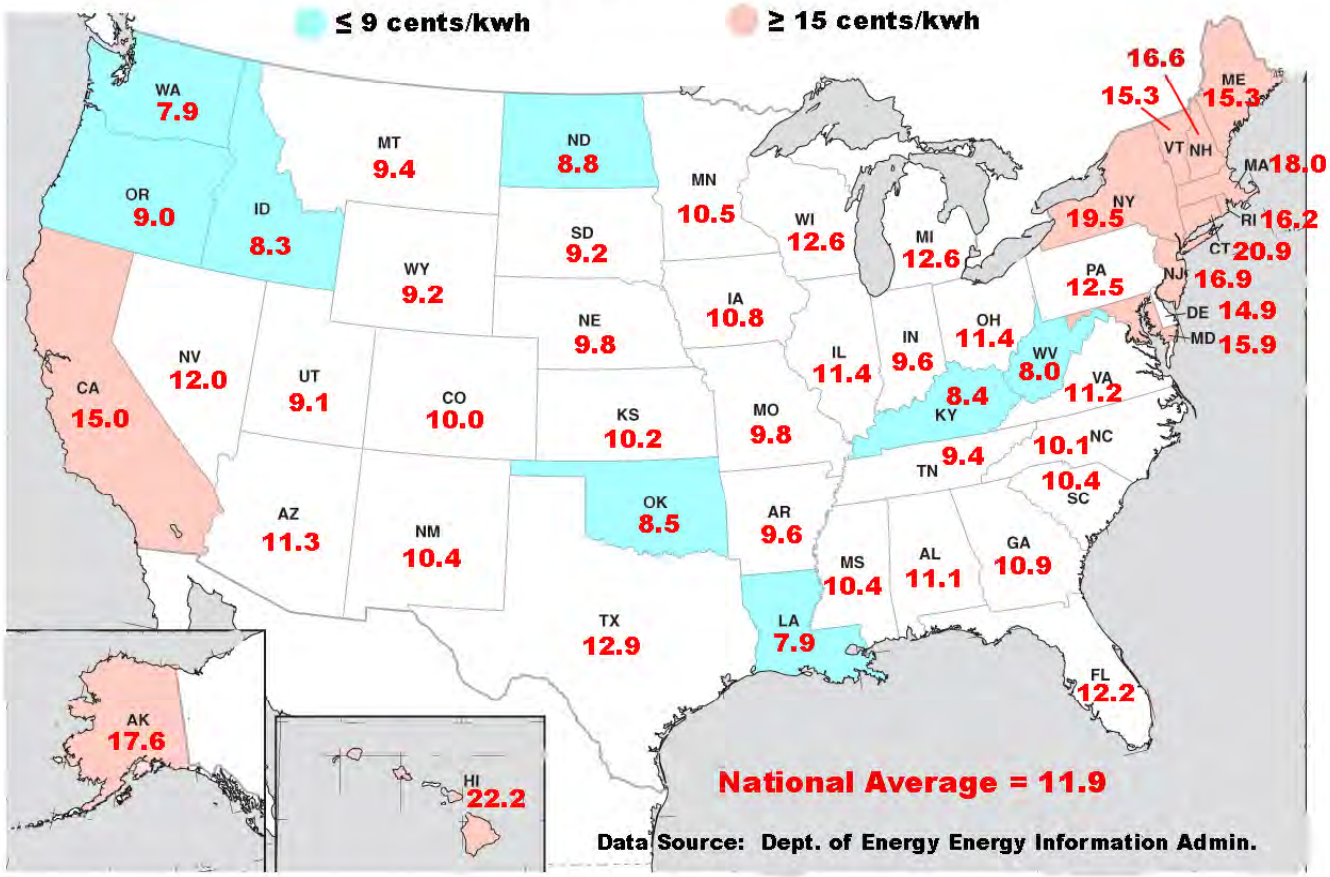
Our Solar Photovoltaic (PV) System

Our Solar PV System

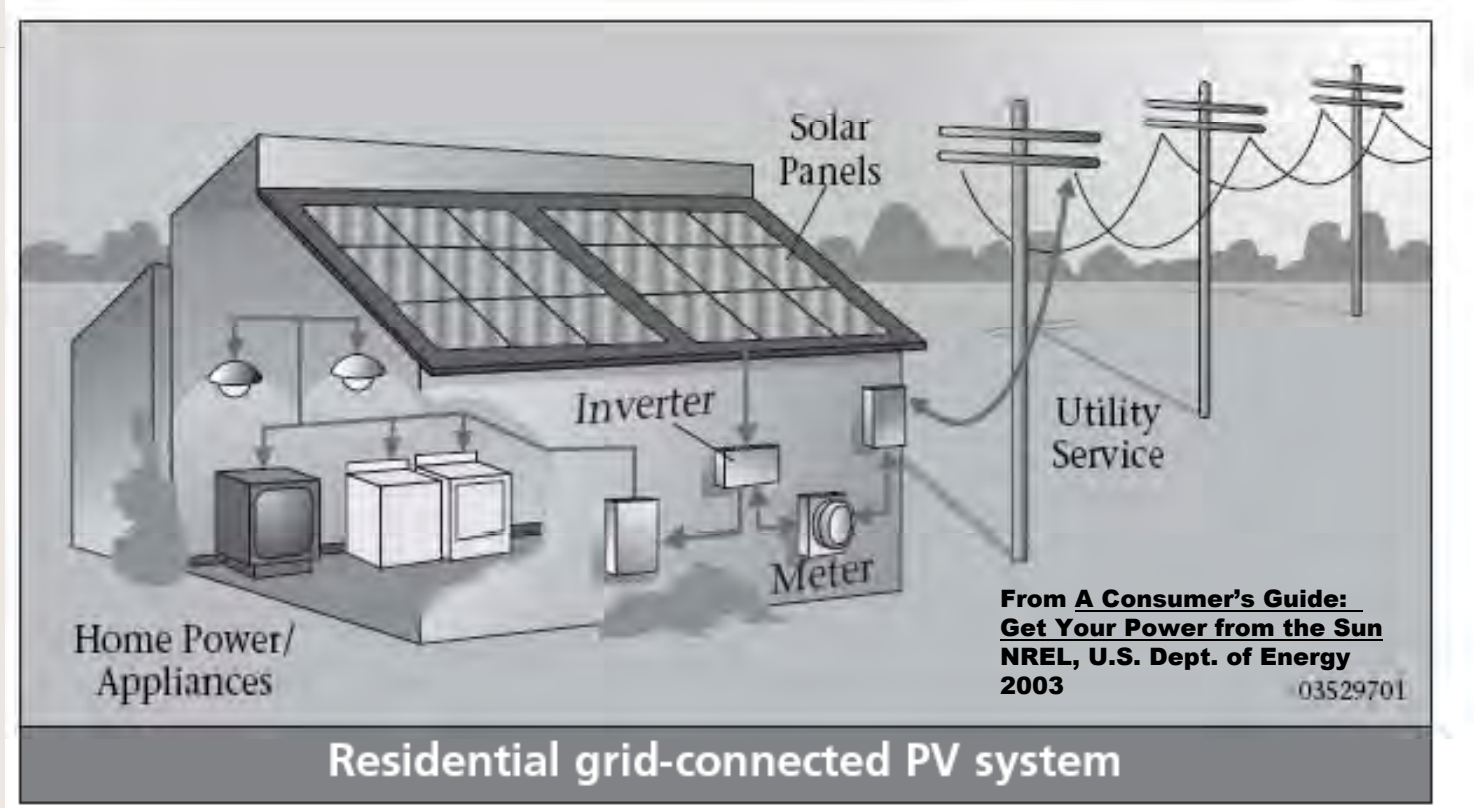
- Near Boulder, Colorado (latitude = 40 deg., alt. = 5300 ft)
- Ground-mounted
- South-facing
- Fixed-tilt at 35 degrees (no moving parts)
- Silicon polycrystalline cells
- Grid-tied, no batteries
- 5.1 kilowatts (DC rating)
- 30 modules (panels) of 170 watts each
- Area = 39.3 m^2 (approx. 52 ft x 8 ft)
- Predicted annual AC energy production ~ 7400 kWh

Average Residential Retail Price of Electricity by State

cents per kilowatt-hour June 2009

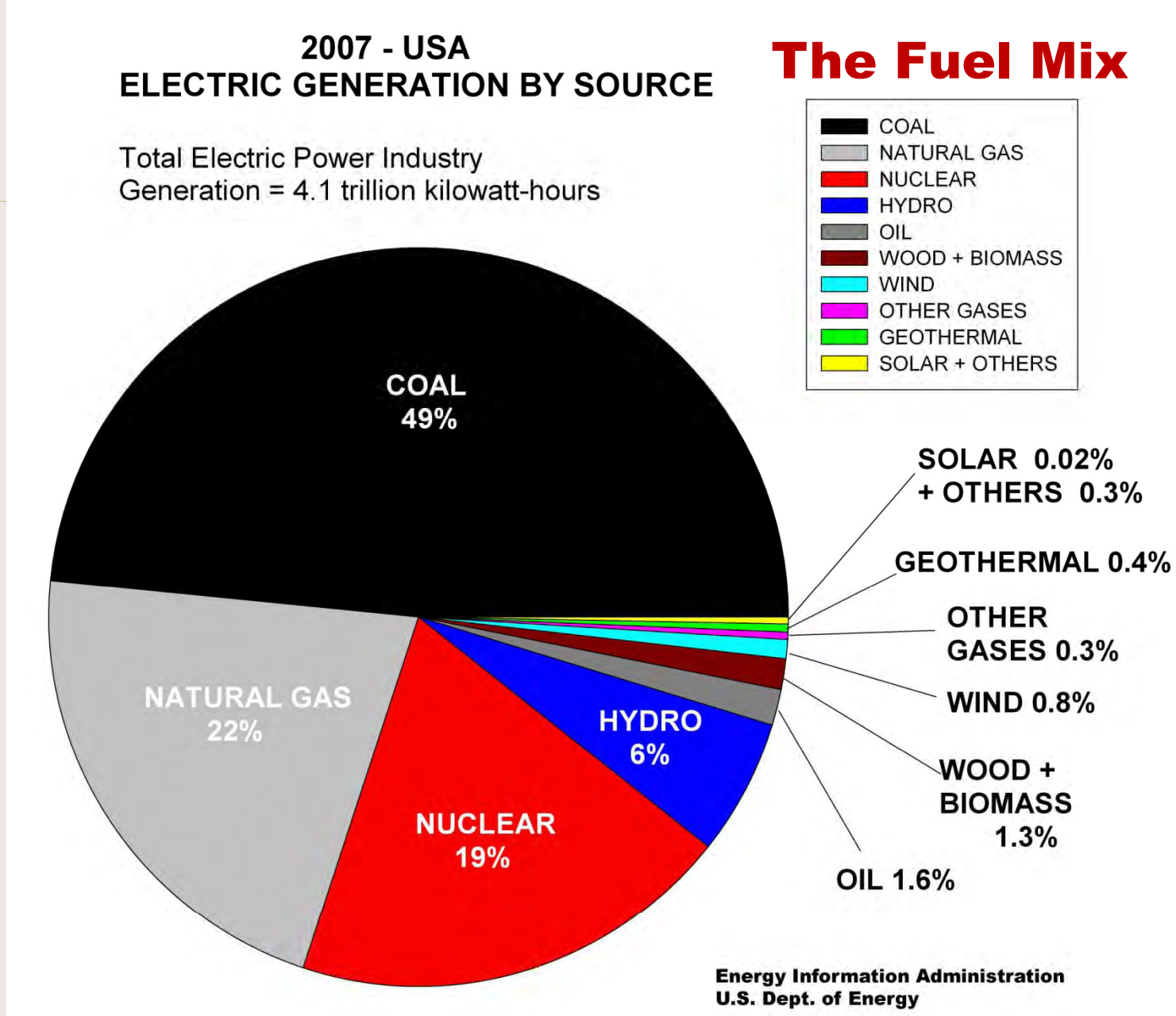


What do you do for electricity when the sun isn't shining?

