Grid Implications of Residential Photovoltaic Energy

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Pitt Energy Conference

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Engineering's Grand Challenges (NAE)

- **Make solar energy economical**
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- **Provide access to clean water (Solar Reverse Osmosis?)**
- Restore and improve urban infrastructure
- Advance health Informatics
- Engineer better medicines
- Reverse-engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- **Advance personalized learning (MOOC?)**
- Engineer the tools of scientific discovery

Issues from My Early Pitt Talks

• Wind vs. Solar	Both (solar leading)
• Silicon vs Thin Film	Silicon
• CSP vs Photovoltaic	PV
• Tracking vs Fixed	Fixed
• Mirrors/Lenses	Neither
• Full inverters vs Micro	Micro for rooftop (shading)
• Solar vs Solar Electric for Hot Water	Not decided
• Professional vs DIY	Still professional
• South only	South, East, West
• Large (tall buildings)	No, PV Co-ops better approach

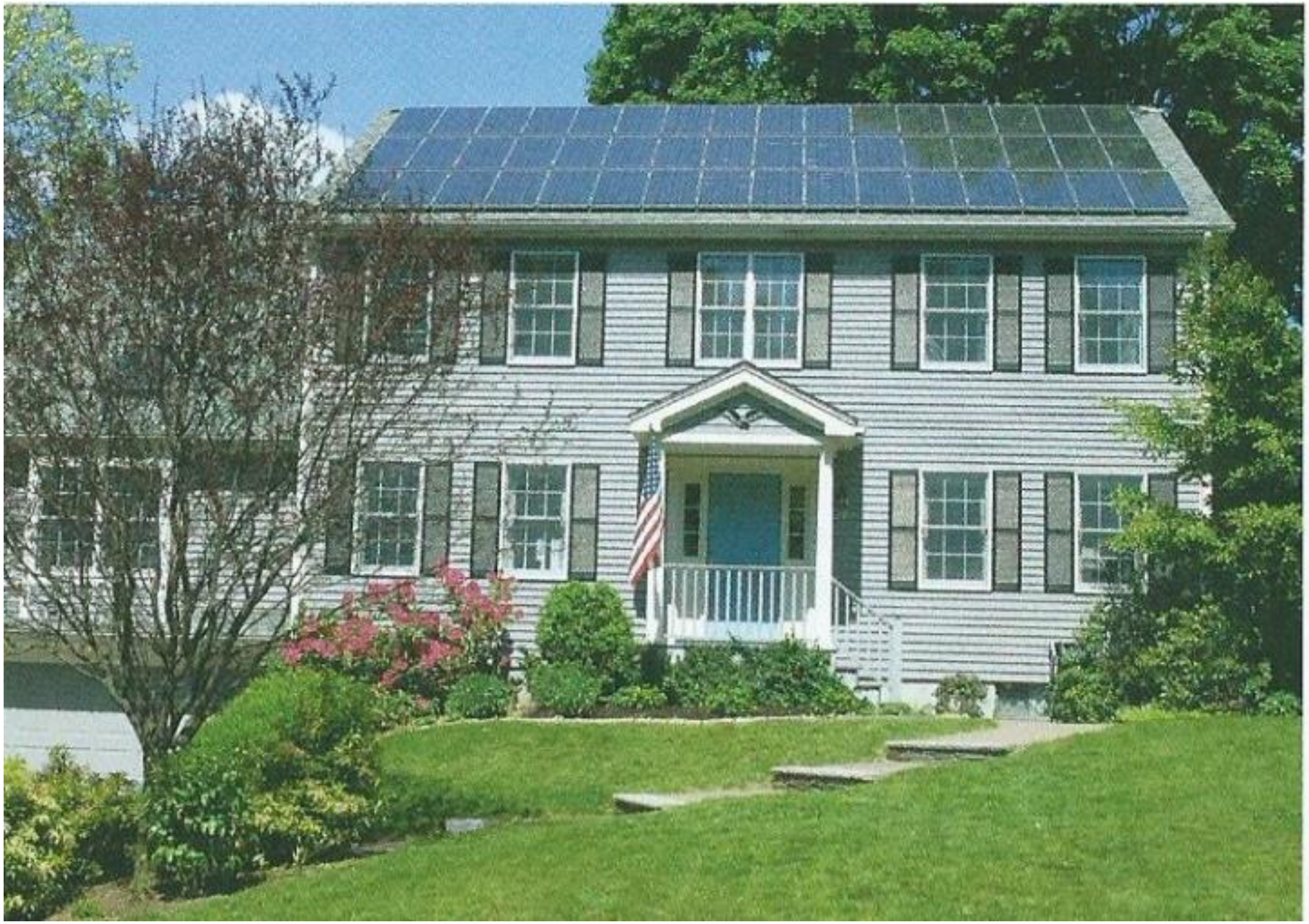
Outline

- Part 1 – Status of Residential Photovoltaics (PV)
- Part 2 – Grid Integration of PV
- Part 3 – Utility Opportunities

Part 1 – Status of Residential PV

- Current Costs ($2.50 to $3.00)
- Projected Costs ($2.00)
  - Best Friends Animal Sanctuary (20.8 kW, $40,000)
- Utility costs are half residential costs
  - A quote which I doubt
- Current and Projected Volume
- Grid concerns with increasing volume
  - Evening ramp rates
  - Cloud variability

