Status of Residential PV Solar Power

John A. Swanson
University of Pittsburgh
Electric Power Industry Conference
November 11, 2013

Outline

- Description of Residential PV Systems
  - Behind the meter systems
- System Economics
- Benefits of Residential Systems
- Market Growth
  - Growth Inhibitors
  - Growth Opportunities
- Concerns for Growth of PV Systems
- Summary

Location and Orientation

- Sloped roof
  - South best, east and west good
    - Example shown later
  - Mount flush to roof
    - Roof angle equal to latitude is optimum, but not essential
- Flat roof
  - Sloped rack mounted, south facing
    - Possibly tilt adjusted 2 to 4 times per year
  - Gravity or bolted
    - Roof load vs. roof penetration

9.1 KW System, 46 panels, 198 watts

Could be 11.5 KW with 250 watt panels

Net Zero New Construction

6.7 Kw System, 28 panels, 240 watts each

Net Zero Late Afternoon

6.7 Kw System, 28 panels, 240 watts each

Flat Roof, Sloped Panels

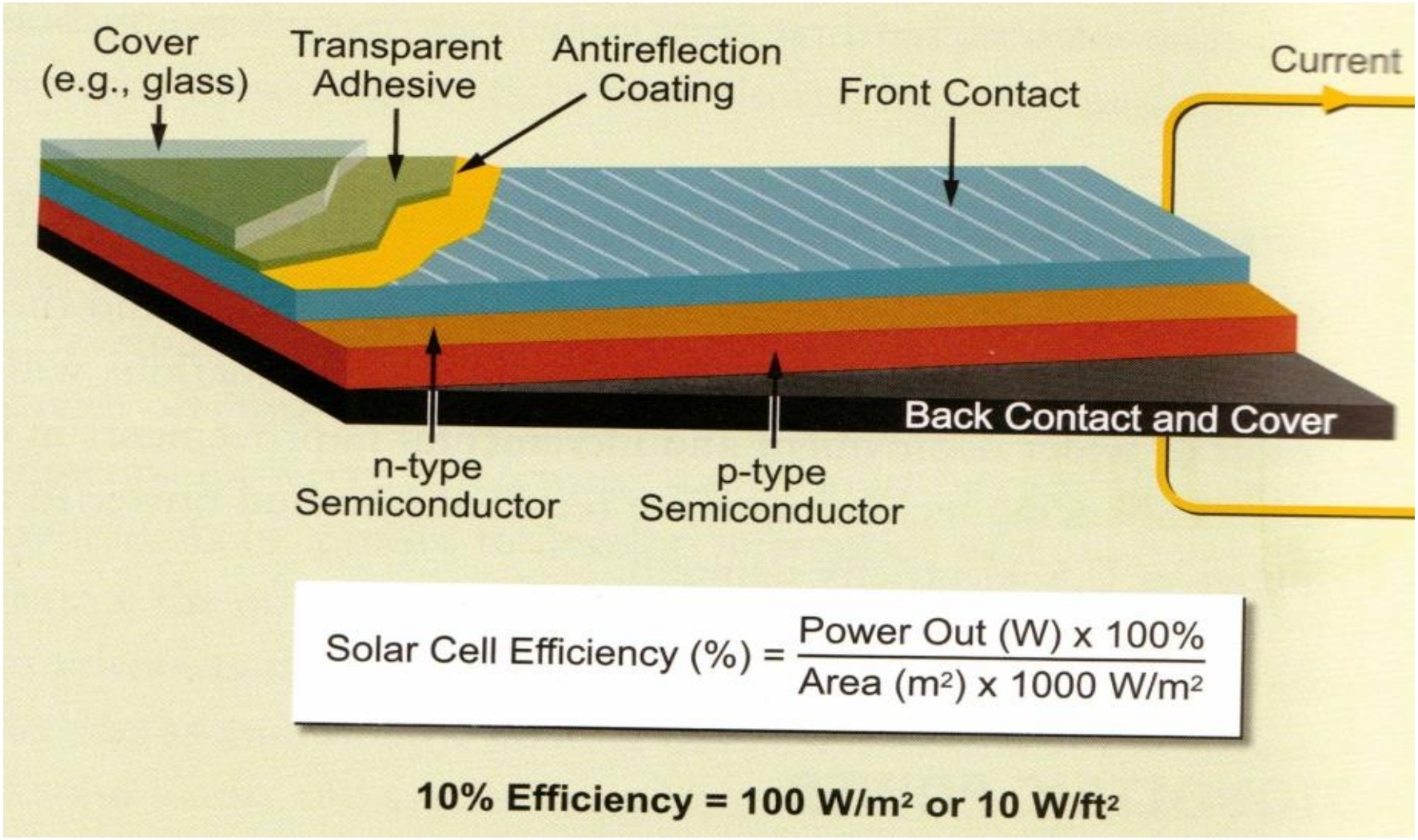
System Components

- Solar Panels
- Inverters (DC to AC)
  - System Inverters (3 Kw to 10 Kw)
  - Microinverters (One per panel)
- Disconnects
  - Inverters
    - Automatic
    - Switches
  - External
    - Accessible to utility
- Wiring
  - DC (System Inverters)
  - AC (Microinverters)
- Utility Connection
  - Circuit breaker panel
    - Sizing

Solar Panels

- Description
  - 240 watts to 330 watts per panel
  - Polycrystalline silicon is the current winner
    - Evolving toward monocrystalline as ingots become larger
    - 15 to 18% efficient typical
  - Thin film are more expensive, more toxic
- Pricing
  - $0.75 per watt, $3,750 for 5 Kw (250 watt panels)
  - I have seen prices as low at $0.52 per watt
- Life
  - Typical warrantee 80% power at 25 years

