PLEXTRONICS
Light. Power. Circuitry.™

Printed Organic Solar Cells:
Pathway and Challenges to Competitive LCOE

Darin Laird
Director, Power Team (OPV)

NSF

COLORADO SCHOOL OF MINES
engineering the way

Renewable Energy Materials Research Science and Engineering Center
REMRSEC

May 6th, 2010

Company Overview

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Key Facts:

- Founded in 2002
- Based in Pittsburgh, PA USA
- Approximately 70 employees
- 190+ individual and pending patents worldwide
- Strategic Investors: SOLVAY; Applied Ventures, LLC (APPLIED MATERIALS)

Business Model:

Develop and manufacture high-performance inks and leading-edge materials for printed electronics

Core Capabilities:

- Molecular design & synthesis
- Scaled polymer manufacturing
- High purity ink formulation
- Large-area processing expertise
- World class quality:

ANAB ACCREDITED

ISO 9001:2008 No. 43632

Target Markets:

- OLED Lighting & Displays
- Printed Solar Power

Product Lines:

Plexcore® OC: Hole Injection Layer (HIL) ink for OLED lighting and displays

Plexcore® PV: Ink systems for OPV solar cells including matched Photoactive (p/n) ink and Hole Transport Layer (HTL) ink

Plexcore® OS: P3HT polymer powder for OPV and transistors

Outline

- OPV and enabling low LCOE
- Commercial activities for OPV at Plextronics
  - Efficiency
  - Lifetime
- OPV and future LCOE prospects
- OPV Industry Commercialization Gaps

  (Breakthroughs to accelerate progress)

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OPV can achieve lowest LCOE

Pathway to lowest LCOE needs to focus on low cost materials for high-throughput processes

Cost

- **High throughput manufacturing lowers module cost**
- **For R2R, materials costs dominate**

LCOE

$/kWh

Efficiency

Higher efficiency = more kW's per module

Lifetime

Longer lifetime = more kWh's per module

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OPV Technology Challenges

$ / kW-hr

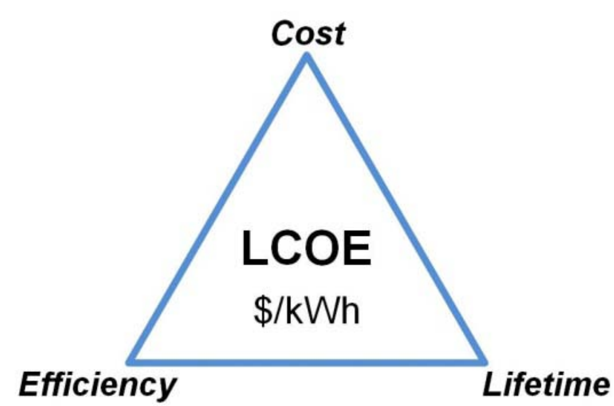
$ / W

$ / m² (mfg cost)
- M >50% of COGS
- D Simple is better
- P High throughput

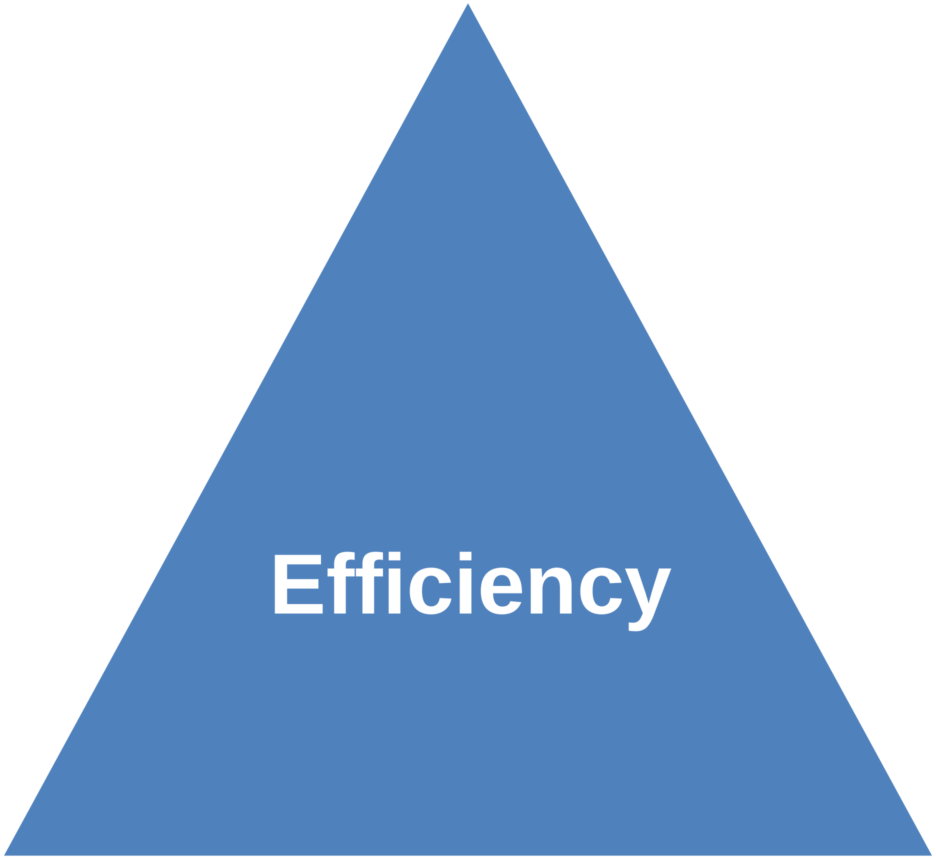
m² / W (efficiency)
- M Key lever
- D Simple is better

