INTERIM REPORT

Long Term Output of Grid-Tied Solar Electric Systems

by
Everett M. Barber, Jr.
everett.barber@gmail.com
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Basis for Performance Comparison

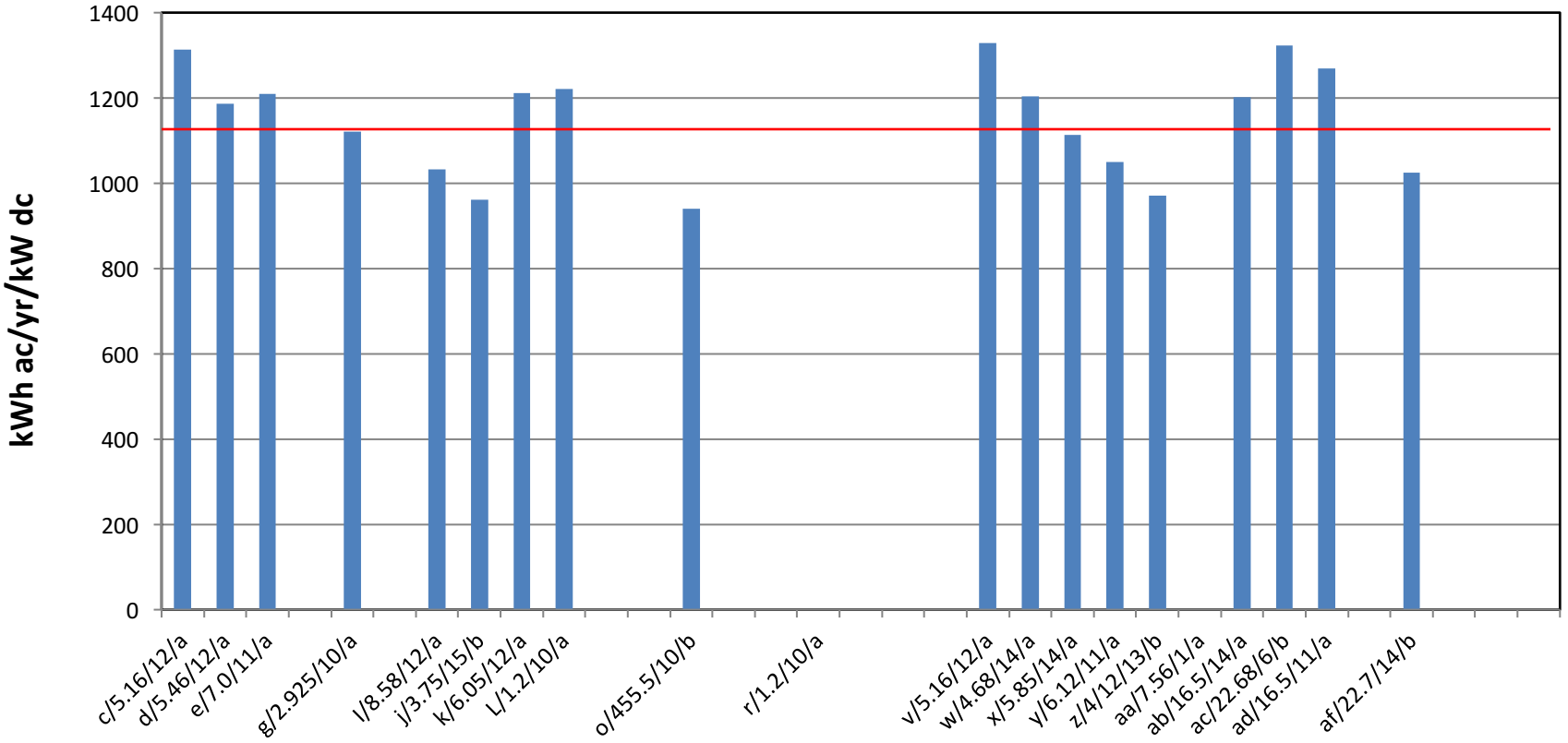
- Energy Produced per year**/**system capacity:
  - kWh(ac) per yr**/**kW(dc)
  - *Numerical example*:
    - 3973 kWh(ac) per yr**/**3.750 kW(dc)=1059.5 kWh(ac) per yr**/**kW(dc)

- Energy Produced per year**/**collector area:
  - kWh(ac) per yr**/**ft²; or **/**m²
  - *Numerical example*:
    - 3973 kWh(ac) per yr**/**311.9 ft² = 12.7 kWh(ac) per yr**/**ft²

    or,

    - 3973 kWh(ac) per yr**/**28.9 m² = 137.5 kWh(ac) per**/**m²

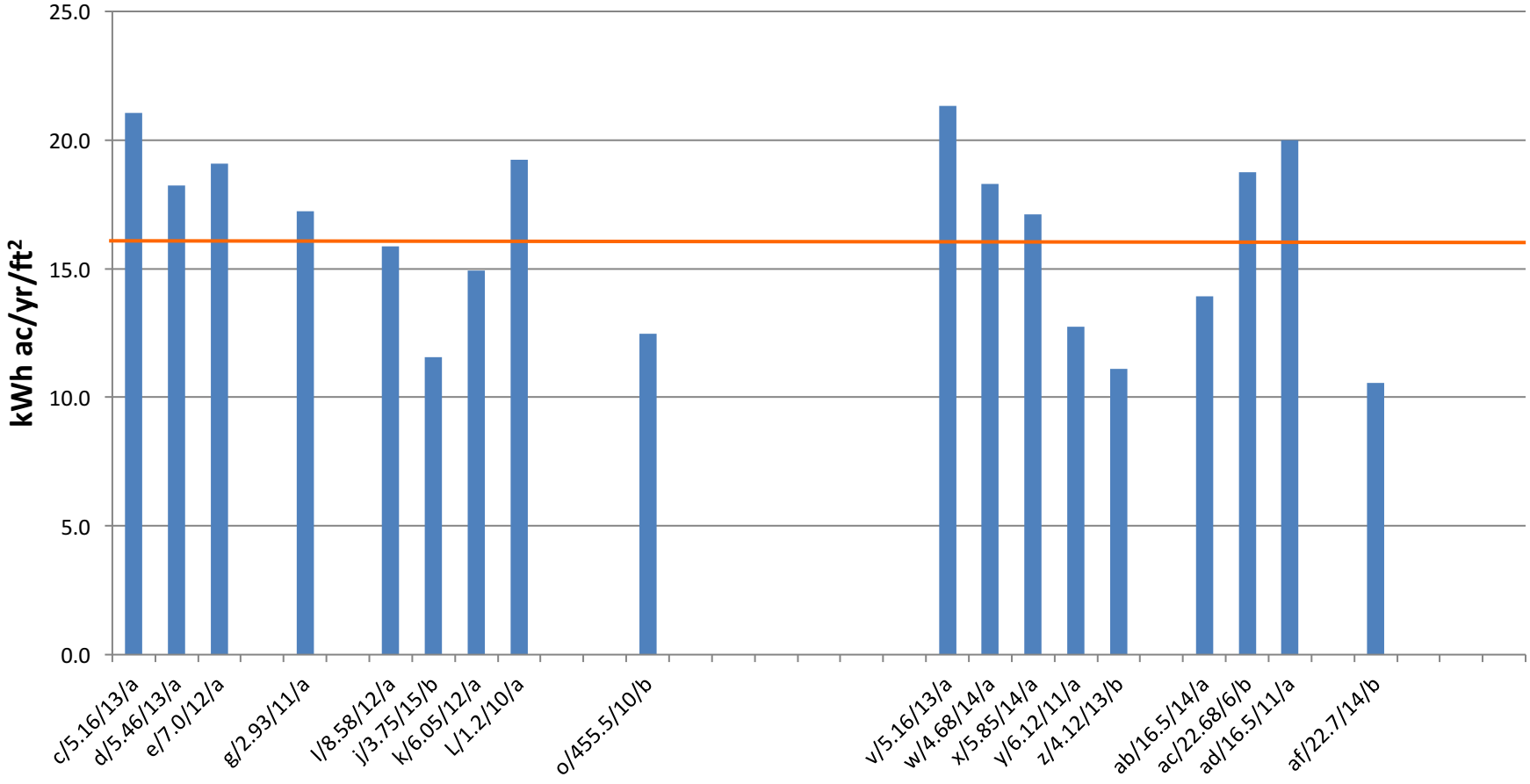
Grid-Tied Solar Electric System Output
Avg. for 18 Fixed Mount Working Systems - Southern New England
Avg. of all fixed systems =1149 kWh ac/yr/kW dc



