Low Cost, Lightweight Solar Modules Based on Organic Photovoltaic Technology

Konarka Technologies, NREL, University of Delaware

SAI Final Review Meeting (September, 2010)

Agenda

1] Overview

2] Stability

3] Performance

- N-type materials

- Bottom grid

- Technology Comparison

Overview - Targets

Timeline
- Project start date: July 1, 2007
- Project end date: June 30, 2010
- Percent complete: 100%

Budget
- Total project funding: $8.79M
- Project Spending
  - DOE share: $3.64M (41%)
  - Contractor share: $5.15M

Barriers
- Stability
  - Accelerated aging (1000hrs@85°C/85%RH)
  - Rooftop stability (>10yrs)
- Performance
  - Cell performance >7%
  - Module performance ~7%
- Cost
  - ~$0.5/watt

Partners
- Project lead: Konarka Technologies
- Interactions/Collaborations
  - NREL and The University of Delaware

Overview - Results

Objectives (Project Year 3)

In order to produce solar modules for rooftop applications the performance and the lifetime must be improved to 5% - 7% and >10 year life.

Task 1. Stability

Improve lifetime of flexible modules: accelerated lifetime - 1000hrs@85°C/85%RH

Approaches taken and results:

- **Adhesives with filler – advantage demoed (in advanced development at KNB)**
- **Solution coatable barrier – improvements demoed (more work needed)**
- **Degradation mechanism – oxygen and water mechanisms demoed**
- **Advanced Film Barriers – best examples: 1000hrs@<u>65</u>°C/85%RH; 200hrs@<u>85</u>°C/85%RH**
- **<u>Glass Packaging - >2000hrs@85°C/85%RH (passes IEC test: 20 years)</u>**

Task 2. Performance – n-Type materials

Stopped work - year 2

Task 3. Performance – Replace bottom electrode (ITO) with metallic grid

Improve performance of cells and modules by use of a grid: improved %T and sheet resistance

- **Surface roughness - target 5nm rms; *current: 2nm rms***
- **Optical transmission - target >85%T; *current 85 – 90%T***
- **Sheet resistance – target 5ohms/sq; *current <1 ohm/sq***
- **Cell performance: *>2.5% (best), 2.0% (average) efficiency* (P3HT/PCBM active layer; lab cells)**
- **Coating/printing – screen, flexo and gravure are options – being evaluated**

Stability

Task 1. Stability

Target: 1000hrs @ 85C/85%RH

Summary

1] Adhesives / fillers to aid barrier properties – done, in production

2] Solution coatable barriers

– target WVTR ~10^{-3}g/m2/day

- current state ~10^{-1}g/m2/day

3] Degradation mechanisms

- oxygen attacks polymer : reversibly and irreversibly

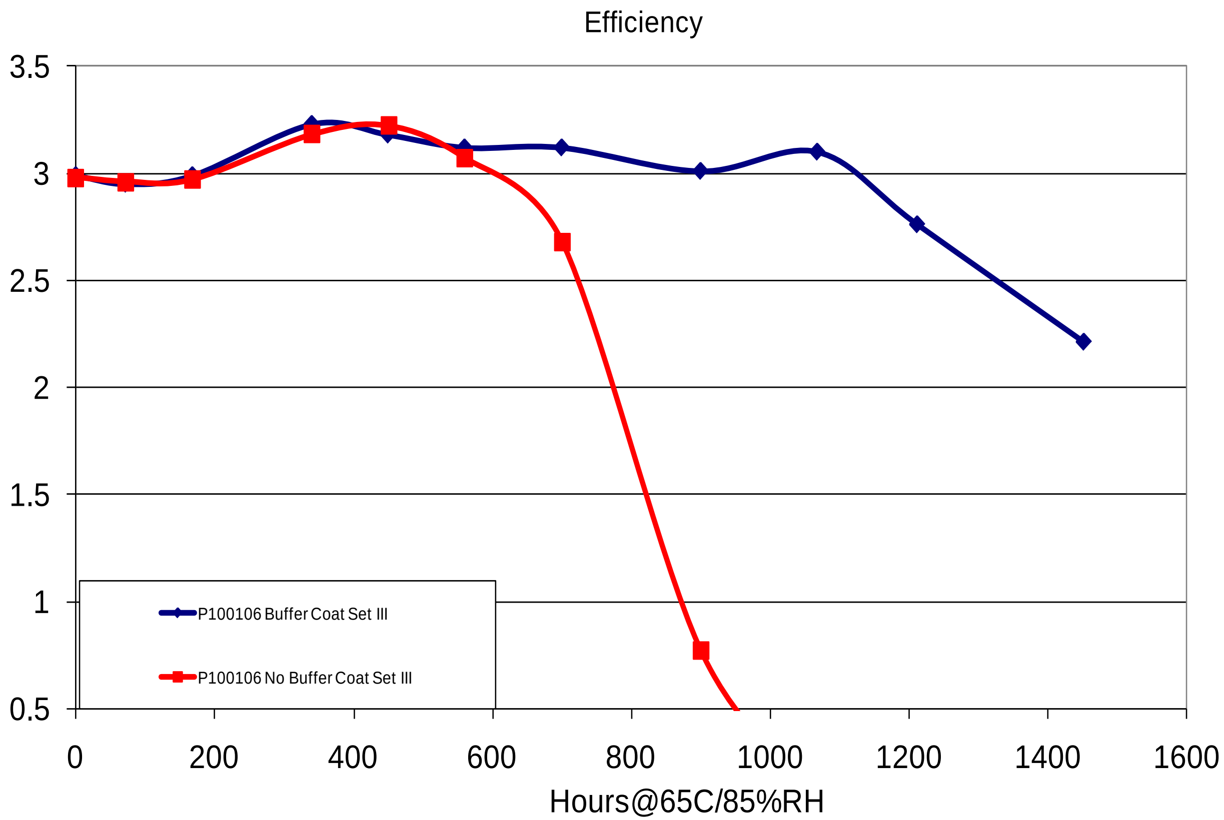
- water affects morphology and interfaces

