NEUE ENTWICKLUNGEN IN DER ORGANISCHEN PHOTOVOLTAIK

03/03/2009 DPG Hamburg **C. J. Brabec**

KONARKA®

Company Overview

- **Founded in 2001, underlying technology subject of Nobel Prize, Chemistry 2000**
- **Leading IP position with over 350 patents and global filings**
- **Strong 80+ person team with technical and industrial expertise**
- **Global presence with staff in US, EU & Asia**

Headquarters:
Lowell, MA

Manufacturing:
New Bedford, MA

Nurnberg, Germany

Linz, Austria

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Renewable energy supply

Solar

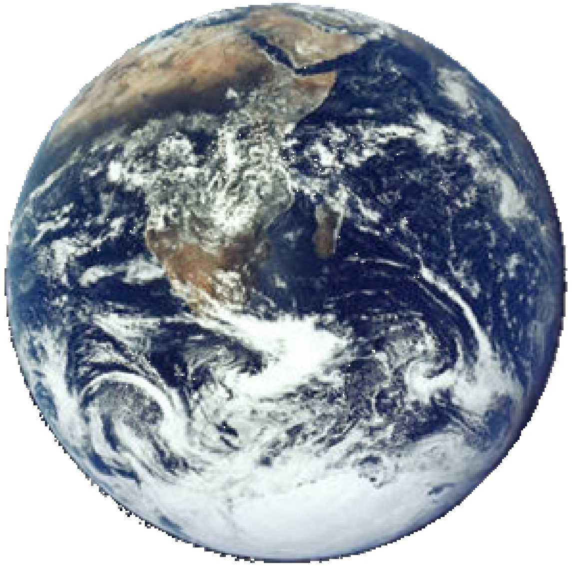
1 x 10^5 TW at Earth surface

10,000 TW (technical value)

It´s about TWs

Wind
14 TW

Tide/Ocean Currents
0.7 TW



Biomass
5-7 TW

Hydroelectric
1.2 TW technically feasible
0.6 TW installed capacity

Geothermal
1.9 TW

Energy gap
~ 14 TW by 2050
~ 33 TW by 2100

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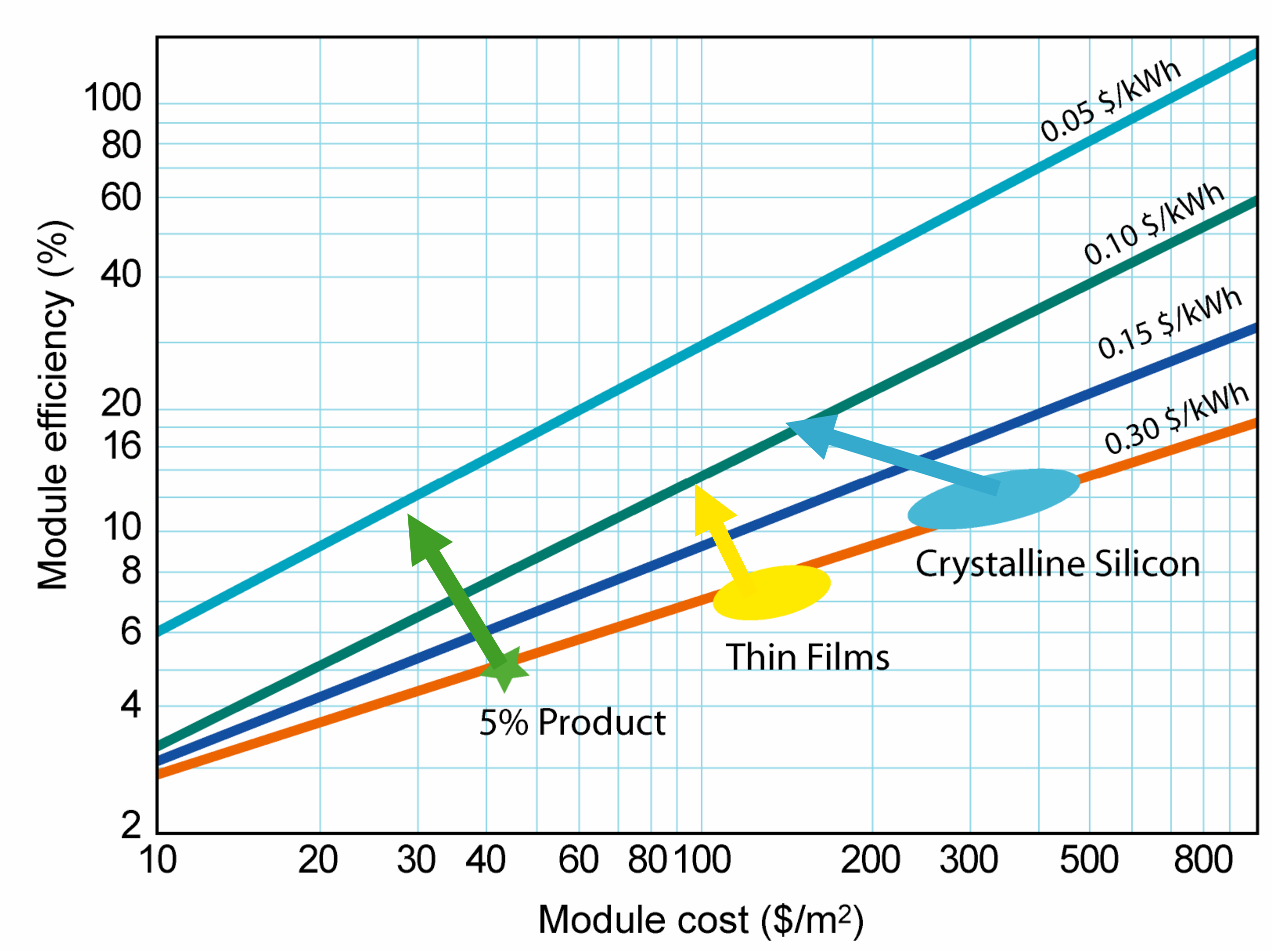
Source: Arthur Nozik

Impact of Costs



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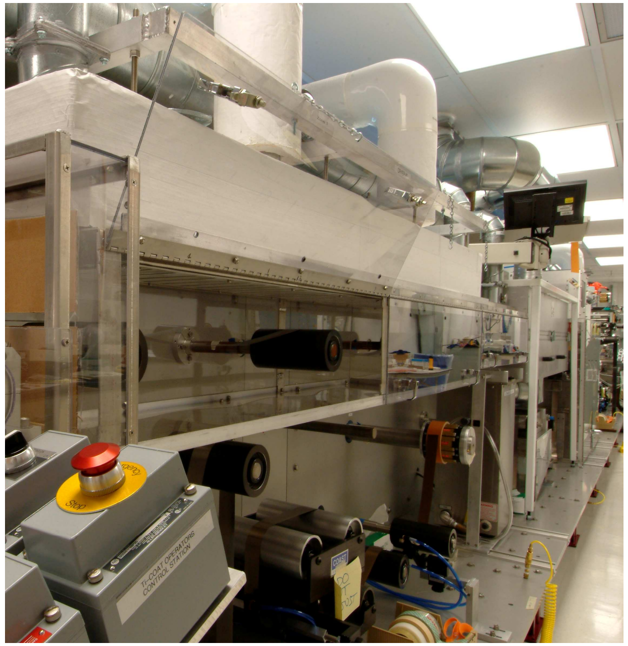
Based on Kazmerski et al, Journal of Electron Spectroscopy, 150 (2006), 105 - 131

Access to low cost PV

A low cost PV technology MUST

- Utilize low cost, high volume & scalable production processes
- Prevent huge factory investments
- use abundant raw materials



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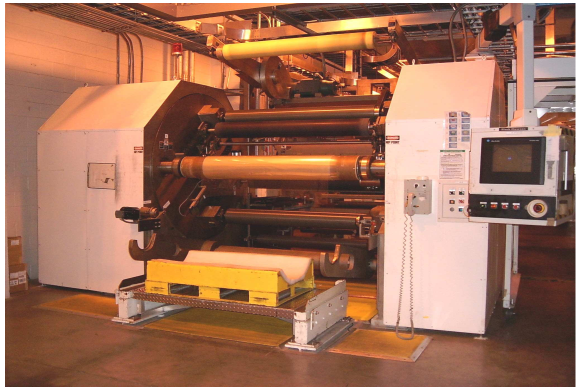
Roll to roll manufacturing of OPV

2006 - Lab Scale

2007 - Pilot

2008 - Production



Pilot Prototypes	Q4, 2007
Commercial Prototypes	First Half, 2008
First Customer Shipments	Second Half, 2008