System/kWdc/years data/Cell type

None of these systems have micro inverters.

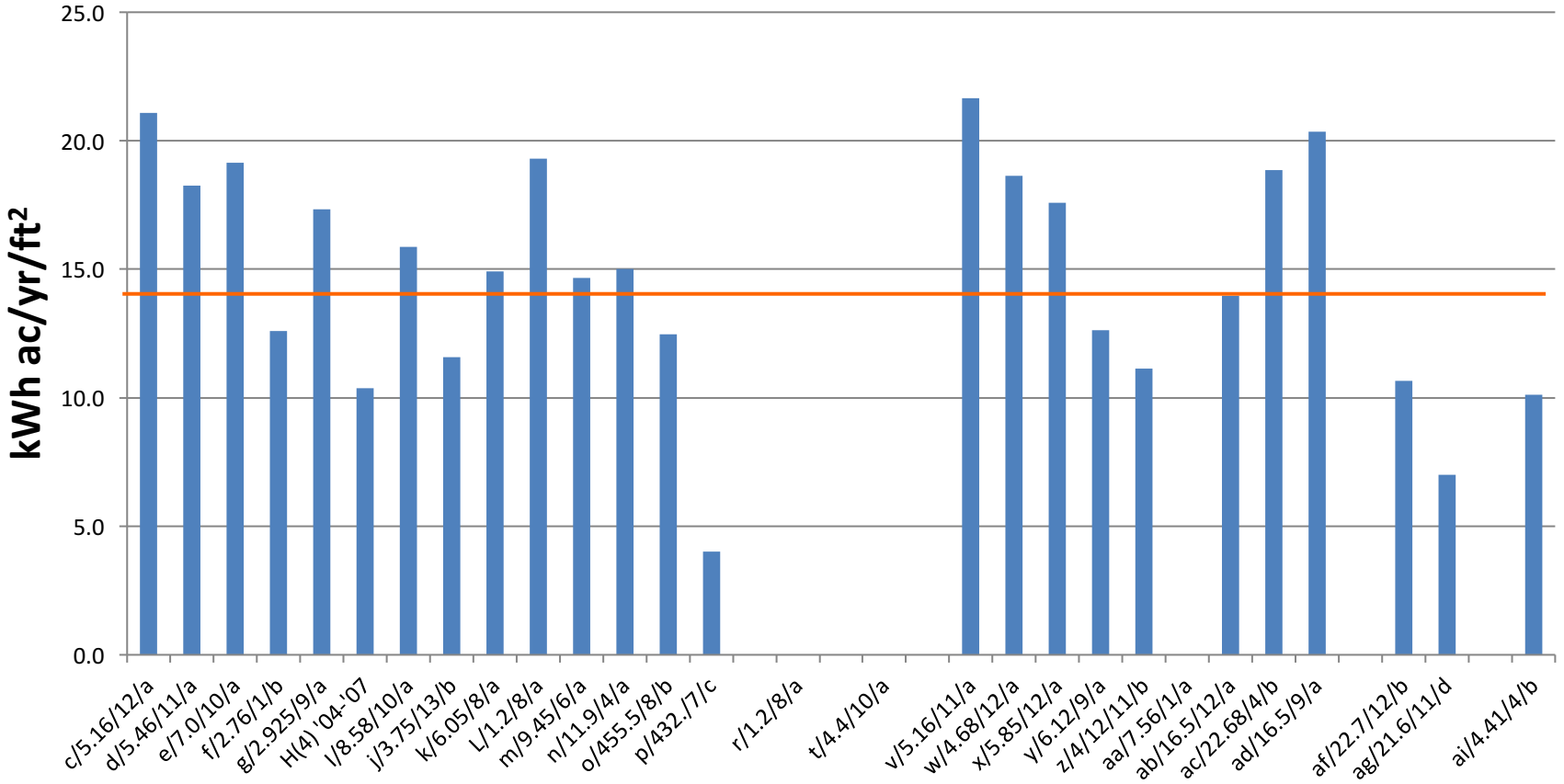
Grid-Tied Solar Electric System Output
Avg. for 18 Fixed Mount Working Systems - Southern New England
16.3 kWh ac/yr/ft² (170.5 kWh ac/yr/m²)



System/kW dc/years data/cell type

None of these systems have micro inverters.

Grid-Tied Solar Electric System Output
Avg. for all 26 Fixed Mount Systems - Southern New England
--- 14.6 kWh ac/yr/ft^2 (157.1 kWh ac/yr/m^2)