Residential Solar Installation



12.0 kW, 48 modules, 250 watts each

Swanson Phase 2

9.1 kW, 46 modules, 198 watts each (could be 15.2 kW with 330 watt modules

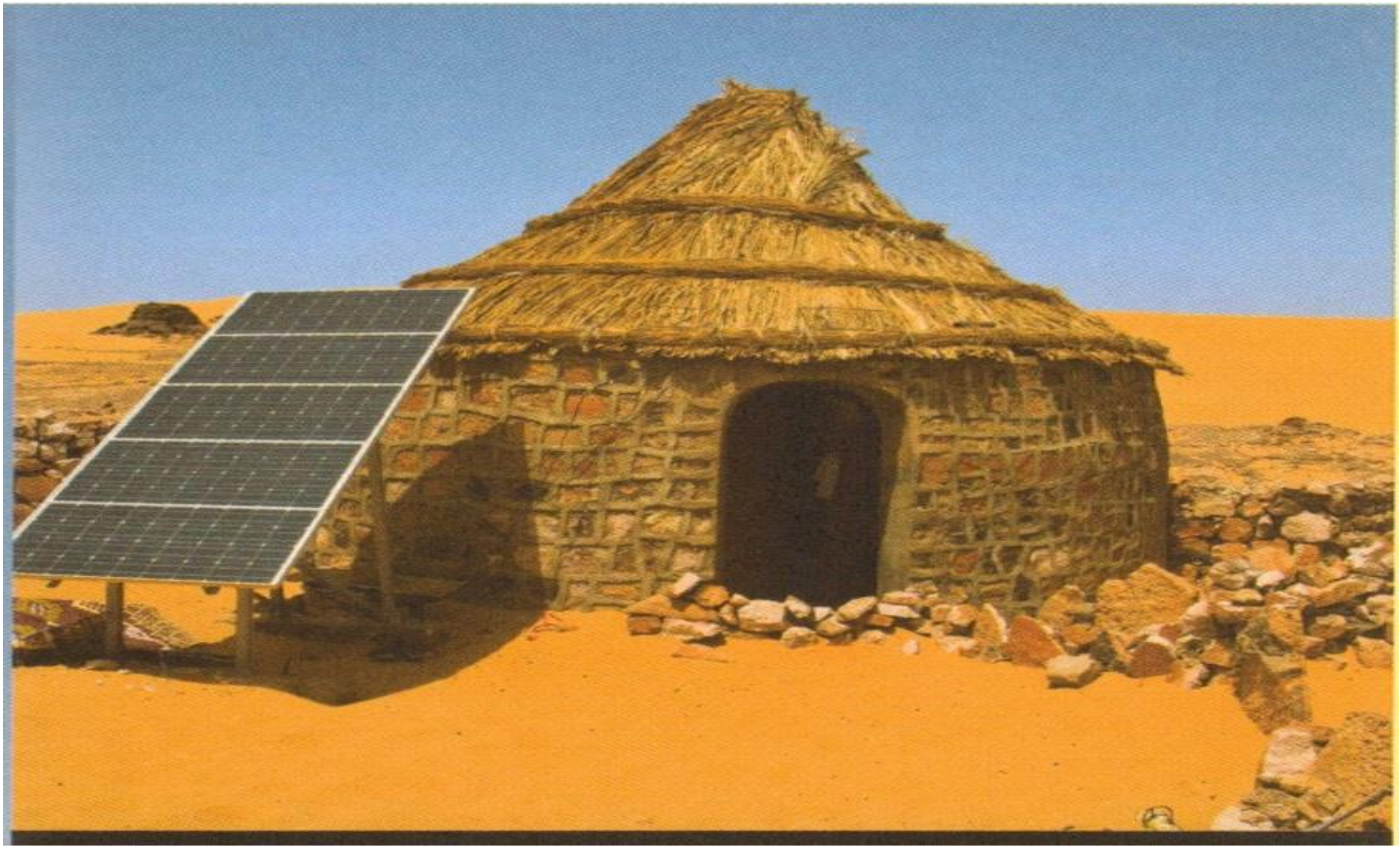
Green Key Village Net-Zero House

6.7 kW System, 28 panels, 240 watts each

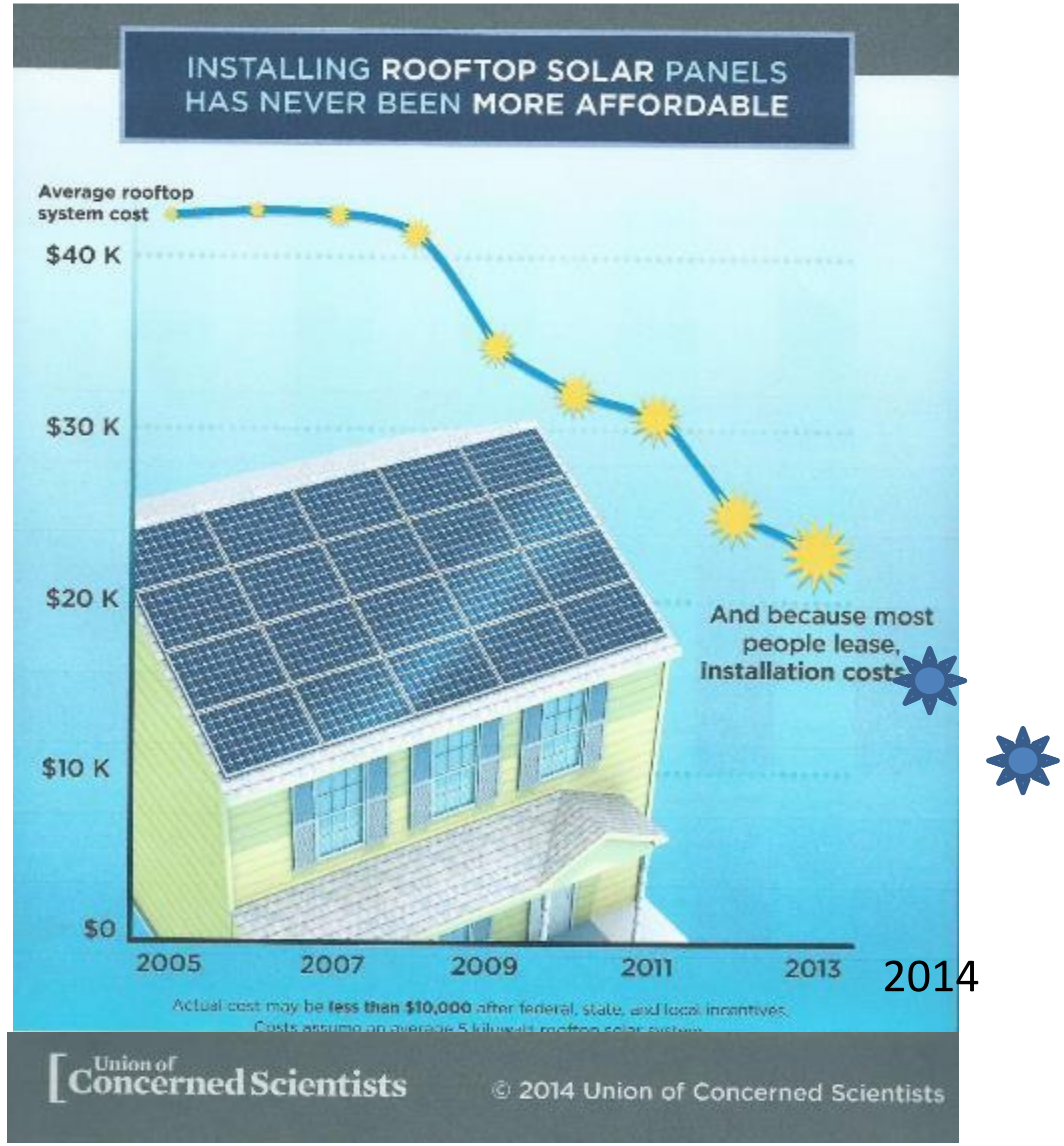