PV Solar Cell Basics



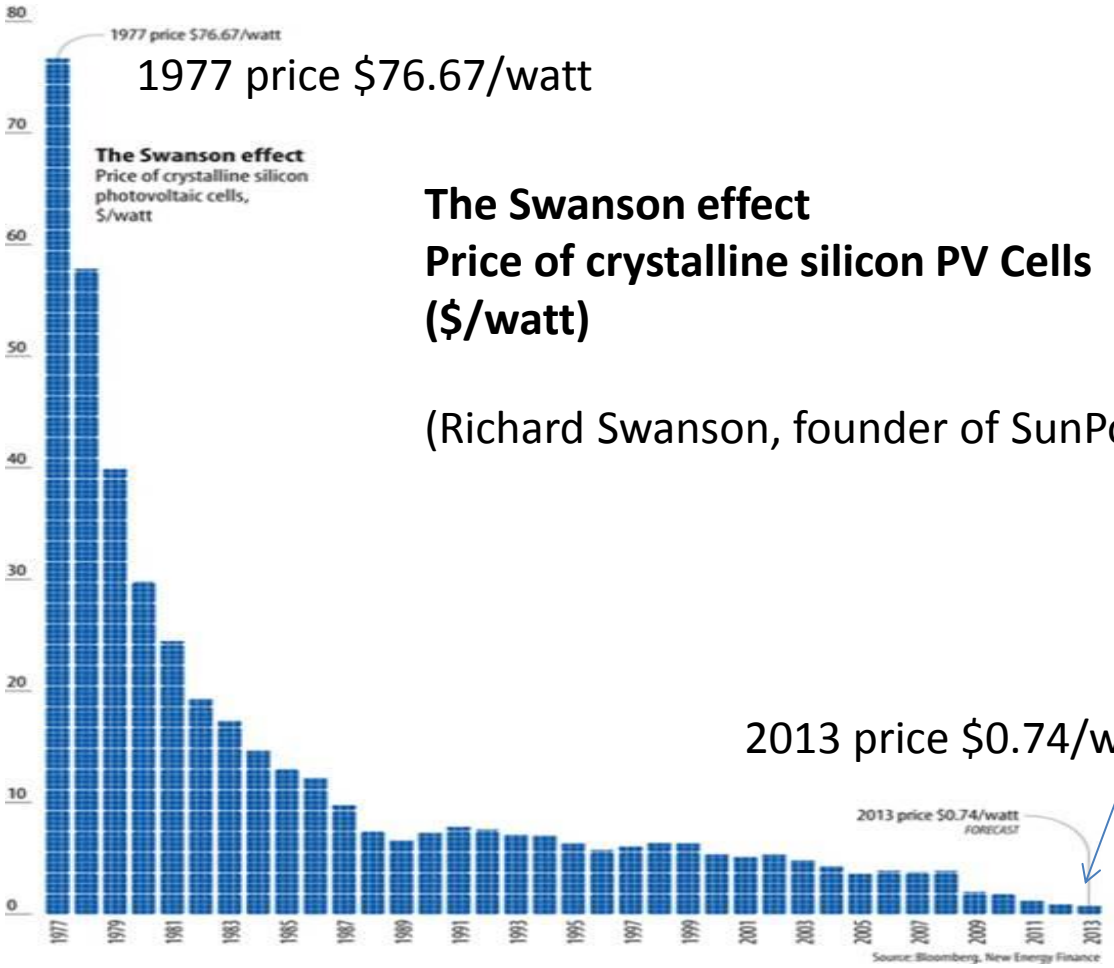
$$\text{Solar Cell Efficiency (\%)} = \frac{\text{Power Out (W)} \times 100\%}{\text{Area (m}^2\text{)} \times 1000\ \text{W/m}^2}$$

10% Efficiency = 100 W/m² or 10 W/ft²

Size of PV Array

- Each panel is about 3 x 5 feet (1.0x1.6 m)
- Weight is about 42 pounds
  - Similar to 3/4 inch plywood
  - Some new panels at 32 pounds
- Panel ratings from 200 to 330 watts
- 5.0 KW – 20 panels (250W) (360 sq ft)
- 10.0 KW – 40 panels (250W) (720 sq ft)
- Estimate 2 watts per residence square foot
  - $70 saving per month for 5 KW (per SECO)

“The Swanson Effect”



1977 price $76.67/watt

$70

The Swanson effect
Price of crystalline silicon PV Cells ($/watt)

(Richard Swanson, founder of SunPower)

$20

$10

2013 price $0.74/watt FORECAST

1977

2013

Inverters

- System Inverters
  - Description
    - 3 to 10 Kw typical
    - Up to 4 strings of panels (about 10 per string)
  - Pricing
    - $2,000 for 5 Kw typical
      - $1513 for 5Kw, $2,630 for 9 Kw (sale prices)
  - Life
    - 10-15 years
      - Extended warrantees available