Lifetime
- M Intrinsic durability
- D Built-in durability

Need to focus on development of low cost, high efficiency materials compatible with high-throughput mfg. processes



Keys to OPV Commercialization



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Plexcore® PV Ink System for Organic Photovoltaics

Plexcore® PV 1000 Series

Standard Ink System for OPV Applications

Typical Performance*: 3.0% - 4.0% Efficiency

Plexcore® PV 2000 Series

High-Performance Ink System for OPV Applications

Typical Performance*: 4.5% - 5.5% Efficiency

Various inks available for different commercial coating processes

Ready-to-Use Ink System commonly used for:

- Process development and scaling
- Novel architecture discovery
- Achieving world-leading performance

* *Performance achieved in Plextronics' lab-based single junction OPV cells and provided for informational purposes only.*

Plexcore PV 2000 NREL Certified at 5.98%

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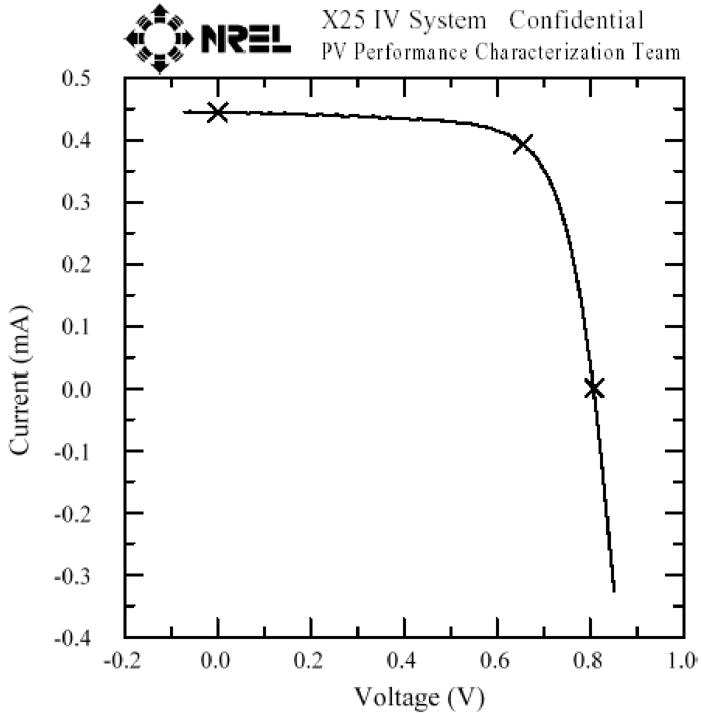
Device ID: 3393-2 pxl 1
Aug 14, 2008 23:17
Spectrum: AM1.5 Global

Device Temperature: 25.0 ± 1.0 °C
Device Area: 0.043 cm^2
Irradiance: 1000.0 W/m^2