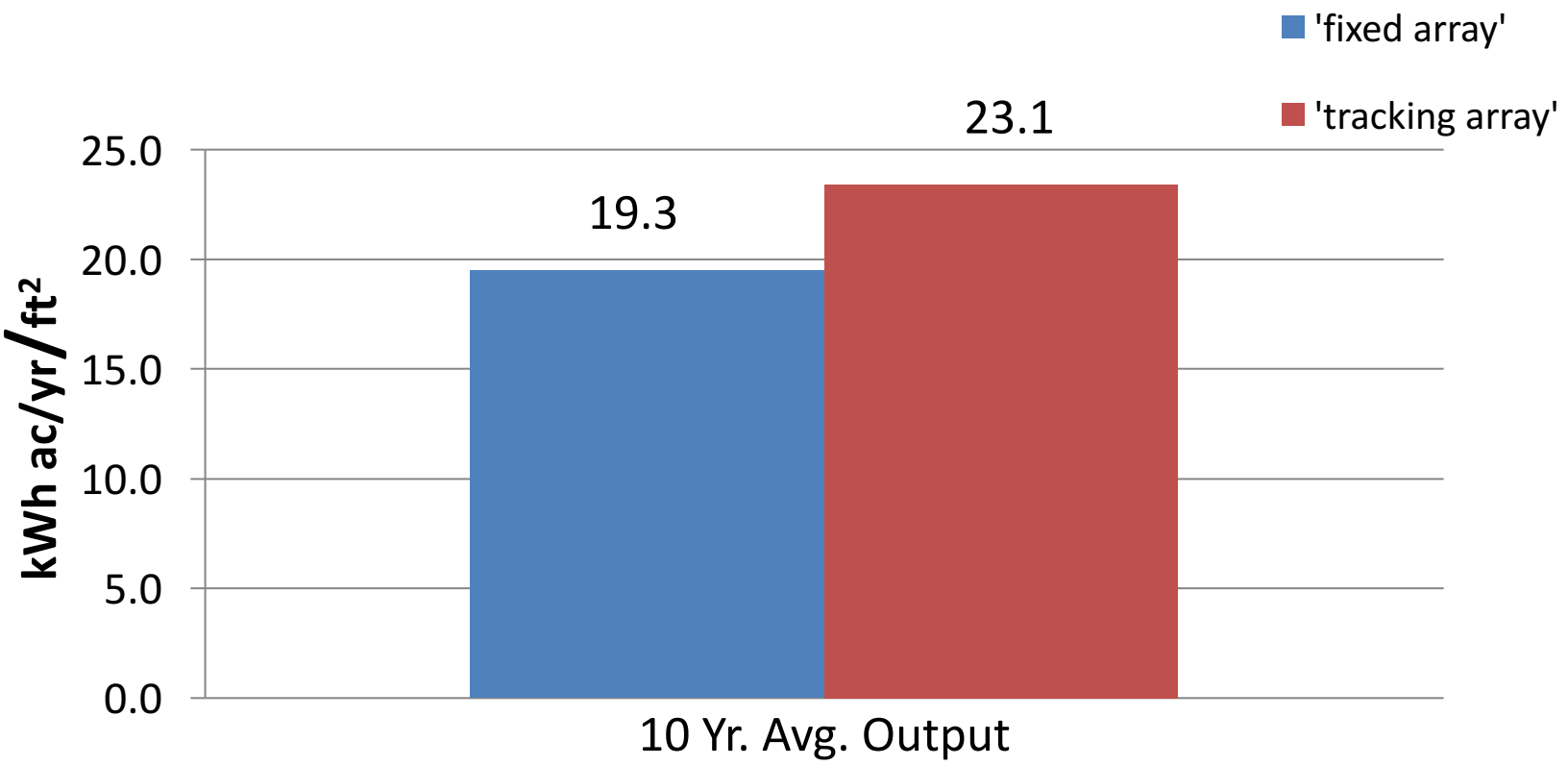


KEY: System/kW dc/years data/cell type

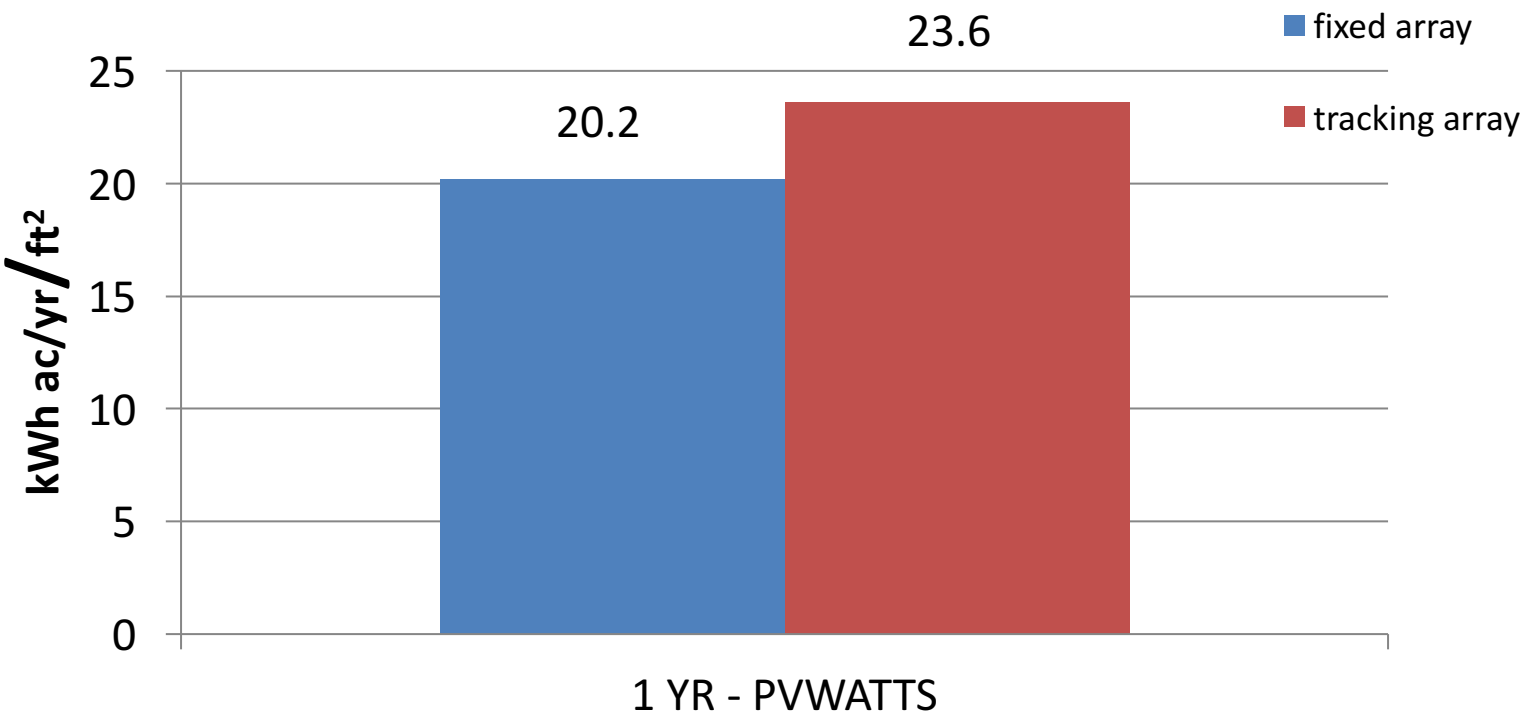
None of these systems have micro inverters.