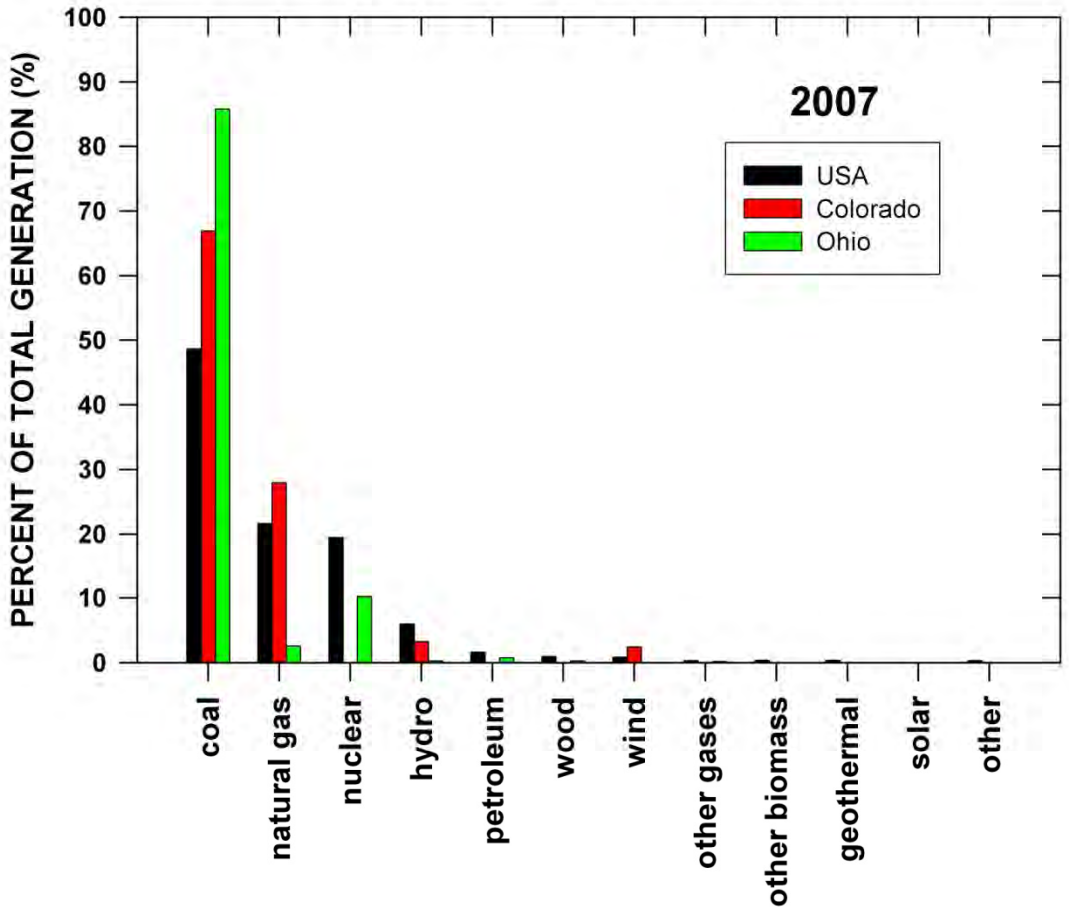


For a grid-tied system, back-up is already in place in the form of the utility company's grid

The Fuel Mix


2007 - USA
ELECTRIC GENERATION BY SOURCE
Total Electric Power Industry
Generation = 4.1 trillion kilowatt-hours
COAL
NATURAL GAS
NUCLEAR
HYDRO
OIL
WOOD + BIOMASS
WIND
OTHER GASES
GEOTHERMAL
SOLAR + OTHERS
COAL 49%
NATURAL GAS 22%
NUCLEAR 19%
HYDRO 6%
OIL 1.6%
WOOD + BIOMASS 1.3%
WIND 0.8%
OTHER GASES 0.3%
GEOTHERMAL 0.4%
SOLAR 0.02% + OTHERS 0.3%
Energy Information Administration
U.S. Dept. of Energy

CONTRIBUTIONS OF FUEL SOURCES
TO TOTAL ELECTRIC GENERATION
(Total Electric Power Industry)



Data Source:
Energy Information Admin.
U.S. Dept. of Energy

Jump-Starting the Arrival of Renewable Energy

Renewable Portfolio Standards

- **Colorado** – It's the law already:
  20% Renewables by 2020
  including 0.8% from solar.
- **Ohio** – It's the law already:
  12.5% Renewables by 2024
  including 0.5% from solar.
- **U.S.A.** – Energy/Climate bill in Congress (passed HR)
  15% Renewables by 2020
  (and 17% reduction of CO_2 by 2020).

Primary Factors Considered

in System Design and Decision to Buy

- Electrical Consumption of the Home
- Solar Radiation Climatology of Region
- Sun Exposure of the Site
- Cost of System
  - Rebates
  - Tax Credits
  - Monthly Savings on Energy Bill
  - = Pay-back Time
- Eco-karma

Electrical Consumption

Xcel Energy®

PUBLIC SERVICE COMPANY OF COLORADO
P O BOX 840
DENVER, CO. 80201
(800) 895-4999

Customer Name	Service Address	Due Date	Account No.	Amount Due
	LAFAYETTE, CO	Dec 18, 2007		$168.11

Account Activity

Date of Bill	Dec 3, 2007	Previous Balance	$163.32
Number of Payments Received	1	Total Payments	($163.32)
Number of Days in Billing Period	31	Balance Forward	$0.00
Statement Number		+ Current Bill	$168.11
Premise Number		Current Balance	$168.11

Electric Service - Account Summary

Invoice Number	0281132727			Residential General	$33.02
Meter No.	000035899617			GRSA	$4.15
Rate	R	Residential General		Air Quality Imp	$0.72
Current Reading	22579	Actual	11/30/2007	Elec Commodity Adj	$21.38
Previous Reading	21730	Actual	10/30/2007	Demand Side Mgmt Cost	$1.16
Kilowatt-Hours Used	849			Purch Cap Cost Adj	$11.57
				Renew. Energy Std Adj	$0.44
				Franchise Fee	$2.25
				Sales Tax	$2.71
				Subtotal	$79.88

Gas Service - Account Summary

Invoice Number	009586365[illegible]			Residential			
Meter No.	000[illegible]9496			Usage Charge	114.00 x	0.08656	$10.10
Rate	RG-T	Residential		Interstate Pipeline	114.00 x	0.06116	$6.97
Current Reading	3216	Actual	11/30/2007	Natural Gas - Nov	110.23 x	0.48356	$53.30
Previous Reading	3085	Actual	10/30/2007	Natural Gas - Oct	3.77 x	0.30508	$1.15
Measured Usage	133			Service & Facility			$11.28
Therm Multiplier	0.9598			Franchise Fee			$2.45
Therms Used	114.00			Sales Tax			$2.98
				Subtotal			$88.23

Comparison Information

			Billing Period	Kwh Usage/Month	Therm Usage	Avg. Daily Temp.
Gas	$88.23 per month	$2.85 per day	This Year	849	114	42°
Electric	$79.88 per month	$2.58 per day	Last Year	755	107	42°

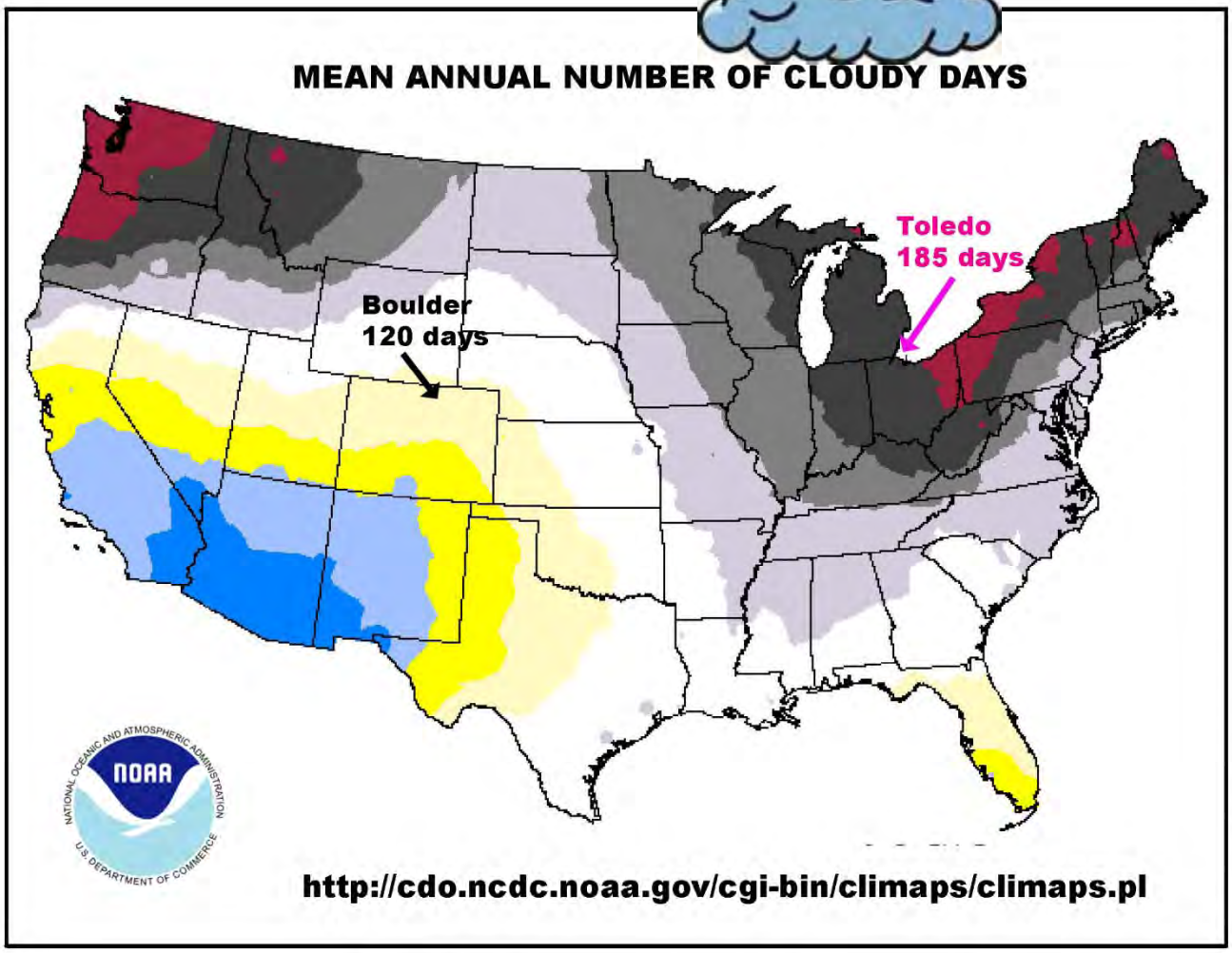
Residential Electrical Consumption - 2007

	Consumption (kWh/year)	Electric Bill ($/year)
• Our house:	7,400	781
• Colorado Average	8,250	789
• Ohio Average	11,112	1063
• U.S. Average	11,232	1196

will require approx. a 5-kW PV system in Boulder, Colorado to offset 100% of annual electric consumption

Climatology of Sunshine

MEAN ANNUAL NUMBER OF CLOUDY DAYS



http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl

NUMBER OF CLOUDY DAYS PER YEAR

- <90
- 90-105
- 105-120
- 120-135
- 135-150
- 150-165
- 165-180
- 180-200
- >200