Polymer-based OPV Solar Cell

Single Photoactive Layer OPV Cell

NREL Certified at 5.98%

Aperture = 0.043 cm^2
Cell Size ~ 0.1 cm^2

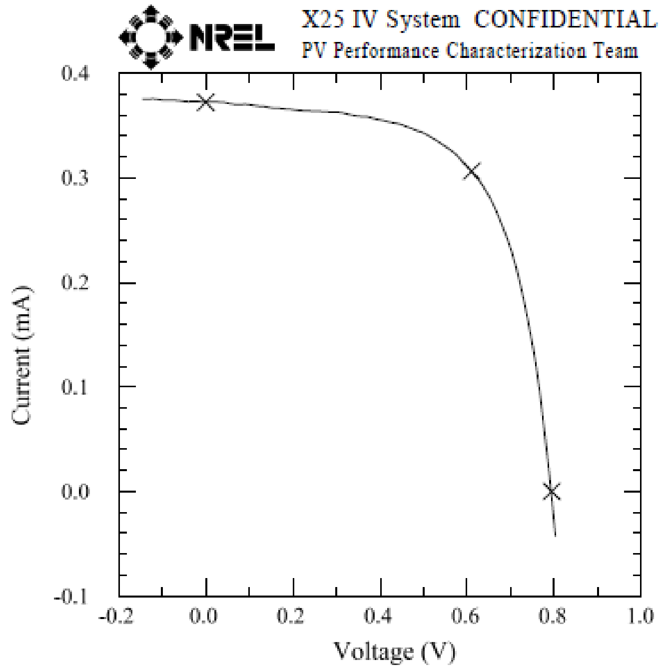
V_{oc} = 0.8079 V
I_{sc} = 0.44438 mA
J_{sc} = 10.321 mA/cm^2
Fill Factor = 71.67 %

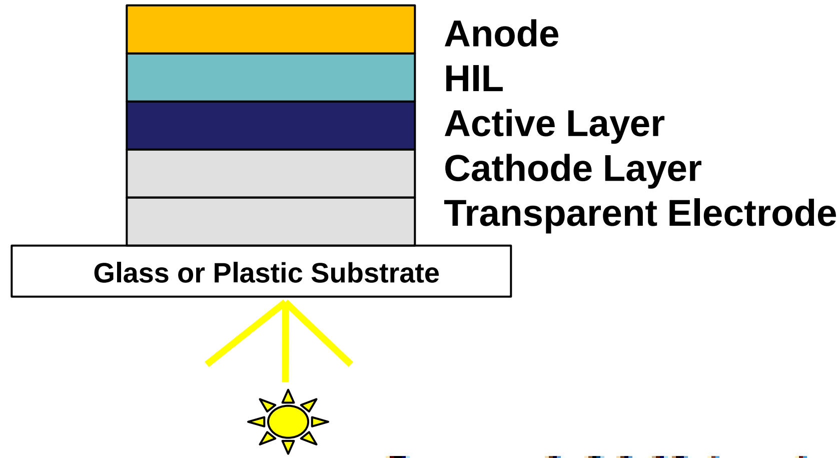
I_{max} = 0.39258 mA
V_{max} = 0.6553 V
P_{max} = 0.25724 mW
Efficiency = 5.98 %

X25 IV System
PV Performance Characterization Team

Plexcore PV 2000 Ink System in Inverted OPV Architecture (R2R-Friendly)

Device ID: 5159-3 pixel 4
Sep 22, 2009 13:59
Spectrum: ASTM G173 global
Device Area: 0.04249 cm^2
Irradiance: 1000.0 W/m^2





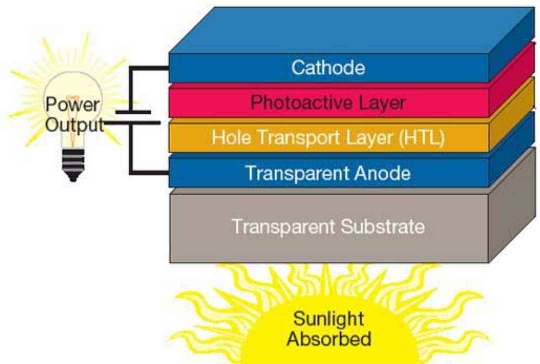
V_{oc} = 0.7942 V
I_{sc} = 0.37227 mA
J_{sc} = 8.7614 mA/cm^2
Fill Factor = 63.27 %

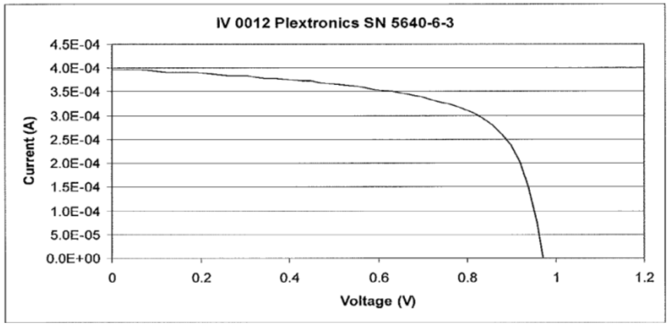
I_{max} = 0.30634 mA
V_{max} = 0.6107 V
P_{max} = 0.18707 mW
Efficiency = 4.40 %