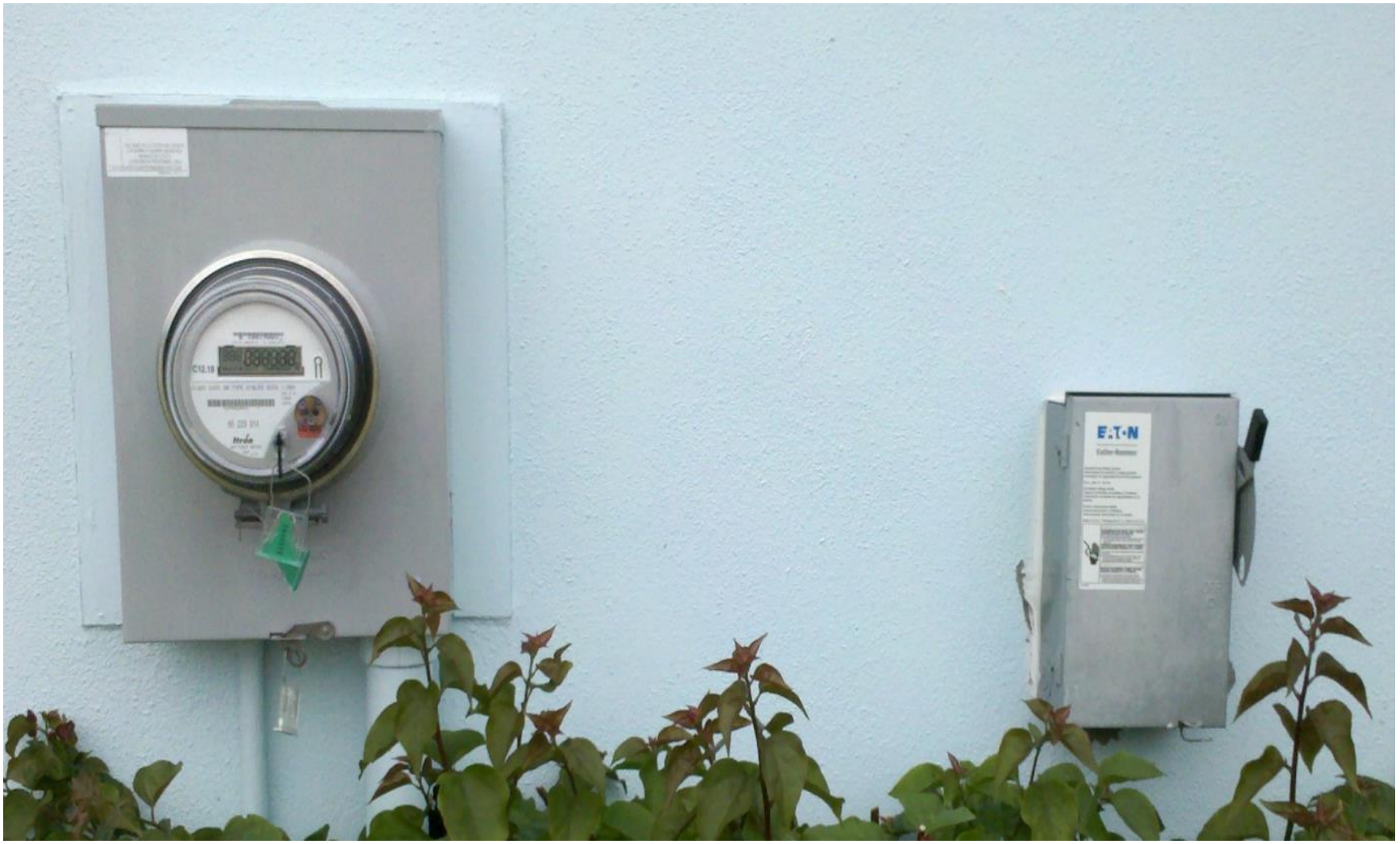
5 KW Inverter

Microinverters

- One inverter per panel
- Direct conversion to AC at point of generation
- Mounts at roof, directly under panel
- AC Cabling to disconnect switch and power panel
- Current price $140 per panel
  - Needs to drop to remain competitive
- $2800 for 20 panel system
  - Vs. about $2000 for 5KW inverter
- Gives real time internet monitoring for each panel
- Automatic disconnect for power outages
- Good for locations with partial shading

Microinverter

Meter and External Disconnect



Wiring

- DC wiring with System Inverters
  - Must be enclosed in metal conduit
  - Must be appropriately labeled
  - Typical voltages 300 to max of 600 volts
- AC wiring (with microinverters)
  - AC wire of appropriate size connects inverters
  - Interior wiring may be standard romex wire
- Appropriate bare solid copper wire grounding
  - typically 6 to 8 AWG

Utility Connection

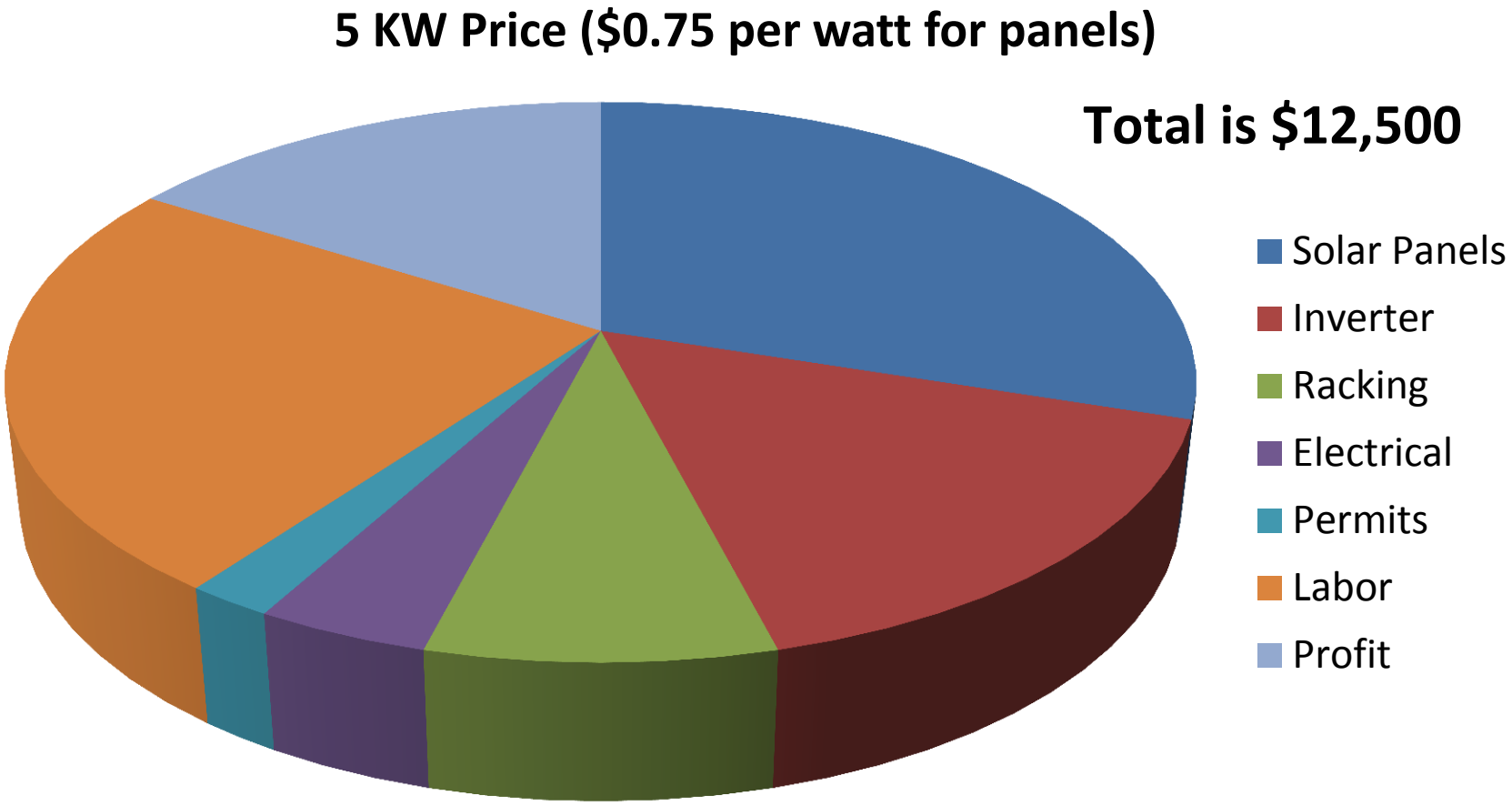
- Appropriately sized breaker in standard panel
- Utility meter usually replaced with dual meter
  - Records current flow into house
  - Records current flow from house (excess generation)
- Net metering
  - Customer is credited for excess generation at same rate as current inflow price
  - Single disk meter will spin backward
  - Fair price set by utility company
    - Value of electricity at the end residential user