10 Year Averaged Actual Output

Commercial Systems
One Fixed & One Single Axis Tracking
modular collectors, West Hartford, CT

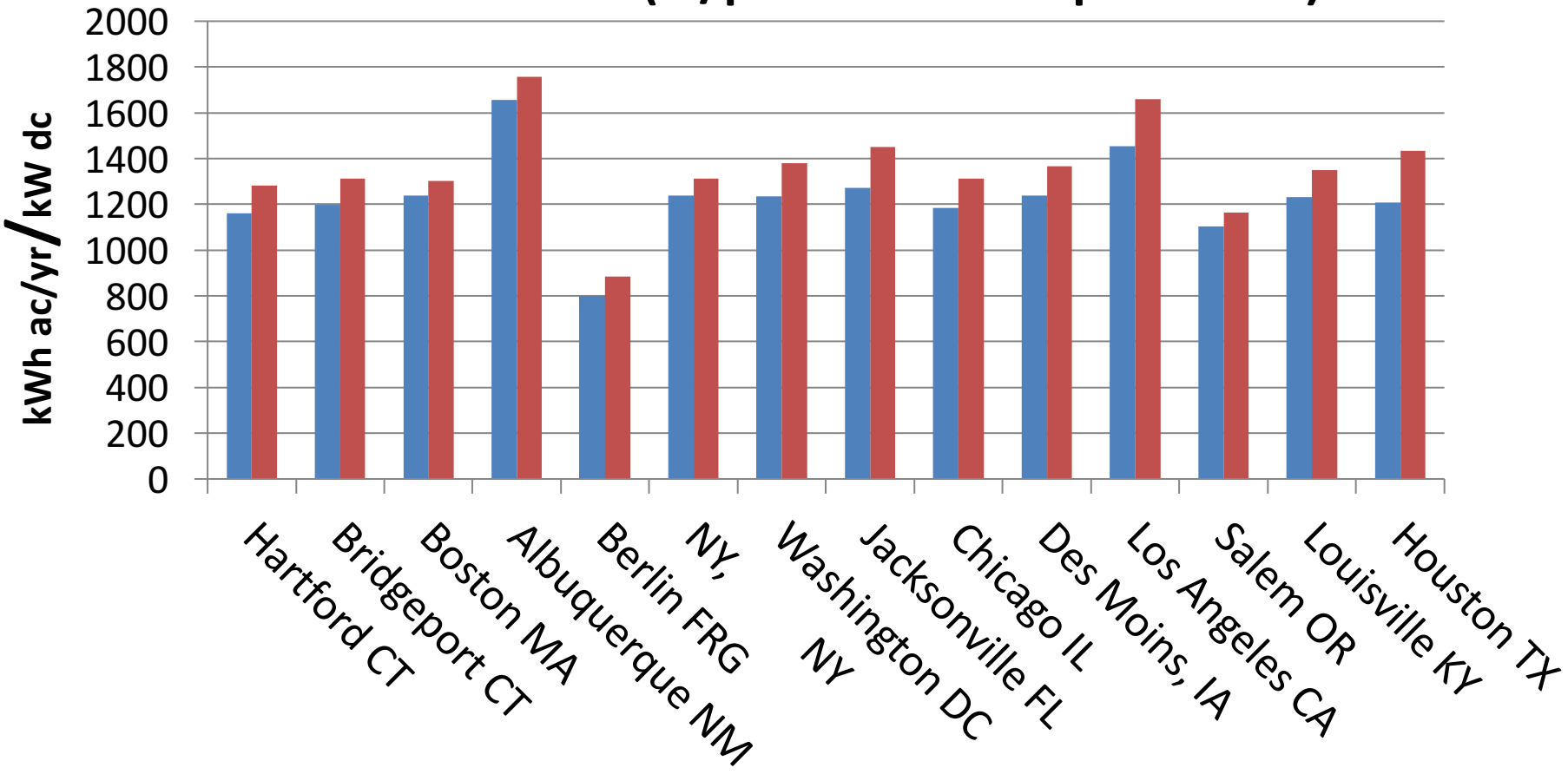


1 Year Output Forecast PVWATTS v1
Commercial Systems
One Fixed & One Single Axis Tracking
modular collectors, Bradley AP, CT (TMY2)



PVWATTs v1 Input		
Default Parameters	2010 ago	present day
tilt (deg.)	35	20
module	std	std
mount	fixed	fixed
azimuth	180	180
sys losses %	22.00	14.08
inverter eff %	96%	96%

Projected Output (PVWATTS v1)
Fixed Mount Array
selected cities (w/parameters on prior slide)