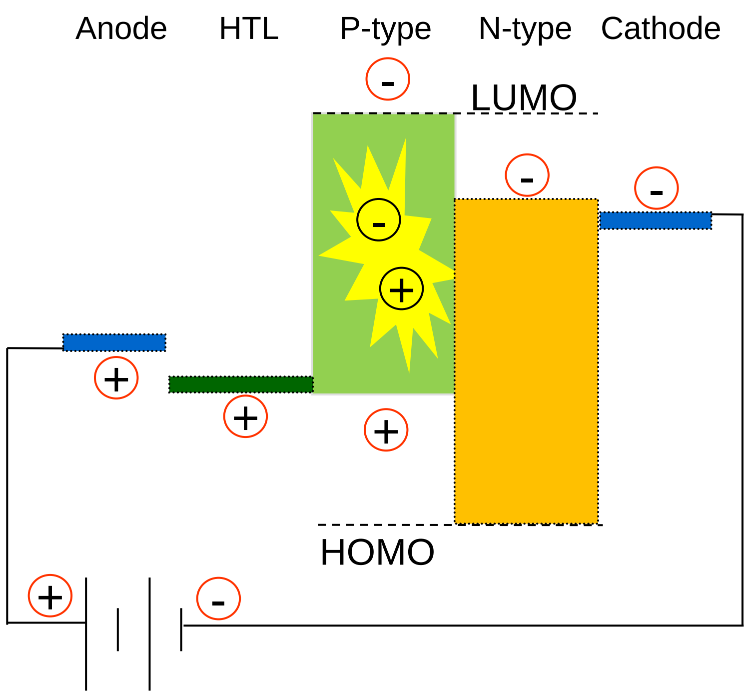
Plexcore PV 2000 achieves 4.4% efficiency

- Inverted ZnO-based device with vapor deposited silver anode
- Voltage significantly improved over P3HT/PCBM
- Plexcore HIL utilized for spin coat on active layer

Beyond PV 2000, Low Band-Gap Systems with Matched HIL Enable High Performance







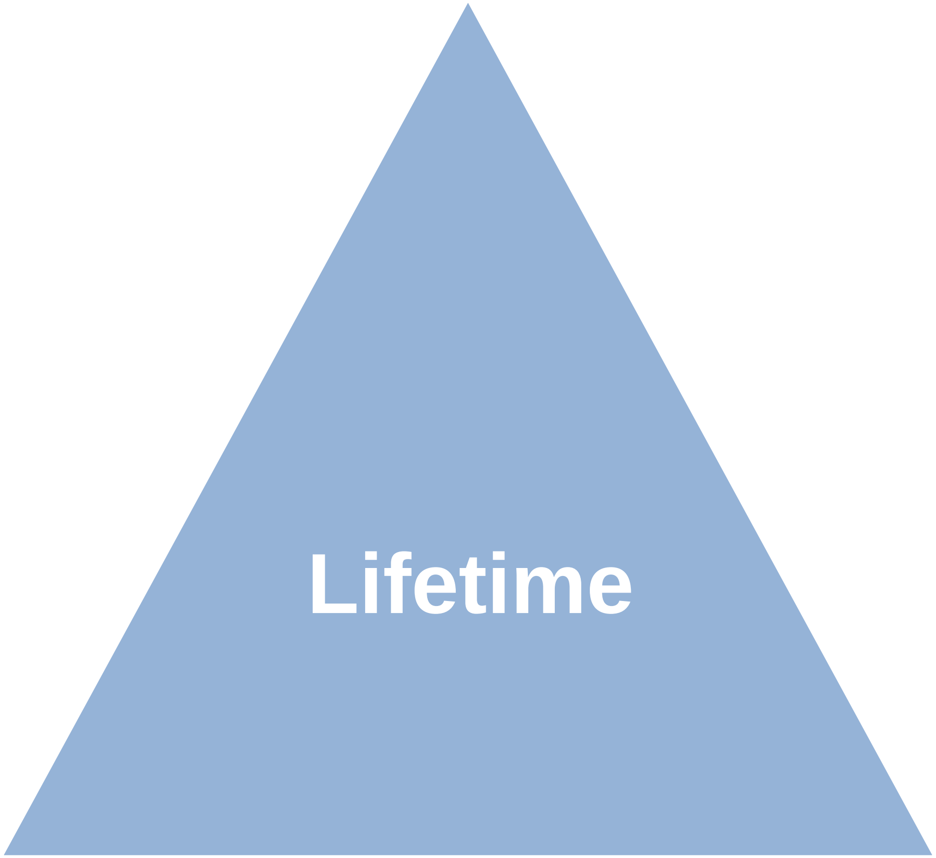
I_{sc}	393 ± 8 µA
V_{oc}	0.97 ± 0.02 V
Area	0.0396 ± 0.0001 cm^2
Efficiency	(6.2 ± 0.2)%