Meter with In-Out Measurements

5 Kw Residential PV Returns

	Florida		Pennsylvania		New York	
System List Price		$12,500		$12,500		$12,500
State Rebate (per watt)	$0.00		$0.75		$1.30	
Total State Rebate	0		$3,750		$6,500	
Federal Tax Credit (30%)	$3,750		$2,625		$1,800	
Net Cost		$8,750		$6,125		$4,200
PVWATTS Calculations						
Solar Radiation (kWh/m2/day)	5.37		4.16		4.10	
DC to AC Derate Factor	0.77		0.77		0.77	
Yearly Generation (AC Kwh)		7,546		5,846		5,762
Electricity Cost (per KWH)		$0.110		$0.096		$0.145
Average Yearly Savings		$830		$561		$835
Return/Investment		9.5%		9.2%		19.9%
Return/Investment (28% tax)		13.2%		12.7%		27.6%
Return/Investment (35% tax)		14.6%		14.1%		30.6%
Return/Investment (39.6% tax)		15.7%		15.2%		32.9%

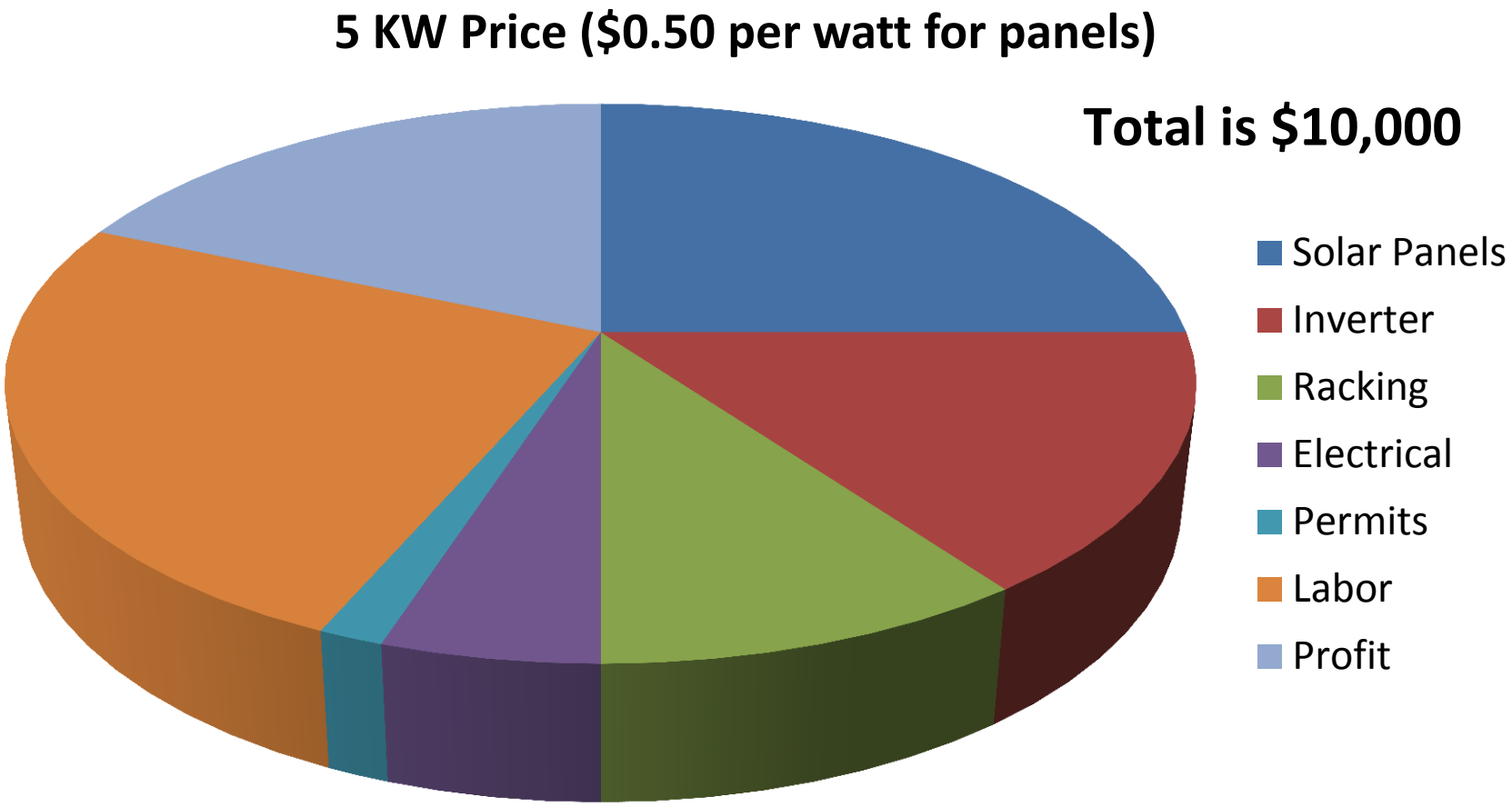
Breakdown of PV Price (2013)



Component Pricing Trends

- Solar Panels
  - Dropping from $0.75 toward $0.50
- Inverters
  - Not dropping as fast, but some progress on system scale inverters
- Racking
  - Some downward movement with volume, upward for material
- Electrical
  - slight upward pressure
- Permits
  - Good progress on standardized permitting, email access
- Labor
  - Opportunity for retraining of returning veterns
- Profit
  - Restraint to 10-15% is appropriate here

Possible PV Price end of 2014



Other Trends

- Residential Electrical Price
  - Upward (Duke Energy just increased 8%)
- Tax Brackets
  - Highest increased from 35% to 39.6%

Benefits of Residential PV Systems

- Positive grid implications
  - Reduces grid load, because generation and use are behind the meter
  - Any excess used nearby
- No noise
- No CO_2 production (about 1 year in manufacturing)
- Long life
- Low maintenance, no moving parts
- Individual (family) capital investment
- Support structure (roof) already exists
- Zero fuel cost for 25 years (warranted lifetime)
- Safe to recycle at end of life