4] Flexible modules with flexible barriers: *1000hrs* @65°C/85%RH

200hrs@ 85°C/85%RH

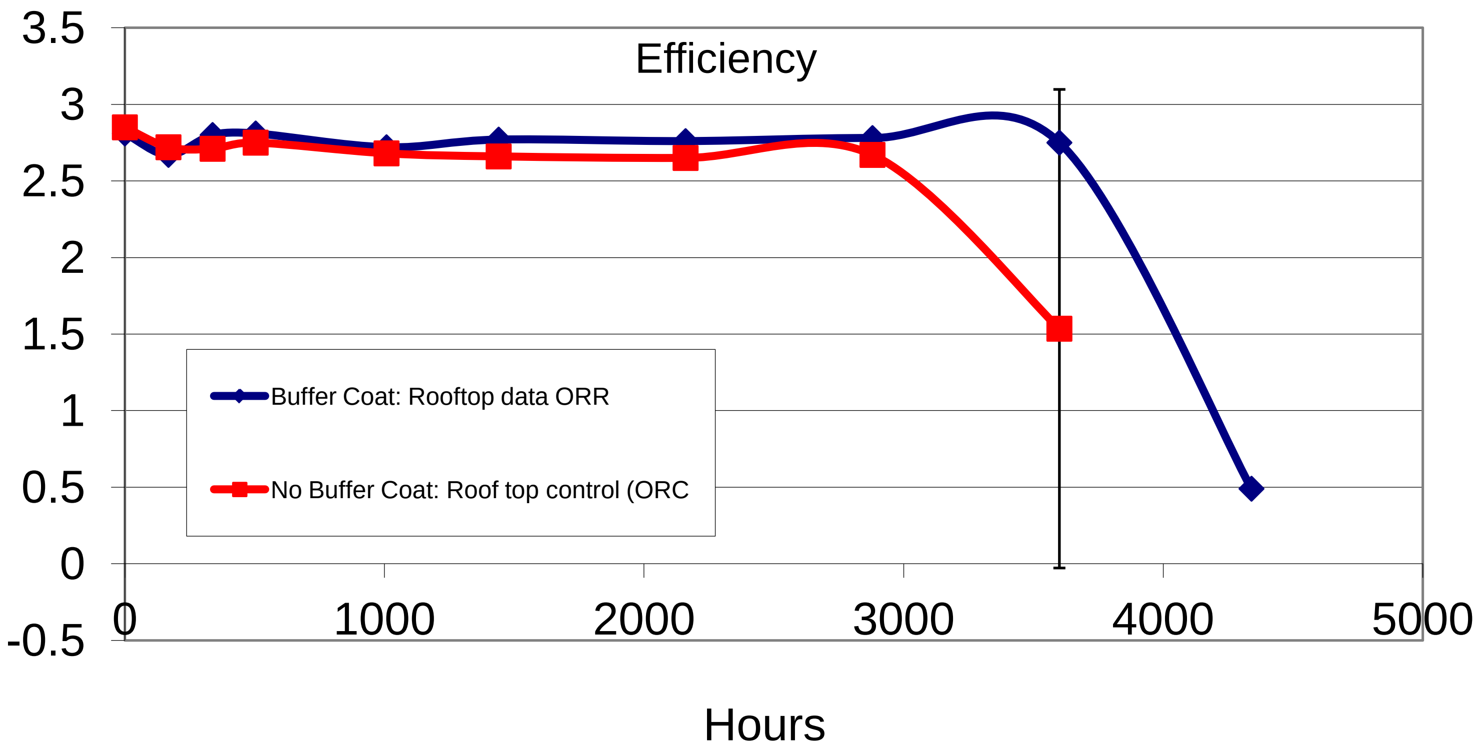
5] Glass packaged flexible modules: >*2000hrs* @ 85°C/85%RH

Module Stability - Effect of Buffer Layer Flexible Barriers



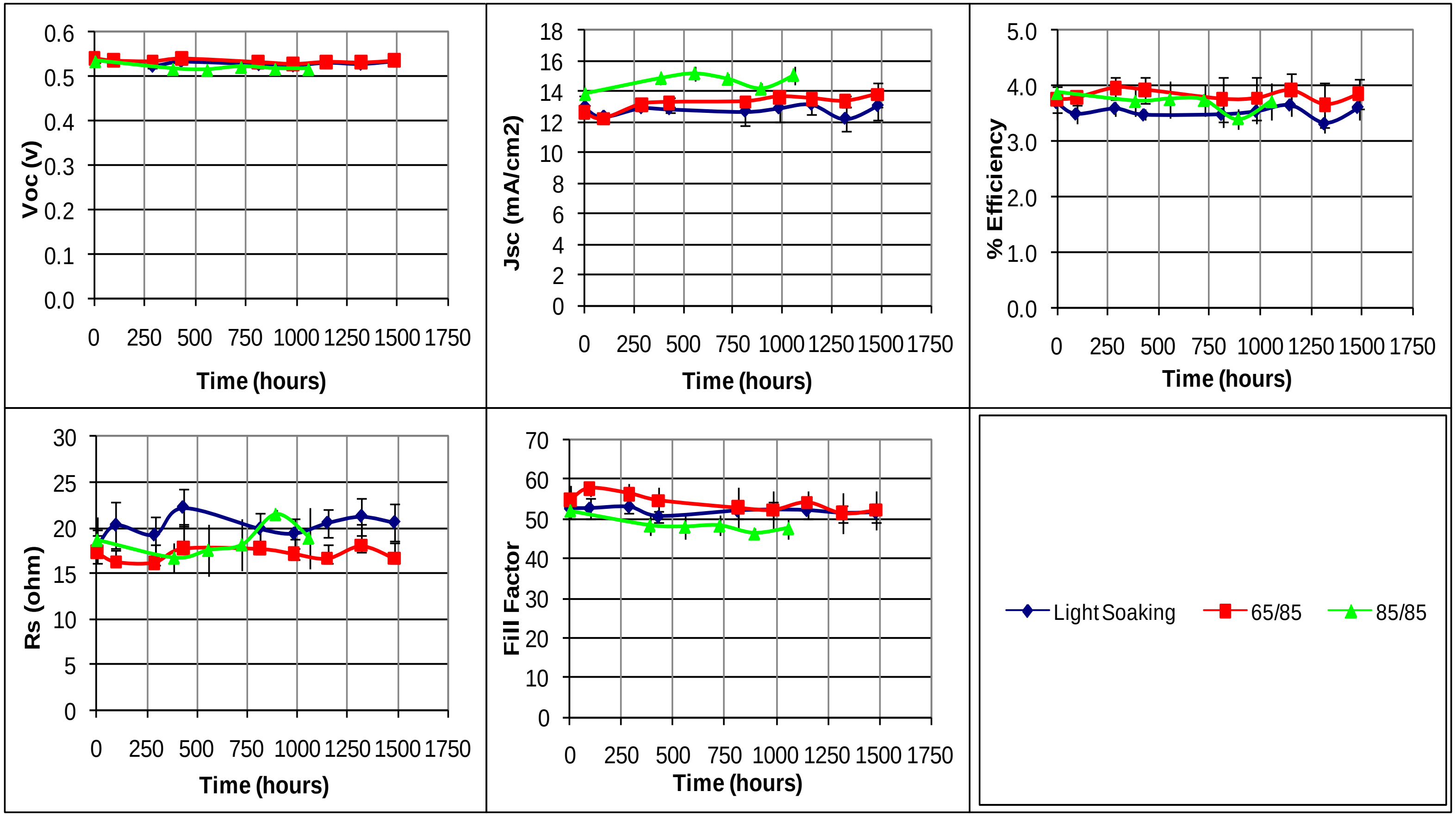
Summary: Buffer layer + filler improves stability accelerated aging

Rooftop Stability (Lowell, MA)
Flexible Barriers



Summary: Rooftop testing in Lowell , MA shows very good stability

Module Stability – Glass Packaging



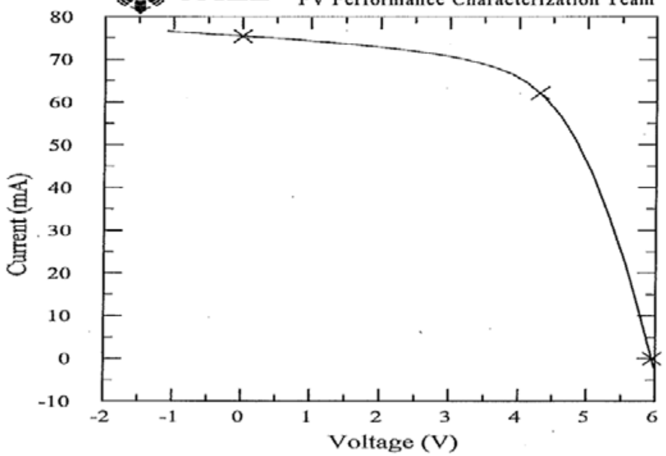
Summary: the polymers in all layers are inherently stable

