Running the Electric Meter Backwards: Real-Life Experience with a Residential Solar Power System

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Lafayette, Colorado

University of Toledo
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PHYS 4400 - Principles and Varieties of Solar Energy
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 with net-metering (no batteries)
• 5.1 kilowatts (DC rating)
• 30 modules (panels) of 170 watts each
• Area = 39.3 m² (approx. 52 ft x 8 ft)
• Predicted annual AC energy production ~ 7400 kWh
2011 Average Residential Electricity Price (cents per kWh)
Retail

National Average = 11.7
What Do You Do for Electricity When the Sun Isn’t Shining (like at night)?

With a “grid-tied” PV system, your back-up is already in place in the form of the utility company’s grid.
Jump-Starting the Arrival of Renewable Energy

Renewable Portfolio Standards

- **Colorado** – It’s the law:
  
  30% Renewables by 2020*
  
  * applies to investor-owned utilities,
  10% renewables for municipal and co-op utilities

- **Ohio** – It’s the law:
  
  12.5% Renewables by 2024
  including 0.5% from solar.
Primary Factors Involved in System Design

- Electrical Consumption of the Home
- Solar Radiation Climatology of Region
- Sun Exposure of the Site
- Cost of System (parts + labor + sales tax)
  - Rebates
  - Tax Credits
  - Monthly Savings on Energy Bill

= Pay-back Time
## Electrical Consumption

### Electric Service - Account Summary

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invoice Number</td>
<td>0201132727</td>
</tr>
<tr>
<td>Meter No.</td>
<td>000035889617</td>
</tr>
<tr>
<td>Rate</td>
<td>Residential General</td>
</tr>
<tr>
<td>Current Reading</td>
<td>22579 Actual 11/30/2007</td>
</tr>
<tr>
<td>Previous Reading</td>
<td>21730 Actual 10/30/2007</td>
</tr>
<tr>
<td>Kilowatt-Hours Used</td>
<td>849</td>
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</tbody>
</table>

### Gas Service - Account Summary

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Invoice Number</td>
<td>0095836510</td>
</tr>
<tr>
<td>Meter No.</td>
<td>000000R519496</td>
</tr>
<tr>
<td>Rate</td>
<td>Residential</td>
</tr>
<tr>
<td>Current Reading</td>
<td>2218 Actual 11/30/2007</td>
</tr>
<tr>
<td>Previous Reading</td>
<td>2085 Actual 10/30/2007</td>
</tr>
<tr>
<td>Measured Usage</td>
<td>133</td>
</tr>
<tr>
<td>Therm Multiplier</td>
<td>0.8596</td>
</tr>
<tr>
<td>Thermo Used</td>
<td>114.00</td>
</tr>
<tr>
<td>Residential Usage Charge</td>
<td>114.00 x 0.08866</td>
</tr>
<tr>
<td>Interstate Pipeline</td>
<td>114.00 x 0.06110</td>
</tr>
<tr>
<td>Natural Gas - Nov</td>
<td>110.23 x 0.48350</td>
</tr>
<tr>
<td>Natural Gas - Oct</td>
<td>3.77 x 0.31600</td>
</tr>
<tr>
<td>Service &amp; Facility</td>
<td></td>
</tr>
<tr>
<td>Franchise Fee</td>
<td></td>
</tr>
<tr>
<td>Sales Tax</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>$86.23</td>
</tr>
</tbody>
</table>

### Comparison Information

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>$88.23 per month/ $2.85 per day</td>
<td>43°</td>
</tr>
<tr>
<td>Electric</td>
<td>$79.88 per month/ $2.58 per day</td>
<td>42°</td>
</tr>
<tr>
<td>Billing Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This Year</td>
<td>849 Kwh Usage/Month</td>
<td></td>
</tr>
<tr>
<td>Last Year</td>
<td>755 Kwh Usage/Month</td>
<td></td>
</tr>
</tbody>
</table>
## Residential Electrical Consumption - 2007

<table>
<thead>
<tr>
<th></th>
<th>Consumption (kWh/year)</th>
<th>Electric Bill ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our house:</td>
<td>7,400</td>
<td>781</td>
</tr>
<tr>
<td>Colorado Average</td>
<td>8,520</td>
<td>789</td>
</tr>
<tr>
<td>Ohio Average</td>
<td>11,112</td>
<td>1063</td>
</tr>
<tr>
<td>U.S. Average</td>
<td>11,232</td>
<td>1196</td>
</tr>
</tbody>
</table>

Data source: Energy Information Admin., U.S. Dept. of Energy

will require approx. a 5-kW PV system in Boulder, Colorado to offset 100% of annual electric consumption.
Climatology of Sunshine
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.
Photovoltaic Solar Resource: Flat Plate Tilted South at Latitude