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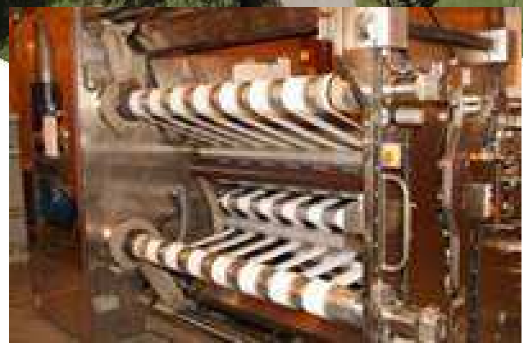
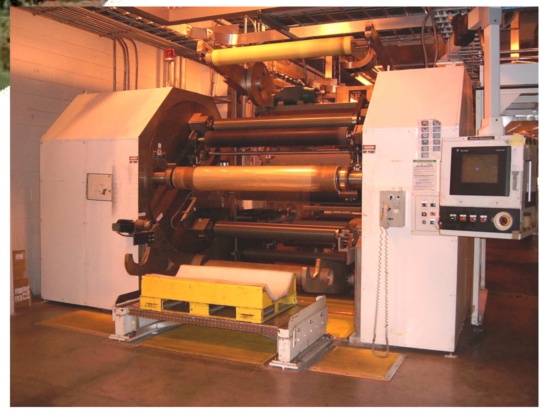
Konarka – production of OPV





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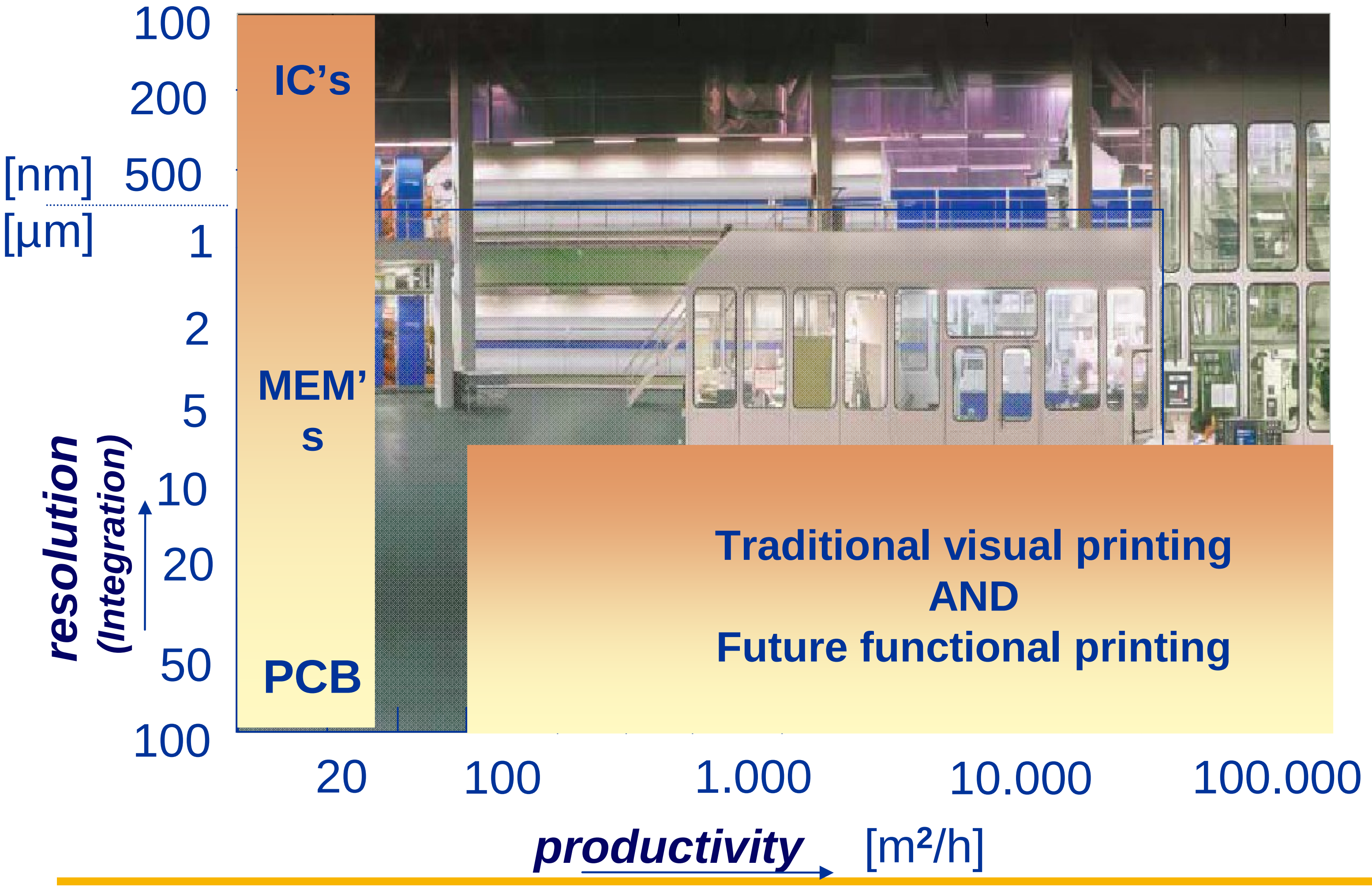
why pure mass printing?



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Source: *Kinnban, Handbookof Printmedia & A. Huebler, Print u Medientechnik, Univ. Chemnitz*

Our vision – from mid day to all day

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Efficiency

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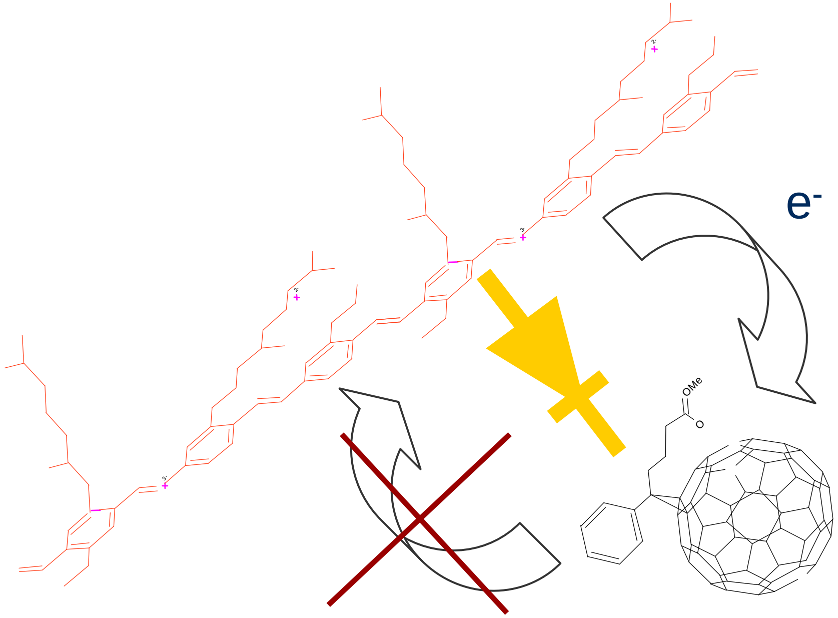
Bulk-heterojunction Composites

- **A PV junction is qualified by its characteristics to act as a "diode" for charge carriers.**