Glass Module Stability

Device ID: F10 0 hours
Jun 08, 2010 14:06
Spectrum: ASTM G173 global

Device Temperature: 25.0 ± 0.5 °C
Irradiance: 1000.0 W/m^2

NREL X25 IV System Confidential
PV Performance Characterization Team



V_{oc} = 5.9560 V
I_{sc} = 75.450 mA

Fill Factor = 59.56 %

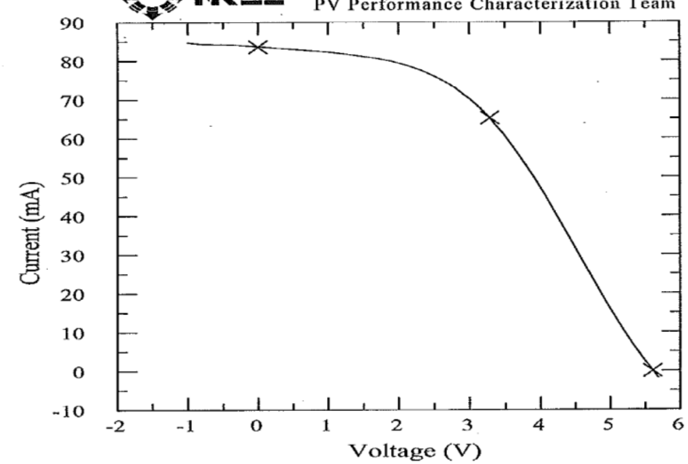
I_{max} = 62.127 mA
V_{max} = 4.3080 V
P_{max} = 0.2676 W

20% Power Reduction
@ 85°C/85%RH (990hrs)

Device ID: F10 0990 hours
Aug 12, 2010 12:44
Spectrum: ASTM G173 global

Device Temperature: 24.9 ± 0.5 °C
Irradiance: 1000.0 W/m^2

NREL X25 IV System CONFIDENTIAL
PV Performance Characterization Team

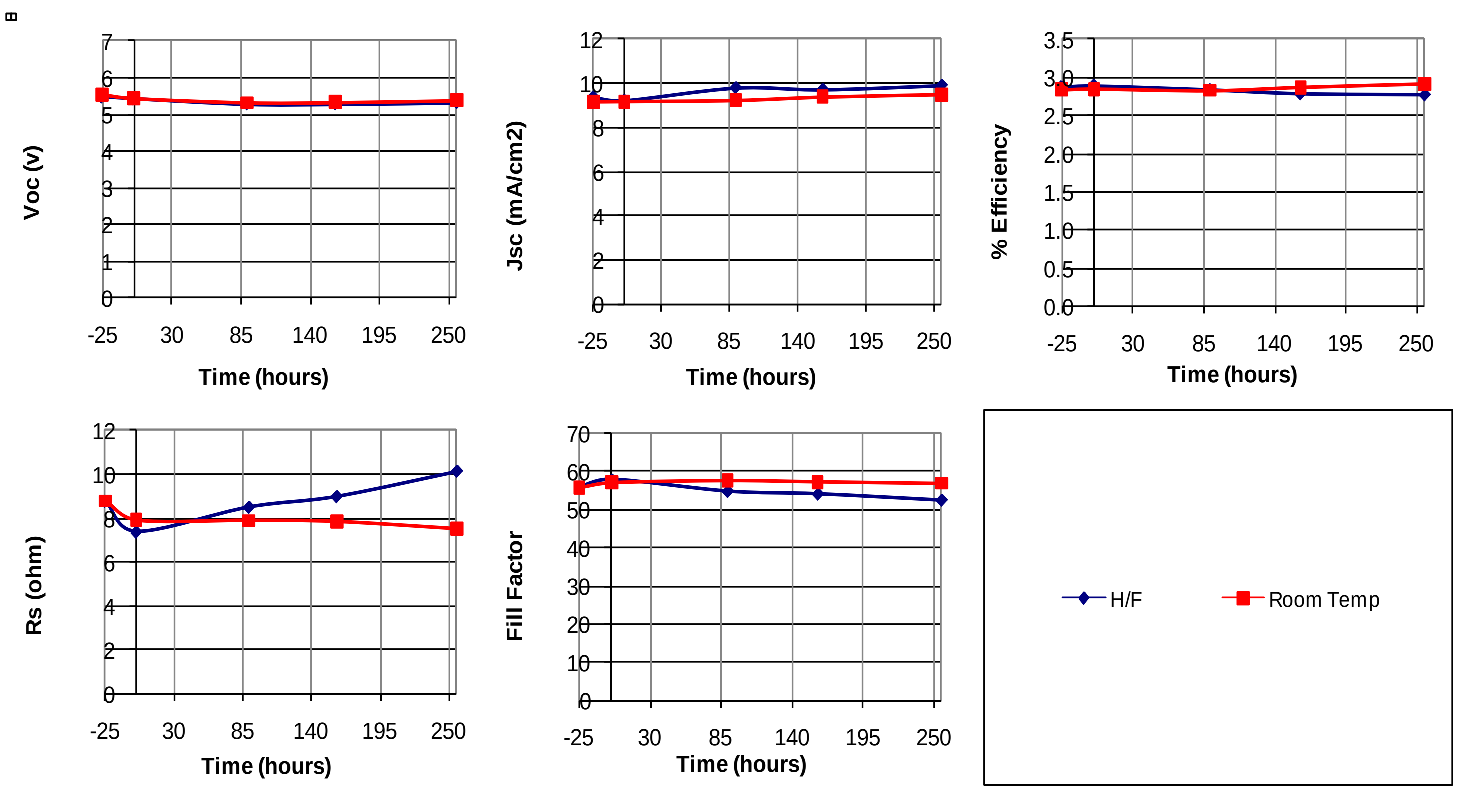


V_{oc} = 5.6102 V
I_{sc} = 83.566 mA

Fill Factor = 45.66 %

I_{max} = 65.228 mA
V_{max} = 3.2820 V
P_{max} = 0.2141 W

Module Stability - Hot /Cold Cycling
Glass Packaging



Summary: Hot/cold cycling has no effect on stability - <5% decrease in Efficiency after 250 hours

Ratio of final to initial parameters for flexible modules in Dry Heat (65°C/10%RH)

Sample ID	Bias	Voc	Isc	FF	Power
230	SC	100.2%	101.8%	97.3%	99.2%
231	SC	101.1%	102.0%	101.5%	104.7%
219	MP	98.3%	102.8%	97.7%	98.8%
222	MP	98.9%	102.2%	89.8%	90.7%
220	OC	99.3%	101.2%	95.1%	95.6%
229	OC	100.4%	100.6%	105.7%	106.9%
232	Dark	96.6%	102.5%	95.2%	94.2%
248	Control	99.5%	101.5%	99.3%	100.0%
249	Control	99.3%	101.3%	97.0%	97.7%

Summary: Modules are thermally stable (dry heat)

Ratio of final to initial parameters for flexible modules in Damp Heat (65°C/85%)

Sample ID	Bias	Voc	Isc	FF	Power
233	SC	96.4%	97.2%	68.0%	63.8%
234	SC	95.1%	99.1%	64.6%	60.9%
237	SC	97.6%	90.5%	47.0%	41.6%
238	MP	97.7%	101.5%	69.6%	69.2%
239	MP	101.1%	100.9%	76.8%	78.5%
242	MP	99.6%	103.7%	79.8%	82.5%
241	OC	101.9%	100.9%	82.4%	84.4%
244	OC	99.9%	103.3%	84.2%	87.0%
245	OC	98.8%	100.3%	78.1%	77.6%
246	Dark	94.5%	104.6%	80.7%	79.9%
248	Control	99.5%	101.5%	99.3%	100.0%
249	Control	99.3%	101.3%	97.0%	97.7%

Summary: heat and humidity causes major instability at *short circuit*

Solution Coatable Barriers - NREL

Performance

Task 2: Performance – *n-Type Materials*

Target : 7% module efficiency

Summary:

1] n-type polymers difficult to synthesize – stopped

2] n-type small molecules (fullerenes)

- 30 – 40 synthesized and tested
- Deep LUMO allows electron transfer from polymers with deep LUMOs
- High cell voltage and improved performance not yet realized due to morphology issues

3] improved cell efficiency with this approach not realized

Task 3. Performance - *Bottom Grids*

Target: Replace ITO with a metallic grid

Summary

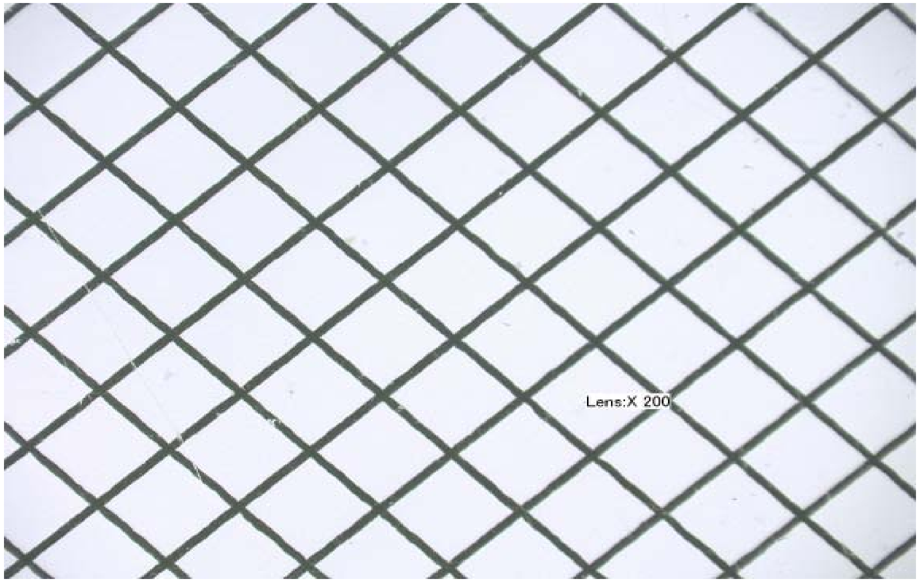
1] a metallic grid is used as the bottom electrode (cell)

- **surface roughness <~5nm; current value <~2nm**
- **fill layer level with top of grid – done**
- **sheet resistance <5ohms/sq ; current value <1ohm/sq**
- **%T>85%; current value 85 – 90%T**

2] metallic grid in a module:

- **targeting equivalent performance to ITO**
- **current status: 2% efficiency (av.); 2.6% (best)**

Printed Silver Grid



<u>Data</u>

<u><</u>90% open area

40 - 50um wire width

Sheet resistance <1ohm/sq

Transmission: >85%T

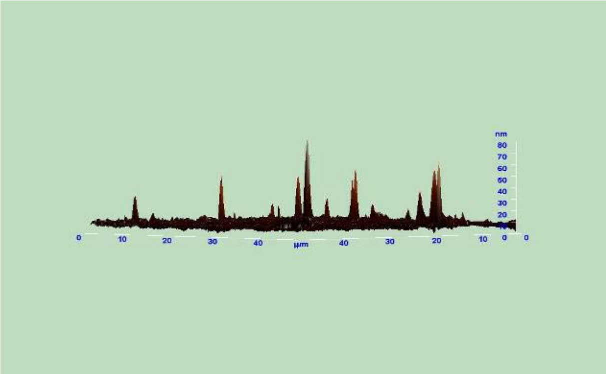
Stability (no change in conductivity)

- **>1000 hrs @ 65°C/85%RH**
- **>1000 hrs @ 85°C (dry)**

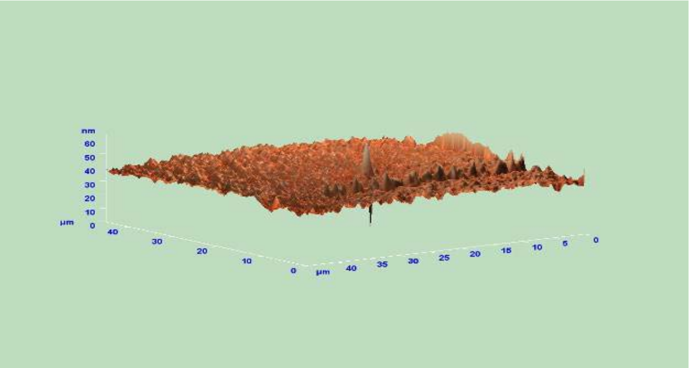
Summary: several printing processes can be used to print grids with 40 – 50um wires and spacing between wires will be adjusted to give the desired transmission

Surface Roughness (AFM) of Grid and Fill layer

	Max peak (nm)	Ten point height (nm)	Av. Peak (nm)	Surface roughness – RMS (nm)
Bare ITO	138 +/-19	68 +/-9	21 +/-3	**6 +/-1**
Polyester Substrate	84 +/- 3	40 +/- 2	15 +/- 7	**2 +/-0**
Surface of Silver grid wires	27 +/-8	14 +/-6	15 +/- 9	**2 +/-1**
Surface of the fill between the grid lines	40 +/-17	21 +/-11	27 +/-11	**2 +/-0**



Polyester Substrate



Space Between Grid Wires

Summary: extremely low surface roughness of the bottom grid is a key coating a cell without shorts

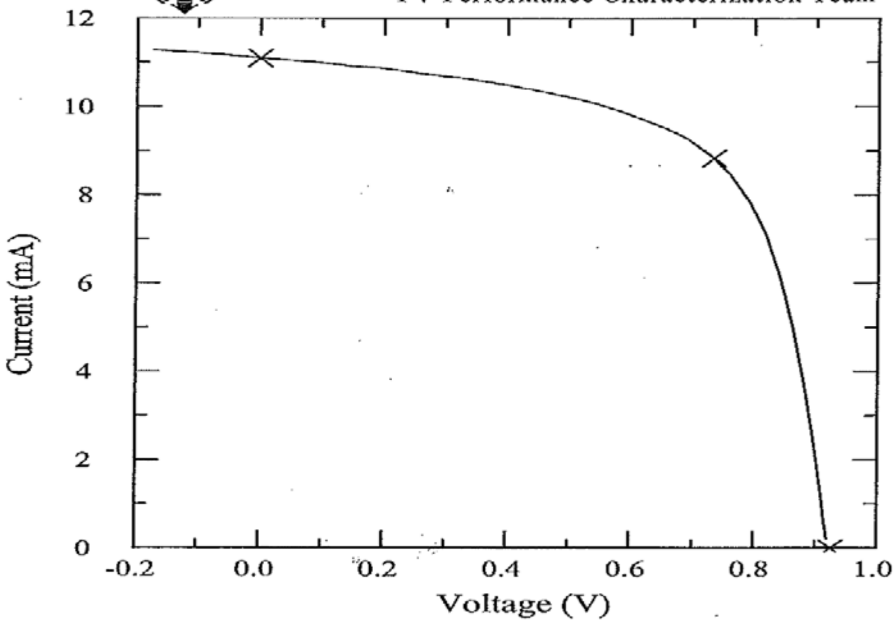
Standard Cell Efficiency

Konarka Technologies
organic Cell

Device ID: TY100716-32
Aug 18, 2010 14:38
Spectrum: ASTM G173 global

Device Temperature: 30.0 ± 10.0 °C
Device Area: 0.9950 cm^2
Irradiance: 1000.0 W/m^2

X25 IV System   Confidential
PV Performance Characterization Team



V_{oc} = 0.9259 V
I_{sc} = 11.093 mA
J_{sc} = 11.149 mA/cm^2
Fill Factor = 63.09 %