Temple Shalom, Oxford, FL

37.6 kW, 160 panels, 235 watts each

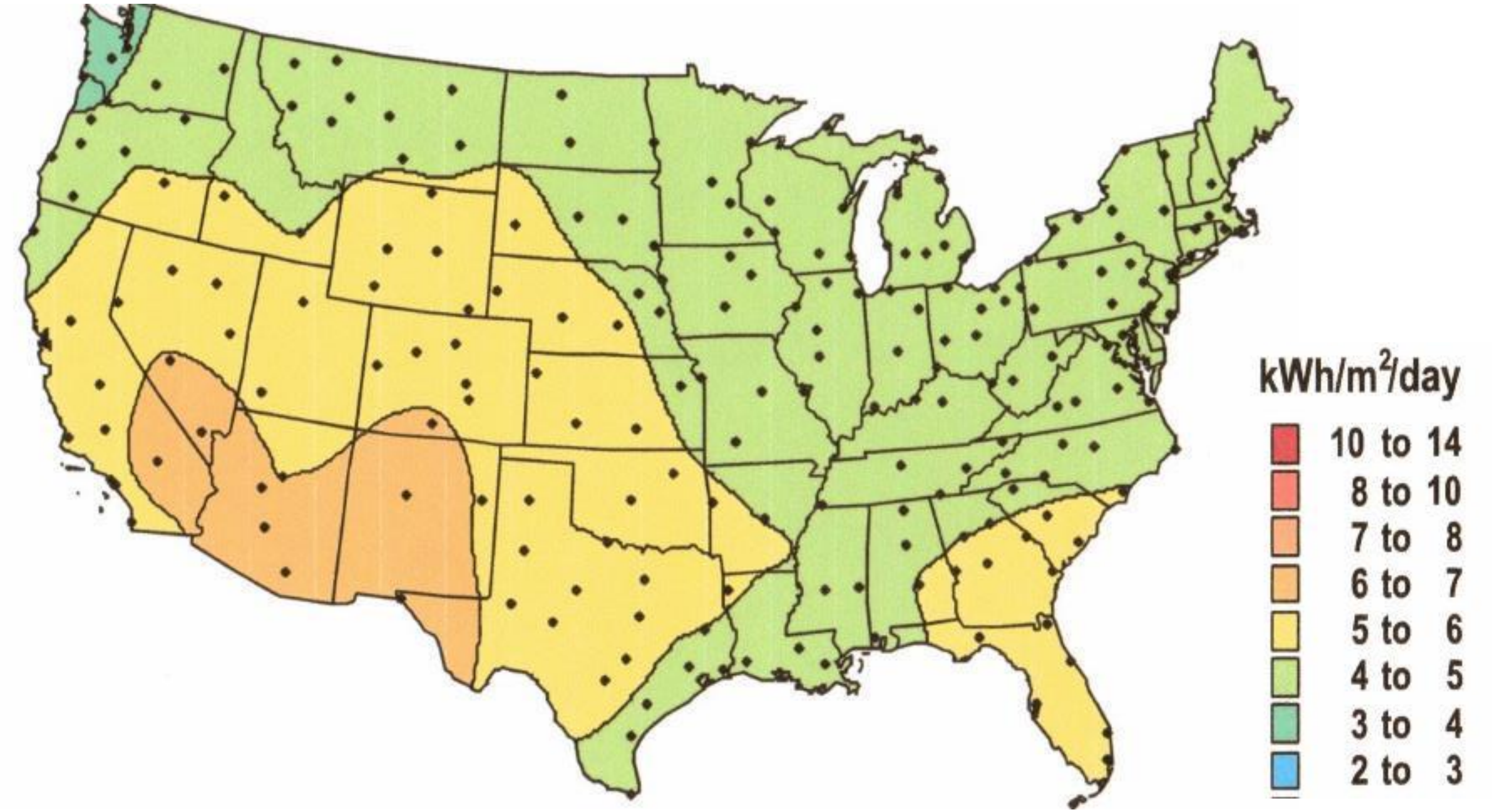
A Micro-grid Application



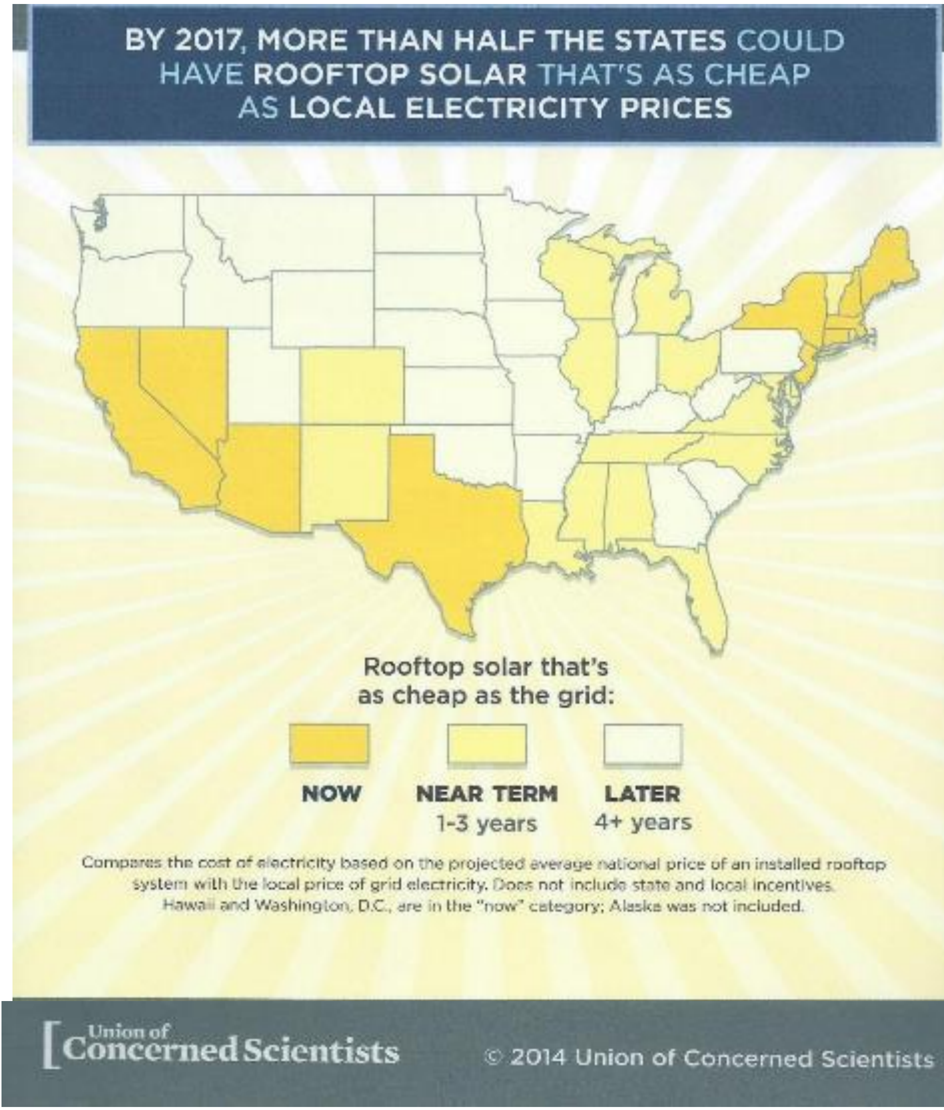
UCS Infographic Oct 2014

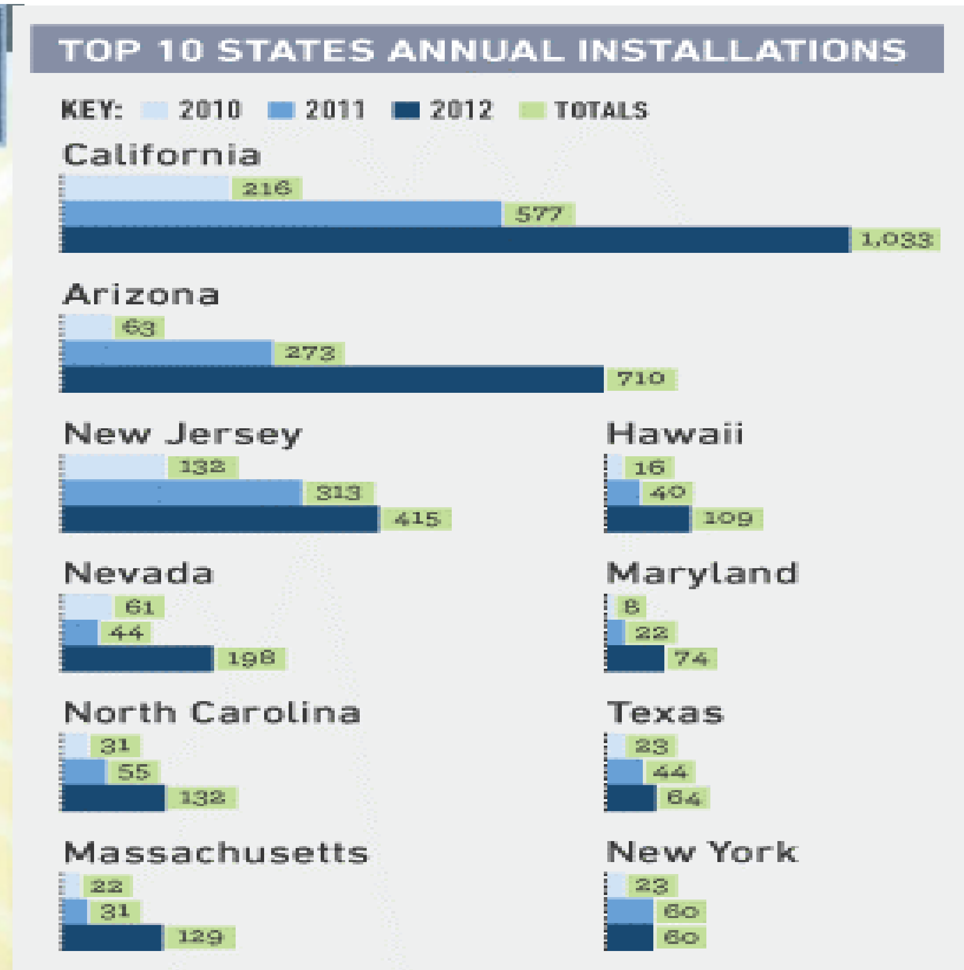


Solar Distribution in the United States

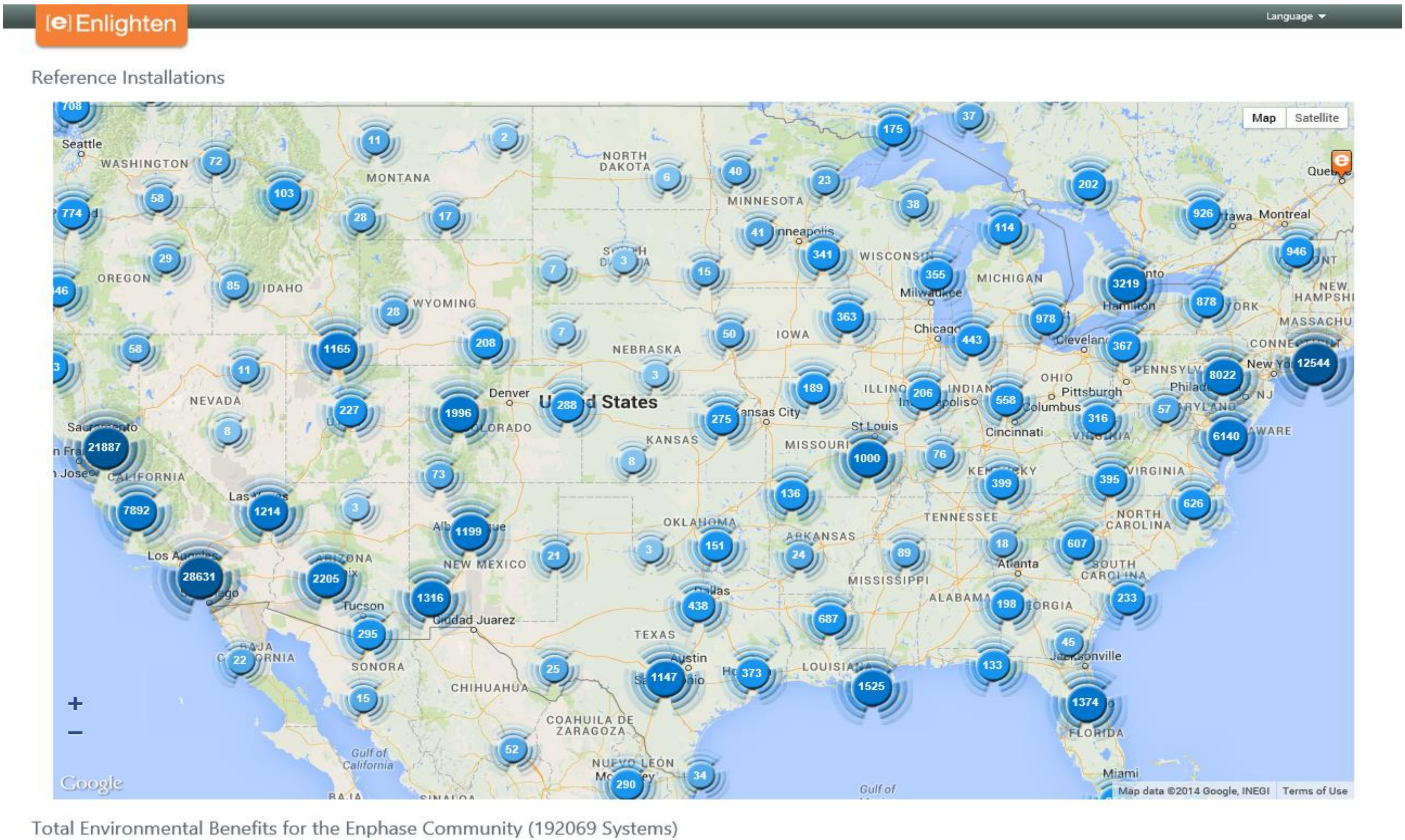


UCS (continued)