Voc
- Driven by HOMO-LUMO and HTL WF
- Very Low Loss system, Eg = 1.75, Voc = 1.0 V

Isc
- Driven by polymer absorption character
- EQE > 60%, absorption edge ~ 710 nm

Efficiency
- 6.2% verified; Newer results to be reported
- Leverages Plexcore OC HTL for high Voc
- Plextronics is developing several scalable, high efficiency platform materials

Commercializing OPV



ISOS 2010 @ Roskilde, Denmark
October 25-27 2010

https://conferences.dtu.dk/conferenceDisplay.py?confId=35

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NREL-Verified OPV Module Lifetime (~'1yr')

(Plexcore PV2000 ink system)

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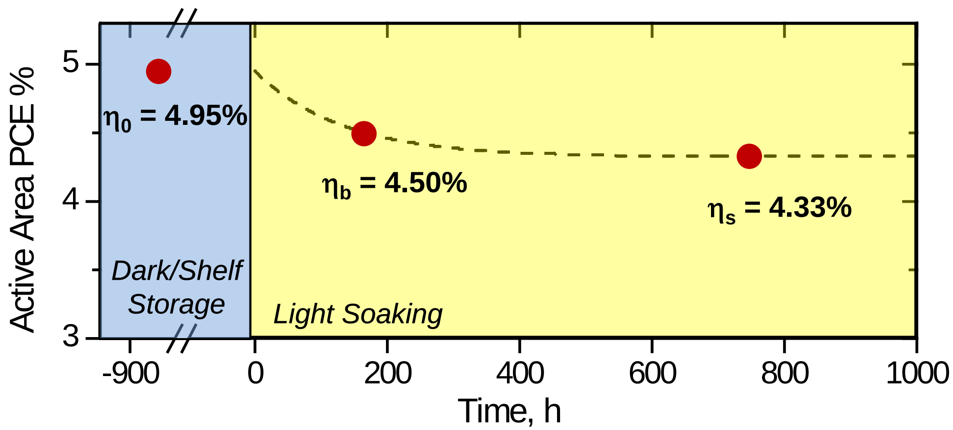
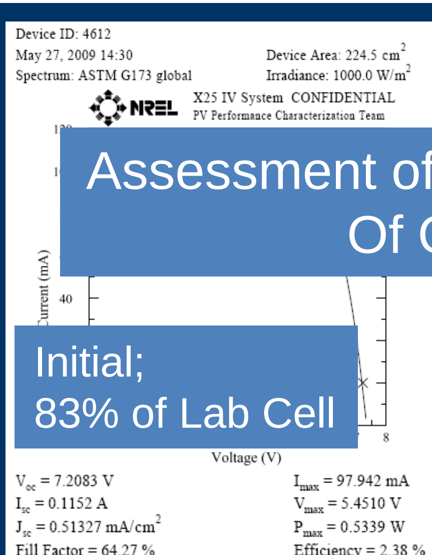
Active Area Degradation Profile:



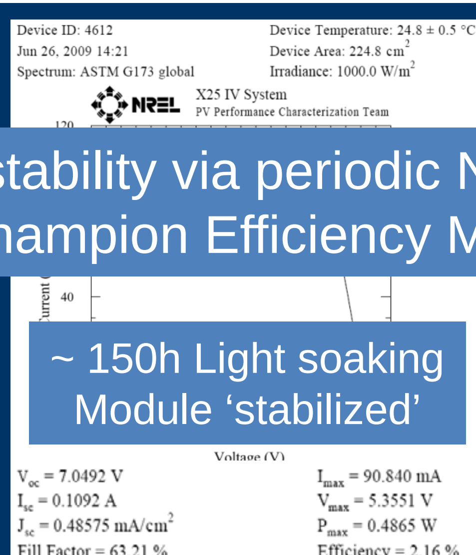
<u>Stress Conditions:</u> 1Sun, Xe lamp, 100% duty cycle, Voc

Assessment of stability via periodic NREL certification Of Champion Efficiency Module


Device ID: 4612
May 27, 2009 14:30
Spectrum: ASTM G173 global
Device Area: 224.5 cm^2
Irradiance: 1000.0 W/m^2
NREL X25 IV System CONFIDENTIAL
PV Performance Characterization Team
Voltage (V)