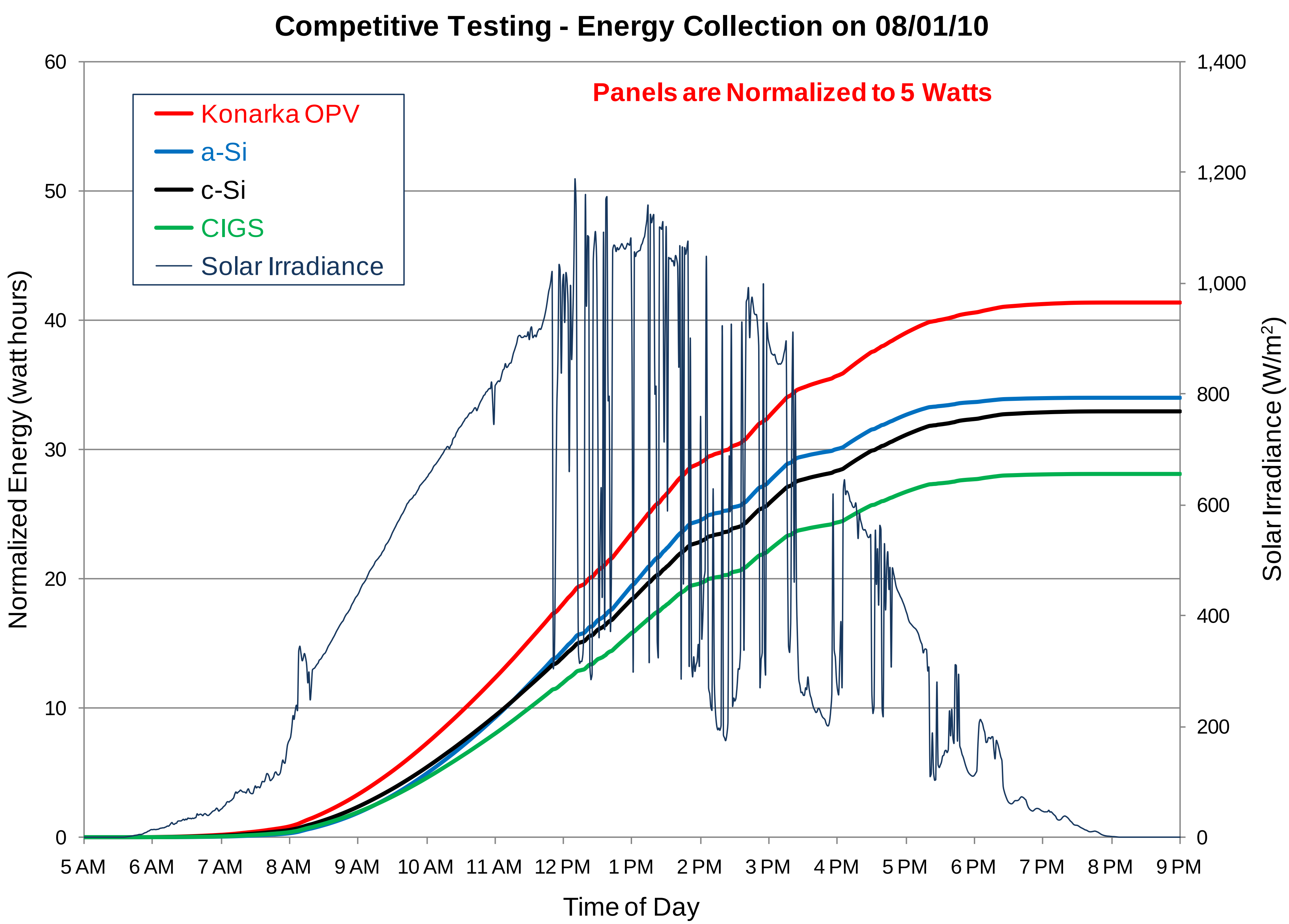
I_{max} = 8.8259 mA
V_{max} = 0.7342 V
P_{max} = 6.4800 mW
Efficiency = 6.51 %

Power Comparison

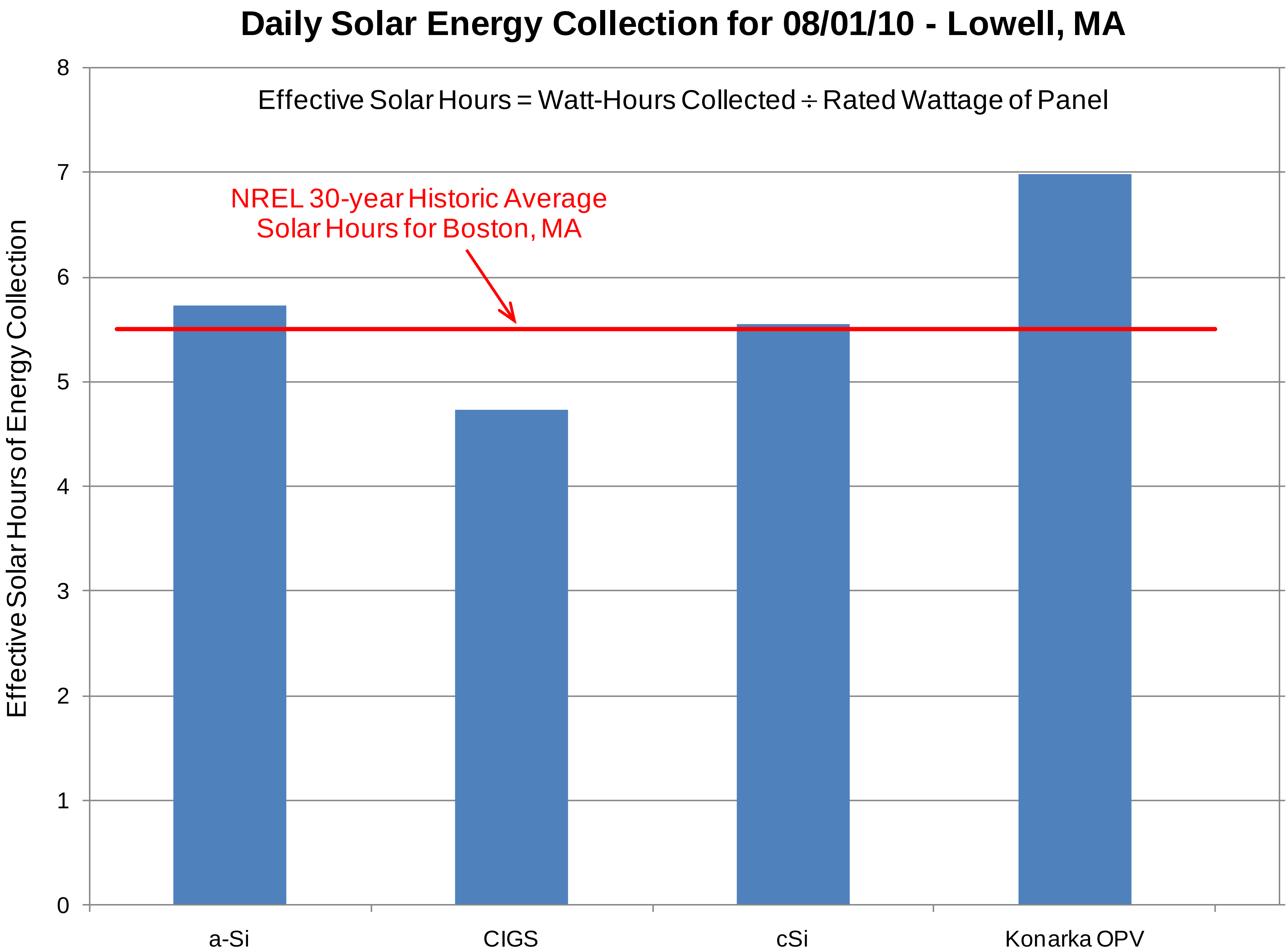
SAI Presentation
Competitive Performance