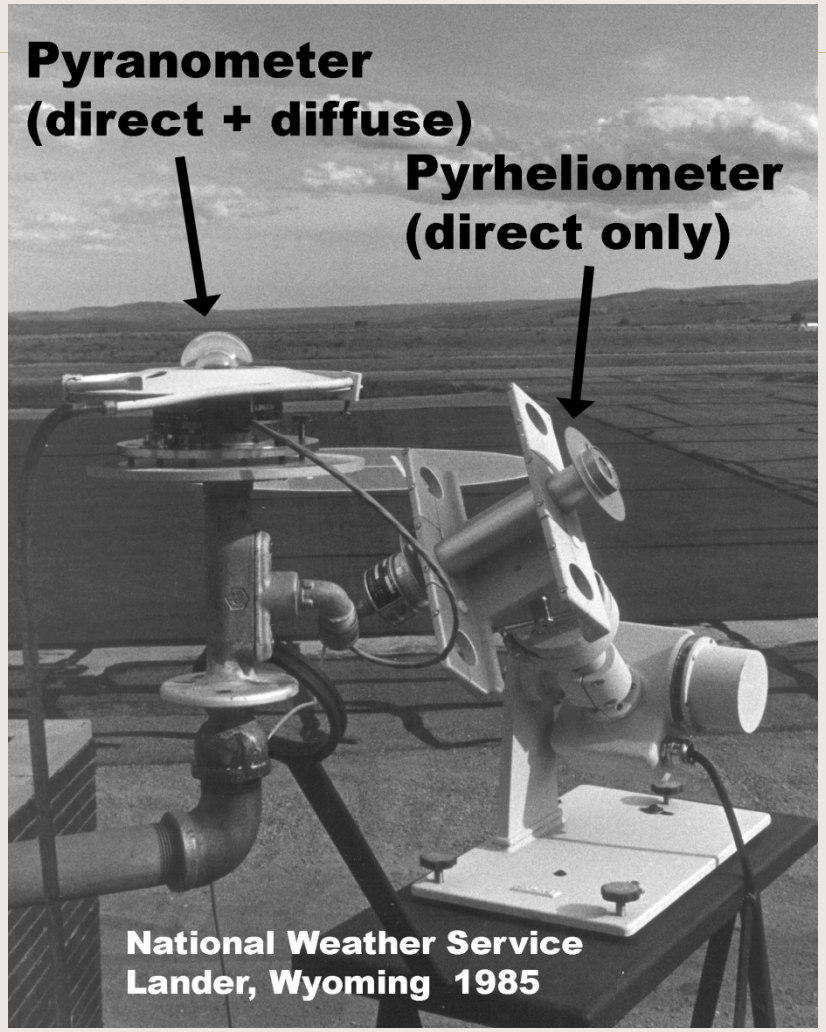
Cloudy Day: more than 75% of sky wss covered by opaque clouds for most of the daylight period

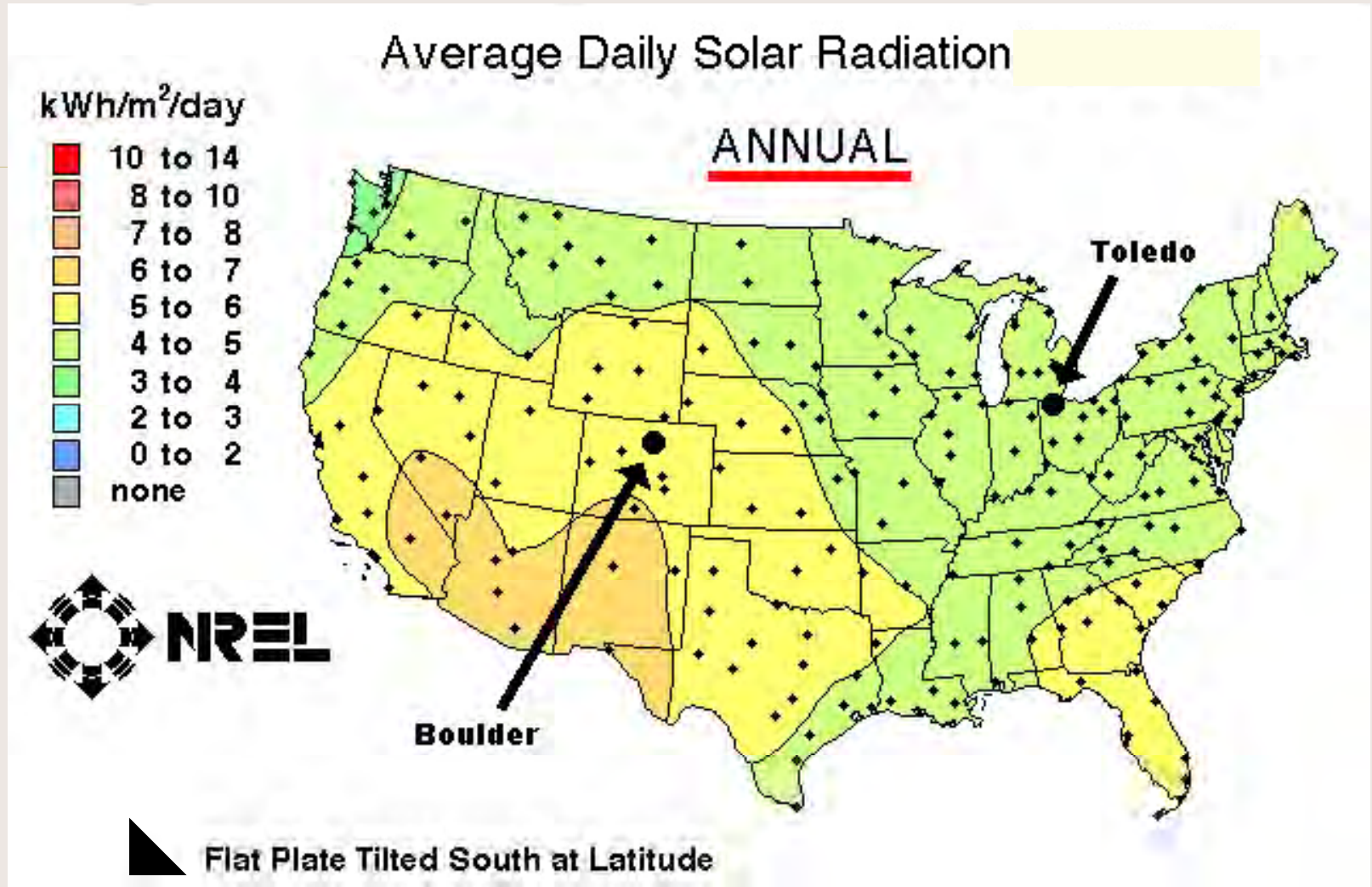
Solar Radiation Measurements:

Long-term, hourly measurements at 44 National Weather Service (NWS) sites ended 1990.

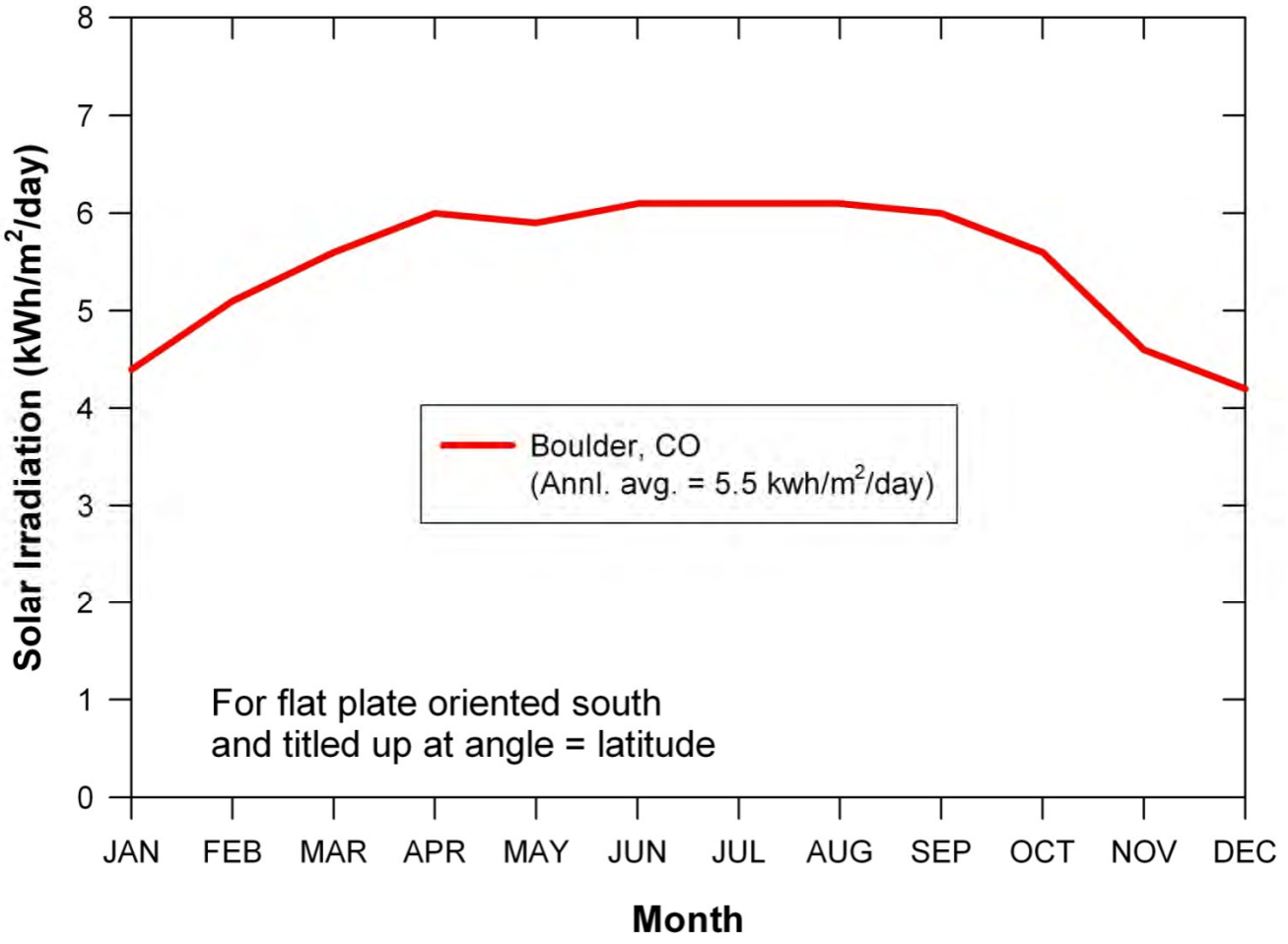
New-site measurements in progress by various agencies, especially DOE.

Interpolated-modeled hourly data are now available for 222 U.S. locations.

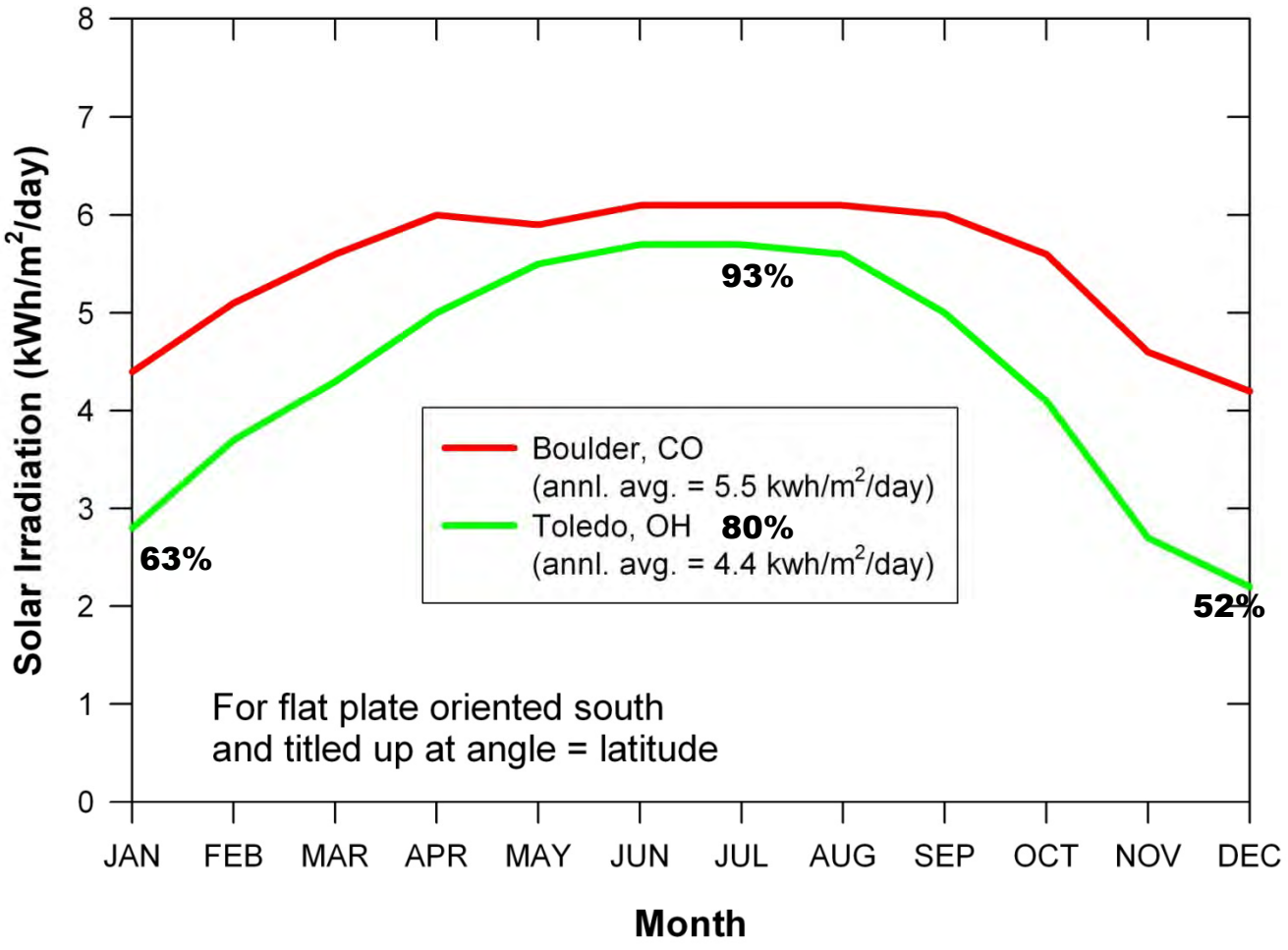




http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/



Data compiled by NREL are from National Weather Service primary and secondary monitoring stations