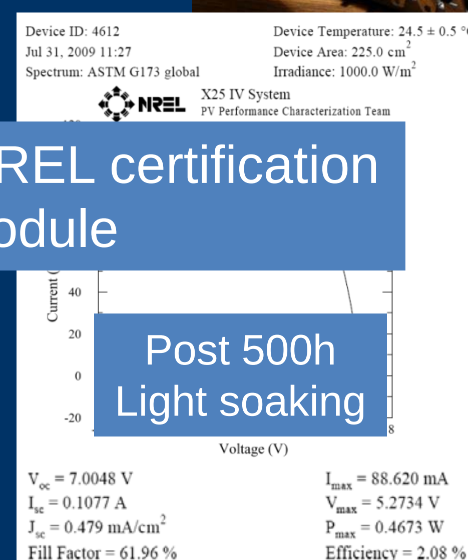
V_{oc} = 7.2083 V
I_{sc} = 0.1152 A
J_{sc} = 0.51327 mA/cm^2
Fill Factor = 64.27 %
I_{max} = 97.942 mA
V_{max} = 5.4510 V
P_{max} = 0.5339 W
Efficiency = 2.38 %

Initial;
83% of Lab Cell


Device ID: 4612
Jun 26, 2009 14:21
Spectrum: ASTM G173 global
Device Temperature: 24.8 ± 0.5 °C
Device Area: 224.8 cm^2
Irradiance: 1000.0 W/m^2
NREL X25 IV System
PV Performance Characterization Team
Voltage (V)

V_{oc} = 7.0492 V
I_{sc} = 0.1092 A
J_{sc} = 0.48575 mA/cm^2
Fill Factor = 63.21 %
I_{max} = 90.840 mA
V_{max} = 5.3551 V
P_{max} = 0.4865 W
Efficiency = 2.16 %

~ 150h Light soaking
Module 'stabilized'


Device ID: 4612
Jul 31, 2009 11:27
Spectrum: ASTM G173 global
Device Temperature: 24.5 ± 0.5 °C
Device Area: 225.0 cm^2
Irradiance: 1000.0 W/m^2
NREL X25 IV System
PV Performance Characterization Team
Voltage (V)

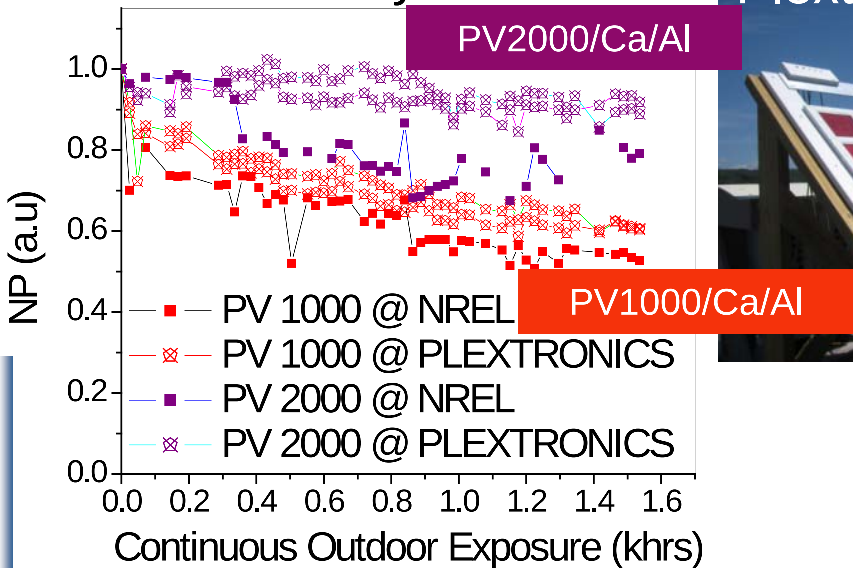
V_{oc} = 7.0048 V
I_{sc} = 0.1077 A
J_{sc} = 0.479 mA/cm^2
Fill Factor = 61.96 %
I_{max} = 88.620 mA
V_{max} = 5.2734 V
P_{max} = 0.4673 W
Efficiency = 2.08 %