- **Majority carriers can not overcome this barrier without recombination.**



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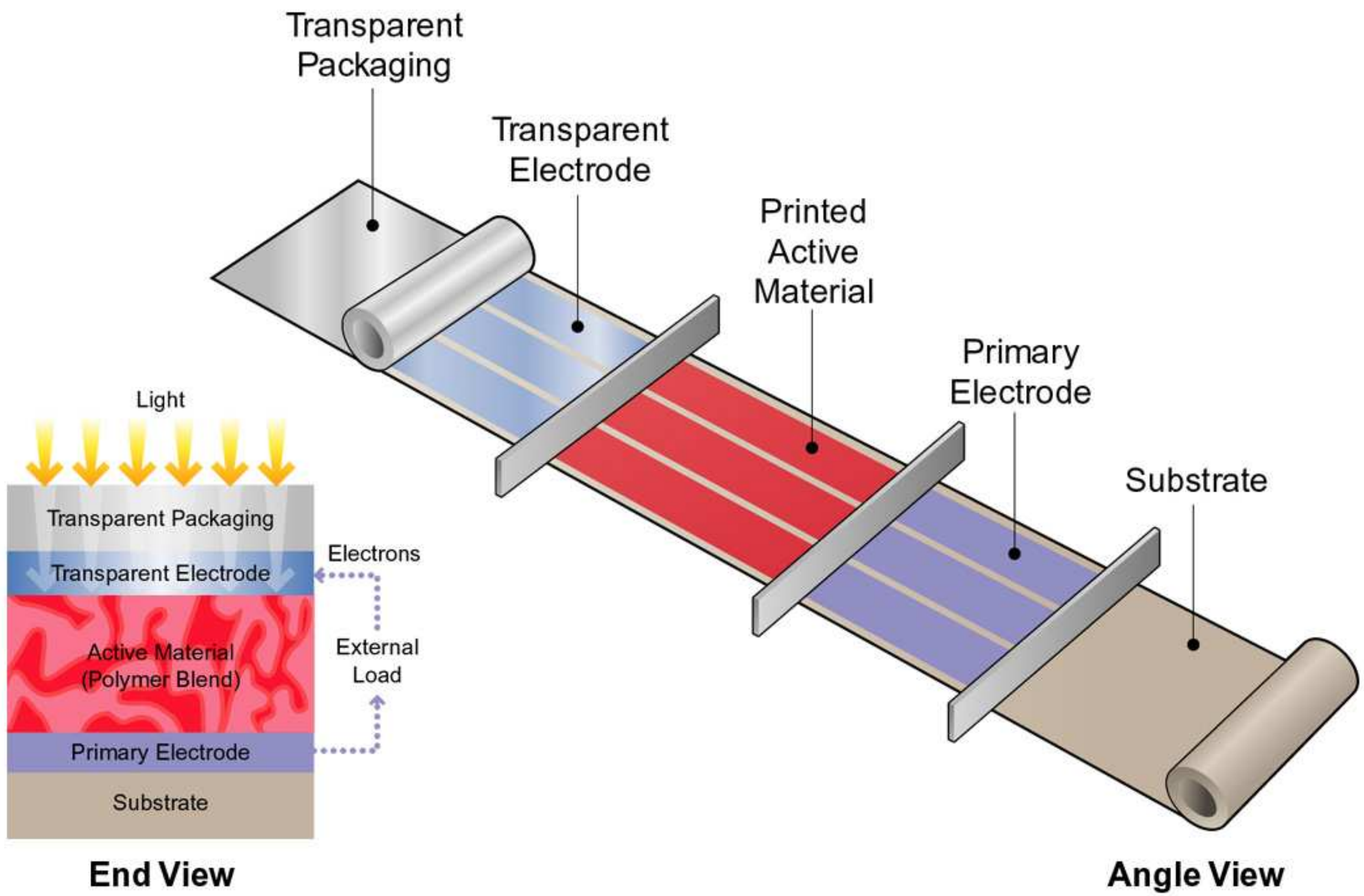
Schilinsky et al, JAP, 2004
Waldauf et al, JAP, 2006

Bulk-heterojunction cells - production



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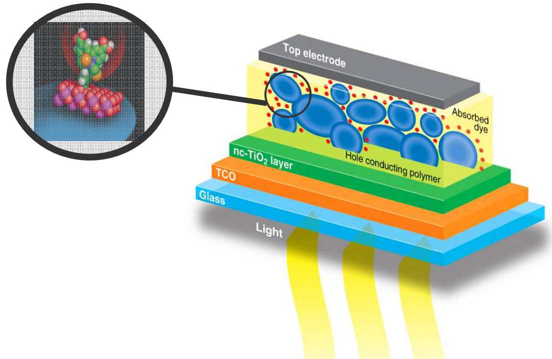
Bulk Heterojunction Composites

- Proven R2R production
- NREL certified at 11 %

DSSC

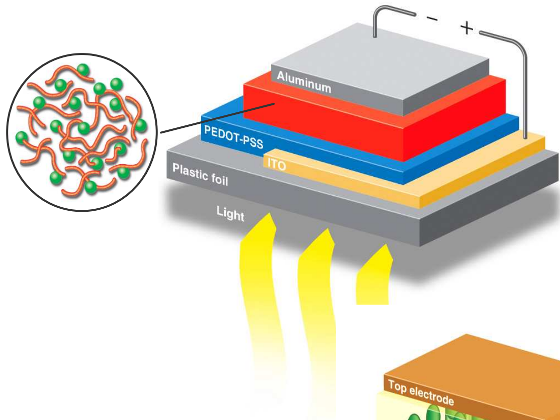
Hybrid template, liquid BHJ



- Proven R2R production
- NREL certified at 6 %

OPV

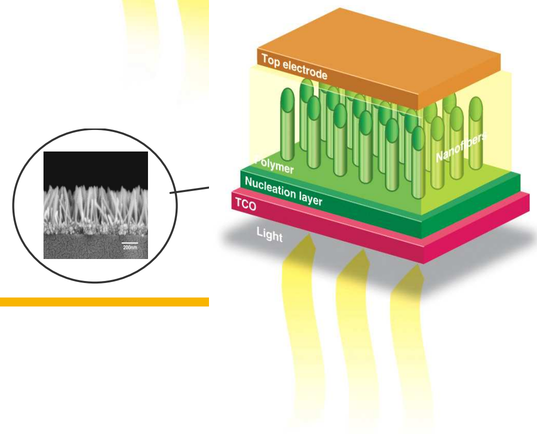
Organic, solid BHJ



- No production efforts
Uncertified with 4.5 %

Hybrid SC

Hybrid template, solid BHJ



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Efficiency

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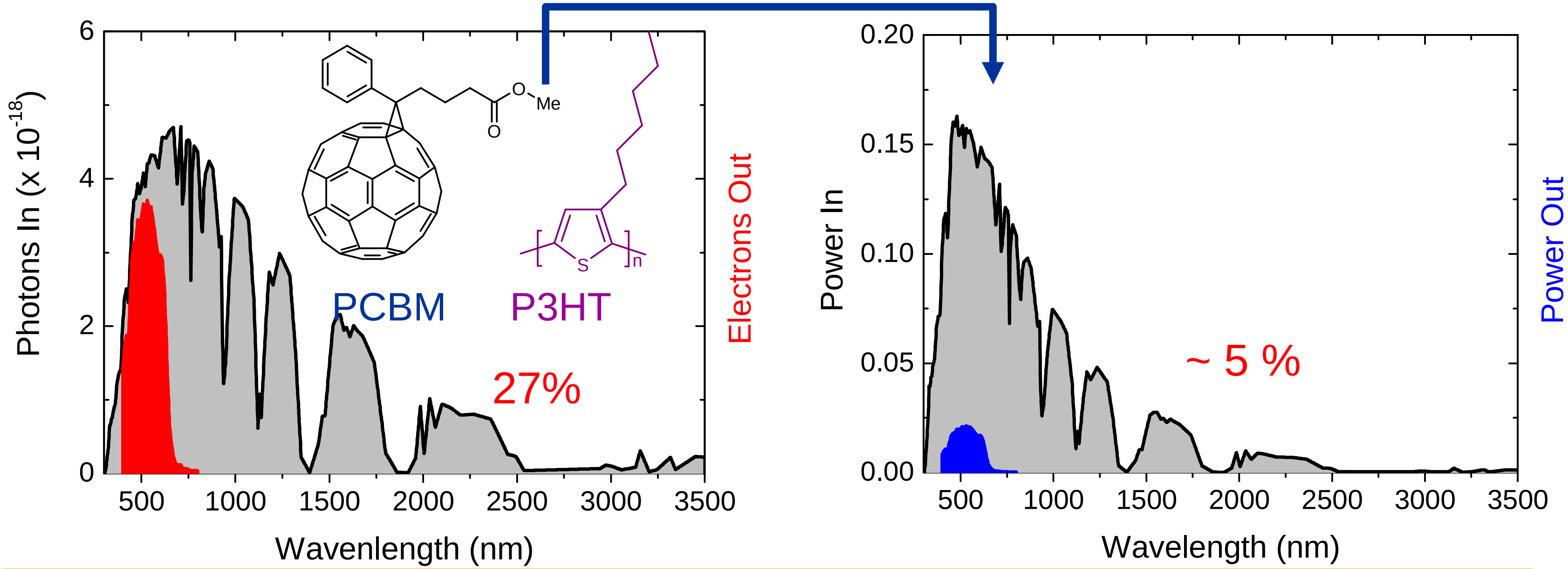
State-of-the-art P3HT:PCBM cells

Uncertified efficiencies of 5 % reported for P3HT/PC_{60}BM

- Unfavorable band gap E_G > 1.8 eV – only 27 % of suns photons absorbed
- Voc only 1/3 of bandgap – major loss in power output