Application:

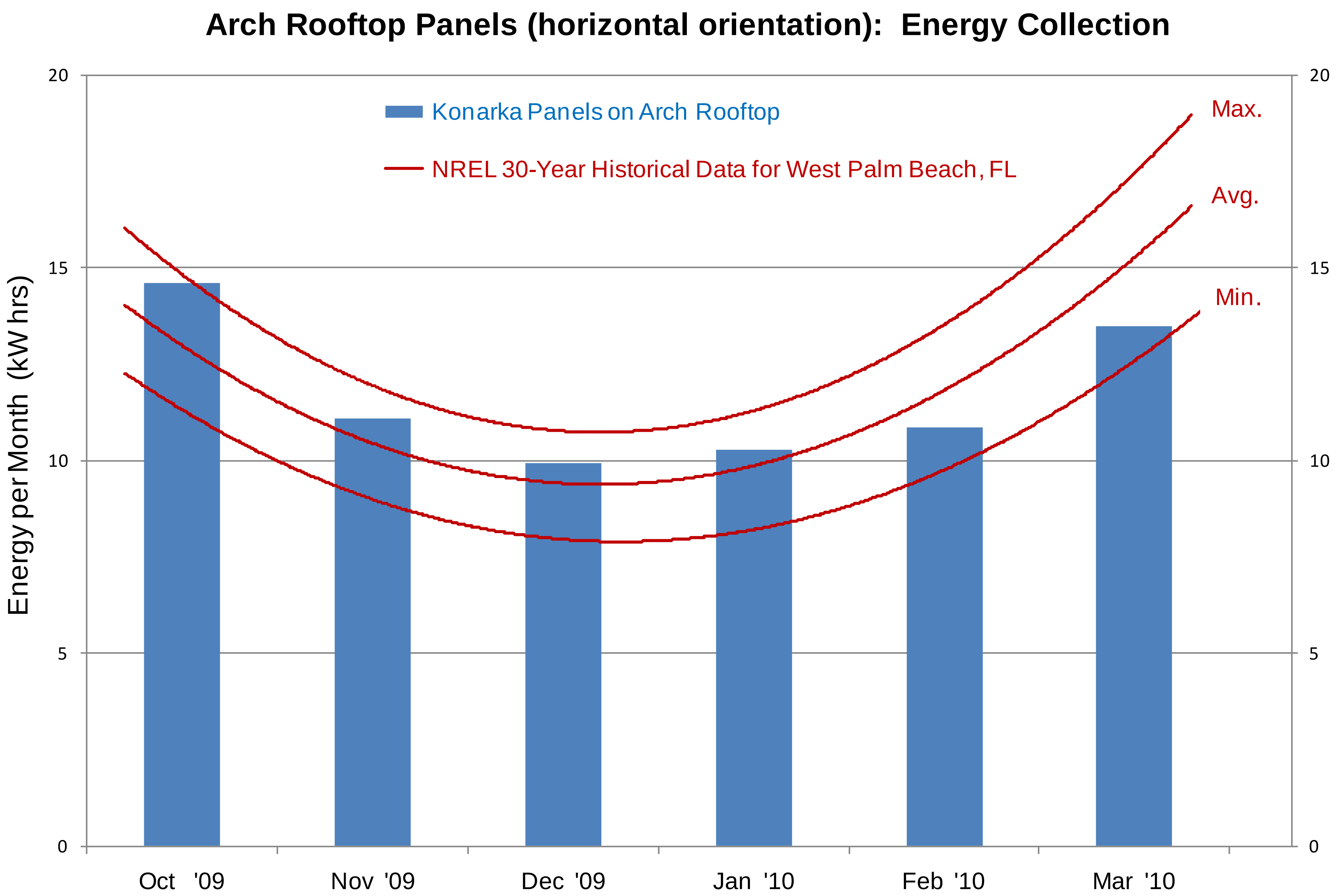
Curtain Wall



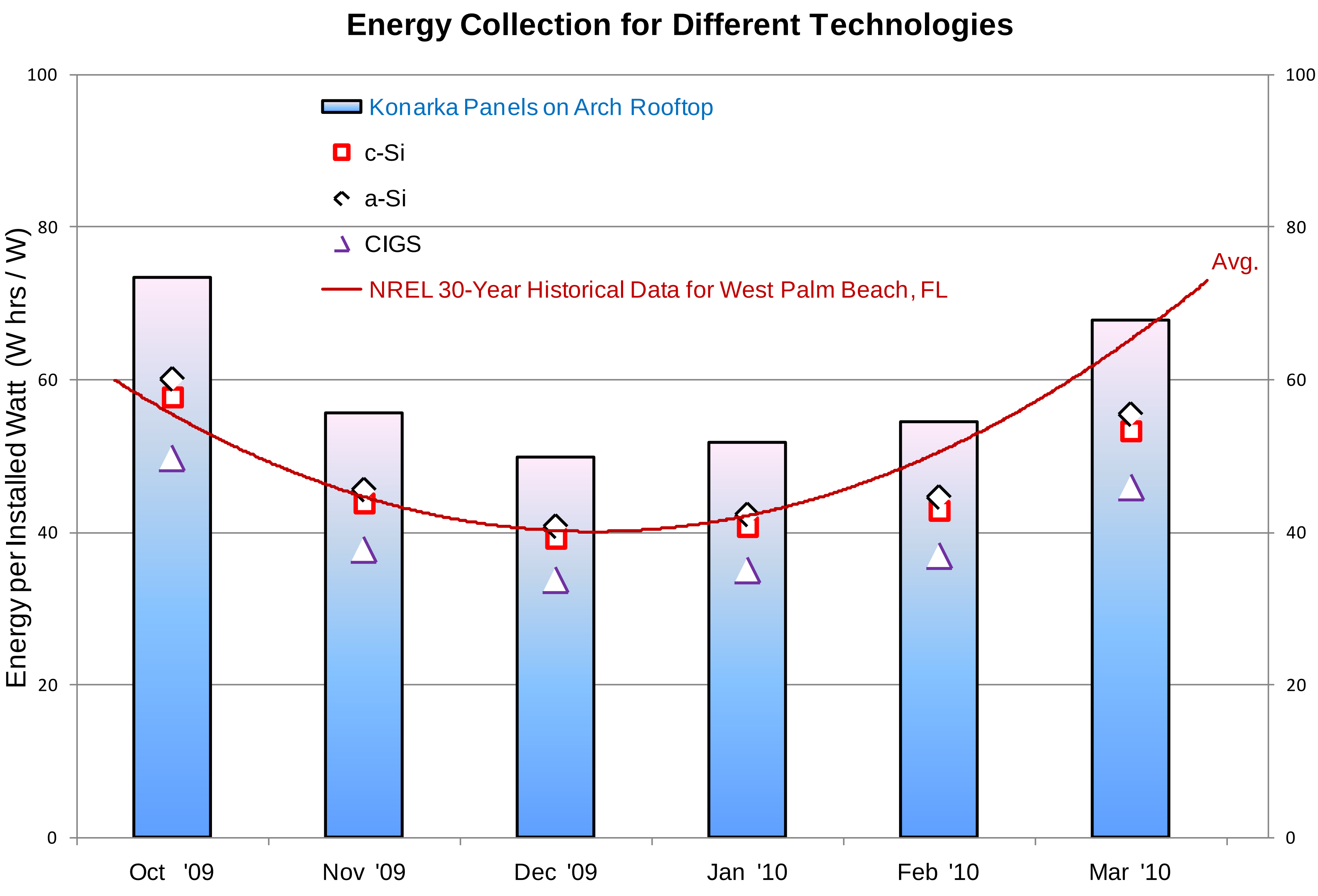
Competitive Testing - Energy Collection on 08/01/10
Panels are Normalized to 5 Watts
Konarka OPV
a-Si
c-Si
CIGS
Solar Irradiance
Normalized Energy (watt hours)
Solar Irradiance (W/m²)
Time of Day
0
10
20
30
40
50
60
0
200
400
600
800
1,000
1,200
1,400
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
8 PM
9 PM