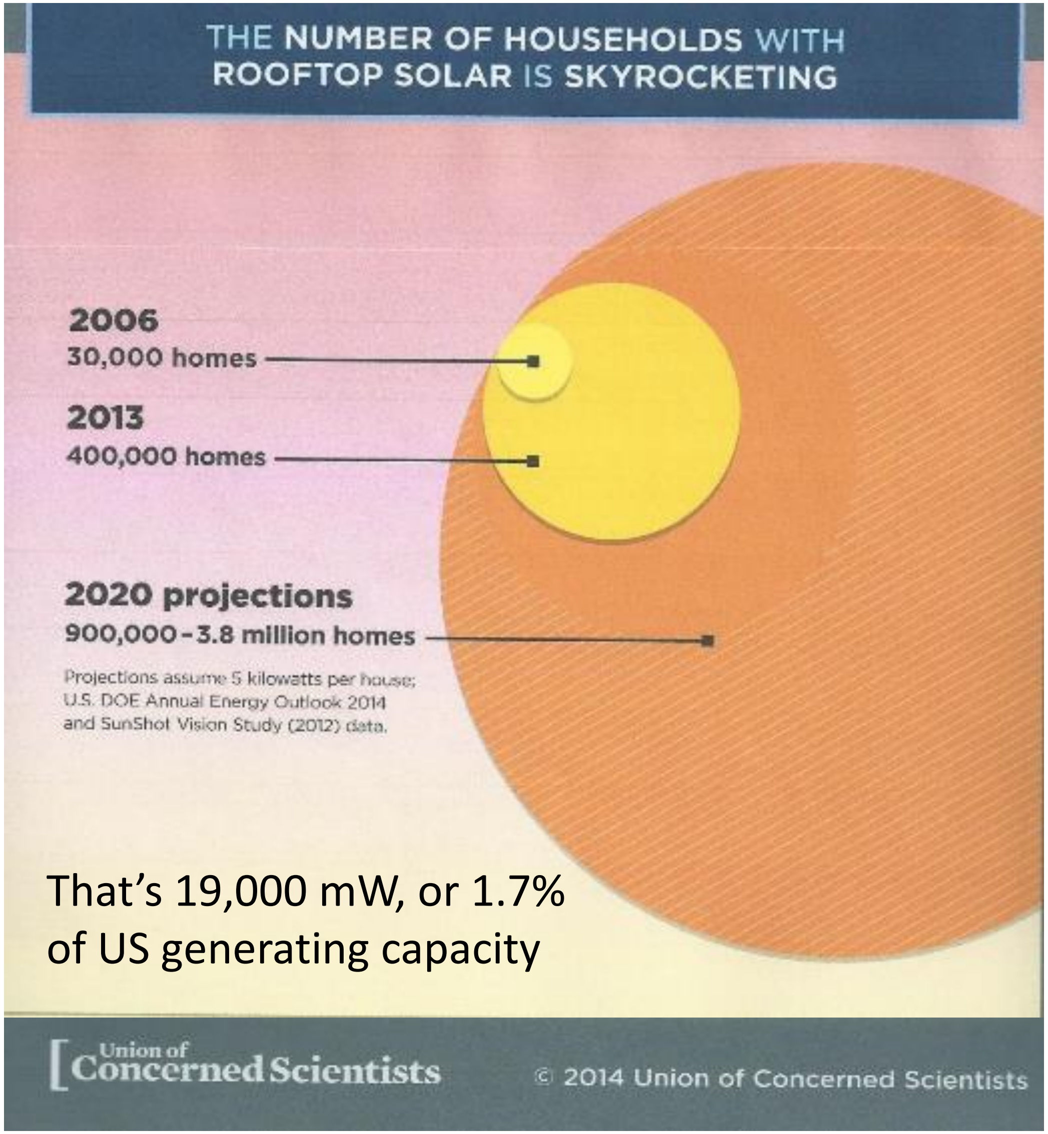




Enphase MicroInverter Systems



UCS (concluded)



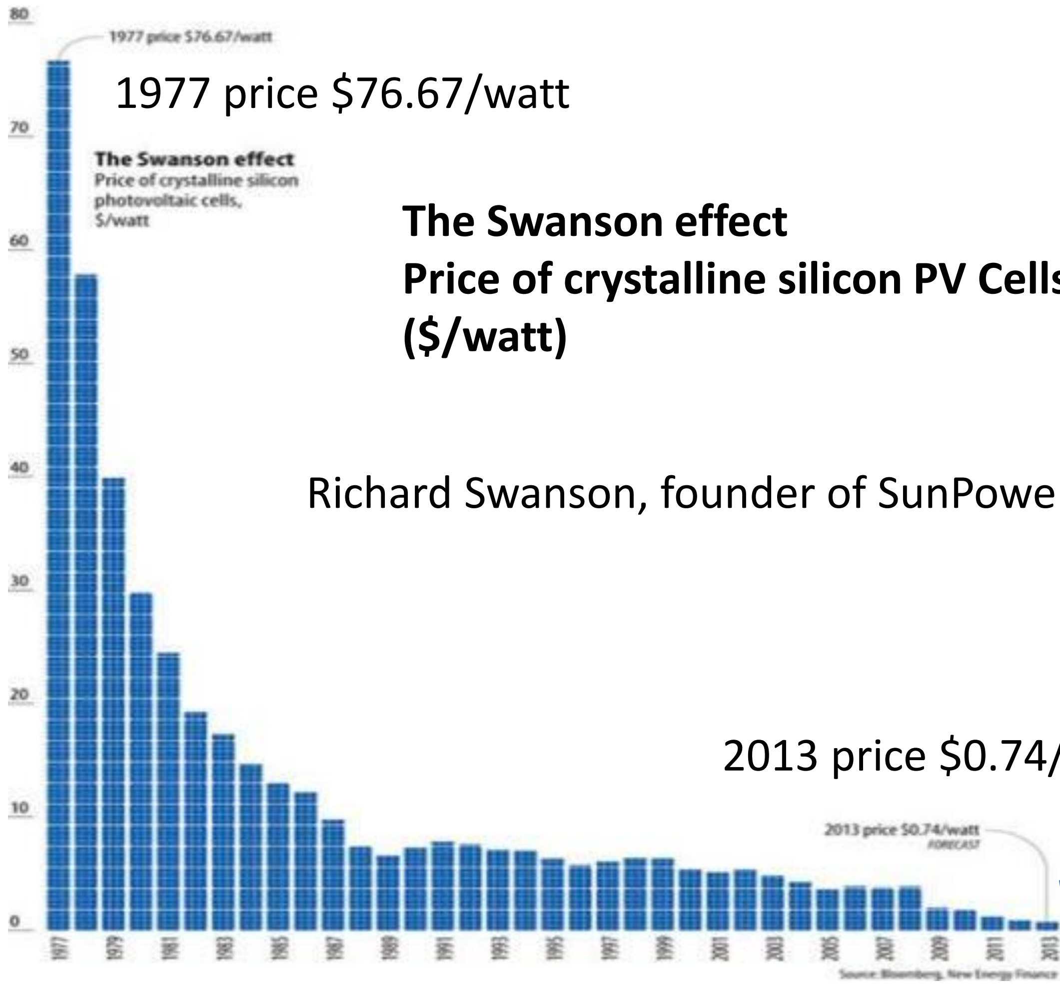
Recent Installations Information

- Olympic Oval in Kearns, Utah
  - 3,100+ modules on parking structures
  - 250 watts(est) * 3,100 modules = 775 kWh
  - Cost $1,400,000 is $1.81 per watt
  - Ref USA Today October 31, 2014

2014 Quantity Economics for 5 kW System

Swanson House Solar Power Report								
	System 1	5KW		System 2	5KW		Quantity	5KW
Installation Date	October 2009			January 2012			Oct 2014	
System List Price		$41,500			$14,500			$12,500
Federal Tax Credit (30%)	$12,450			$4,350			$3,750	
Florida Solar Rebate	$10,437			$0			$0	
Net Cost		$18,613			$10,150			$8,750
Average Yearly Generation		8,795			8,795			8,795
DC-AC Conversion Efficiency (est.)		0.90			0.90			0.90
SECO Electric Charge (per KWH)		$0.11			$0.11			$0.11
Average Yearly Savings		$869			$869			$869
Return / Investment		4.7%			8.6%			9.9%
Tax Bracket		35%			35%			35%
After tax Annuity		7.2%			13.2%			15.3%

“The Swanson Effect”



1977 price $76.67/watt

$70

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

Richard Swanson, founder of SunPower Corp.