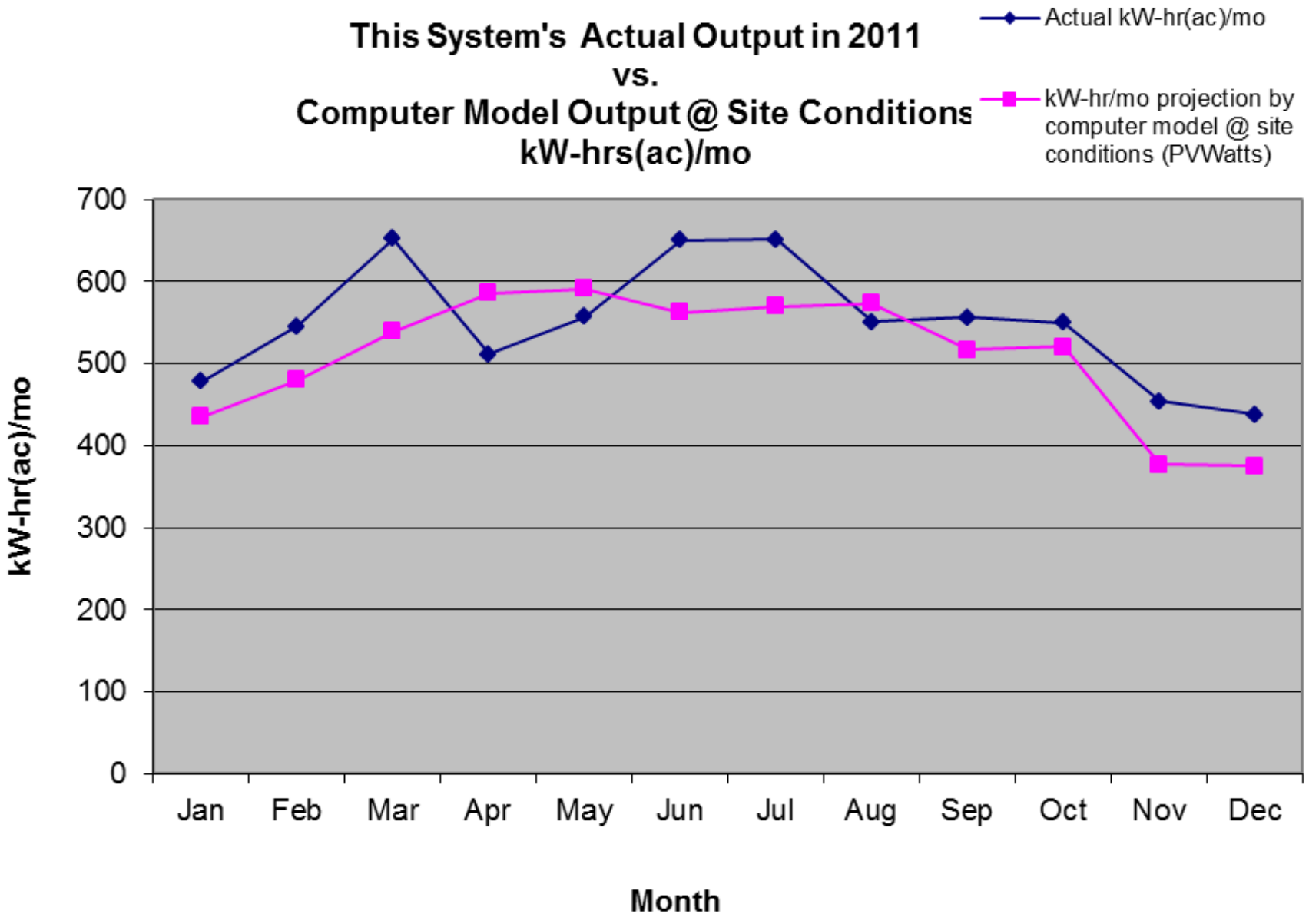


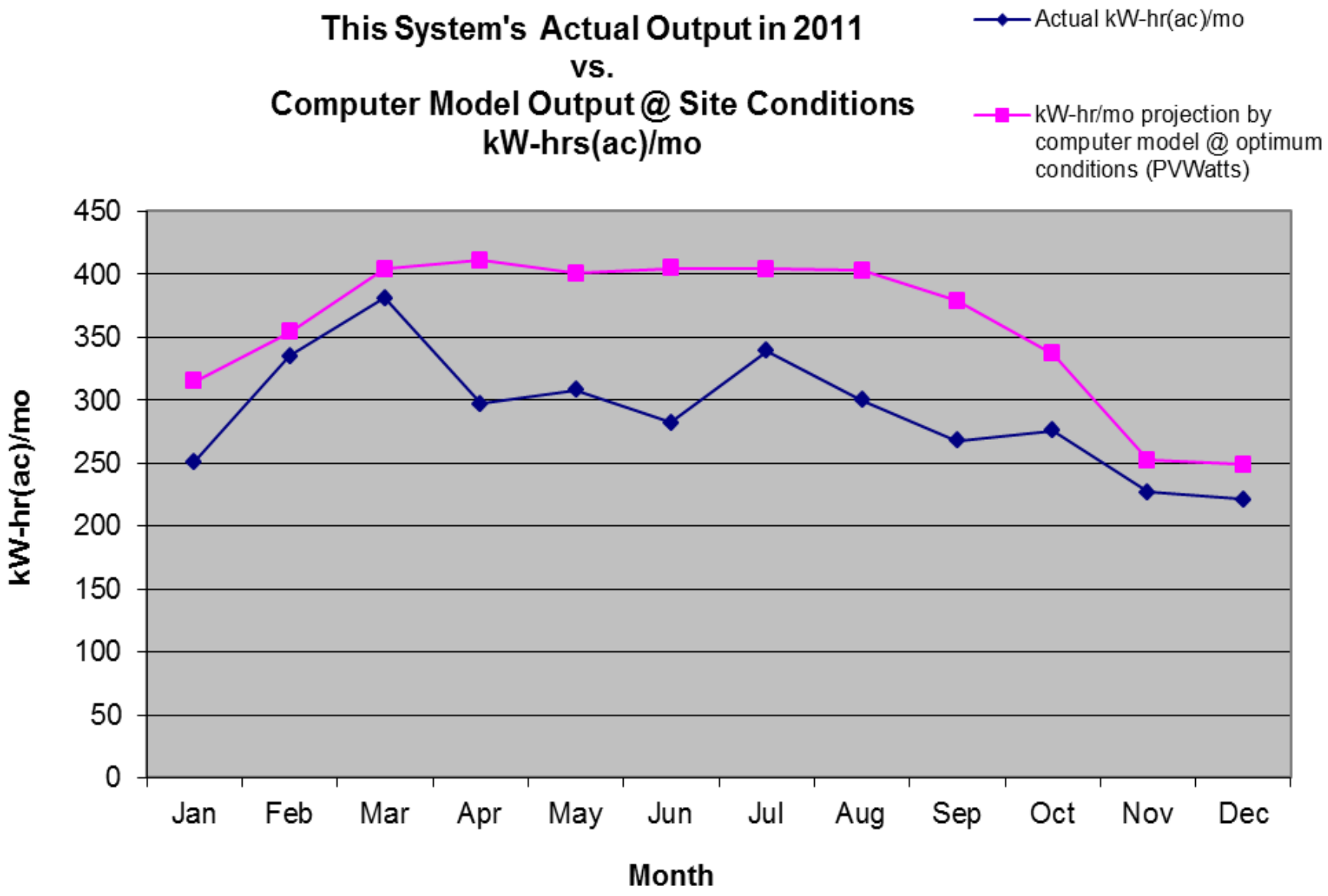
n.b. The present 'default' parameters for PVWATTS yield outputs ~10% higher than observed here.

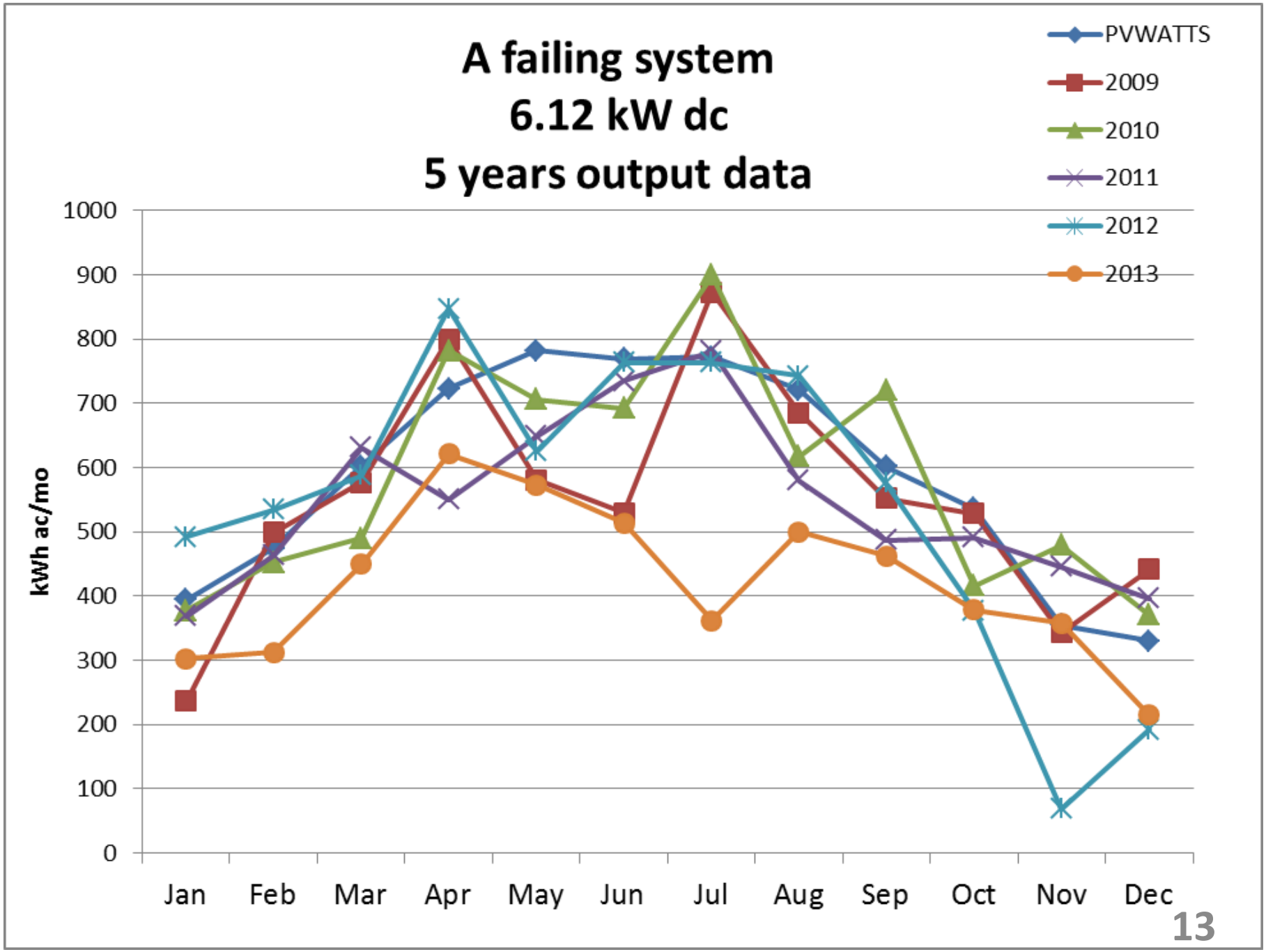
Avg. for Fixed Mount Array. (PVWATTs v1)