Market Growth

- Current market size
  - Enphase shows more than 115,000 public systems
  - California has 170,000 grid tied systems
- Growth Inhibitors
- Growth Encouragement

Enphase Public Systems

Growth Inhibitors

- PV solar is still viewed as too expensive.
  - Previous system prices were $5 to $8 per watt
  - Present price is less than $3 (before incentives)
- Licensing fees sometimes exceed $1,000 (CA)
  - This is being addressed at local and state levels
  - $150-$200 is now more typical
- Aesthetics – PV still viewed by some as ugly
  - But we will get over this (ex. Cell towers)

Growth Opportunities

- All non-shaded South sloped roofs are profitable in the United States
- East and West sloped roofs are profitable in much of the United States
- PV supplies are sufficient for an expanded growth rate (prices are still dropping)

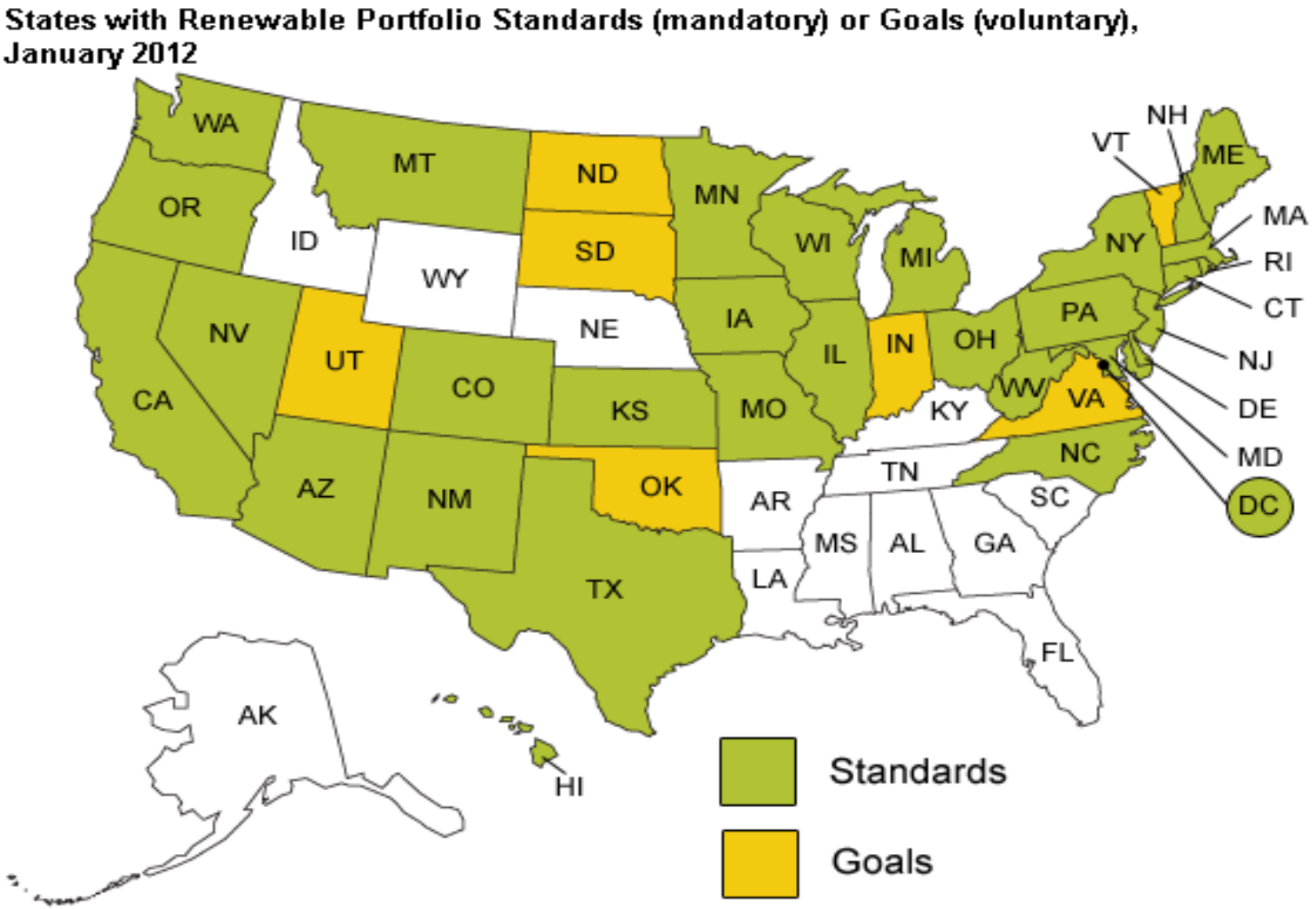
Growth Encouragement

- Education
  - Colleges and Universities
  - K-12
  - Adult Education
- Utilities
  - Newsletters
  - Incentives
  - Projects
- Builders and Contractors
  - Net-zero communities
  - Install on existing buildings
- Communities
  - Net-zero subdivisions
  - Neighbor experience (word of mouth)
- Public Policy
  - Billboards, ads, articles, etc.
- Government (Federal and State)
  - Various incentive programs

Solar Incentive Programs

- Federal Tax Credit (30% to 2016)
  - Not available for schools, churches, non-profits
- Rebates (cash)
  - State
    - FL none available
    - PA $0.75 per watt (nearly gone)
    - NY $1.30 per watt
  - Utility (rare and rapidly taken)
    - Recent $20,000 on 10KW system!
- Renewable Portfolio Standard (RPS)
  - State set required renewable percentage
    - Solar carve-outs
  - Creates Solar Renewable Energy Credits (SREC)
    - Within state or across state boundaries
- Feed-in Tariff (FIT) (Local utility, rare) (Canada)
  - Payment of yy Kwh produced for next xx years
- State sales tax exemption on solar components
- Property Tax Exemption for value of system

States with Renewable Portfolio Standards



Other Incentives

- Time-of-day pricing (California)
- Feed in tariffs (Europe)
- Carbon dioxide penalties (Europe)
  - Carbon Tax
  - Cap-and-trade
  - Carbon Rebate Program (JAS)
    - Pro-rata return of carbon fee to taxpayers