FF < 0.7 V_{oc} < 0.65 V EQE ~ 70%



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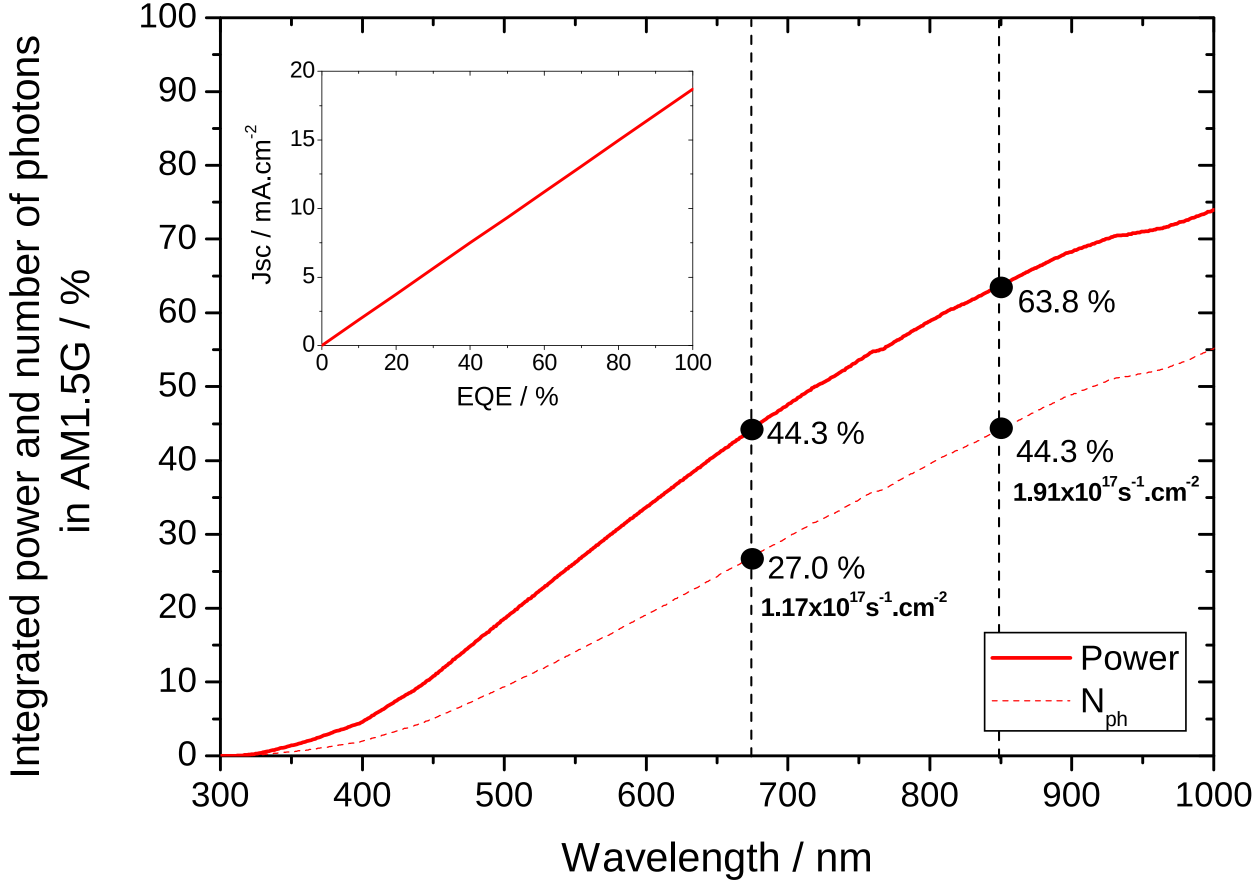
Theoretical performance of a 2 eV absorber



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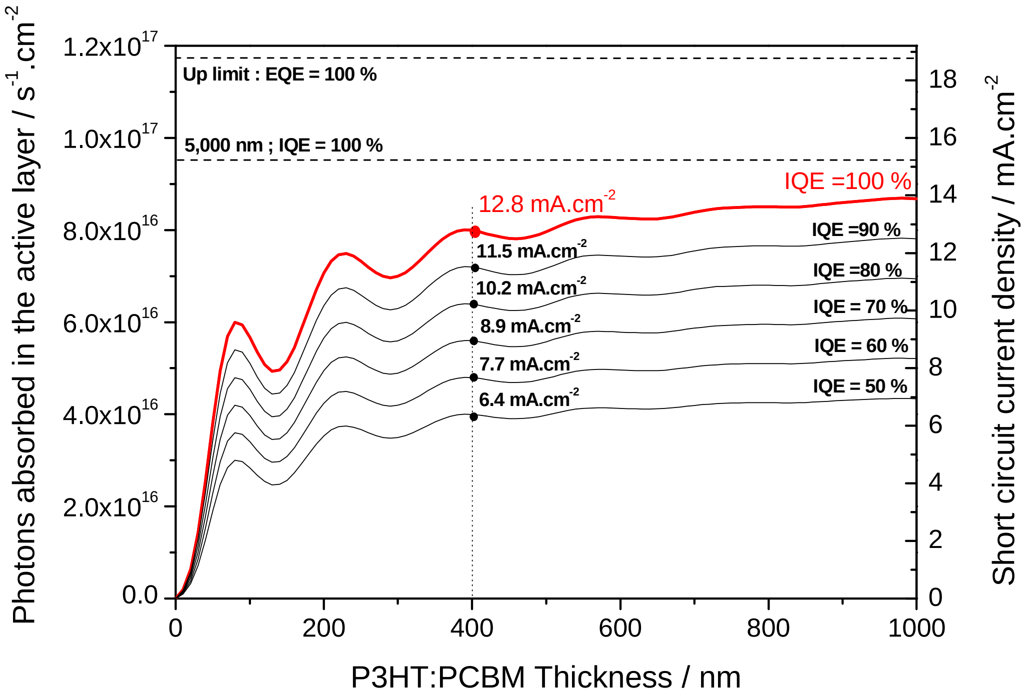
State-of-the-art P3HT:PCBM cells

Under quite comparable, though uncertified conditions (~ AM1.5, 100 mW/cm^2), multiple groups reported P3HT / PCBM efficiencies in the order of 5 %

Year	P3HT Provider	Mw (g.Mol-1)	Ratio to PCBM (weight)	Layer thickness (nm)	Solvent	Annealing time (min)	Annealing Temp. ©	Max EQE (%)	Voc (V)	FF	Jsc (mA.cm-2)	Eff (%)	Light intensity (mW.cm-2)	
2002	--	--	1:3	350	--	--	--	76	0.58	0.55	8.7	2.8	100	
2003	--	--	--	≈ 110	DCB	4	75	70	0.55	0.6	8.5	3.5	80	
2004	Rieke	--	1:2	350	CB	4	75	65	0.54	0.37	15.2	3.1	100	
2005	Rieke	100000	1:1	≈ 70	DCB	60	120	58	0.615	0.61	7.2	2.7	100	
2005	Merck	11600	1:1	--	CB	15	140	58	0.61	0.53	9.4	3.0	100	
2005	--	--	1:1	63	DCB	10	110	--	0.61	0.62	10.6	4.0	100	
2005	Rieke	--	1:1	≈ 220	DCB	10	110	63	0.61	0.67	10.6	4.4	100	
2005	Aldrich	87000	1:0.8	--	CB	5	155	--	0.65	0.54	11.1	4.9	80	
2005	Rieke	--	1:0.8	--	CB	30	150	--	0.63	0.68	9.5	5.0	80	
2006	Merck	21100	1:1	175	CB	120	140	70	0.6	0.52	12	4.4	85	
2006	--	--	1:0.8	--	CB	10	150	88	0.61	0.66	11.1	5.0	90	
2006	Rieke	--	1:1	320	DCB	10	110	82	0.56	0.48	11.2	3.0	100	

Realistic performance of a 2 eV absorber

- Absorption spectrum calculated according to Matrix formalism
- Therefore corrected for optical losses from the substrate, ITO and PEDOT



Dennler et al, *Adv Mat, submitted*

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Towards competitive efficiency

Better material combinations	50 - 100 %	- 1.5 eV bandgap gives jsc > 20 mA
Increase IQE from 70% to > 85%	10 - 30 %	- reduce recombination losses (bulk and interface)
Reduce absorption losses	10 - 20 %	- more transparent electrodes - antireflection coating - light management
Reduce thermodynamic losses	20 - 35 %	- tandem cells
Reduce e-transfer losses	20 - 30 %	- ~ 0.3 eV are lost to guarantee a high yield charge transfer process