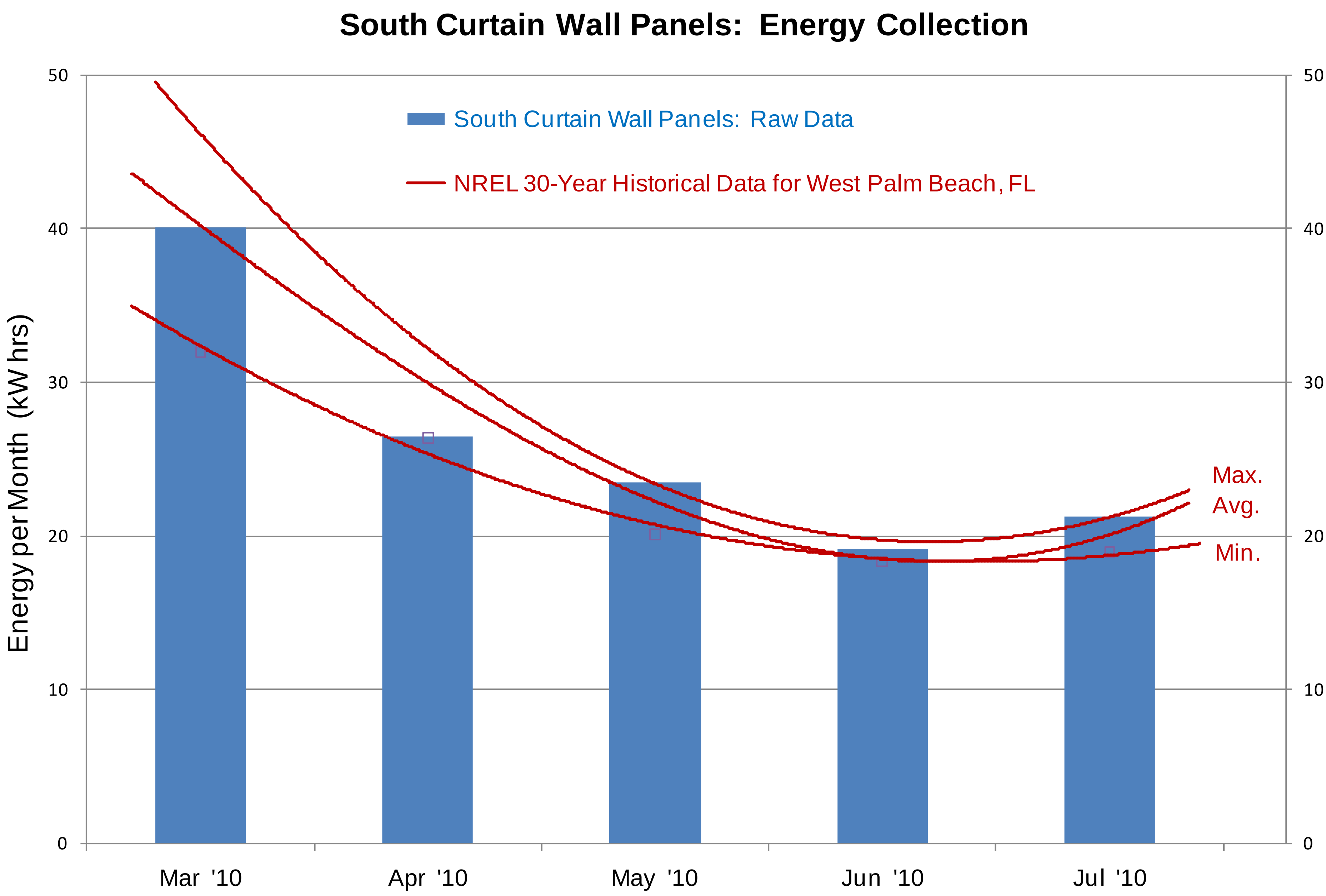
Daily Solar Energy Collection for 08/01/10 - Lowell, MA
Effective Solar Hours = Watt-Hours Collected ÷ Rated Wattage of Panel
NREL 30-year Historic Average
Solar Hours for Boston, MA
Effective Solar Hours of Energy Collection
0
1
2
3
4
5
6
7
8
a-Si
CIGS
cSi
Konarka OPV