Data compiled by NREL are from National Weather Service primary and secondary monitoring stations

Calculating PV System Expected Electrical Production

- Using NREL's **PV-Watts** on-line calculator

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

- Input:

  Geographic location **Boulder, Colorado**

  DC rating of array **5.1 kW**

  Type of array **fixed tilt**

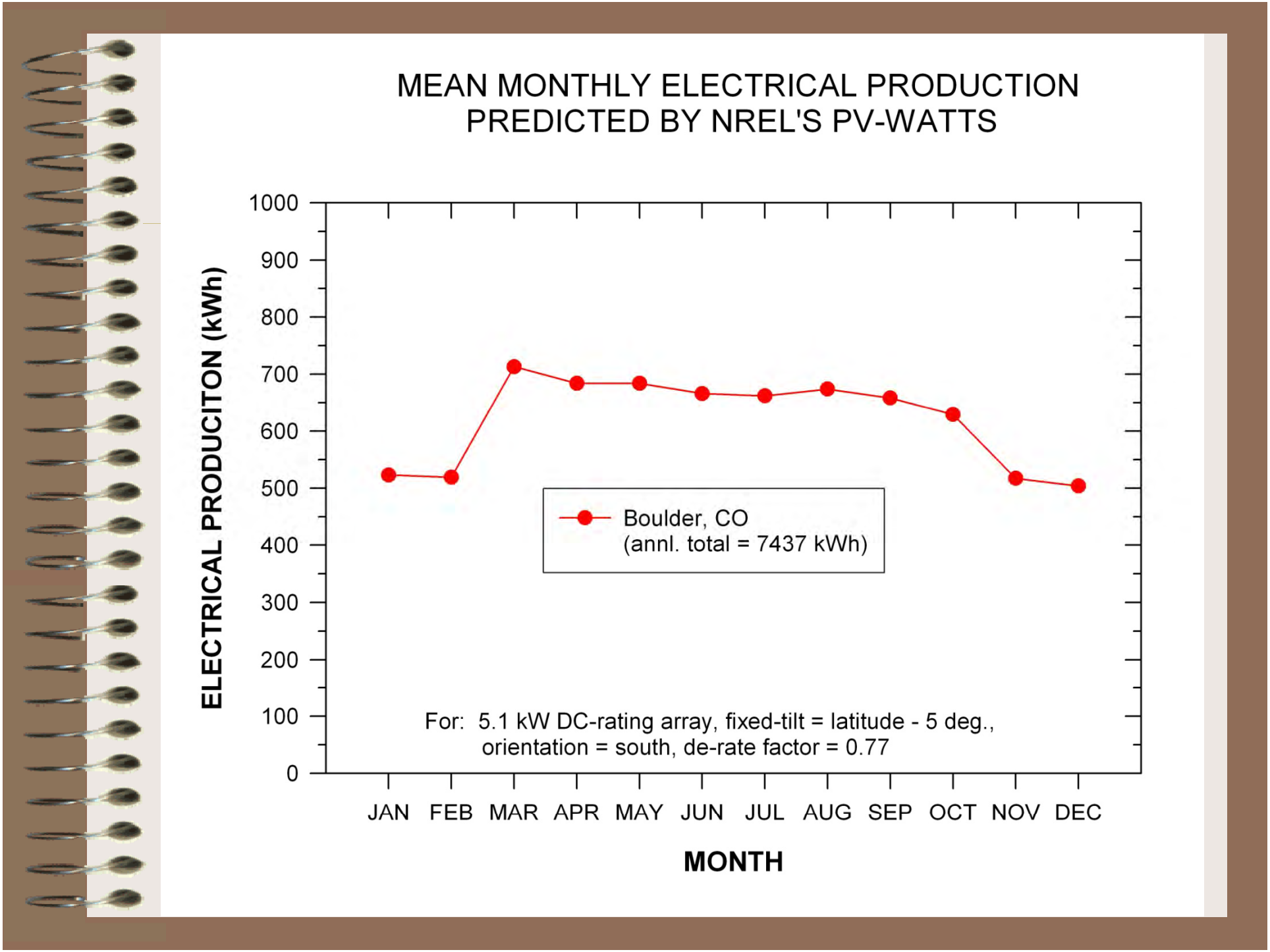
  Tilt **35 deg.**

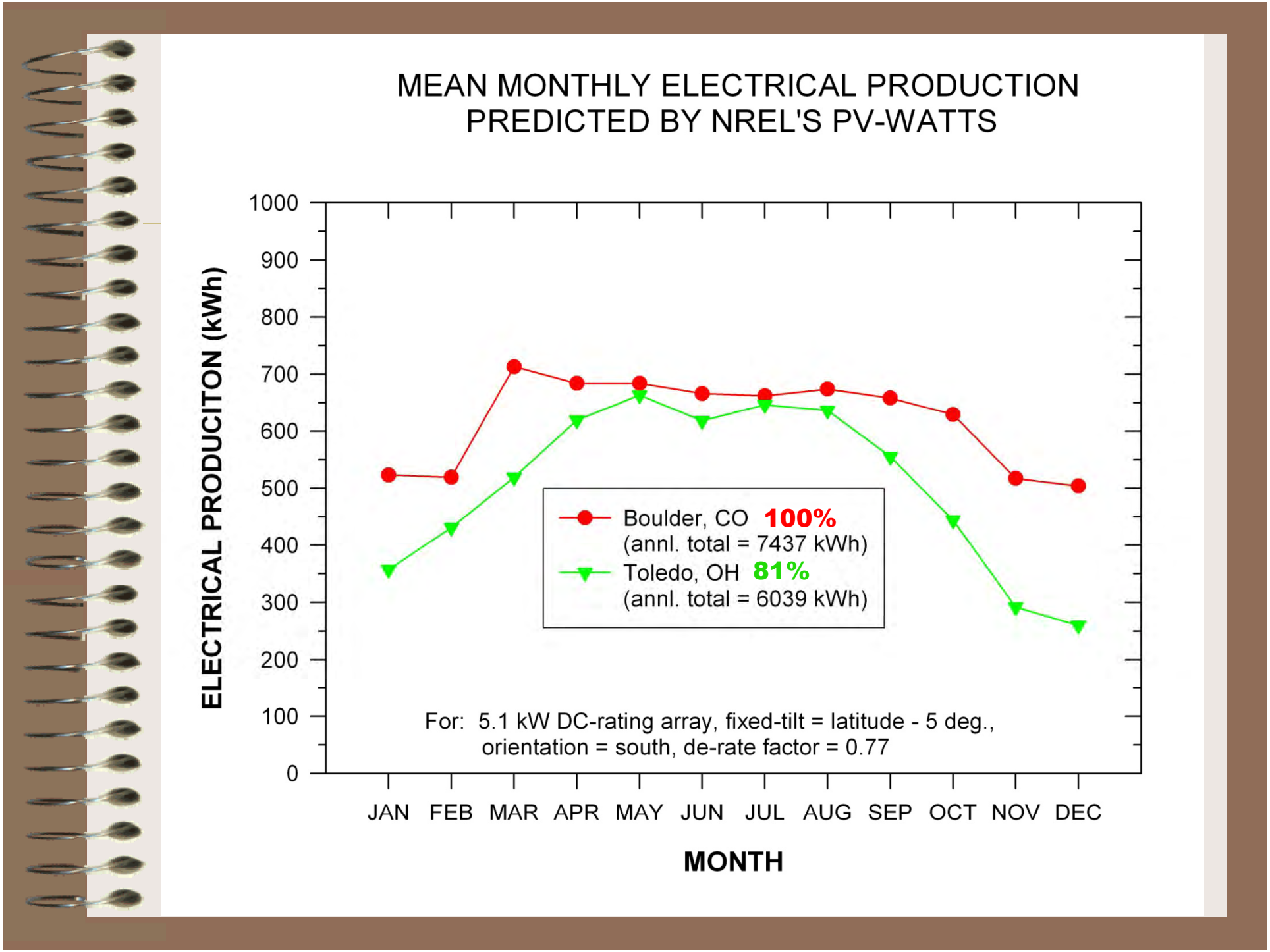
  Orientation **south**

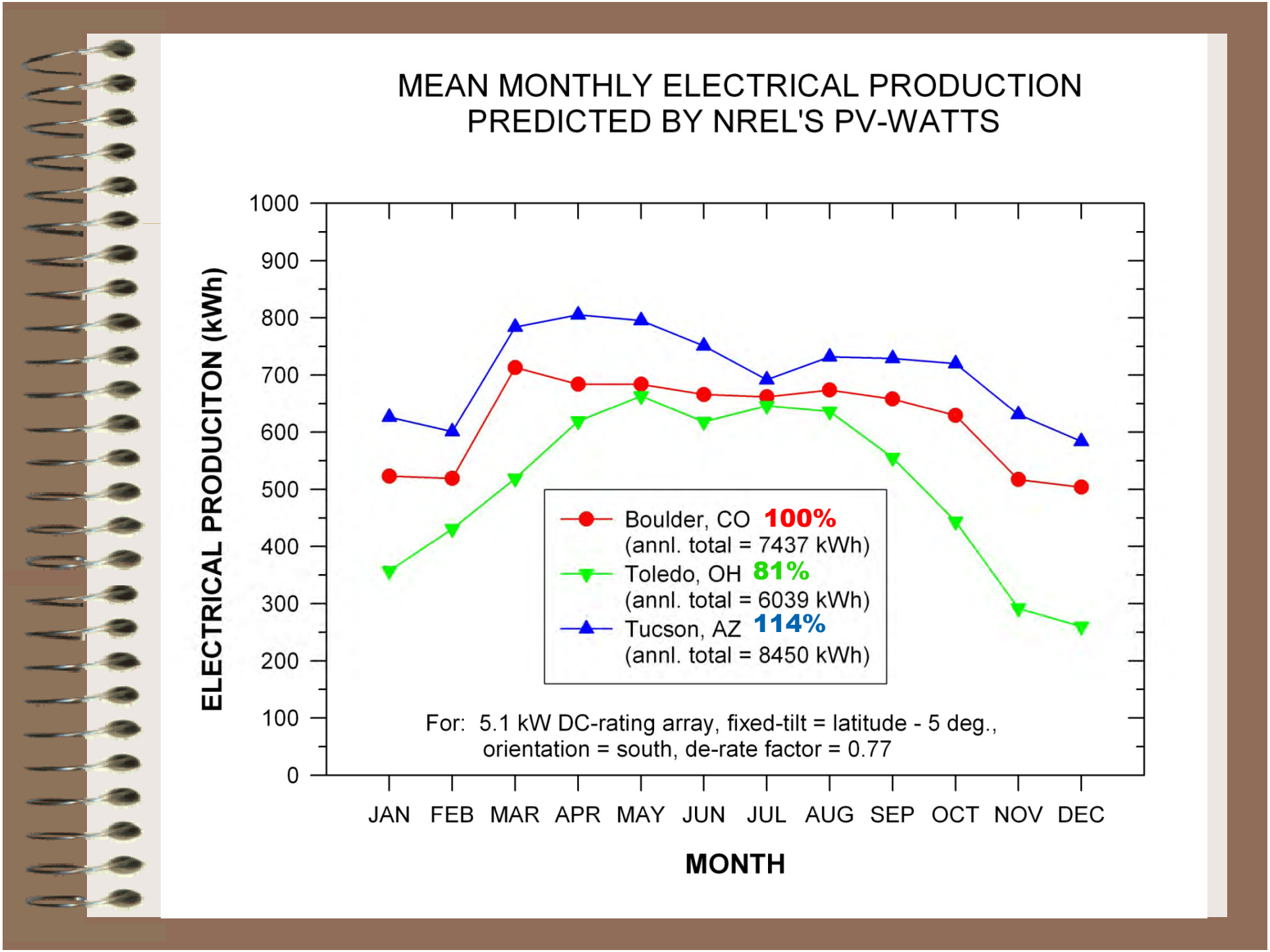
- Output:

  Avg. electric production for each month of the year:

  Jan = 523 kWh, Feb = 519 kWh, Mar = 713 kWh, … etc.