PVWATTS output is within ±5 % of cities shown

Calc. avg; (omit Albuquerque, LA & FRG.)		
Hartford, CT	1159	kWh ac/yr/kw dc
Bridgeport, CT	1197	
Boston, MA	1239	
NY, NY	1239	
Wash, DC	1234	
Jacksonville, FL	1271	
Chicago, IL	1184	
Des Moines, IA	1239	
Salem, OR	1104	
Louisville, KY	1231	
Houston, TX	1208	
Σ	13305	
avg.	1210	
5%+	1270	
5%-	1149	


This System's Actual Output in 2011
vs.
Computer Model Output @ Site Conditions
kW-hrs(ac)/mo
Actual kW-hr(ac)/mo
kW-hr/mo projection by computer model @ site conditions (PVWatts)
kW-hr(ac)/mo
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


This System's Actual Output in 2011
vs.
Computer Model Output @ Site Conditions
kW-hrs(ac)/mo
Actual kW-hr(ac)/mo
kW-hr/mo projection by computer model @ optimum conditions (PVWatts)
kW-hr(ac)/mo
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

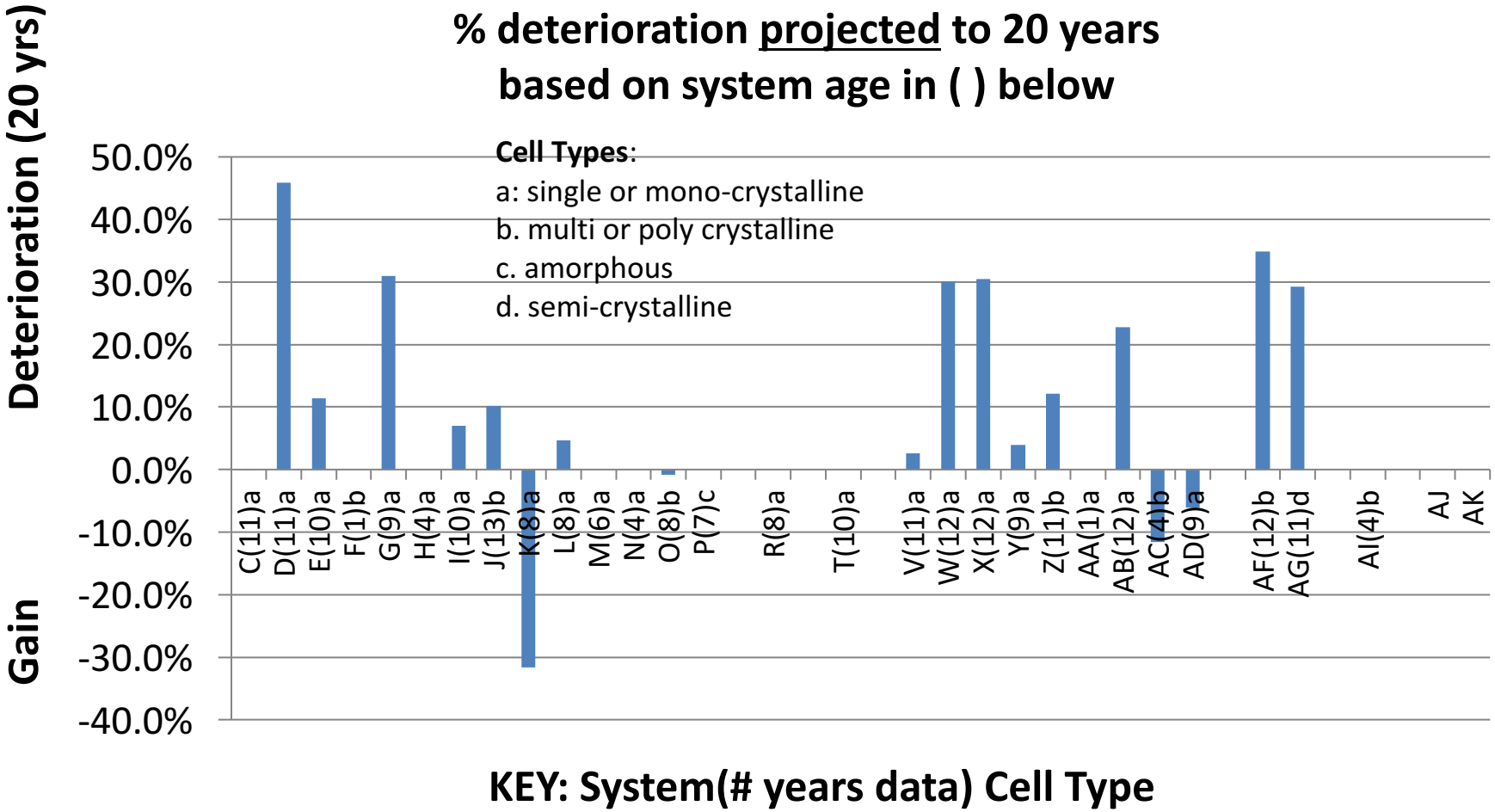

A failing system
6.12 kW dc
5 years output data
PVWATTS
2009
2010
2011
2012
2013
kWh ac/mo
1000
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Solar Electric System Output Deterioration