Annual

http://www.nrel.gov/gis/solar.html
Mean Monthly Solar Radiation
Long-term Averages

Solar Irradiation (kWh/m²/day)

- **Boulder, CO**
  (annual avg. = 5.6 kWh/m²/day)
- **Toledo, OH**
  (annual avg. = 4.4 kWh/m²/day)
- **Tucson, AZ**
  (annual avg. = 6.6 kWh/m²/day)

For flat plate oriented south and titled up at angle = latitude

Month

JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
Calculating a PV System’s 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

assumes no shadowing of panels

ELECTRICAL PRODUCTION (kWh)

For: 5.1 kW DC-rating array, fixed-tilt = latitude - 5 deg., orientation = south, de-rate factor = 0.77

- Boulder, CO 100%
  (annl. total = 7437 kWh)
- Toledo, OH 81%
  (annl. total = 6039 kWh)
- Tucson, AZ 114%
  (annl. total = 8450 kWh)
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
Weather station

south
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
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 (expected) in the utility company’s price for electricity

<table>
<thead>
<tr>
<th>Average Annual Increase (%)</th>
<th>Pay-back in:</th>
<th>Net savings in 25 years:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>22 years</td>
<td>$1,900</td>
</tr>
<tr>
<td>5%</td>
<td>15 years</td>
<td>$18,800</td>
</tr>
<tr>
<td>10%</td>
<td>12 years</td>
<td>$56,500</td>
</tr>
<tr>
<td>15%</td>
<td>10½ years</td>
<td>$141,700</td>
</tr>
</tbody>
</table>

~ 14 years
Estimated “Eco-Karma” Benefits

Every year:

- Clean energy production: 7440 kWh
- CO₂ emissions averted*: 7 tons

* = compared with coal-fired electric plant
Factors We Weighed
in Our Decision to Go Solar (or not)

**Buy:**

* Very good sunshine climate
* Excellent rebates from utility company
* Good tax credits
* Good “eco-karma”
* Increases re-sale value of home?
* Ideal un-shaded site

**Don’t Buy:**

* High initial cost
* Long pay-back time

The Beginning
Installation
Installation
Installation
Installation
Installation
Installation
Installation

2008.04.22
Installation

inverter
Installation

Inverter

Disconnect switches:
- DC
- AC

Fuse box

Meter box

Display shows:
- Watts
- Kwh
- Volts
- Hours
- Etc.
Installation

The Net Meter

Start-up date: 9MAY08
Performance in the First 5 Years

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 Energy Production
5.1-KW Solar Photovoltaic System
Lafayette, Colorado

Monthly Electrical Production (kWh)

- Actual Production
- Production Predicted by NREL's PV-WATTS with 0.77 De-Rate

DATE

2008  2009  2010  2011  2012  2013

0  200  400  600  800  1000
$65/month

$7/month
The Effect of Clouds
Three Example Days

Solar Electric Production:
- CLOUDLESS DAY
  April 6, 2009
  - TMAX = 52 F
  - Solar Irradiation: 7.5 kWh/m²
  - Solar Electric Production: 35.5 kWh
- PARTLY CLOUDY DAY
  April 22, 2009
  - TMAX = 76 F
  - Solar Irradiation: 6.3 kWh/m²
  - Solar Electric Production: 22.4 kWh
- OVERCAST RAINY DAY
  April 25, 2009
  - TMAX = 46 F
  - Solar Irradiation: 1.3 kWh/m²
  - Solar Electric Production: 4.1 kWh
Solar PV System and Weather Station Data
Lafayette, Colorado
Daily Totals 10May08 - 30Jun09

ELECTRICAL PRODUCTION (kWh)

SOLAR IRRADIATION* (kWh/m²)

*Tmax ≥ 90F

Tmax ≤ 45F

Days with Clouds
Cloudless Days

* = direct + diffuse on horizontal surface
Approx. 3% efficiency loss for temperature rise of 20°F (~0.5% per degree C)
Less than 1 inch of snow cover can completely shut down the panels’ electrical production.
Summary of Primary Environmental Factors (Weather and Sun-Geometry) that Reduce Our Solar-Panel Electrical Production

- Cloudiness
  - sky coverage
  - thickness
  - timing
- Sun angle departure from perpendicular
- Short daylight period
- Snow cover
- Hot days
Our Solar-PV Experience So Far?

☼ Zero problems with the system.
☼ Our typical monthly electric bill is 85-90% lower now.
☼ We have produced almost 40 Megawatt-hours of clean electricity.
☼ We have elevated our “eco-karma” and reduced our carbon footprint by:
  32 tons of CO₂ emissions
  = 85,000 fewer miles driven
  = 3,000 trees planted.
☼ The sun-scorched Colorado drought is not all bad.
The dawn of solar?