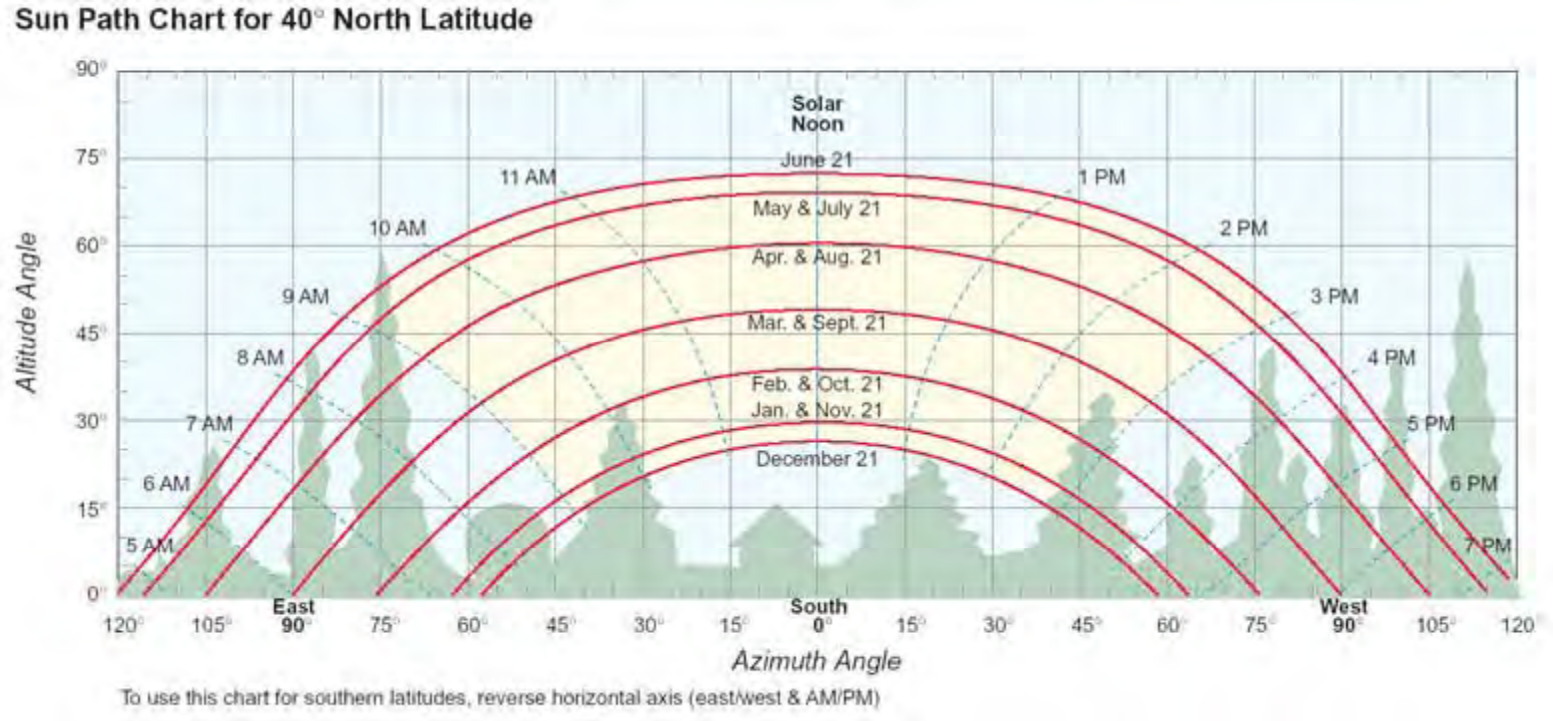

MEAN MONTHLY ELECTRICAL PRODUCTION
PREDICTED BY NREL'S PV-WATTS
ELECTRICAL PRODUCITON (kWh)
1000
900
800
700
600
500
400
300
200
100
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
Boulder, CO
(annl. total = 7437 kWh)
For: 5.1 kW DC-rating array, fixed-tilt = latitude - 5 deg.,
orientation = south, de-rate factor = 0.77

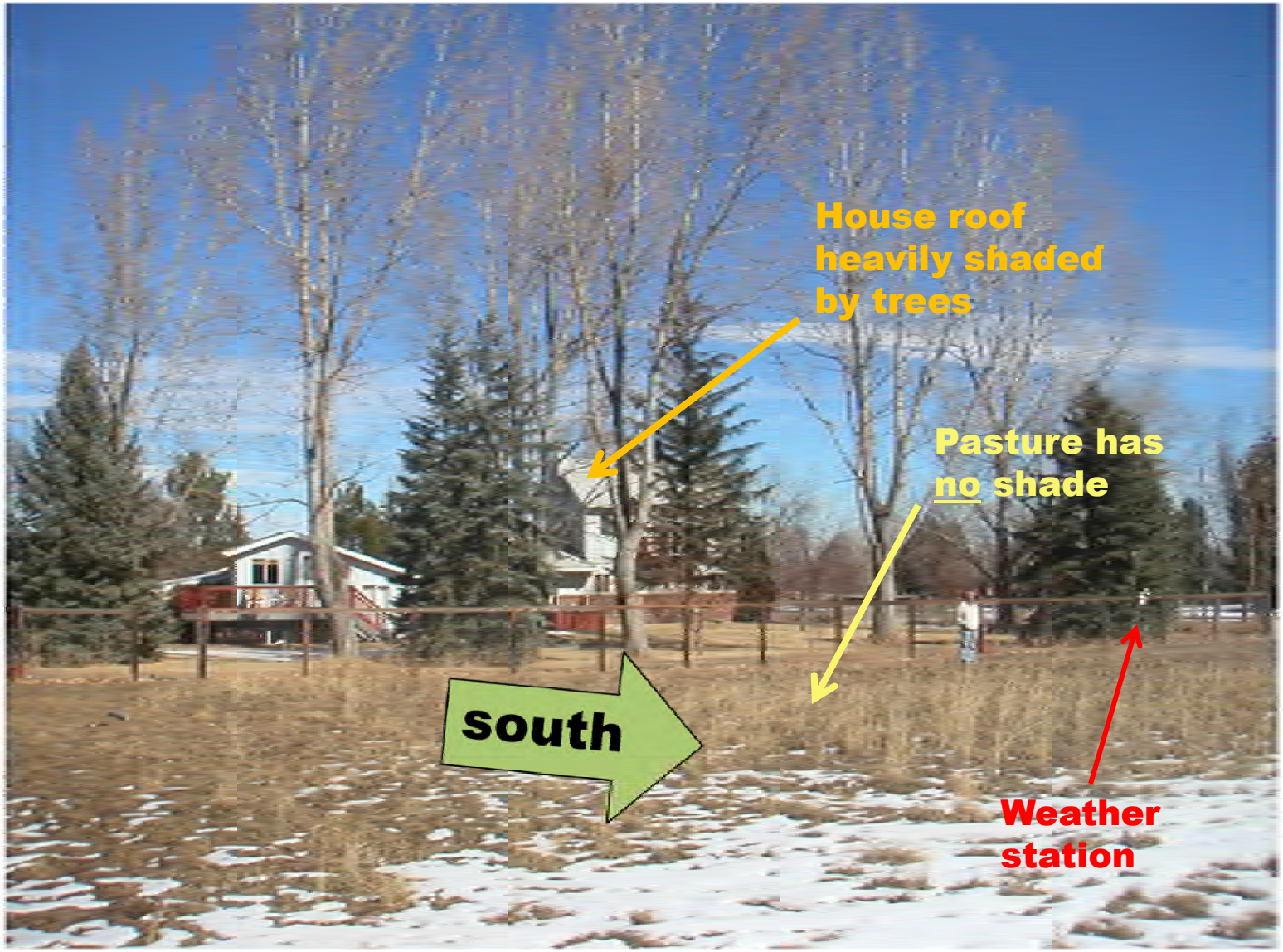

MEAN MONTHLY ELECTRICAL PRODUCTION
PREDICTED BY NREL'S PV-WATTS
ELECTRICAL PRODUCITON (kWh)
1000
900
800
700
600
500
400
300
200
100
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
Boulder, CO 100%
(annl. total = 7437 kWh)
Toledo, OH 81%
(annl. total = 6039 kWh)
For: 5.1 kW DC-rating array, fixed-tilt = latitude - 5 deg.,
orientation = south, de-rate factor = 0.77


MEAN MONTHLY ELECTRICAL PRODUCTION
PREDICTED BY NREL'S PV-WATTS
ELECTRICAL PRODUCITON (kWh)
1000
900
800
700
600
500
400
300
200
100
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH
Boulder, CO 100%
(annl. total = 7437 kWh)
Toledo, OH 81%
(annl. total = 6039 kWh)
Tucson, AZ 114%
(annl. total = 8450 kWh)
For: 5.1 kW DC-rating array, fixed-tilt = latitude - 5 deg.,
orientation = south, de-rate factor = 0.77

Sun Exposure of Site

Selecting a site that has little of no shading year-long

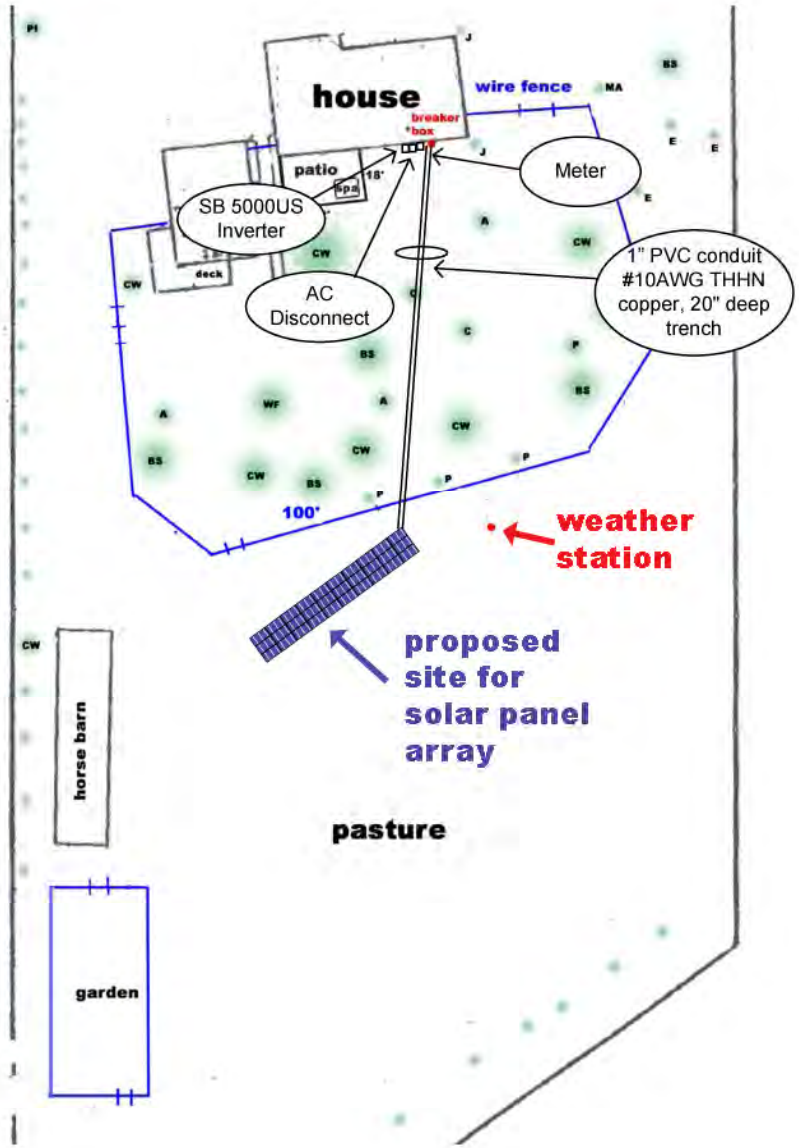



House roof
heavily shaded
by trees
Pasture has
no shade
South
Weather
station

Namaste Solar — Electric —	Customer: Brooks Martner Address: Lafayette, CO
Drawn by: Dan Yechout	Date: 06 February 2008
Scale : Drawn to Scale	Project type : Solar PV