$20

2013 price $0.74/watt FORECAST

$10

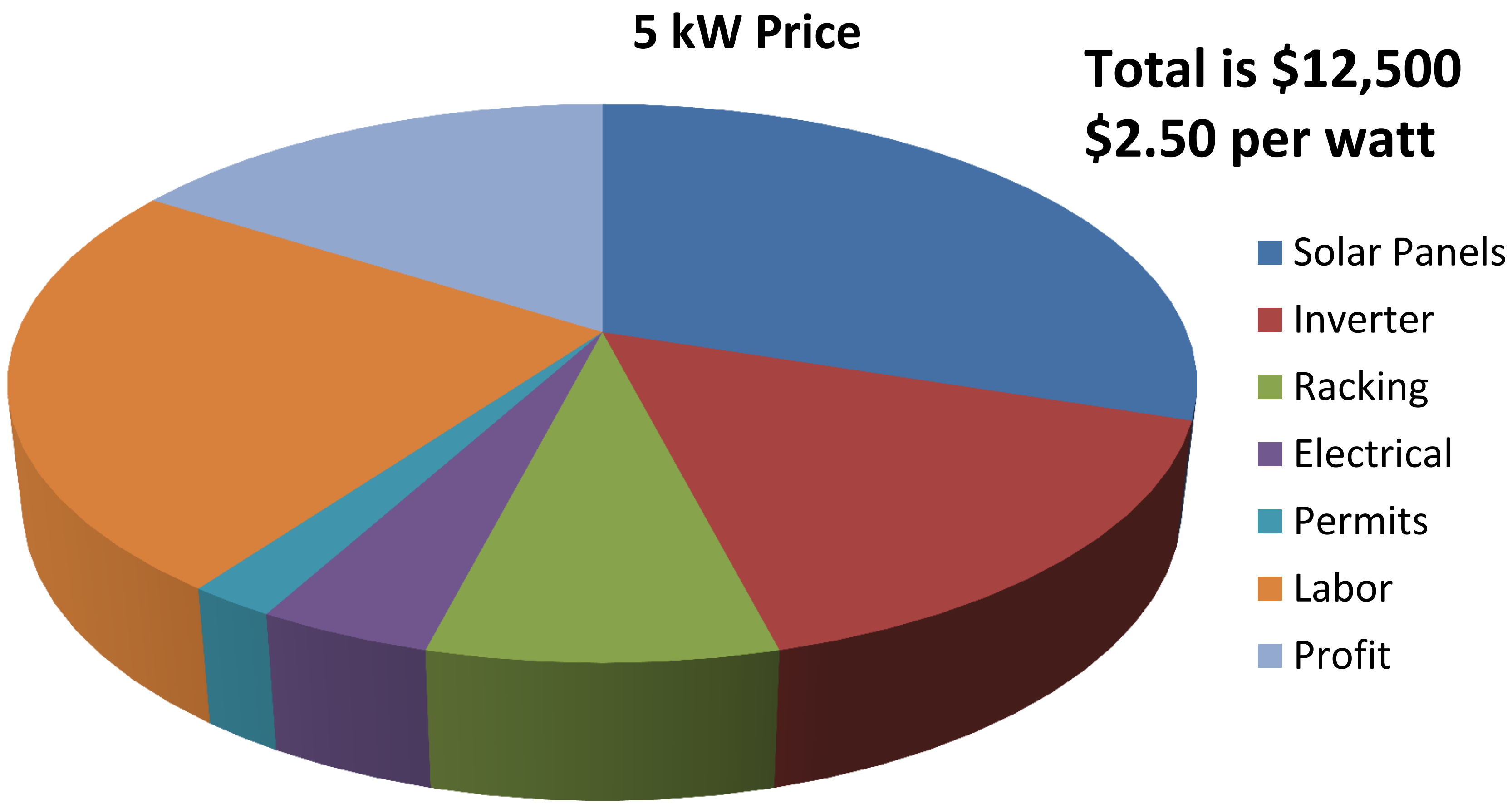
1977

2013

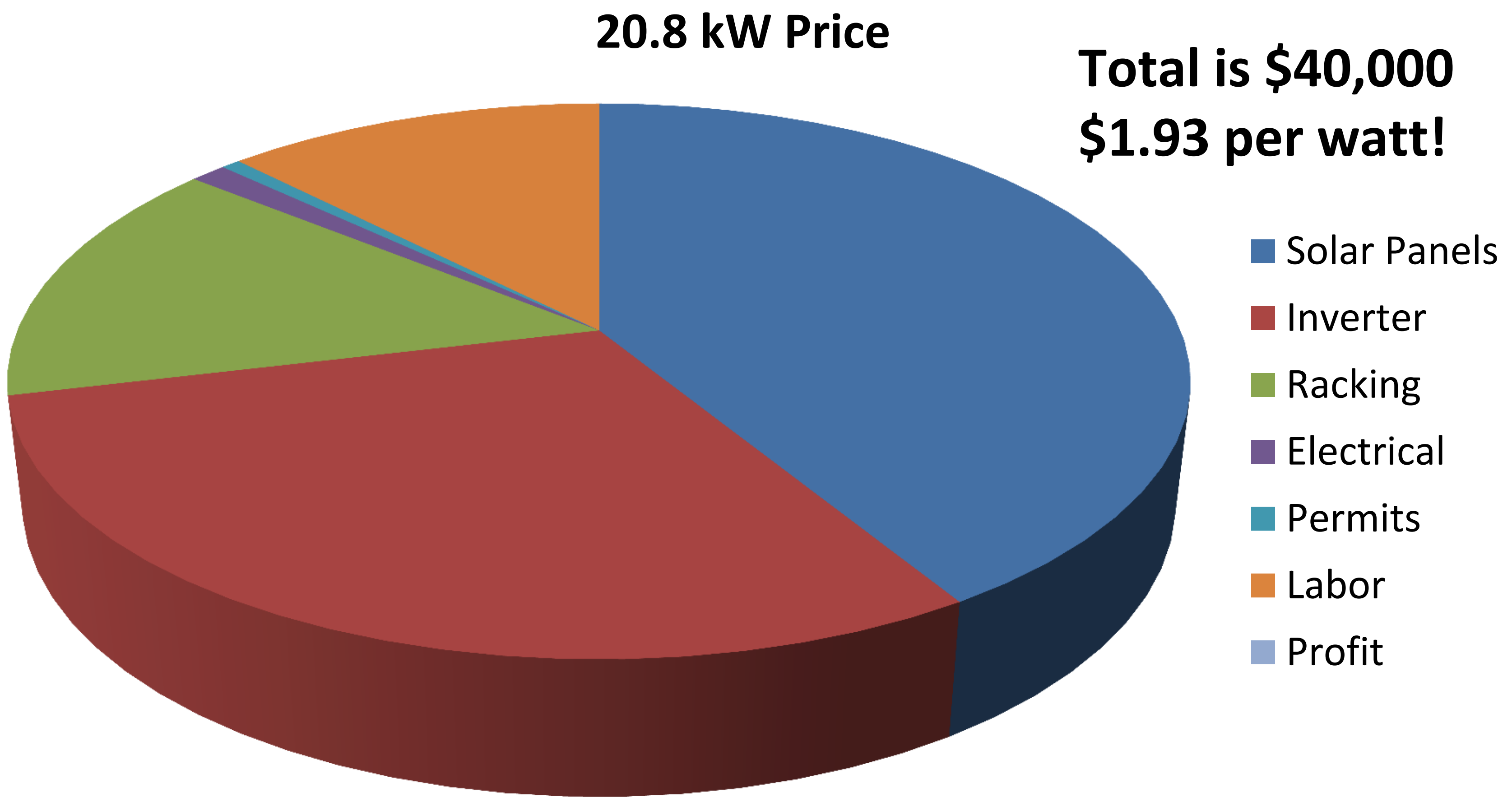
The Residential PV System

- Solar Modules (panels)
  - Produce DC current when the sunlight falls on them
- Inverter(s)
  - Either one system inverter or micro-inverters under each panel (recommended). Converts DC to AC.
- Racking
  - The hardware attaching the modules to the structure
- Balance of System
  - Wires, circuit breakers, disconnects

Breakdown of Current Price (2014)



Best Friends Animal Shelter



Information for Donors

Install Price	$2.00	Dollars per watt							
Panel Rating	250	Watts							
Solar Rating	6.0	Peak Hrs per day							
Efficiency	85.0%	Losses DC/AC, wiring, etc							
Electric Rate	$ 0.0581	Per kWh							
Donor Tax	39.6%	Tax Bracket							
CO2 savings	2.121	lb. per kWh (Utah uses coal fired power)							
System	Number	Ave. Daily	Yearly	Donation	Fed. Tax	Net	Energy	Return/	CO2 Saving
Size (kW)	of Panels	Gen (kWh)	Gen kWh)	Amount	Saving	Cost	Savings	Net Cost	(tons/yr)
5	20	25.5	9,308	$10,000	$3,960	$6,040	$ 541	9.0%	9.9
10	40	51.0	18,615	$20,000	$7,920	$12,080	$ 1,082	9.0%	19.7
20	80	102.0	37,230	$40,000	$15,840	$24,160	$ 2,163	9.0%	39.5
Notes:									
Life of system is 25 years (or longer)									
Warranty is 80% power at end of 25 years									
Assumes no increase in electric prices! Federal Tax Credit does not apply!									

What is Net Metering?

- If you are generating more than you need
  - Utility buys excess at current price
- If you need more than you are generating
  - You buy from utility at current price
- Eliminates the need for local storage
  - Batteries are still expensive
- Net metering is the law in many states
- “Behind the meter”
  - Priced at the meter, the highest electricity price
- Forces utilities to use all renewables being generated
- No incentive for owner load balancing

Advantages of PV Solar Power

- Produced at point of use
  - No utility network loads
  - No large distribution lines needed
- Environment effects
  - No noise
  - No CO_2 production
  - Reduces individual Carbon Footprint
  - Silicon based panels have no toxic materials
- Improved United States energy independence
  - Zero fuel cost

Lease Options

- Pay fixed monthly fee to lease company
- Pay reduced bill to electric company
- Little (or no) up front cost
- Lease company installs, owns, maintains system
- Largest Lease Companies
  - Solar City (AZ,CA,CO,DE,HI,MD,MA,NJ,NY,PA,TX,DC)
  - SunRun (AZ,CA,CO,HI,MD,MA,NJ,NY,OR,PA)
  - Sungevity (AZ,CA,CO,NY,MA,NJ,DE,MD)
- More than 70% of new systems are leased

Green Key Village

- Lake Ella Road, Lady Lake, FL
- 142 Net-zero houses, 3 phases
- Houses computer analyzed to be “smart green”
- Optimized HVAC, windows, walls, hot water
- Energy generated with PV modules on roofs
- Beautiful houses, beautiful location
- $20,000 to $30,000 premium over standard construction
- Native plants, recycled water for lawns
- www.GreenKeyVillage.com