Concerns for Growth of PV Systems

- Daily cycles
  - Sunrise, Sunset
  - Very predicable
- Daily Variability
  - Clouds
- Morning and evening ramp rates
- Excess Generation

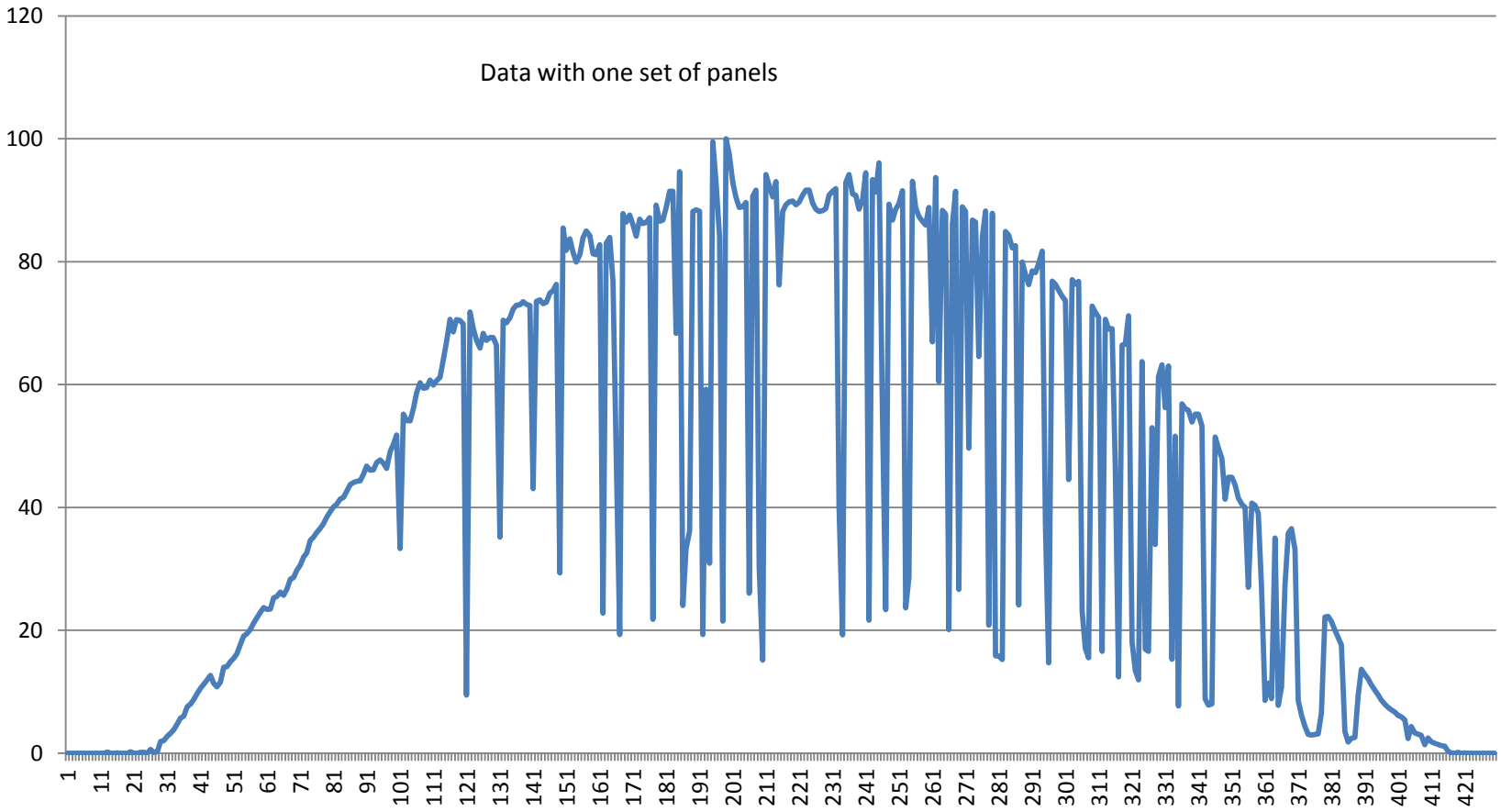
Daily Cycles

- No generation at night
- Load and generation both peak in mid-day, especially in summer with Air Conditioning load (now most of United States)
- Industrial/office peaks during daytime
- Other generation sources must be available to match supply with demand when sun is not shining
- Wind is stronger at night, which helps
- The daily pattern is very predictable
- 12 hours of storage would be a big win
- Enter electric vehicles with significant energy storage