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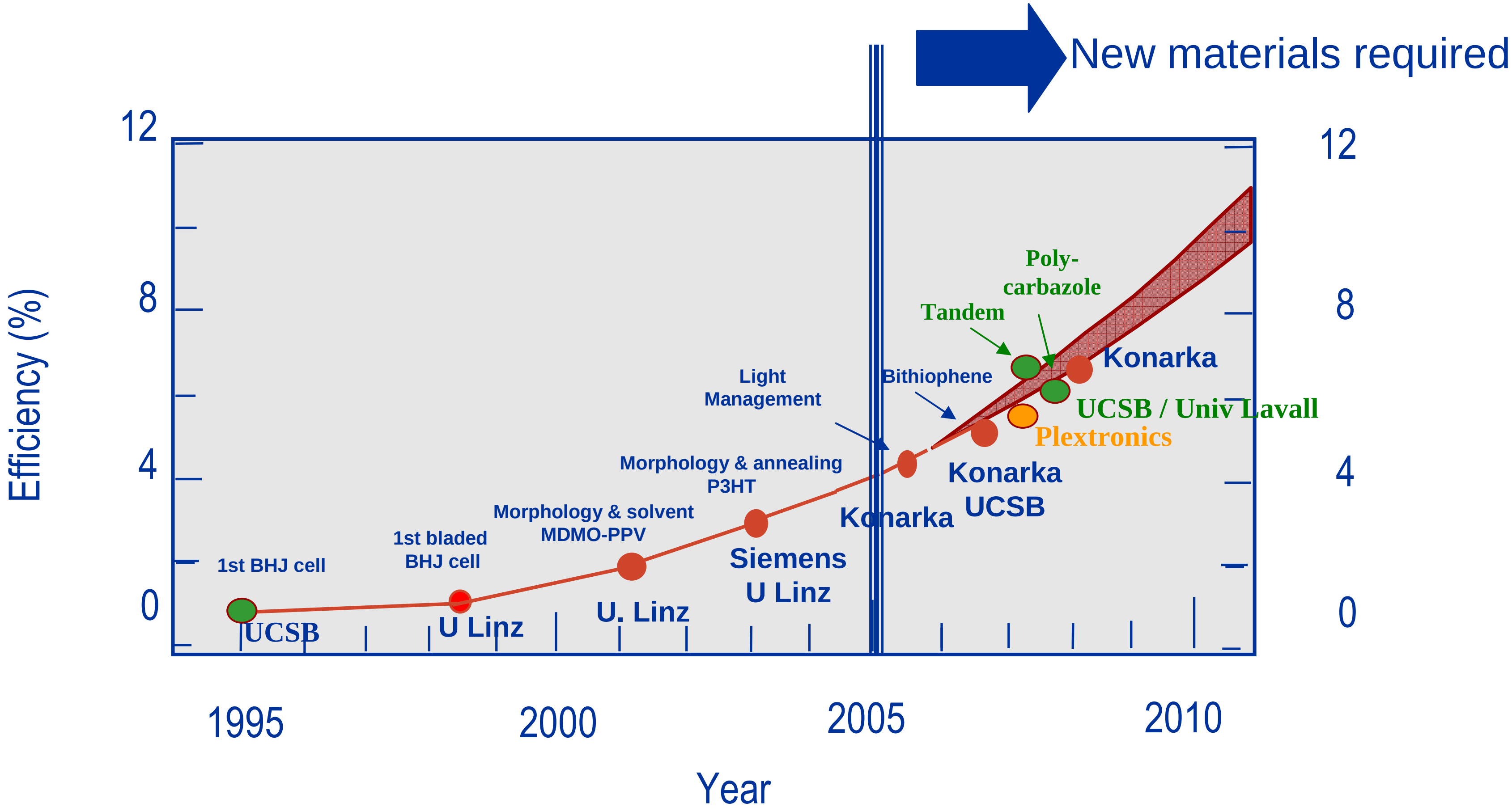
Efficiency Roadmap



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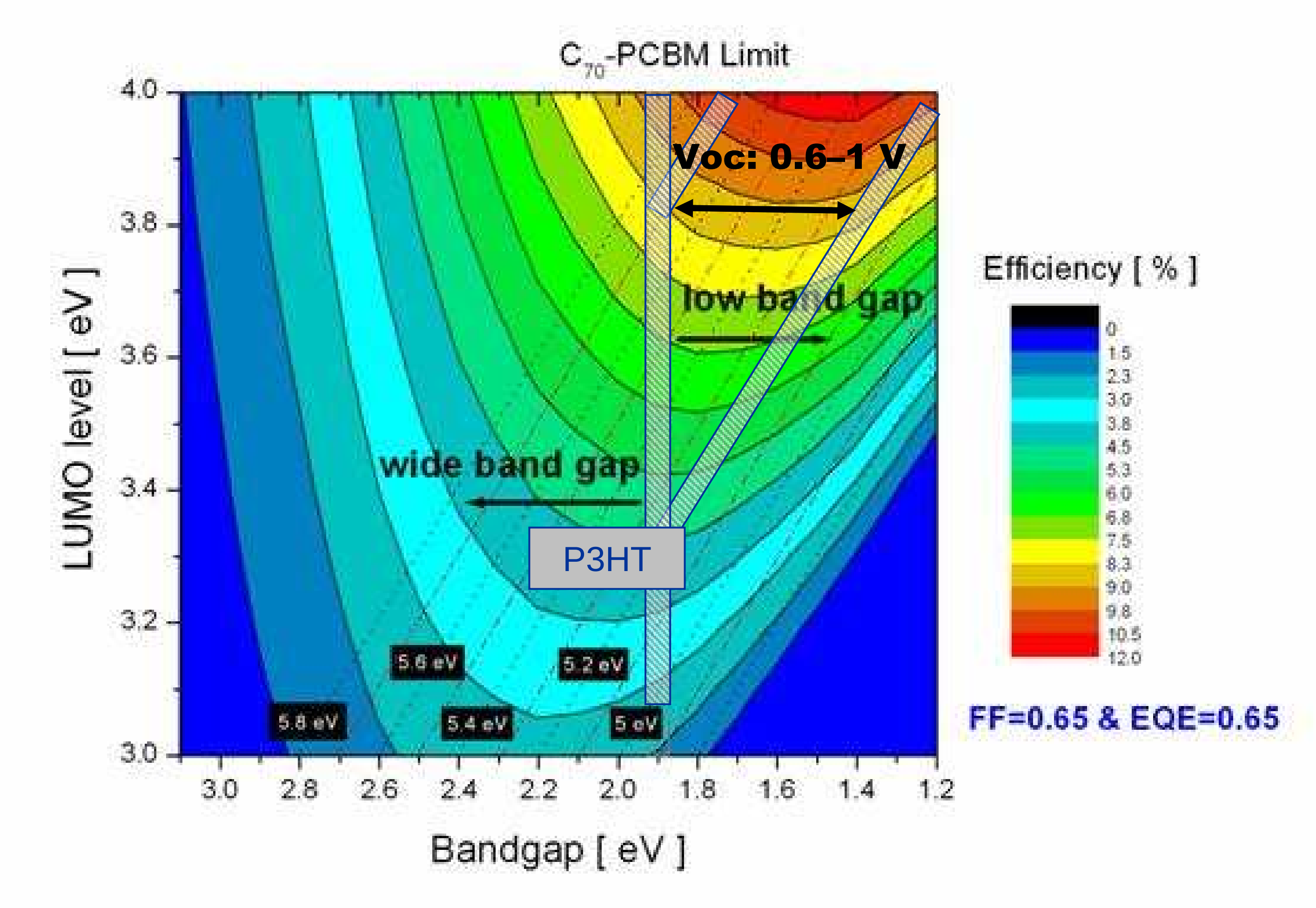
Material requirements for high performance