18 Fixed-Mount Systems - Southern New England

% deterioration projected to 20 years

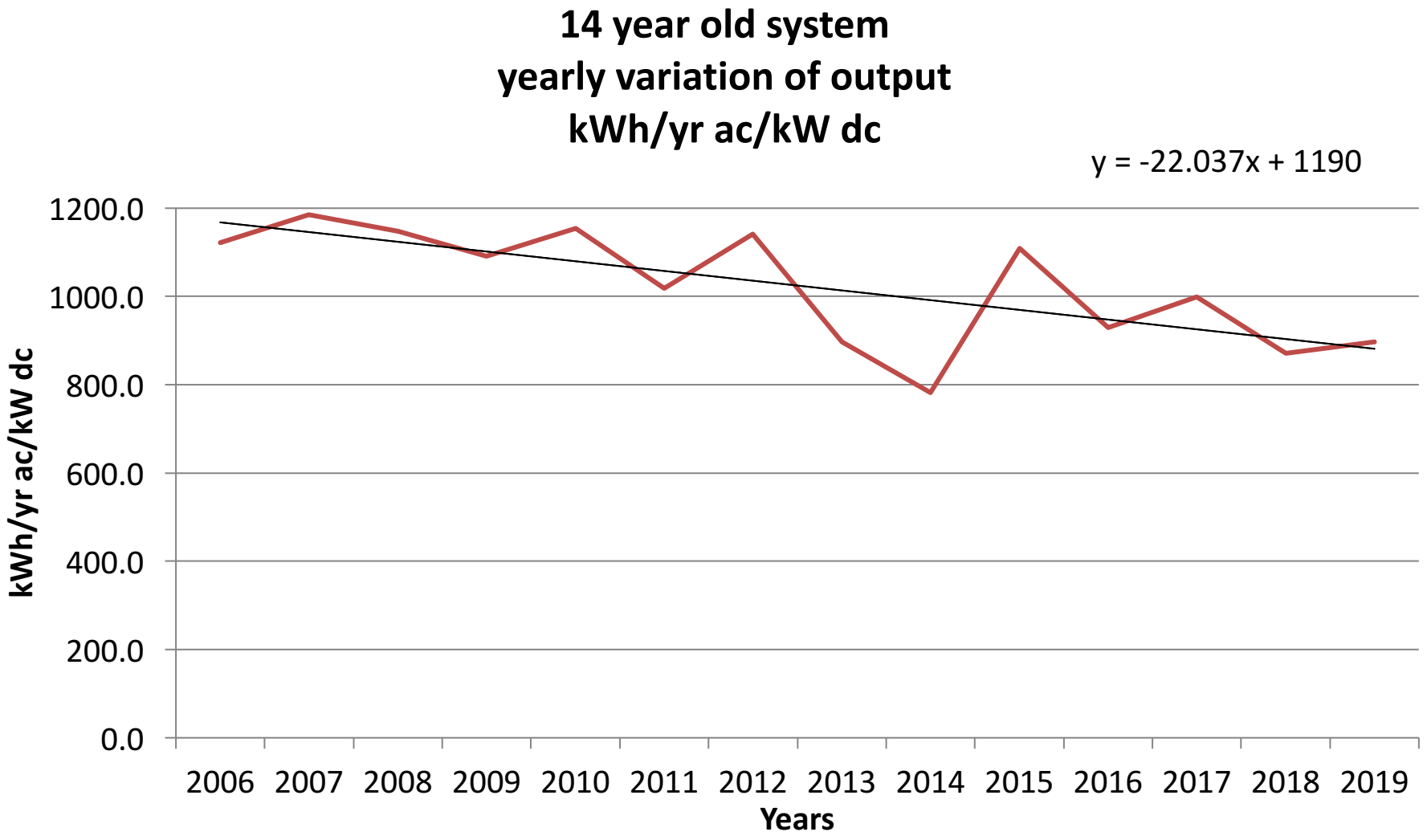
based on system age in ( ) below



KEY: System(# years data) Cell Type

A few systems with negative % (gain) had poor output during early years of use. No data for some systems since data no longer available from sys. owners.

Example Output Projection



n.b. Above equation generated by EXCEL's Trendline function

Estimating Long Term Output Loss

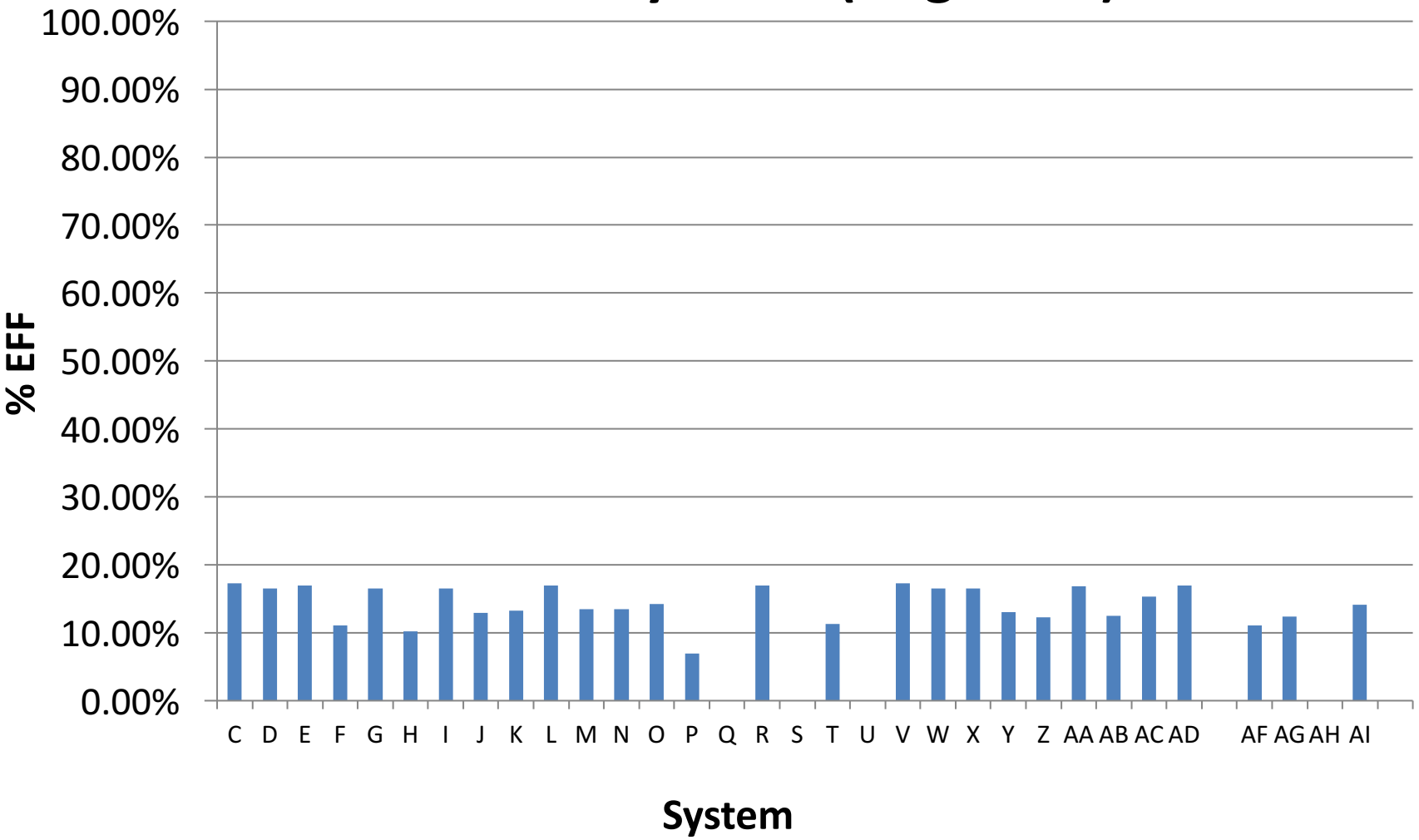
Solve Equation for %Loss			
eqn.	y=-23.257*X +1333.2	output decay	
solve for y	year	# years	% Loss
1309.943	2006	1	
1263.429	2008	3	3.6%
1216.915	2010	5	7.1%
1100.630	2015	10	16.0%
868.060	2025	20	33.7%
	means projection		