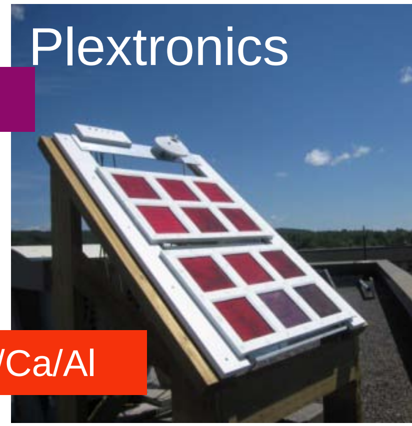
Post 500h
Light soaking

NREL X25 IV System
PV Performance Characterization Team

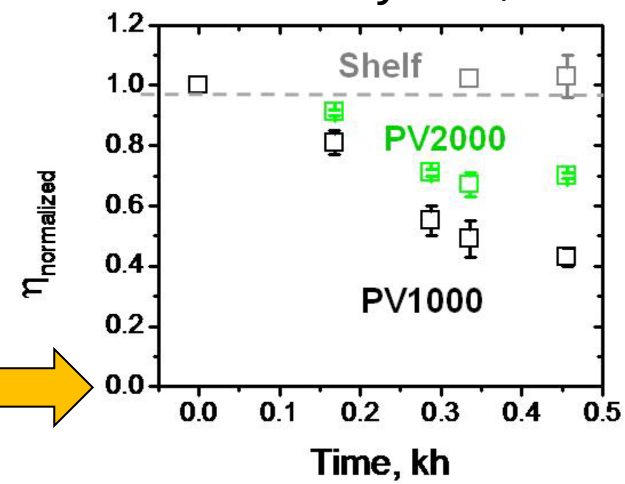
Fullerene Dependent Stability of OPV Cells: P3HT:PCBM vs. P3HT:bis-indene[c60]

Outdoor Stability:



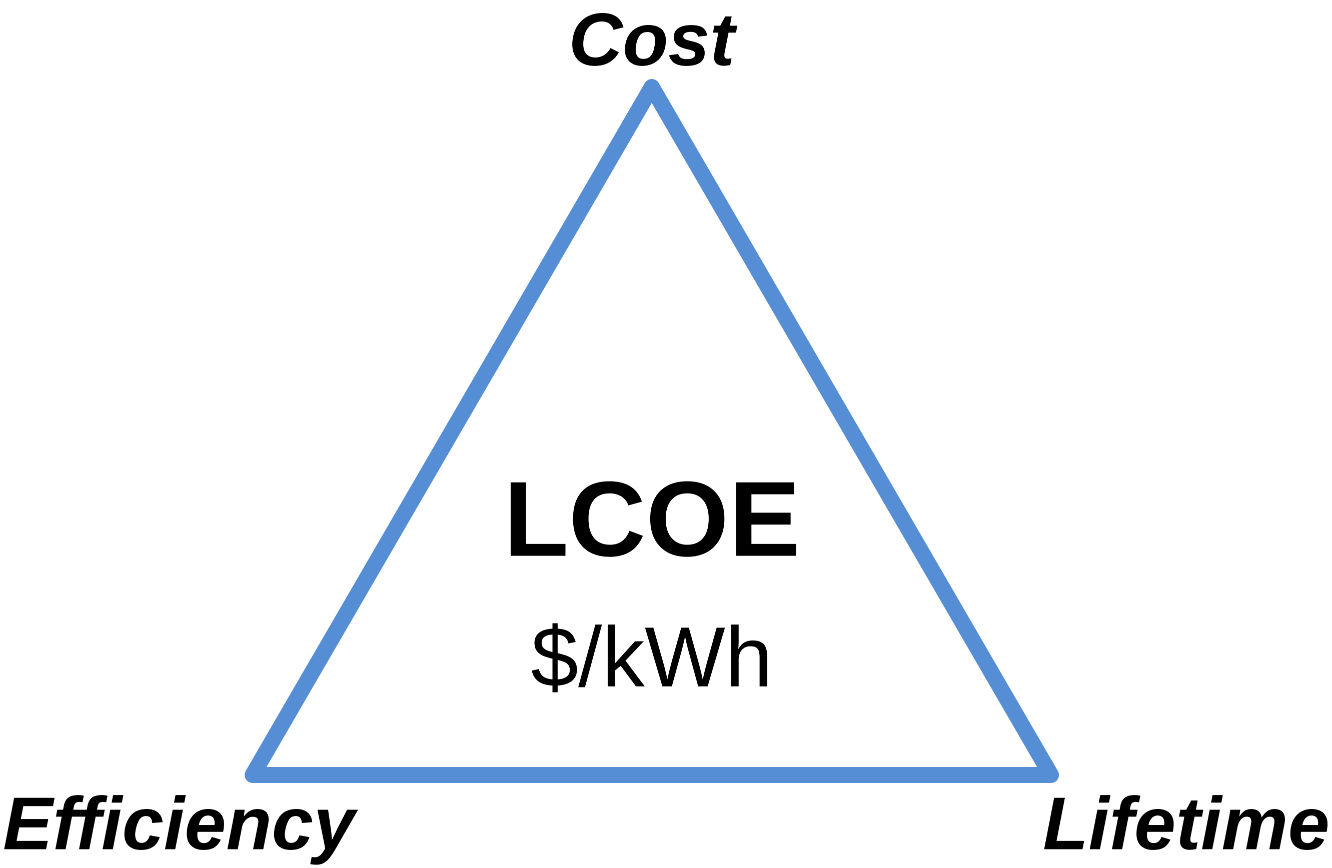


Indoor Stability: Xe, 1 Sun



- PV2000 exhibits improved stability over PV1000
- Plex degradation slower than @ NREL
  - Higher Irradiance is initial primary suspect
  - 35% higher irradiance in CO vs. PA
- Consistent with indoor testing