Green Key Village Net-Zero Houses

Effect of Panel Orientation on Power Ramp Rate

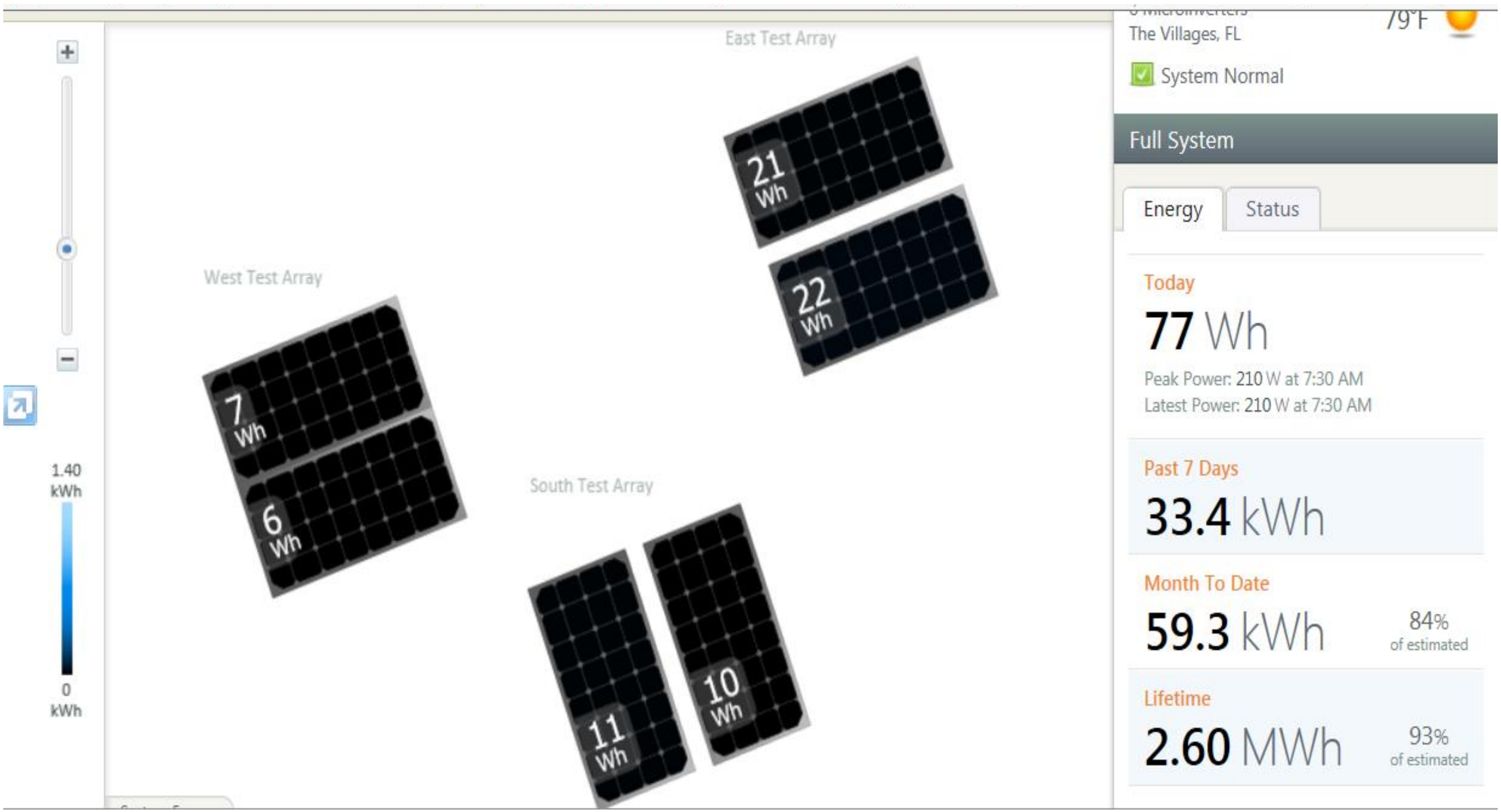
John A. Swanson
Member, National Academy of Engineering
October 2014

Background

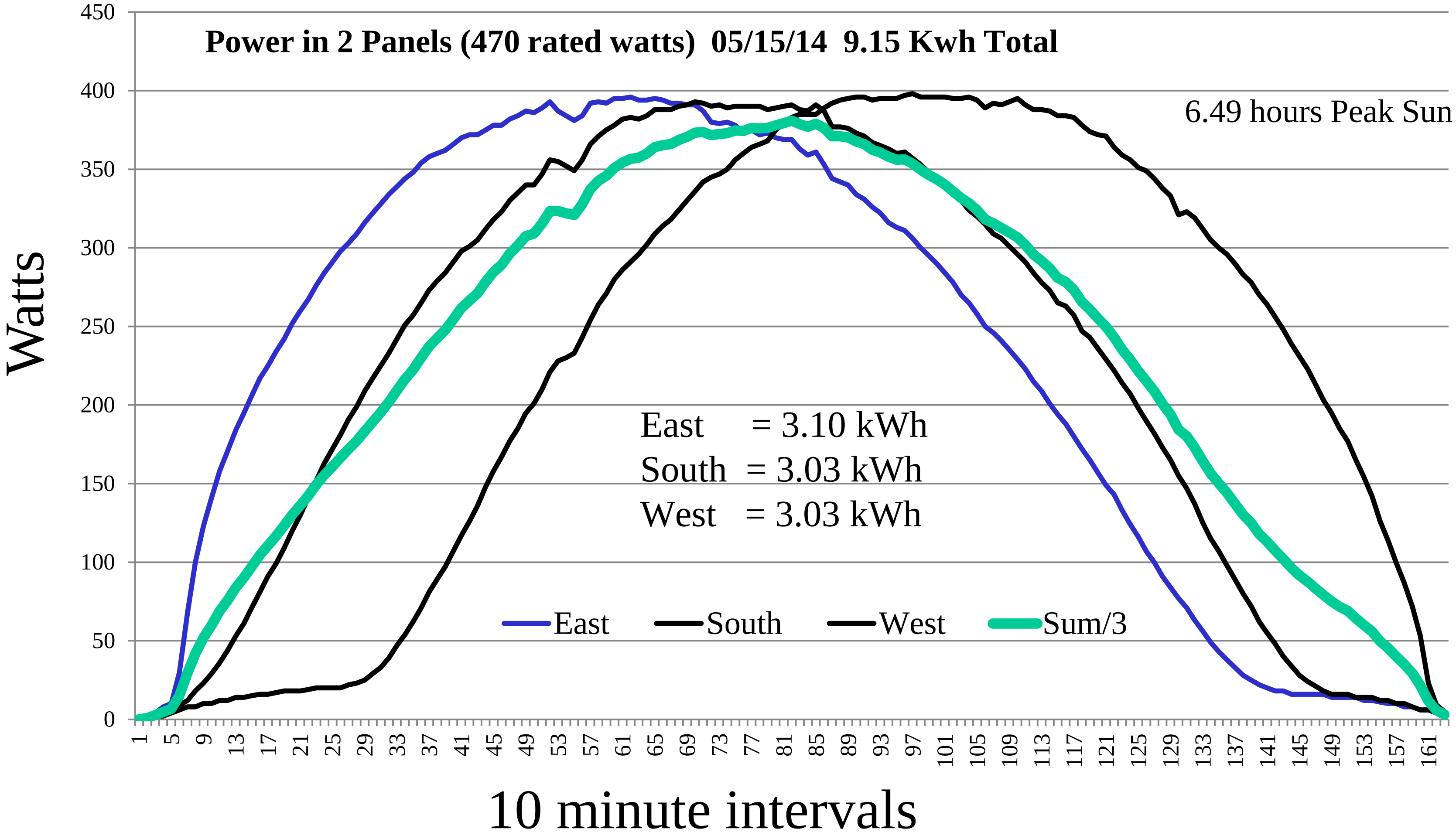
- There has been concern about the effect of the high negative power ramp rate at the end of the day when significant quantities of PV is being used.
- I believe previous studies assumed that all panels faced South (the optimum position)
- I believe that this is a smaller issue if there are multiple residential systems feeding power into the grid
- These systems will be orientated in a variety of directions because they are installed on existing roofs