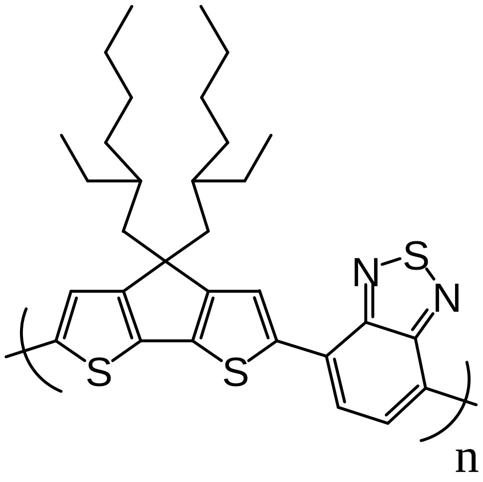
High LUMO
==
High Voc

Low Bandgap
==
High Jsc



Scharber et al, *Adv Mat, 2006*

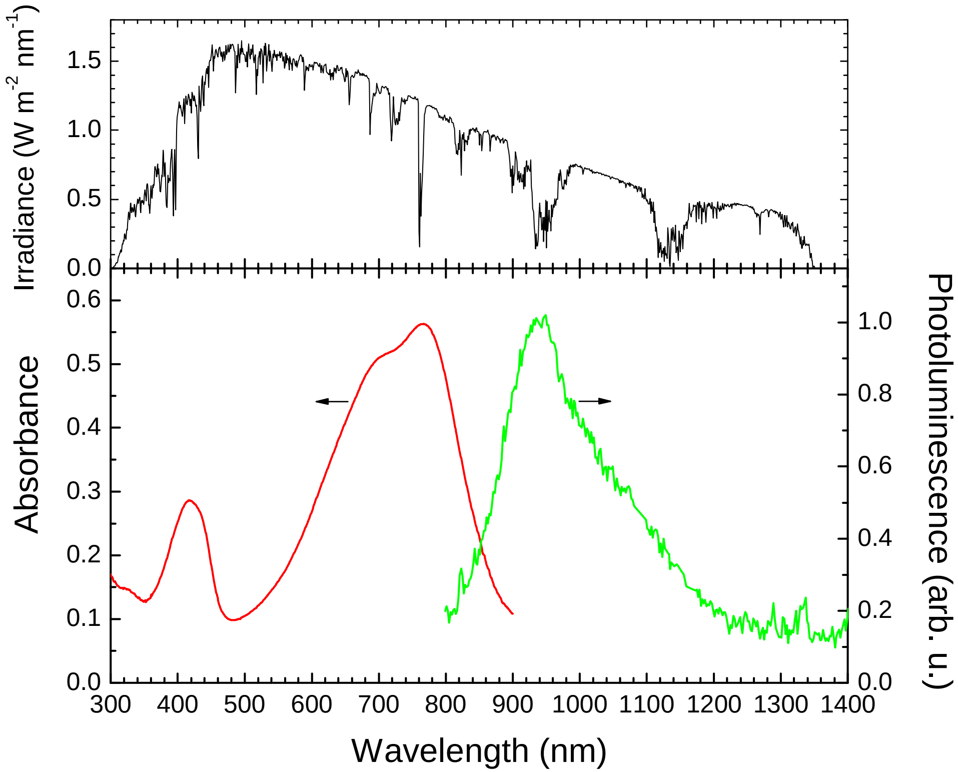
PCPDT-X, a new class of low-bandgap polymers



PCPDTBT

Poly(cyclopentadithiophene-*alt*-benzothiadiazole)

Eg=1.46 eV



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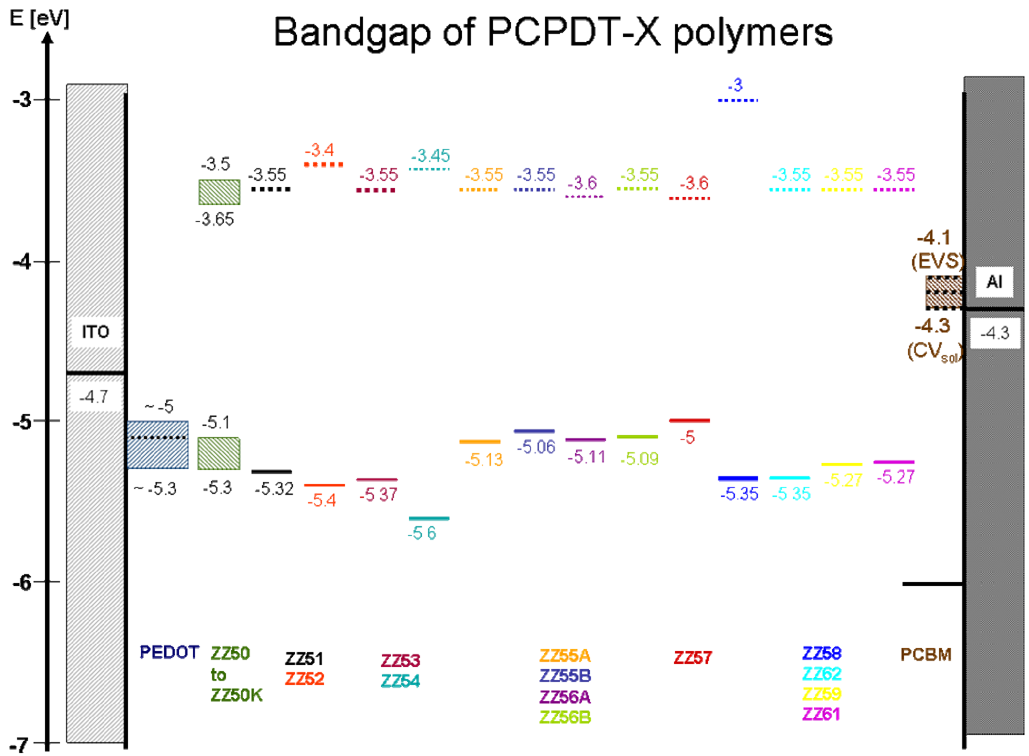
Mühlbacher et al, *Adv Mat, 2006*

Lot´s of modifications

PCPDT-X class offers broad tuning opportunities of the bandgap, absorption strength as well as of the HOMO / LUMO level position



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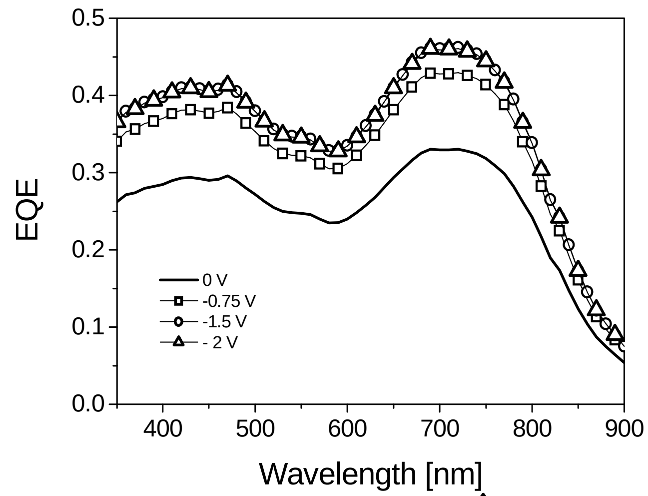
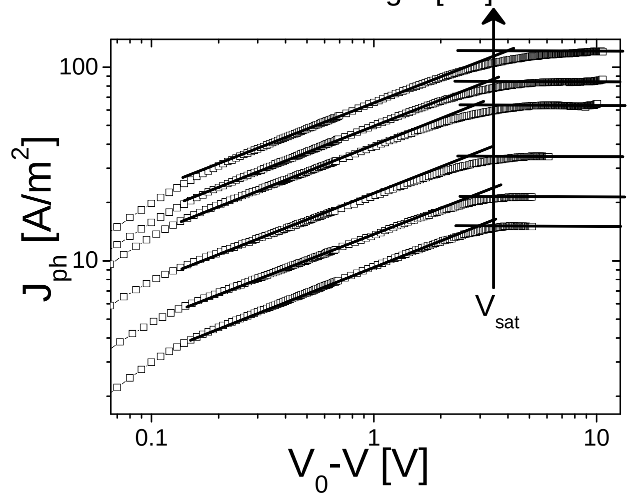
Performance of PCPDTBT

- PCPDTBT has a serious loss mechanism
  - the polaron pair lifetime is in the order of 10-7 seconds, i.e., orders in magnitude lower than for other polymers

- This leads to
  - Reduced charge carrier concentration
  - Reduced FF

- UNFAVORABLE, TOO INTIMATE MORPHOLOGY!





Blom et al, AFM, in print

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Morphology control with alkane-additives

Different additives cause different domain sizes in phase separation.