OPV can achieve lowest LCOE



OPV Adoption Pathways

Sub $0.50/W is a Key Target

$ / kW-hr

Improvements over time

Module Efficiency	Lifetime	Module Cost	LCOE
5%	5 year	$1.25 / W	n/a
5%	10 year	$1.00 / W	$.35 / kWh
7%	15 year	$.75 / W	$.17 / kWh
10%	20 year	$.50 / W	$.10 / kWh

OPV performance improvements drive lower LCOE.

OPV Adoption Pathways

Sub $0.50/W is a Key Target

$ / kW-hr

Module Efficiency	Lifetime	Module Cost	LCOE
5%	5 year	$1.25 / W	n/a
5%	10 year	$1.00 / W	$.35 / kWh
7%	15 year	$.75 / W	$.17 / kWh
10%	20 year	$.50 / W	$.10 / kWh

Initial offerings meets requirements for off-grid markets.

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OPV Adoption Pathways

Sub $0.50/W is a Key Target

$ / kW-hr

Module Efficiency	Lifetime	Module Cost	LCOE
5%	5 year	$1.25 / W	n/a
5%	10 year	$1.00 / W	$.35 / kWh
7%	15 year	$.75 / W	$.17 / kWh
10%	20 year	$.50 / W	$.10 / kWh

Performance increases drive BIPV applications and on-grid projects (in higher cost markets).

OPV Adoption Pathways

Sub $0.50/W is a Key Target

$ / kW-hr

Breakthroughs to Accelerate Progress to < $0.50/W

Module Efficiency	Lifetime	Module Cost	LCOE
5%	5 year	$1.25 / W	n/a
5%	10 year	$1.00 / W	$.35 / kWh
7%	15 year	$.75 / W	$.17 / kWh
10%	20 year	$.50 / W	$.10 / kWh

Ultimately, OPV provides a cost structure which is better than grid competitive

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OPV Industry Commercialization Gaps
Funding Opportunities for Acceleration

Need to drive:

High module efficiency (>5% at production)

- >10% lab cells (8% current SOA)
- R2R-Friendly high performance device stacks
- Translate performance from lab to R2R processes
- Large-area module design (low electrical losses, aperture ratio, etc)

And

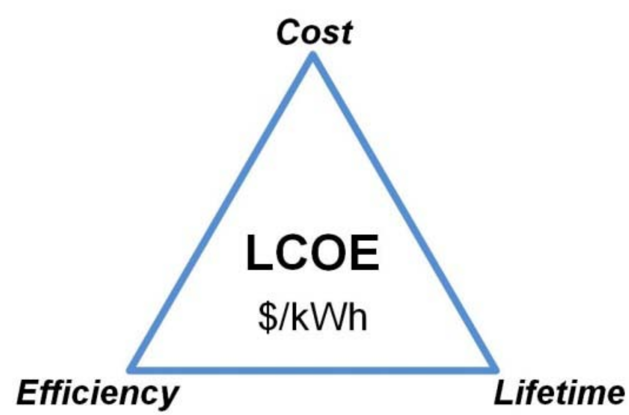
> 10 years device stability

- Understand fundamentals of metal/organic contact interactions
- Reduce device sensitivity to water/oxygen
- Elucidate & Mitigate photochemical-related degradation processes

And

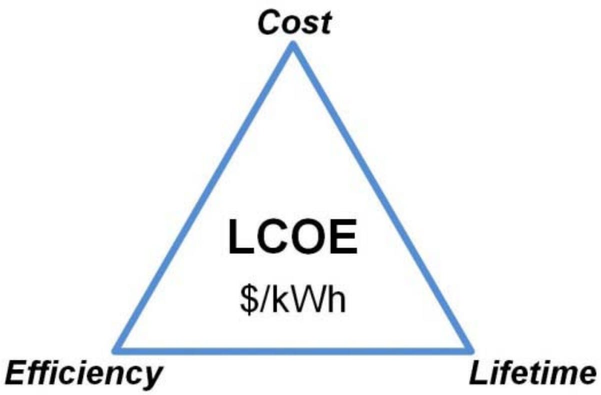
Low materials cost

- Scale materials to multi-kilogram production
- Utilize production processes with
  - High throughput
  - High materials utilization



Thank You

Darin Laird
Director, OPV Technology
dlaird@plextronics.com



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R&D volumes of select products available through:
www.aldrich.com

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