Swanson Roof 2013

Swanson Directional Array



Individual Directions and Sum/3



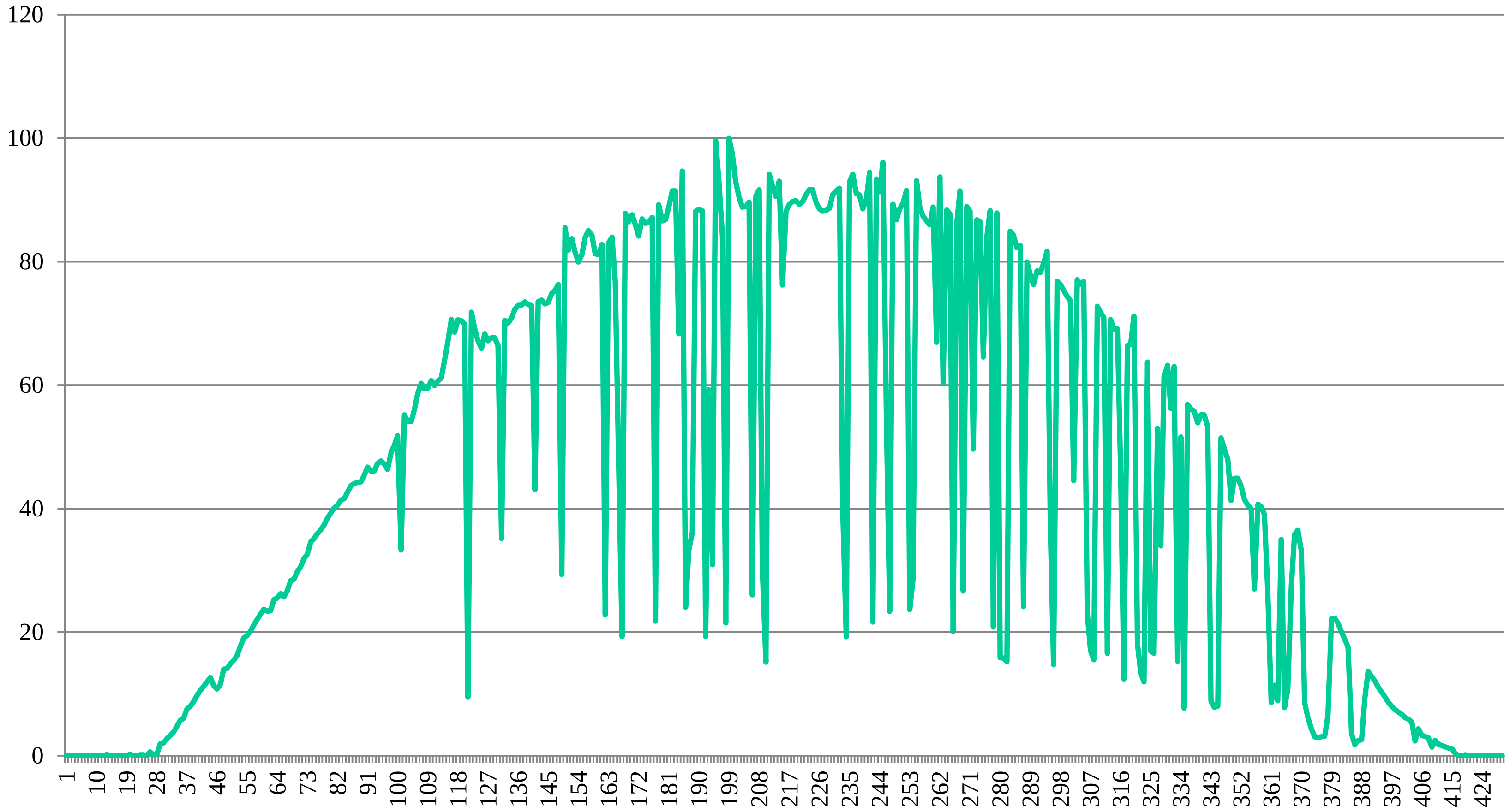
Effect of Multiple Systems on Cloud Shading

John A. Swanson
Member, National Academy of Engineering
October 2014

Background

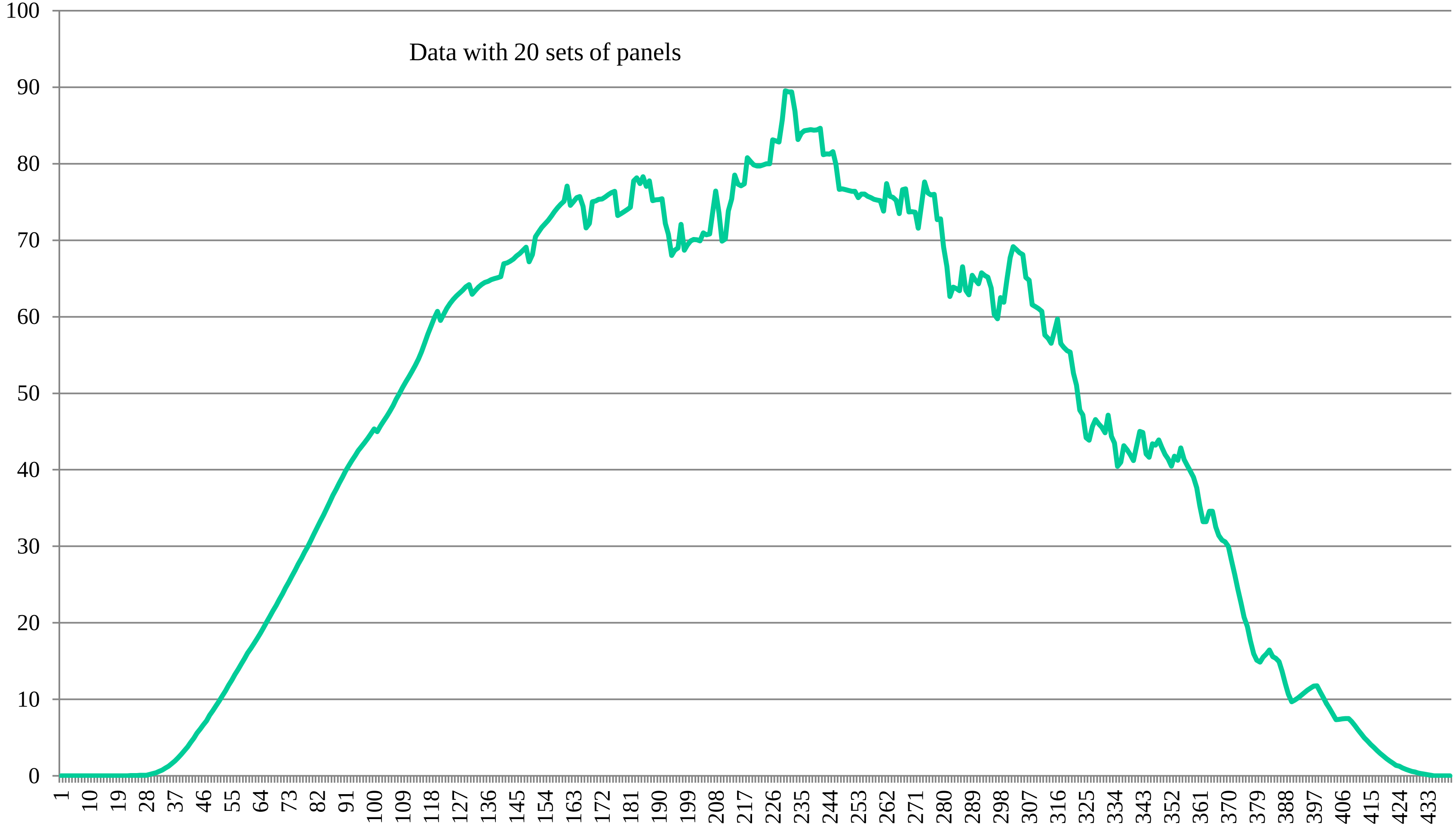
- The next figure shows measured power output of a solar PV system
- This caused a degree of panic because of the difficulty of the grid following such a profile
- Notice the title “20 PowerPoint Slides That Shook the Earth”
- Solar PV has no inertia

Data with one set of panels



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

Data with 20 sets of panels



Part 2 – Grid Integration of PV

- Disruptive Technologies
- Utility Electricity Pricing Models
- Matching Supply to Demand
- Battery development
- Utility Company Opportunities

Disruptive Technologies

- Computers
  - Workstations, PCs, Pads
- Cell Phones
  - Everywhere
  - Emerging countries
- Electricity
  - Photovoltaics, wind
  - Micro-grids

Utility Electric Pricing Models

- Present residential (SECO, FL)
  - Fixed monthly charge ($14.50)
  - Charge per kWh usage ($0.104 per kWh)
  - PCA (Power cost adjustment) (0.009 per kWh)
  - Equipment lease (surge protector)   ($5.50)
  - Taxes ($3.79)
  - Net metering adds credits for excess kWh production

Utility Electric Pricing Models

- Present commercial (SECO, FL)
  - Fixed monthly charge ($55.00)
  - Charge per kWh usage ($0.07208 per kWh)
  - PCA (Power cost adjustment) (0.0069 per kWh)
  - Demand charge ($5.75 per max kW) (15 minutes)
  - Taxes ($24.77)
  - Net metering adds credits excess for kWh production

Utility Electric Pricing Models

- Time of Day Pricing (TOD Pricing)
  - Day and Night Rates variable
    - California PG&E rate schedule is multiple pages long
      - Business days, weekends, holidays, climate location (9)
      - Published yearly (in advance)
      - Multiple Usage Tiers, each more expensive
        - » 12.0, 16.5, 25.2, 31.2 cents per kWh
      - Time of day pricing
        - » $.184 Midnight to 10 am, 9 pm to midnight
        - » $.220 10 am to 1 pm, 7 pm to 9 pm
        - » $.336 1pm to 7 pm

California PG&E Energy Statement Daniel Swanson

- Tier 1 Allowance   10.1 kWh/day (lowest rate)
- Tier 1 Pricing
  - Peak (12 noon to 6 pm) $0.34885 per Kwh
    - Monday thru Friday
  - Off Peak (all other times) $0.10070
- October 10, 2014 thru Oct 28 (with solar modules)
  - Peak   -100.5015 kWh @ 0.34885 = -35.06
  - Off Peak   312.4080 kWh @ 0.10070 = 33.01
  - Energy Commission Tax   0.06
  - Total NEM Energy Charges   -$6.55
- Net Electric Usage This Period: 208.888 kWh

Possible Future Utility Electric Pricing

- Dynamic Time of Day Pricing (TOD)
  - Rates adjusted hourly based on expected supply/demand
  - Rates published 24 hours in advance
  - Utilizes demand forecasts
  - Utilizes renewable production forecasts
    - Solar based on cloud cover (satellites)
    - Wind based on weather reports
  - Customers may perturb supply/demand
    - Should flatten pricing variation