Scale:
50 feet

= Trees



Financial: Costs

Colorado - 2008

• PV system equipment costs:	
Solar panels (30 Sharp 170-watt)	$24,097
Inverter (5-kW Sunny Boy)	3,008
Rack for ground-mounting panels (ULA)	1,837
Other electrical components	165
• Civil works (pylon & trench digging, concrete)	3,663
• Installation labor	8,198
• County sales tax	1,382
• Total Value	$42,350

Financial: Rebates, etc.

In 2008:

• Utility company rebate + RE credit ($4.50/watt)	-$22,950
• State sales tax rebate	- 699
• Federal income tax credit	- 2,000
• Total incentives	-$25,649

Financial: Bottom Line

• Total value of system	$42,350
• Total rebates, etc.	- 25,649
• Buyer's grand total cost	$16,701

= $3.27/watt

Estimated Energy-Bill Savings and Pay-Back Period

Assuming:

- Initial cost = $16,700
- Solar production = 7446 kWh per year
- Initial electric rate = $0.10 per kWh
- Average annual increase in the utility company's price for electricity

	Pay-back in:	Net savings in 25 years:
0%	22 years	$1,900
5%	15 years	$18,800
10%	12 years	$56,500
15 %	10½ years	$141,700

Estimated Eco-Karma Benefits

Every year:

Clean energy production	7445 kWh
CO_2 emissions averted*	7 tons

* = compared with coal-fired electric plant

Installation

Installation

Installation

Installation

Installation

Installation

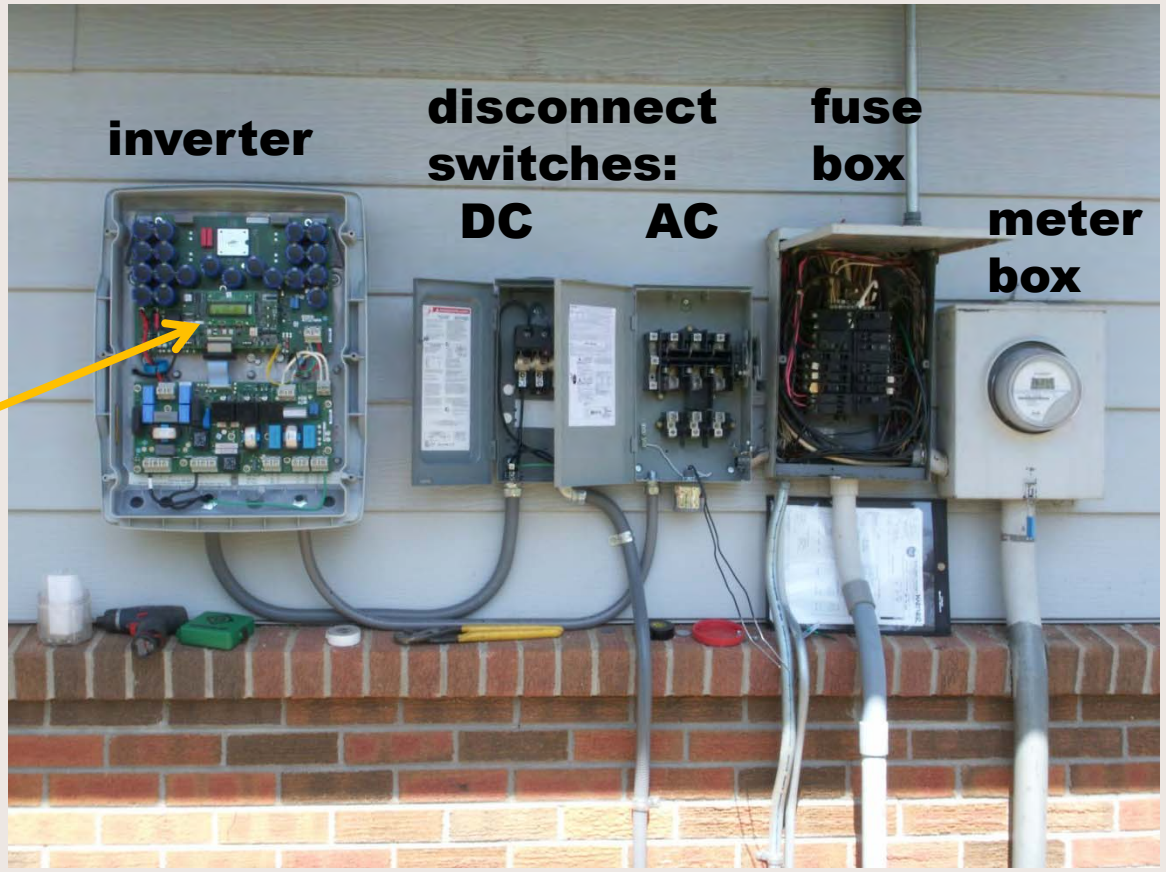
Installation

Installation

Installation

inverter

Installation



display shows:
watts
kwh
volts
hours
etc.

Installation

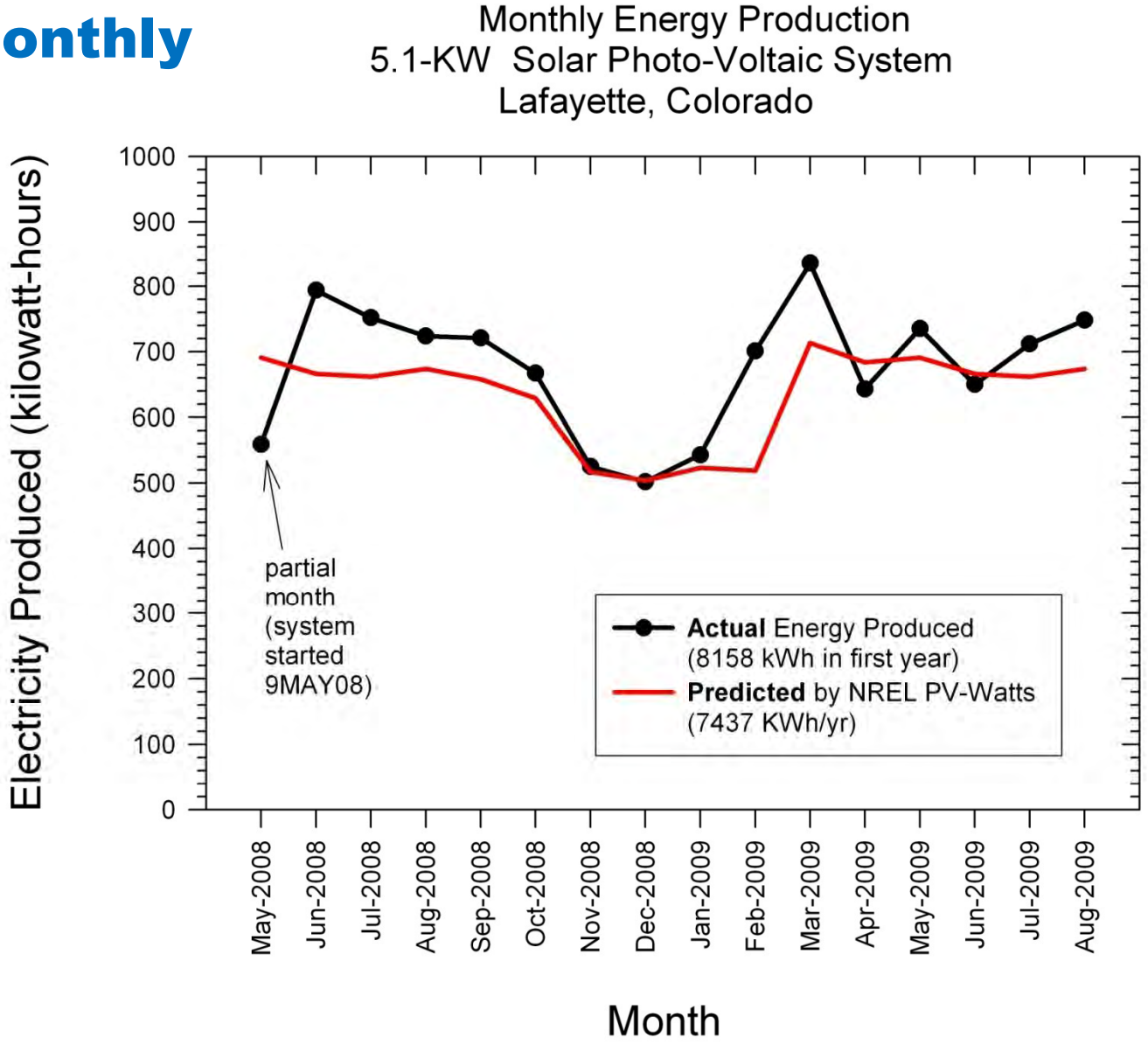
Start-up date: 9MAY08

Performance in the First Year

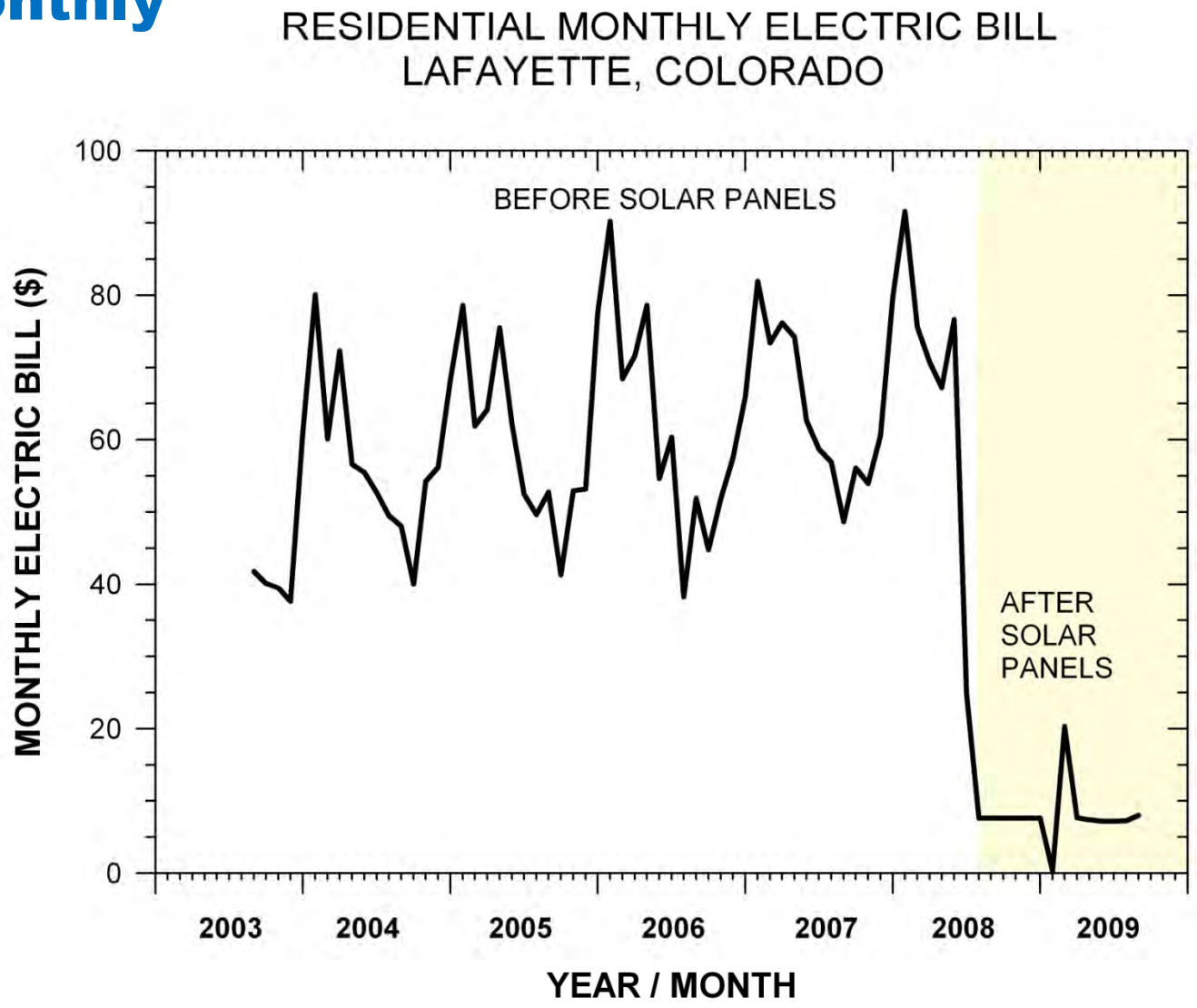
Tracking the electricity production of the solar panels with daily readings of the inverter's data display