Large phase separation and no bi-continuous networks observed for chloro, cyano and acetate alkanes

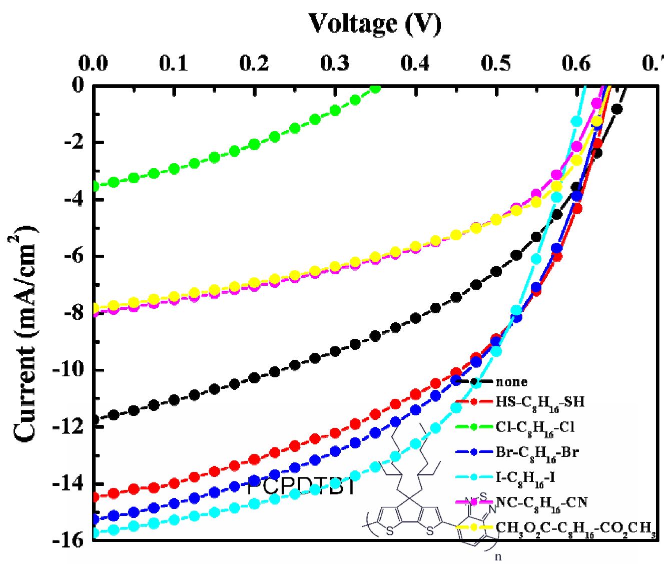
bad

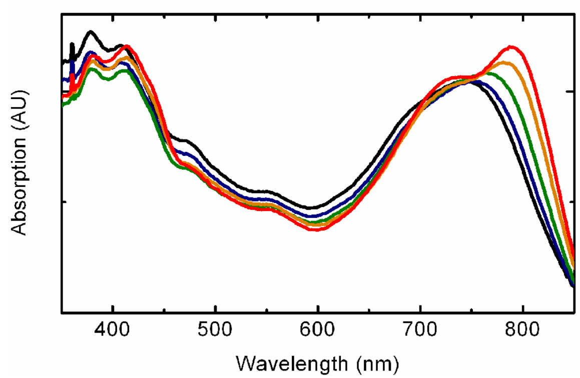
1,8-dicholorooctane (green)
1,8-dicyanooctane (magenta)
1,8-octanediacetate (yellow)

none (black)

1,8-octanedithiol (red)
1,8-dibromooctane (blue)
1,8-diiodooctane (cyan)

good





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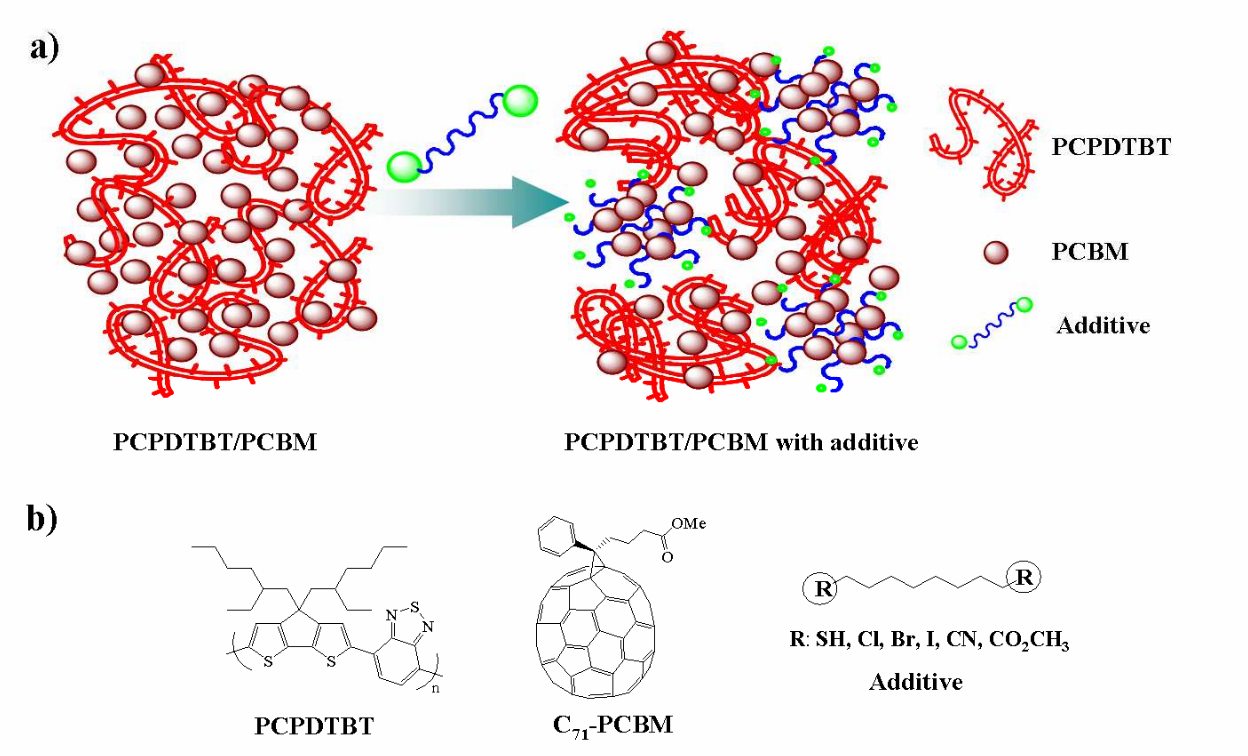
J. K Lee et al, JACS, 2008

The effect of processing additives

Mechanism:

(i) Selective (differential) solubility of the fullerene component

(ii) Higher boiling point than the host solvent.



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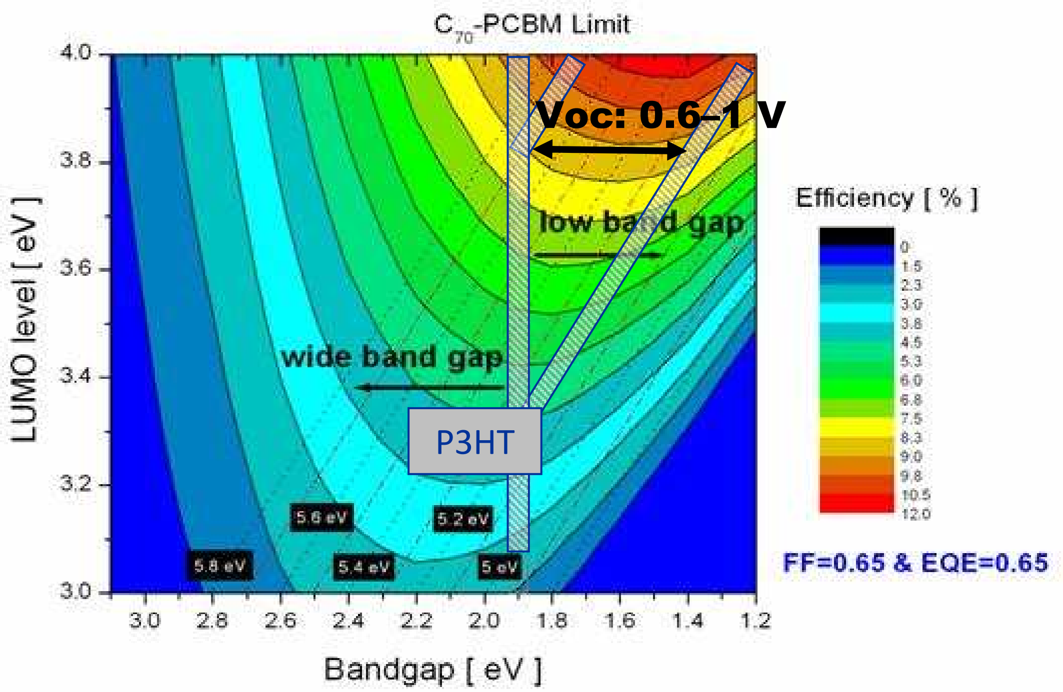
J. K Lee et al, JACS, 2008

Material requirements for high performance

- **Bridged bithiophenes have fantastic low bandgap.**
- **However, the high lying HOMO results in rather low open circuit voltages of 600 mV**
- **A Voc of 800 mV and more is required for efficiencies of 10 %**



Scharber et al, *Adv Mat, 2006*

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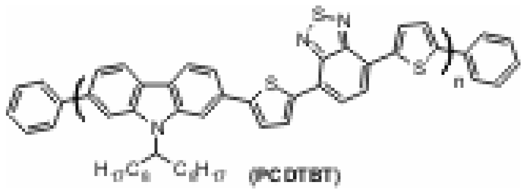
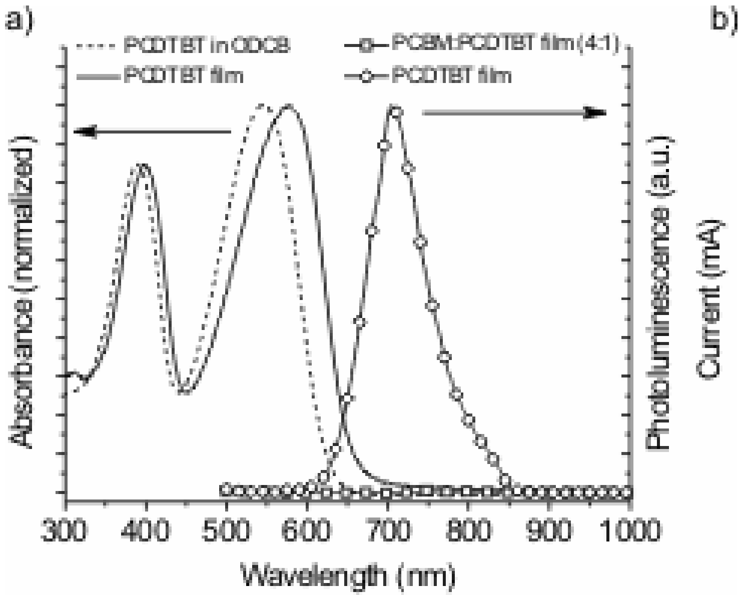
Polycarbazoles – a high Voc material class