Opportunity with TOD Pricing

- Residential Power Optimization
  - Remember night phone rates?
  - Hot water
  - Electric car charging
  - Household automation software
    - HVAC, Laundry, Hot Water, Dish Washer, Refrigerator
    - Appliance must provide requirement information
      - Urgency, amount, amp rate
  - PV Generation
  - Battery Storage

Supply Options for Utility

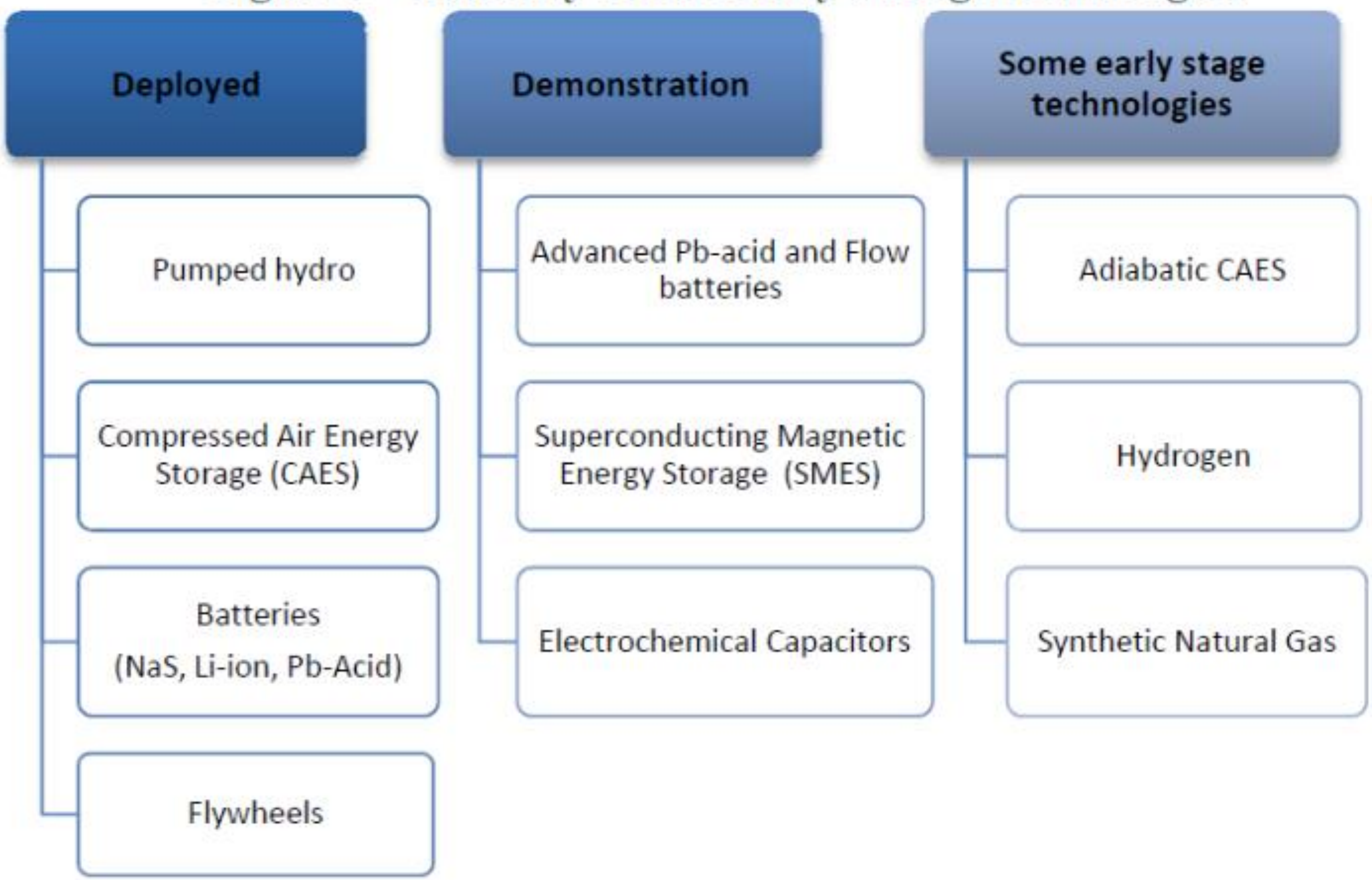
- Non-Renewable
  - Nuclear – Always on
  - Coal – Hourly variation
  - Gas – Minute variation
- Renewable
  - Hydro – Minute variation
  - Wind – Variable, may be curtailed
  - PV – Variable, no curtailment
  - PV – Utility owned – Curtailment in seconds???
- Storage (very little)
  - Flywheels – Respond in seconds
  - Batteries – Respond in seconds
  - Capacitors – Respond in seconds

Demand

- Residential
  - Peaks in morning, evening
- Commercial/shopping
  - Peaks during day, evening
- Offices
  - Peak during day
- Industrial
  - May be around the clock
  - May be able to be curtailed
  - May be scheduled (NERVA testing)

Energy Storage Technologies

Figure 3 - Maturity of electricity storage technologies



Grid Energy Storage, U.S. Dept. of Energy, December 2013

Battery Technology

- “Argonne National Laboratory, for instance, is leading a major multi-institution effort to build a battery with five times the energy density of today’s best, at one-fifth the cost”
- Notice this is a total factor of five improvement, not 25
- “Making a World of Difference” National Academy of Engineering 2014

Battery Technology

- Aquion Energy, Pittsburgh PA
- Jay Whitacre at CMU is Founder and CTO
- Aqueous Hybrid Ion Batteries
- Sodium, Manganese, Carbon
- Non-toxic
- Objective is low price, not high energy density
- Not for mobile applications

Aquion Energy AHI Technology

Aquion Energy AHI Technology

Clean, Cheap Energy Storage

Stationary batteries can store surplus wind and solar energy, turning a highly variable power source into a steady flow of electrons. But most are made from highly toxic or flammable materials. The Aqueous Hybrid Ion (AHI) battery relies on a salt water-based electrolyte to carry the charge. It's nontoxic, low-cost, and modular, and it can't overheat. It has a long life cycle and a high capacity. And it can be scaled for home use or the grid. In other words, it's basically everything today's batteries are not.

Popular Science December 2014 page 026

Battery Technology

- Sakti3, a Michigan startup
- CEO Ann Marie Sastry
- Current Tesla batteries $500 per kWh
- New Tesla factory target is $250 per kWh
- Sakti3 target $100 per kWh
- Solid state battery (no liquid electrolyte)

Utility Opportunities

- Transportation
  - Provide support and encouragement for the EV market
- System Management
  - Look at the IBM model
- Renewable energy farms
  - If others can generate cheap energy, why not utilities
  - They can control the production of their own farms
  - Provides rapid adjustment of supply (downward only)
  - Economies of scale apply here (less than $2.00 per kWh)

Transportation

- Transportation
  - Convert their own vehicle fleets to electricity
  - Actively encourage electric vehicles (EV) (offer incentives? Provide charging stations?)
  - Own and control EV charging infrastructure
  - This is a full scale attack on “Big Oil”
  - This will be a big battle for a large market
  - Other players, CNG, LNG, Biodiesel
  - Consistent with conversion of generation to renewables

Utilities Should Own Charging Stations

- Residential
  - Nighttime charging to full charge
  - Some vehicles may be available for charging during daytime
- Business/Office
  - Parked during daytime, must be full by quitting time
- Shopping Centers
  - Parking meter model (pay for amount of time)
  - Also pay for desired amount of charge
- Airport
  - Full charge first night, topping charge as needed
  - Price added to parking charge
- Highway
  - Premium price for fast charging
  - $3.30 per 100 miles at $0.10 per kWh

Utility Charger Ownership Advantages

- Huge market
- Premium price for electricity
- Steady and predictable load
- Control of charging rate to balance load
- But cannot extract energy from batteries
  - Degrades the batteries
- Reduces up-front cost of EV

Electric Car Market Size

- 15,000 miles per year, 200 days (75 miles/day)
- Chevrolet Volt projects 200 miles on 18.4 kWh
- Charge at 90% efficiency is 7.5 kWh per day
- 1.5 mWh per year (about $150/year)
- 7.5 kWh per day (about 6 solar modules)
- 7.5 kWh is about 1/4 average residence usage
- 100 million cars is $16 billion electricity market

Gasoline Market Size

- 15,000 miles per year, 200 days (75 miles/day)
- 30 MPG, 500 gal/year
- $3.00 per gal (about $1,500/year)
- 100 million cars is $150 billion gasoline market
- Compare with $16 billion electric market

System Management

- System Management
  - Remove “behind the meter” restrictions
  - Install, control, and manage residential and commercial systems
  - Install and control EV charging infrastructure
  - Add renewable energy farms for cheap energy
  - Add other demand opportunities for load balancing
    - Desalination
      - » 2.4 kWh per cubic meter of fresh water
      - » $0.65 total at $0.06/kWh (2009)
      - » We need clean water!

The Future

- The weakness of the PV systems is that the sun does not shine 24 hours
- There is no storage in the basic PV system
- Net-metering is the short term option
- Need time-of-day pricing to encourage load shifting
- Low cost storage (probably batteries) is the missing piece
  - Will battery technology follow the price-performance improvement of solar modules? Can we reach $100 per kWh?
  - Can we program EV battery charging to help balance supply/demand

Summary

- Residential/commercial PV Solar Power is growing rapidly
  - Cost effective if:
    - Behind the meter
    - Net metering is available
    - Electric Marginal Cost > $0.10 per watt
- Changes are happening fast!
- Questions?