n.b. above equation generated by EXCEL's Trendline function.

Causes for System Output Deterioration

- Inverter: (warranty length: 5 yrs; 10 yrs.)
- Inattention to output loss; procrastination when found
- Difficulty in finding a service contractor
- Tree growth
- Incorrect string fuse resistance
- Inverter fuse damage caused by lightning
- Squirrels shorting string (wire) insulation.
- Long Term Cell Deterioration
- System off: various reasons gen. was run; bldg. vacant; etc.
- System Removed or abandoned by owner

Solar Electric Collector Efficiency When New 28 Systems (mfg. data)



PV Module Mfg's in this compilation of systems

~~Andalay ST170-1~~
~~AstroPower AP-100~~
~~AstroPower AP-110~~
~~BP3125S~~
Canadian Solar CS6P-230P
~~Evergreen EC 115~~
Kyocera 210
Sanyo 195
Sanyo 200
Sanyo HIP-200BA3
Sanyo HIP-200BA4

~~Schuco S180-SPU-4~~
~~Schott 300~~
~~Sharp 175~~
~~Sharp 175~~
~~Shell Solar Power Max SQ-165~~
SunPower 215
SunPower SPR-210-WHT
~~Unisolar ePVL-144~~
SunPower SPR-215

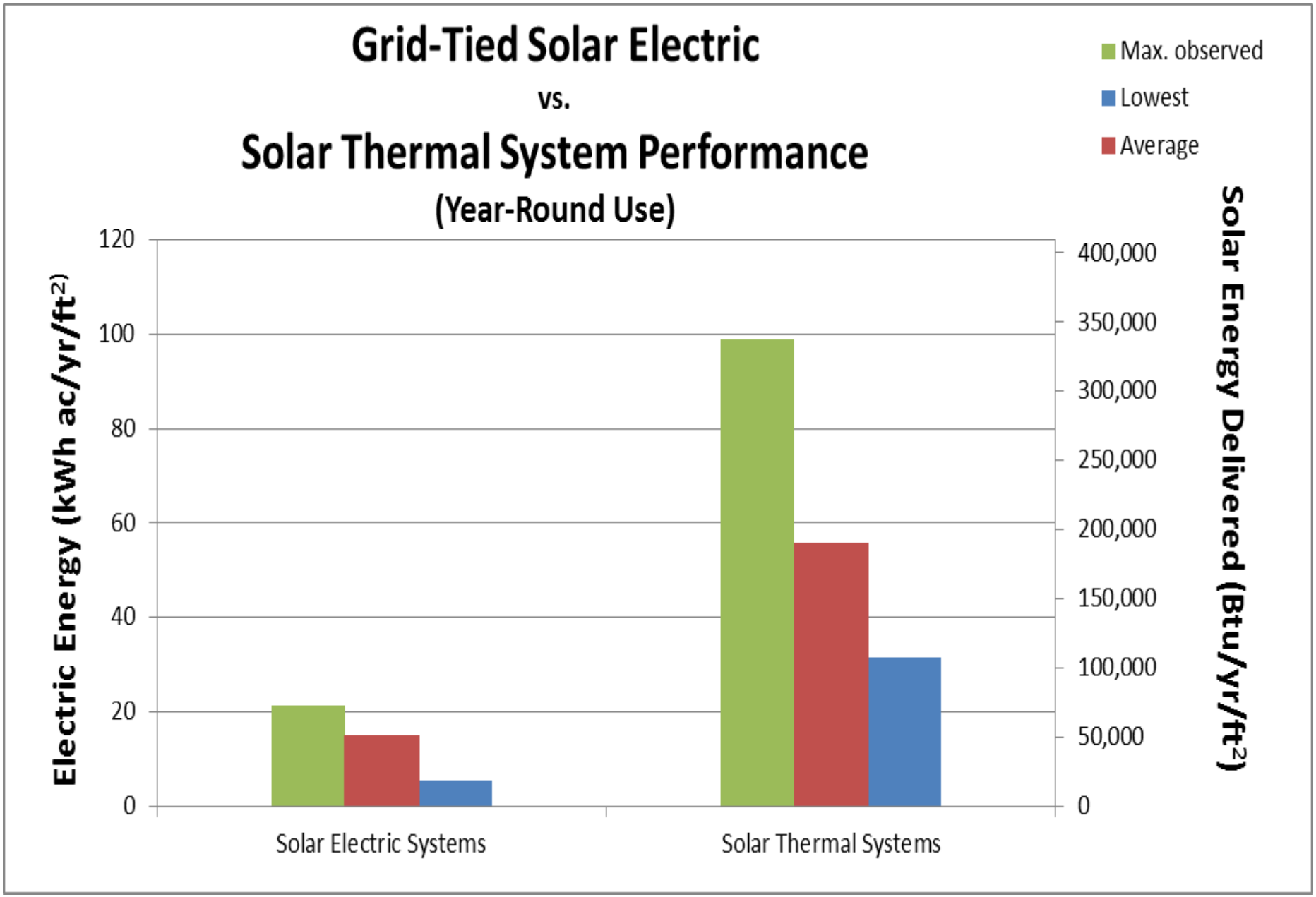
~~Lined thru~~: Out of Business
Red Text: Solar biz: Sold to Panasonic

Other 1 Yr. Studies

- See:
  1. http://www.nrel.gov/docs/fy12osti/51664.pdf

     An NREL review of the literature dated June 2012.
  2. https://openpv.nrel.gov/

     An NREL compilation of PV Systems throughout the US. Includes some output data; costs; etc.
- No references were found that have compiled multi-year data.


Grid-Tied Solar Electric
vs.
Solar Thermal System Performance
(Year-Round Use)
Max. observed
Lowest
Average
Electric Energy (kWh ac/yr/ft2)
Solar Energy Delivered (Btu/yr/ft2)
120
100
80
60
40
20
0
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Solar Electric Systems
Solar Thermal Systems