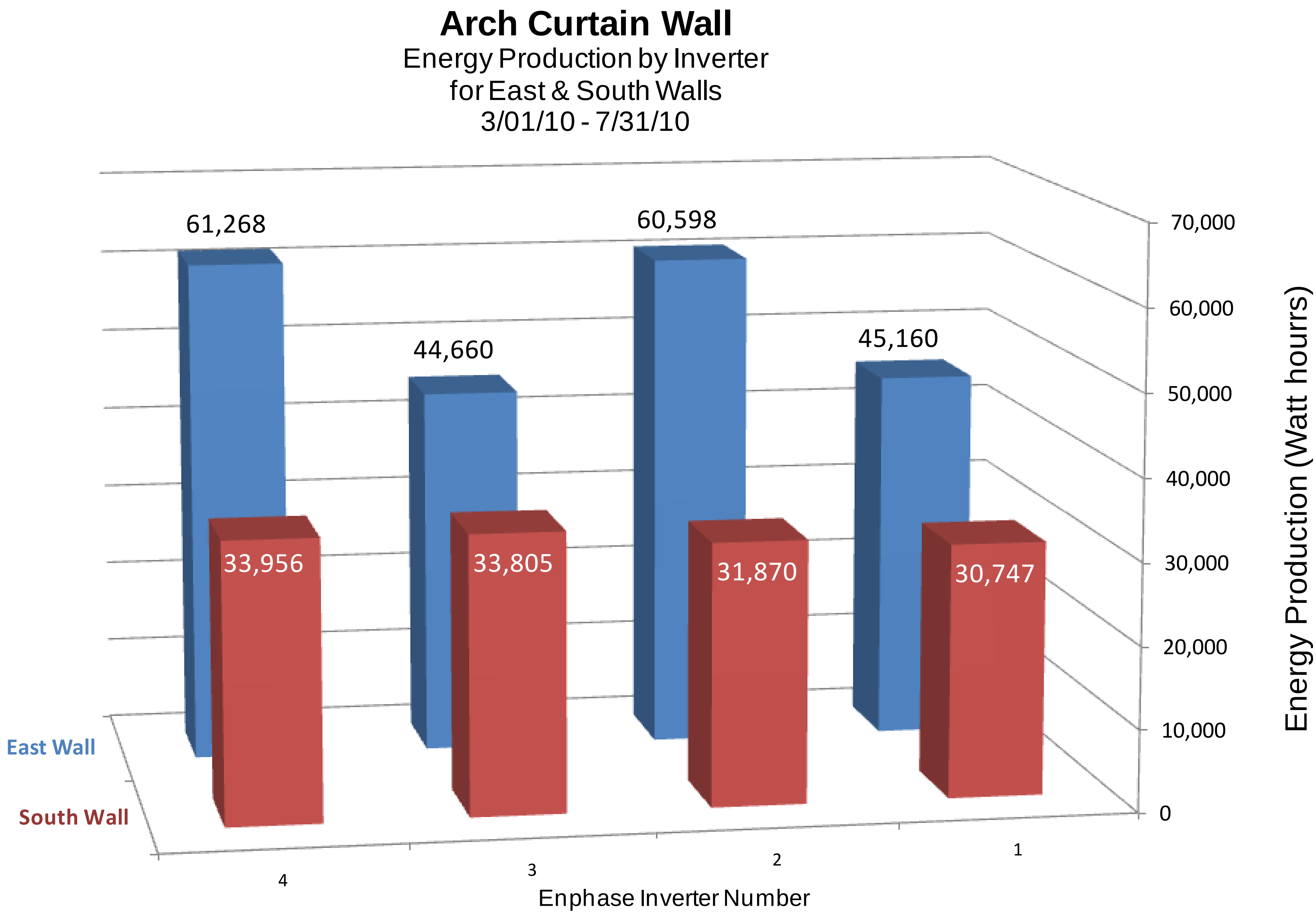


Arch Rooftop Panels (horizontal orientation): Energy Collection
Konarka Panels on Arch Rooftop
NREL 30-Year Historical Data for West Palm Beach, FL
Max.
Avg.
Min.
Energy per Month (kW hrs)
20
15
10
5
0
Oct '09
Nov '09
Dec '09
Jan '10
Feb '10
Mar '10

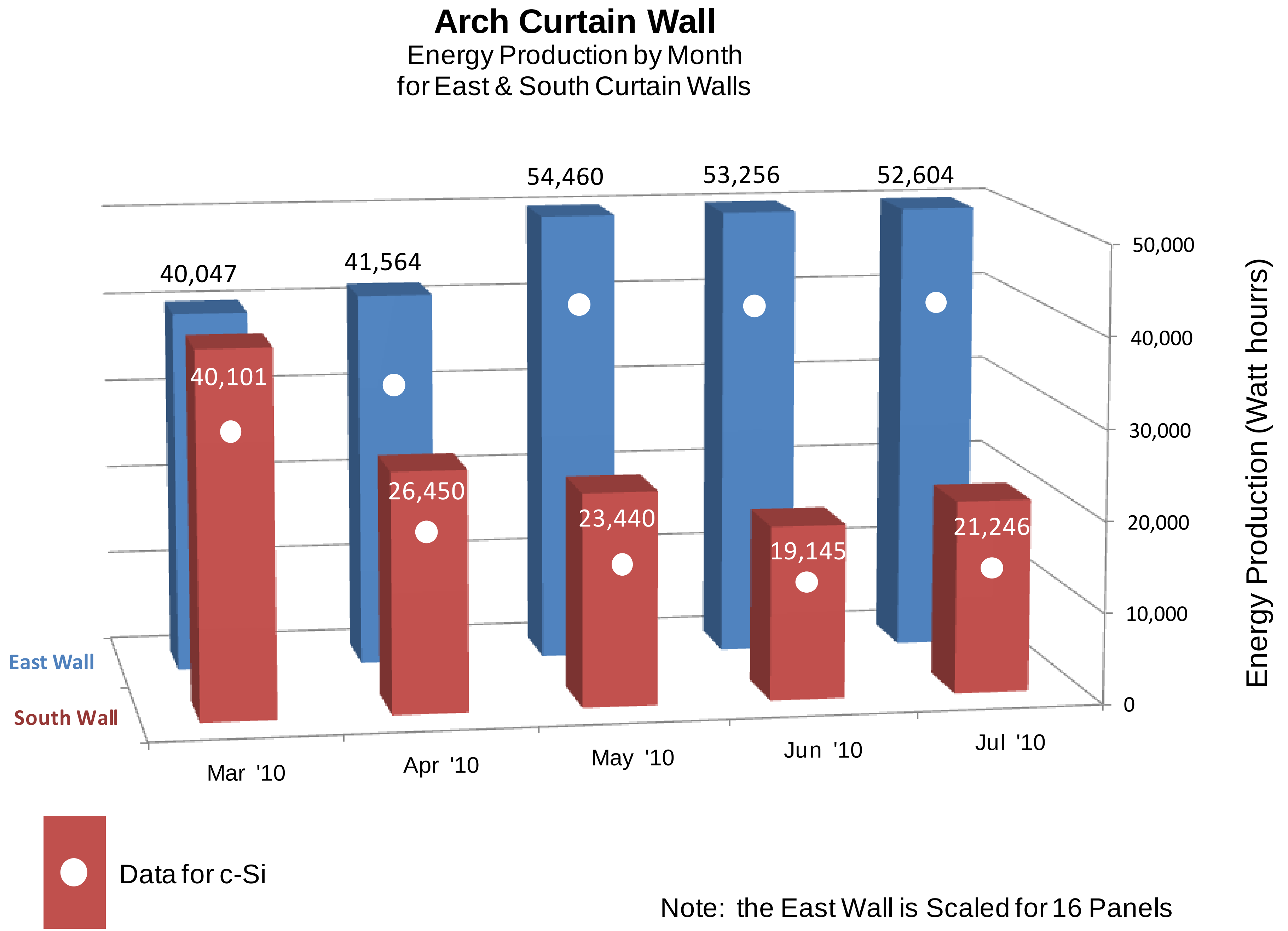


Energy Collection for Different Technologies
Konarka Panels on Arch Rooftop
c-Si
a-Si
CIGS
NREL 30-Year Historical Data for West Palm Beach, FL
Avg.
Energy per Installed Watt (W hrs / W)
100
80
60
40
20
0
Oct '09
Nov '09
Dec '09
Jan '10
Feb '10
Mar '10


South Curtain Wall Panels: Energy Collection
South Curtain Wall Panels: Raw Data
NREL 30-Year Historical Data for West Palm Beach, FL
Energy per Month (kW hrs)
0
10
20
30
40
50
Mar '10
Apr '10
May '10
Jun '10
Jul '10
Max.
Avg.
Min.



Arch Curtain Wall
Energy Production by Inverter
for East & South Walls
3/01/10 - 7/31/10
61,268
44,660
60,598
45,160
33,956
33,805
31,870
30,747
East Wall
South Wall
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Energy Production (Watt hours)
4
3
2
1
Enphase Inverter Number


Arch Curtain Wall
Energy Production by Month
for East & South Curtain Walls
40,047
41,564
54,460
53,256
52,604
40,101
26,450
23,440
19,145
21,246
50,000
40,000
30,000
20,000
10,000
0
Energy Production (Watt hours)
East Wall
South Wall
Mar '10
Apr '10
May '10
Jun '10
Jul '10
Data for c-Si
Note: the East Wall is Scaled for 16 Panels

Summary

Task 1 – Stability

- Flexible modules are stable to 1000hrs at 65°C/85%RH
- Flexible modules in glass are stable to >2000hrs at 85°C/85%RH (no decrease in performance)
- Adhesive + filler helps stabilize modules
- Solution coatable barriers exhibit good WVTR; work in-progress

Task 2 – Performance: n-type charge carriers

- N-type polymers could not be synthesized
- More than 30 fullerene derivatives synthesized and tested
  - Several deep LUMO derivatives accept charge from deep LUMO polymers: higher voltage observed
  - Improvement in cell efficiency not observed – morphology problem

Task 3 – Performance: grid electrode

- Exceeded flatness and roughness goals
- Exceeds sheet resistance goals
- Achieved %T goals
- Performance equivalent to ITO – 2% Efficiency (av.); work in-progress

Current Cell and Module Performance

- World record (1cm^2 cell area)= 6.51%

- Cumulative power production larger than competitive technologies