Correlating with meteorological data from our home weather station located beside the panels

Monthly

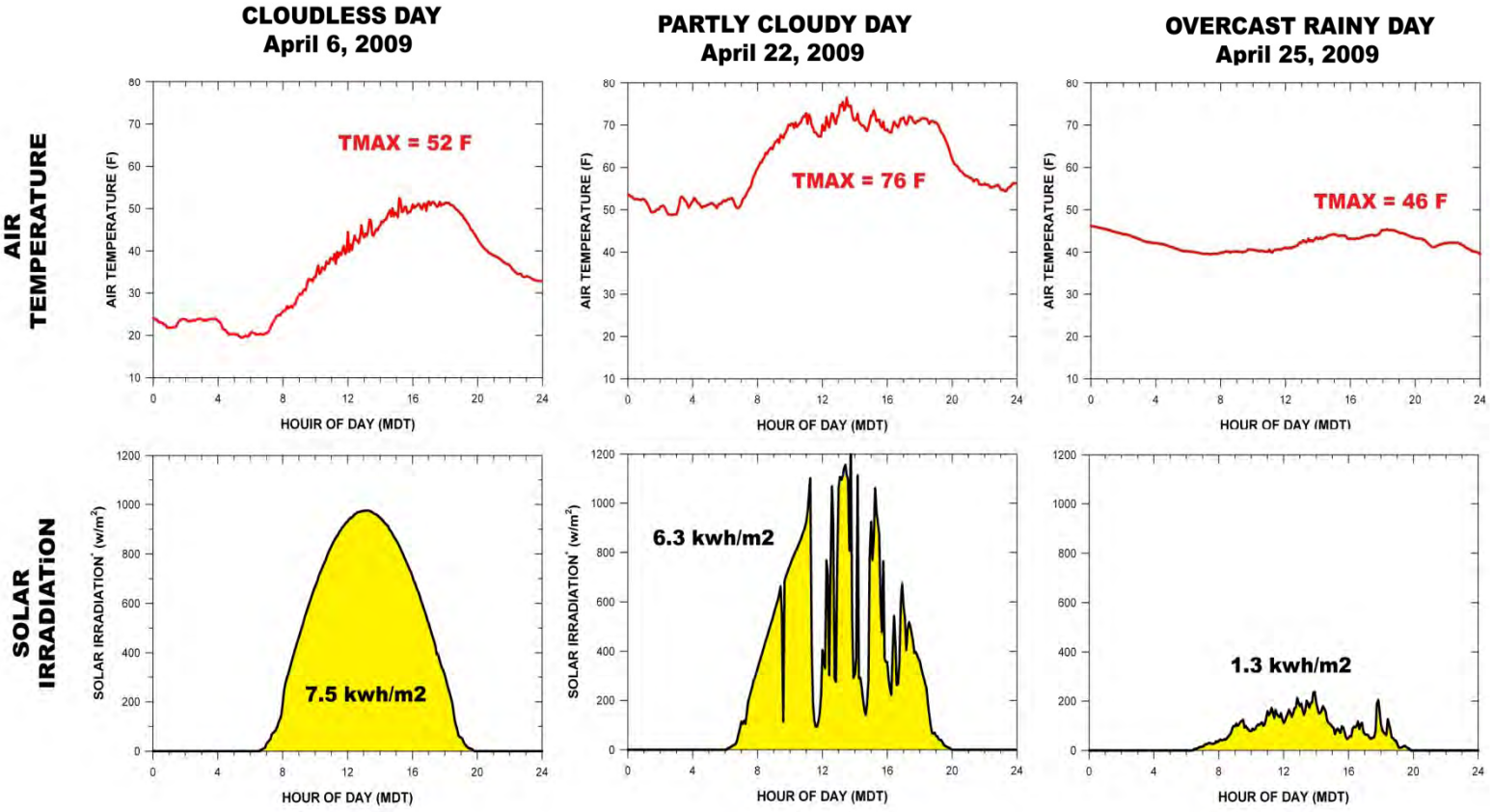

Monthly Energy Production
5.1-KW Solar Photo-Voltaic System
Lafayette, Colorado
Electricity Produced (kilowatt-hours)
1000
900
800
700
600
500
400
300
200
100
0
partial month (system started 9MAY08)
Actual Energy Produced (8158 kWh in first year)
Predicted by NREL PV-Watts (7437 KWh/yr)
May-2008
Jun-2008
Jul-2008
Aug-2008
Sep-2008
Oct-2008
Nov-2008
Dec-2008
Jan-2009
Feb-2009
Mar-2009
Apr-2009
May-2009
Jun-2009
Jul-2009
Aug-2009
Month

Monthly

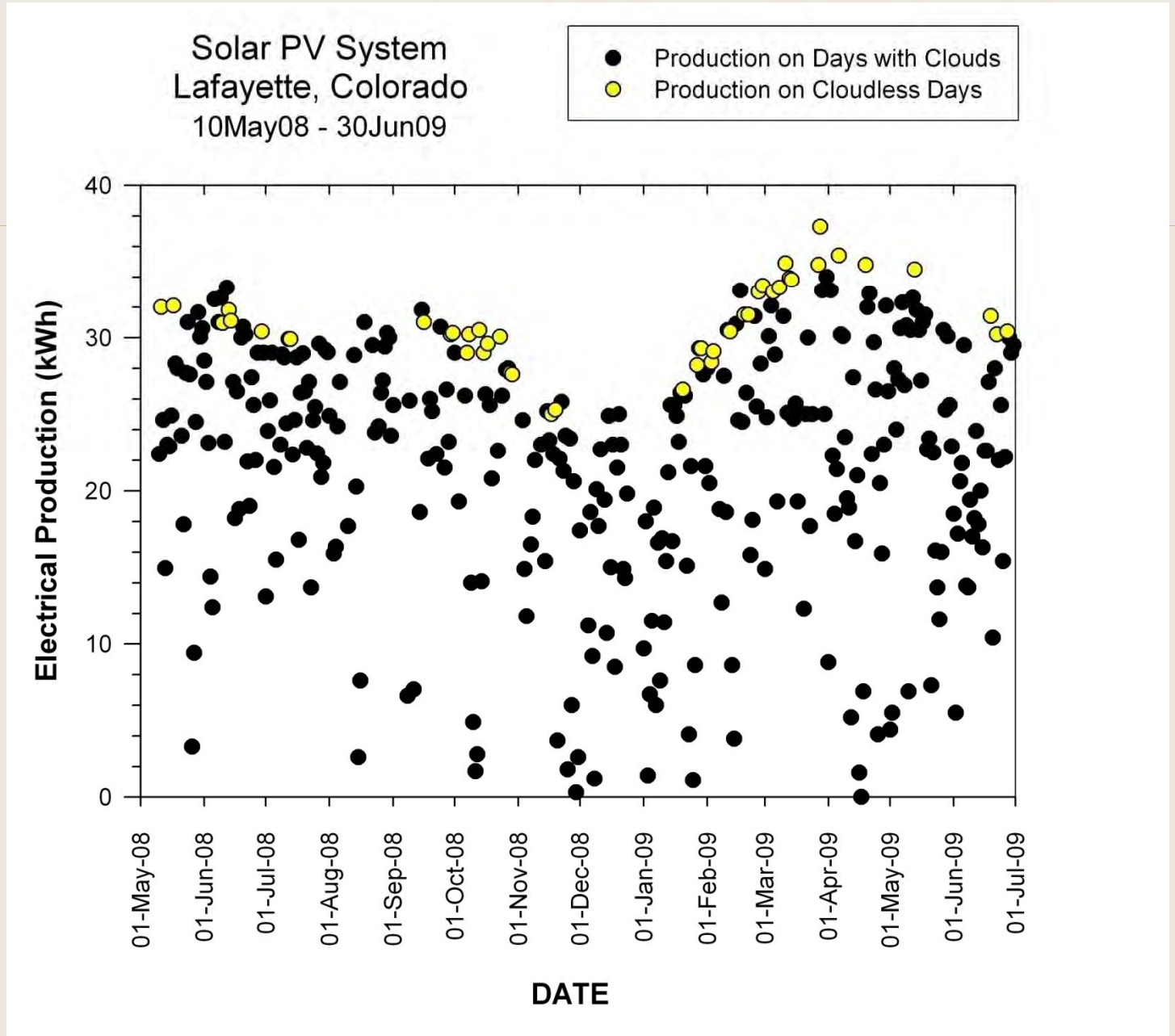

RESIDENTIAL MONTHLY ELECTRIC BILL
LAFAYETTE, COLORADO
BEFORE SOLAR PANELS
AFTER
SOLAR
PANELS
MONTHLY ELECTRIC BILL ($)
100
80
60
40
20
0
2003
2004
2005
2006
2007
2008
2009
YEAR / MONTH