Variability

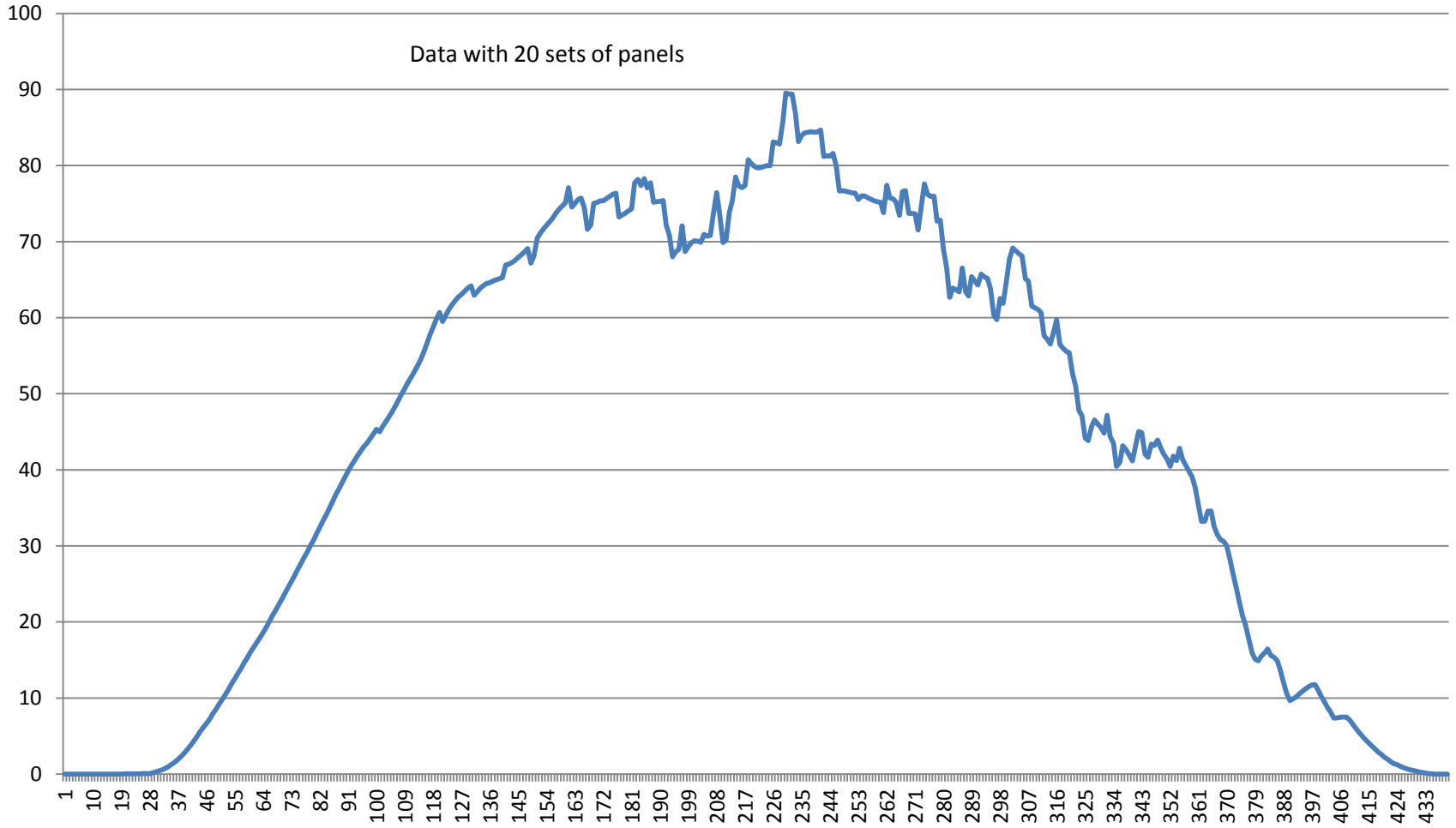
- In addition to the predictable daily cycles, solar PV has large variations during the day, due to clouds. PV has no inertia, but clouds do.
- As PV becomes wide spread, the rate of variability decreases, eventually becoming just the percentage of cloud cover over the generating area
- Satellites provide real time coverage
- Weather forecasting will allow reasonable future generation prediction (24 hours ahead)
- Wind power short time variability decrease 87% when just 4 wind farms were networked. (Apt,et all)

Data with one set of panels



Source: 20 PowerPoint Slides That Shook the Earth (Greentech Media)

Data with 20 sets of panels



Widely Distributed PV Solar Power (Florida)

Variability (continued)

- Worst case is storm with full day or days of cloud cover
  - Must have sufficient backup to match the missing solar capacity
  - The load may be reduced (A/C demand, for example)
  - Power may be available from adjacent non-cloudy regions
  - Load shedding may be possible
    - Voluntary (contracted)
    - Involuntary (roving blackouts) – NOT GOOD

Variability (continued)

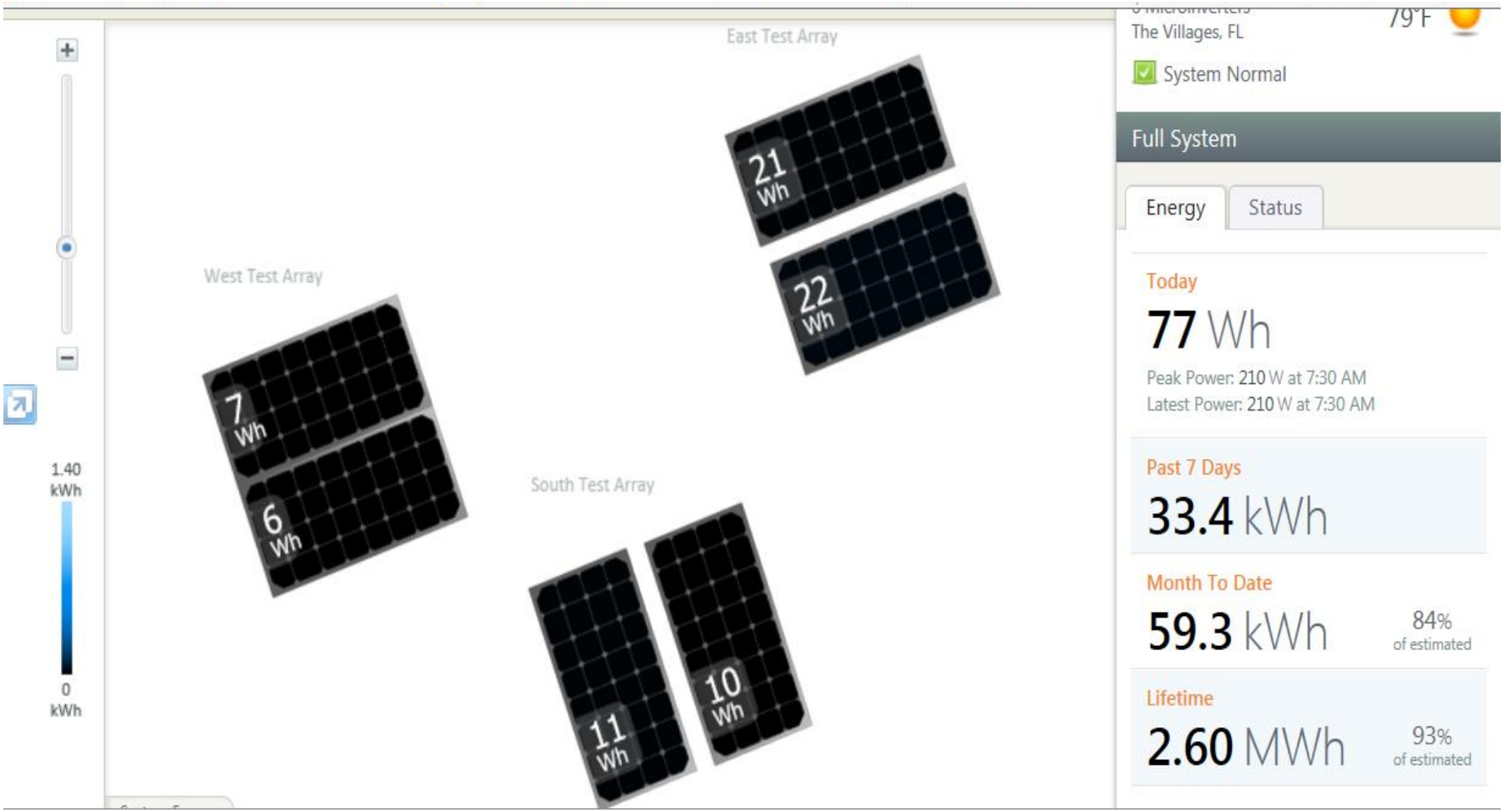
- Flexible loads
  - Residential
    - Hot water heaters (Daily cycle)
    - Refrigerators, Freezers (Hourly cycle)
    - Electric automobiles and golf carts (Daily Cycle)
  - Commercial
    - Manufacturing processes
- Flexible sources
  - Electric automobiles