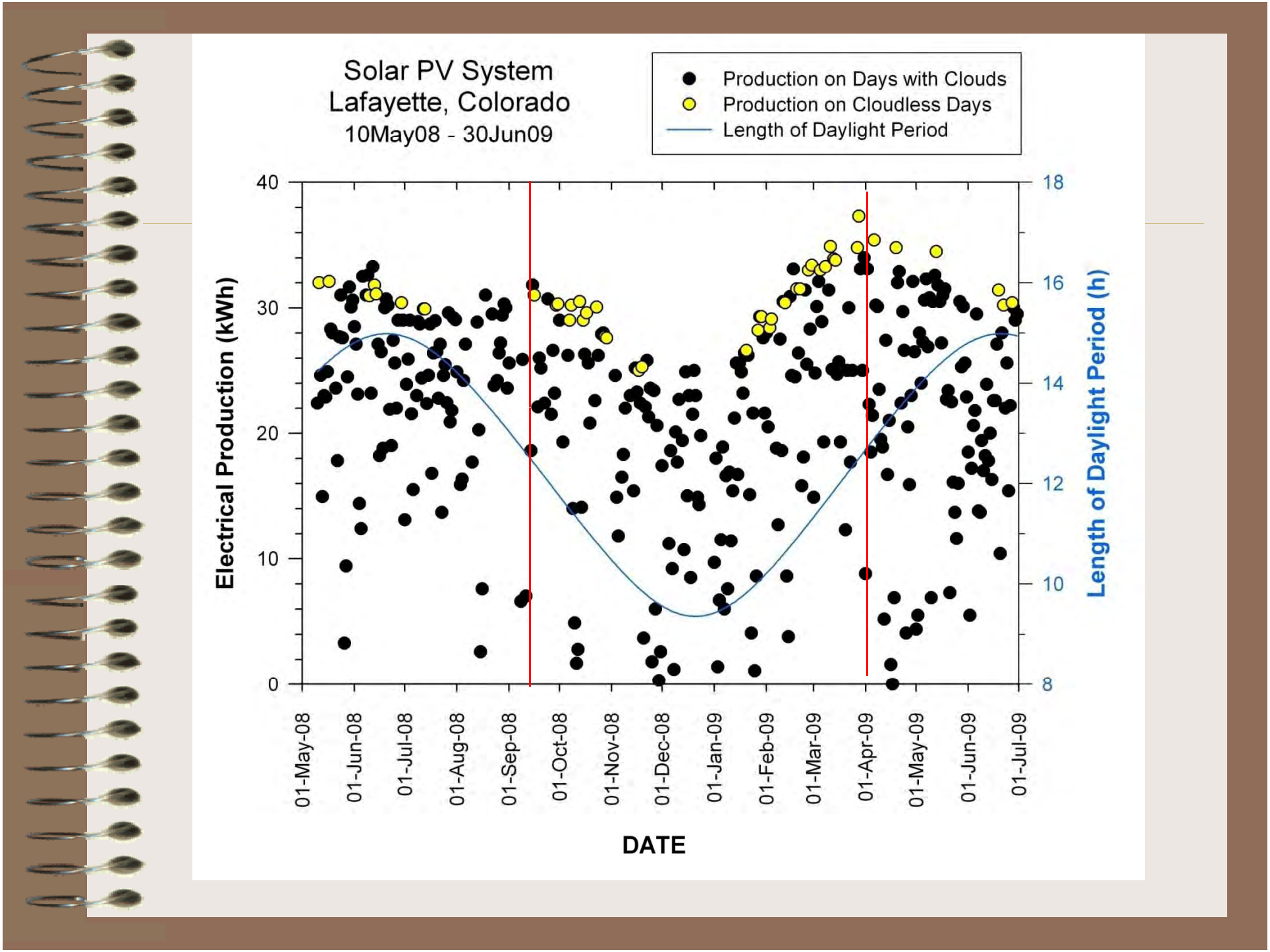
Daily

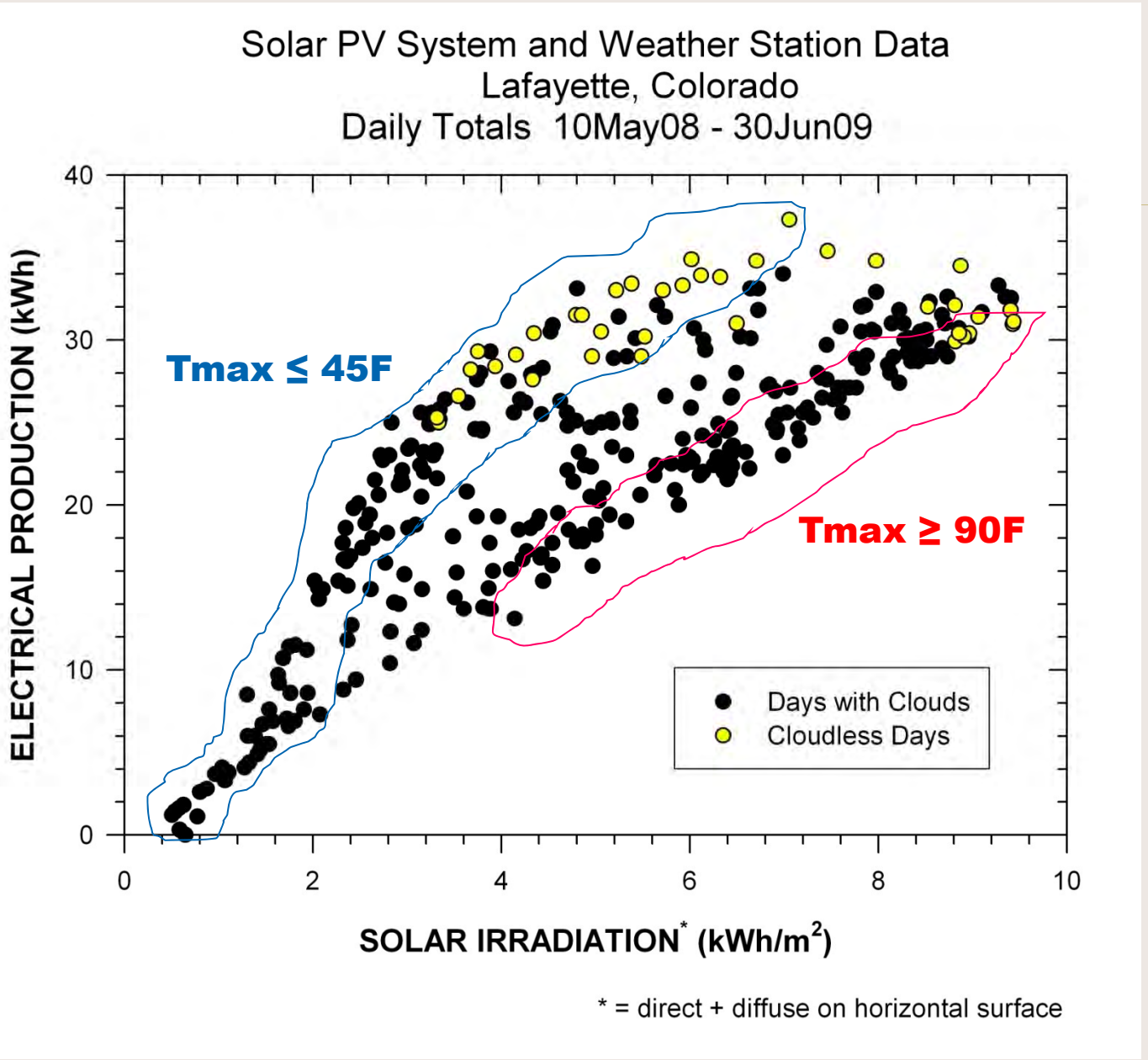
Three Example Days

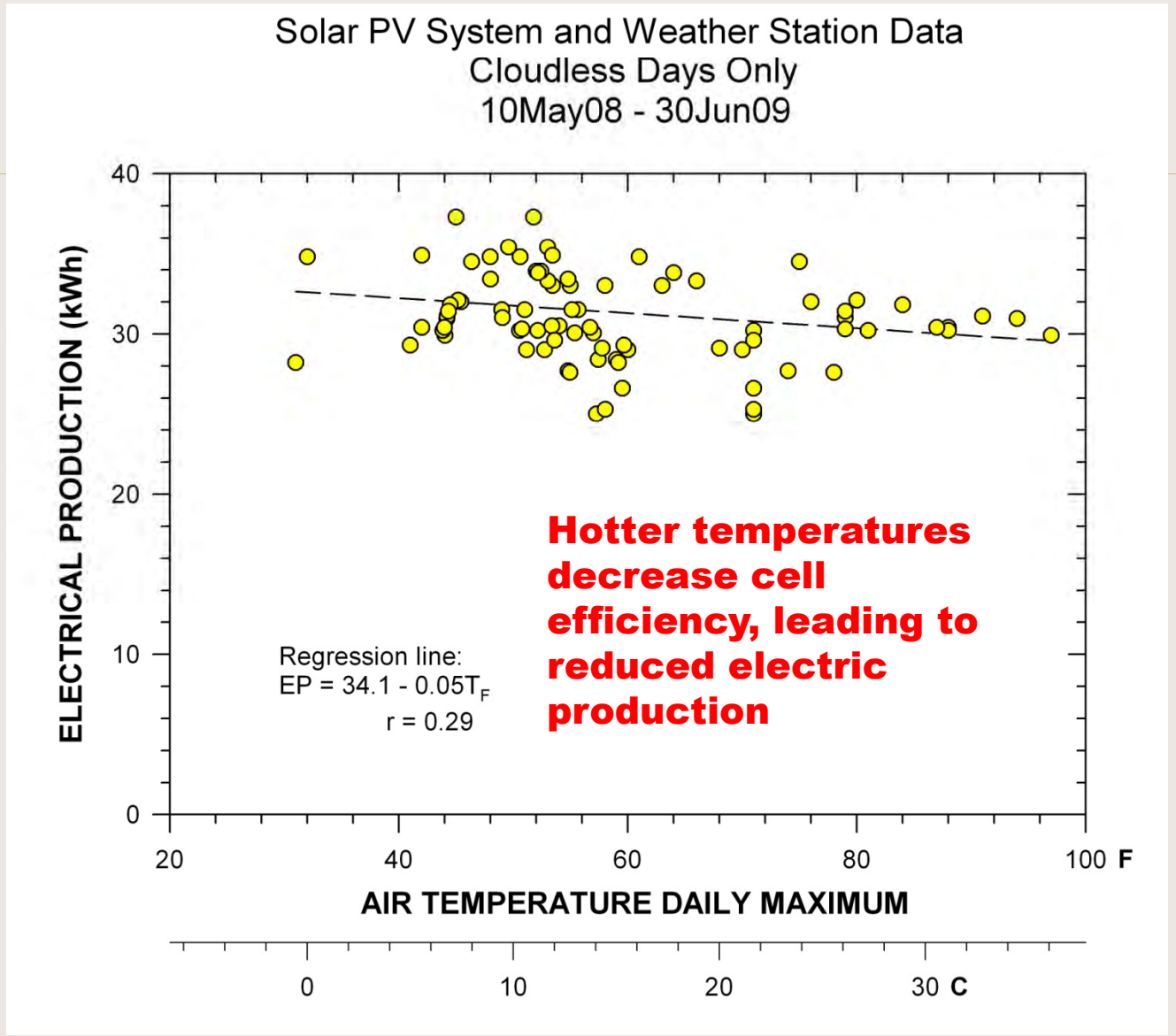


Solar Electric Production: 35.5 kWh | 22.4 kWh | 4.1 kWh


Solar PV System
Lafayette, Colorado
10May08 - 30Jun09
Production on Days with Clouds
Production on Cloudless Days
Electrical Production (kWh)
0
10
20
30
40
01-May-08
01-Jun-08
01-Jul-08
01-Aug-08
01-Sep-08
01-Oct-08
01-Nov-08
01-Dec-08
01-Jan-09
01-Feb-09
01-Mar-09
01-Apr-09
01-May-09
01-Jun-09
01-Jul-09
DATE


Solar PV System
Lafayette, Colorado
10May08 - 30Jun09
Production on Days with Clouds
Production on Cloudless Days
Length of Daylight Period
Electrical Production (kWh)
Length of Daylight Period (h)
DATE
0
10
20
30
40
8
10
12
14
16
18
01-May-08
01-Jun-08
01-Jul-08
01-Aug-08
01-Sep-08
01-Oct-08
01-Nov-08
01-Dec-08
01-Jan-09
01-Feb-09
01-Mar-09
01-Apr-09
01-May-09
01-Jun-09
01-Jul-09


Solar PV System and Weather Station Data
Lafayette, Colorado
Daily Totals 10May08 - 30Jun09
ELECTRICAL PRODUCTION (kWh)
SOLAR IRRADIATION* (kWh/m2)
Tmax ≤ 45F
Tmax ≥ 90F
Days with Clouds
Cloudless Days
0
10
20
30
40
0
2
4
6
8
10
* = direct + diffuse on horizontal surface


Solar PV System and Weather Station Data
Cloudless Days Only
10May08 - 30Jun09
ELECTRICAL PRODUCTION (kWh)
40
30
20
10
0
Regression line:
EP = 34.1 - 0.05T_F
r = 0.29
Hotter temperatures decrease cell efficiency, leading to reduced electric production
20
40
60
80
100 F
AIR TEMPERATURE DAILY MAXIMUM
0
10
20
30 C

Less than 1 inch of snow cover can completely shut down the panels' electrical production

Summary of Primary Environmental Factors that Reduced Our Solar-Panel Electrical Production

- Cloudiness
  - sky coverage
  - thickness
  - timing
- Sun angle departure from perpendicular
- Short daylight period
- Snow cover
- Hot days

The dawn of solar ?