Ramp Rate

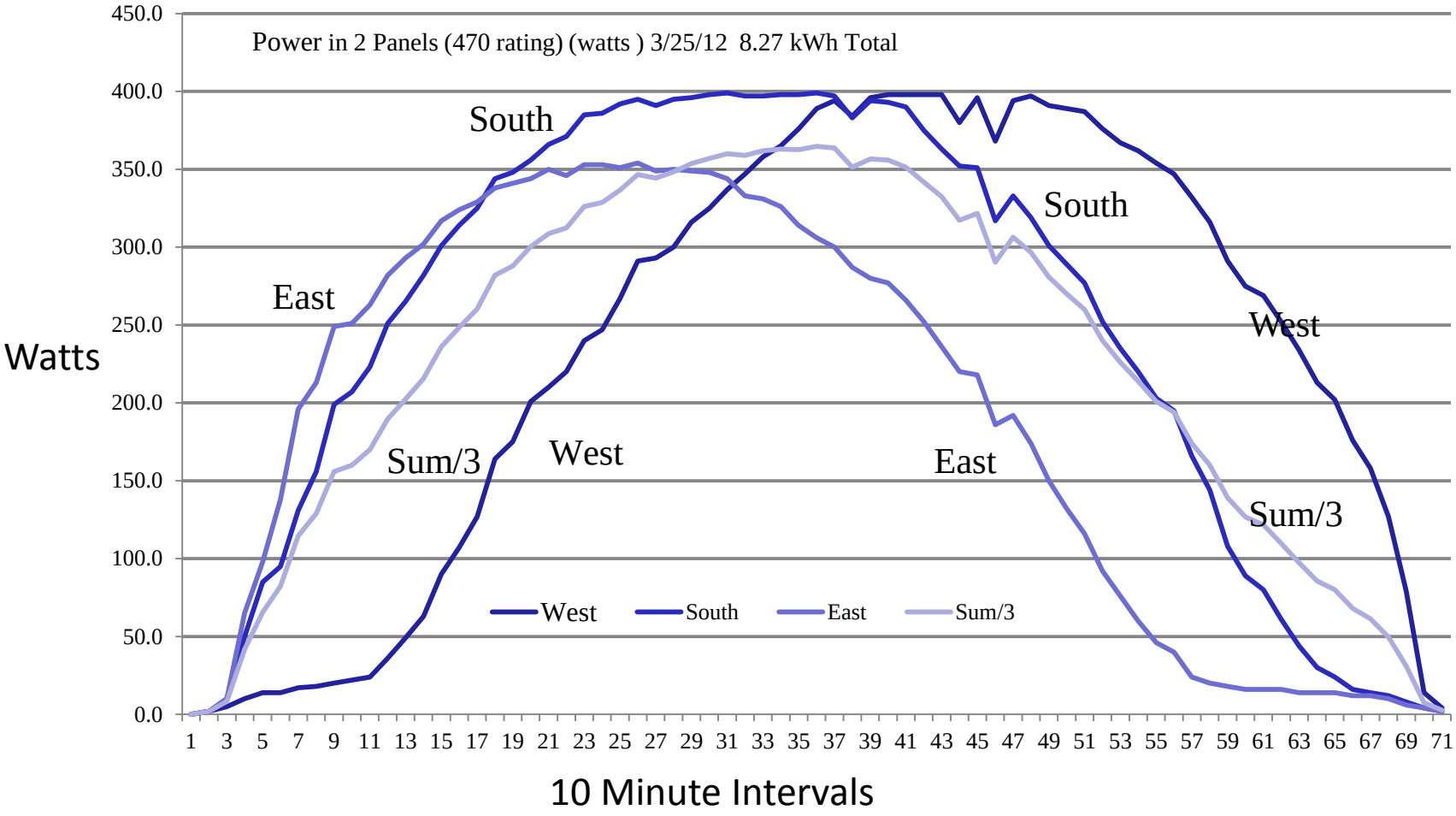
- Solar PV has a high ramp rate in the morning and evening. This has been posed as a problem in matching supply and demand.
- This can be reduced by using panels in South, East, and West orientations.
- It will also be reduced by morning and evening shading in real installations.
- Ramp rates can be made worse by single axis tracking panels, but these are generally not economical.
- Natural gas generation can easily respond to ramp rate

Swanson Roof 2013

Swanson Directional Array



Individual Directions and Sum/3



Excess Generation

- Solar PV generates when the sun shines
- At high levels of solar PV, periods of low demand (Spring, Fall) renewable generation could force reduction in other sources of supply
- This is unlikely to be a problem unless renewables become more than 25% solar
- Is not a problem as long as renewables are less than the natural gas generation availability

Excess Generation (continued)

- If this becomes an issue, then
  - Move load to excess generation times
    - Hot water
    - Electric Automobiles
  - Add absorbing loads
    - Desalination
    - Hydrogen Production by electrolysis
      - Could be used in Fuel Cells to balance loads?
  - Shut down some renewables
    - Degrades economics of renewables

Summary

- Residential PV Solar has reached the point where it is cost effective in the present environment
  - Panel prices are less than $0.75 per watt
  - Federal tax incentive is 30% (but not a rebate)
  - 5 to 10 KW Residential systems are available at less than $2.00 per watt with only the federal incentive
  - This gives an after tax return per investment of greater that 10%
  - Local governments encourage residential PV

Predictions

- PV installations (yearly wattage) will double each year for the next 2 years
- Growth rate beyond 2016 will depend on Federal incentives
- PV will reach 10% of peak load by 2020
- PV will exceed land based wind by 2020
- Utilities will become major players in renewable energy