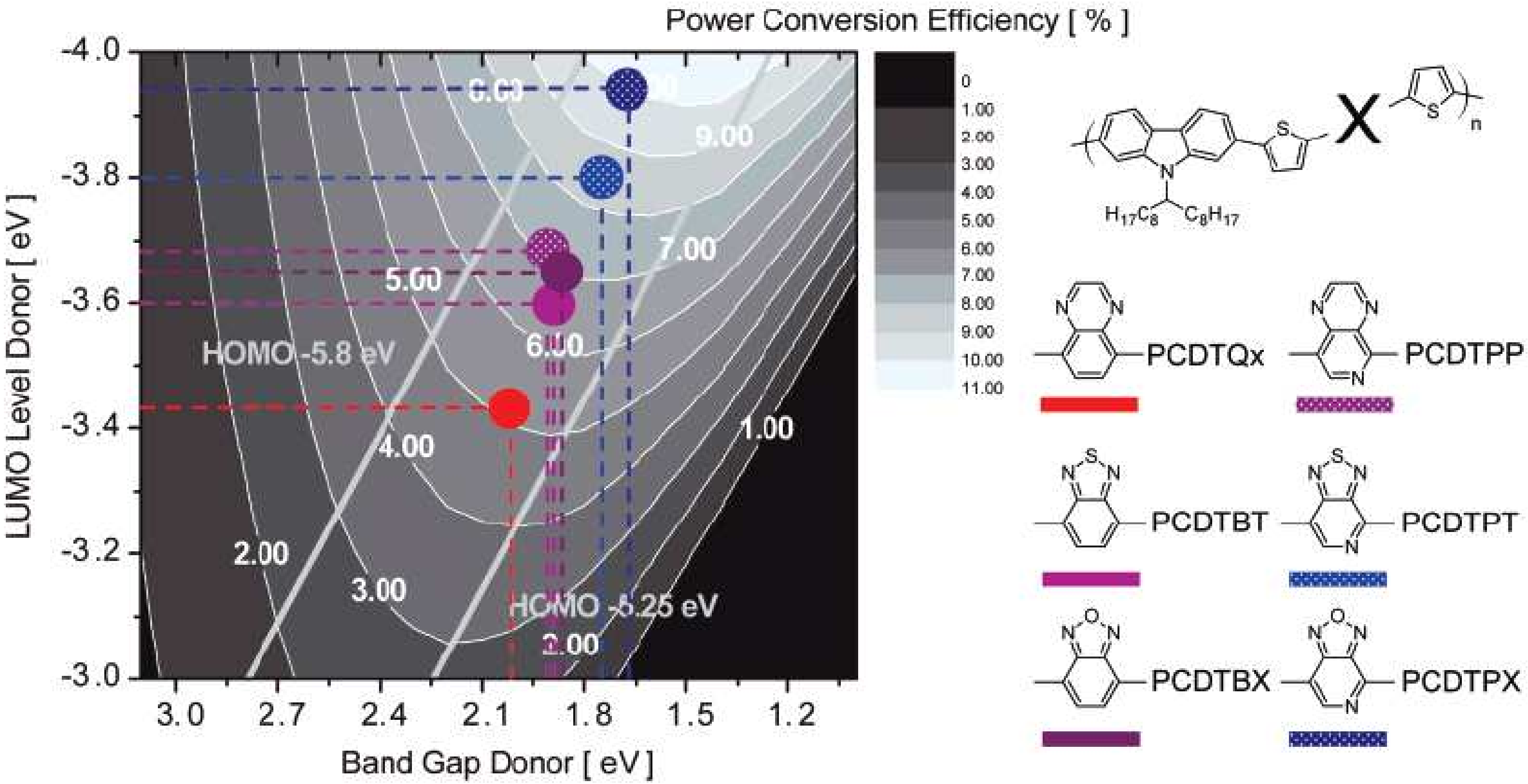


- **Poly (2,7 Carbazole) derivatives are very comparable to the class of polyfluorenes**
- **HOMO, mobility, absorption strength is similar to the PFs**
- **Choosing the right acceptor for the D-A couple determines the bandgap**



N. Blouin et al., *JACS* **130**, 732 (2008).

Polycarbazoles – potential for 10 %



N. Blouin et al., *JACS* **130**, 732 (2008).

Material requirements for high performance

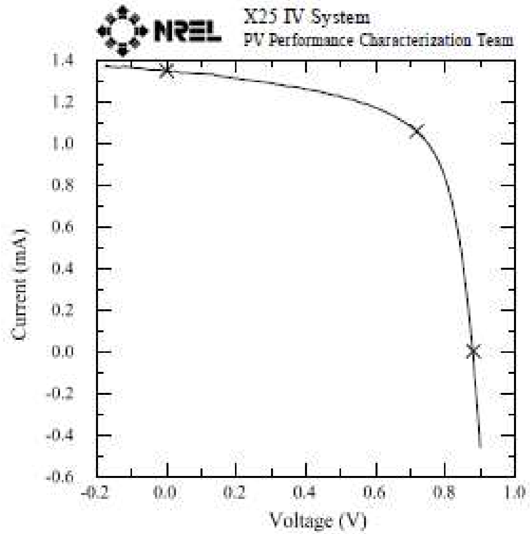
Polycarbazoles hit the 6 % level recently last year

- **Voc up to 1 V**
- **Good FF (65 %)**
- **Good EQE (60 – 65 %)**

page 4

UCSB
organic Cell

Device ID: P703 pixel 2	Device Temperature: 25.0 ± 1.0 °C
Oct 16, 2008 01:28	Device Area: 0.1270 cm^2
Spectrum: ASTM G173 global	Irradiance: 1000.0 W/m^2



V_{oc} = 0.8800 V	I_{max} = 1.0560 mA
I_{sc} = 1.3453 mA	V_{max} = 0.7173 V
J_{sc} = 10.593 mA/cm^2	P_{max} = 0.75748 mW
Fill Factor = 63.98 %	Efficiency = 5.96 %

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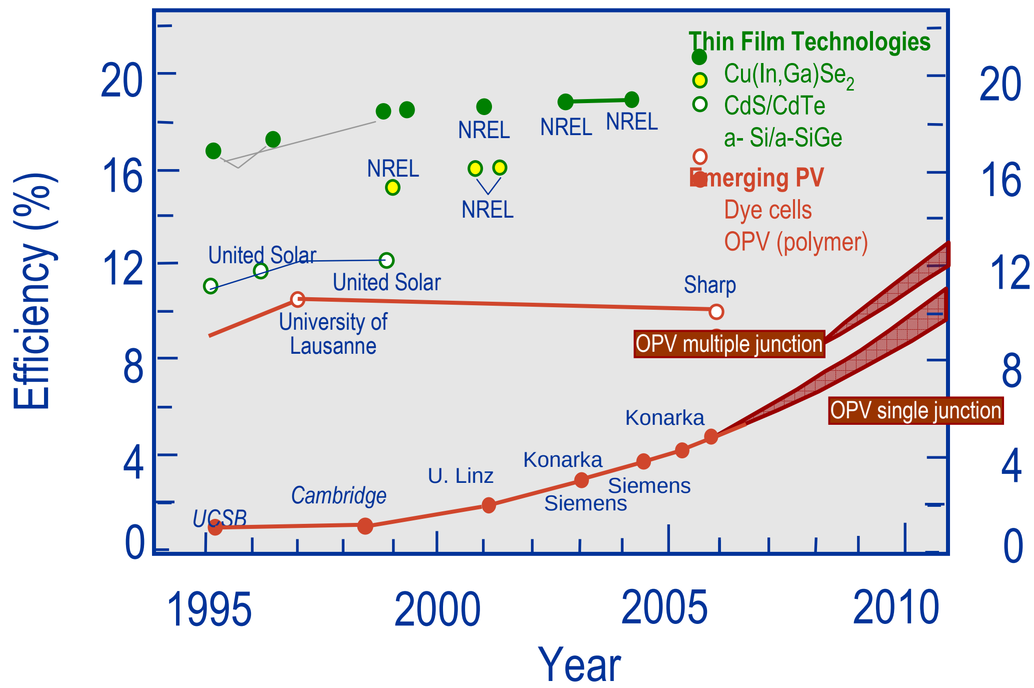
Heeger et al (UCSB) and Leclerc et al (Univ. Lavall)

Summary Efficiency Roadmap

- Single junction materials will go beyond 10% within few years.

- Multiple junction concepts will drive efficiency from 2010.

- No fundamental obstacles till 20%.



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Production aspects & challenges

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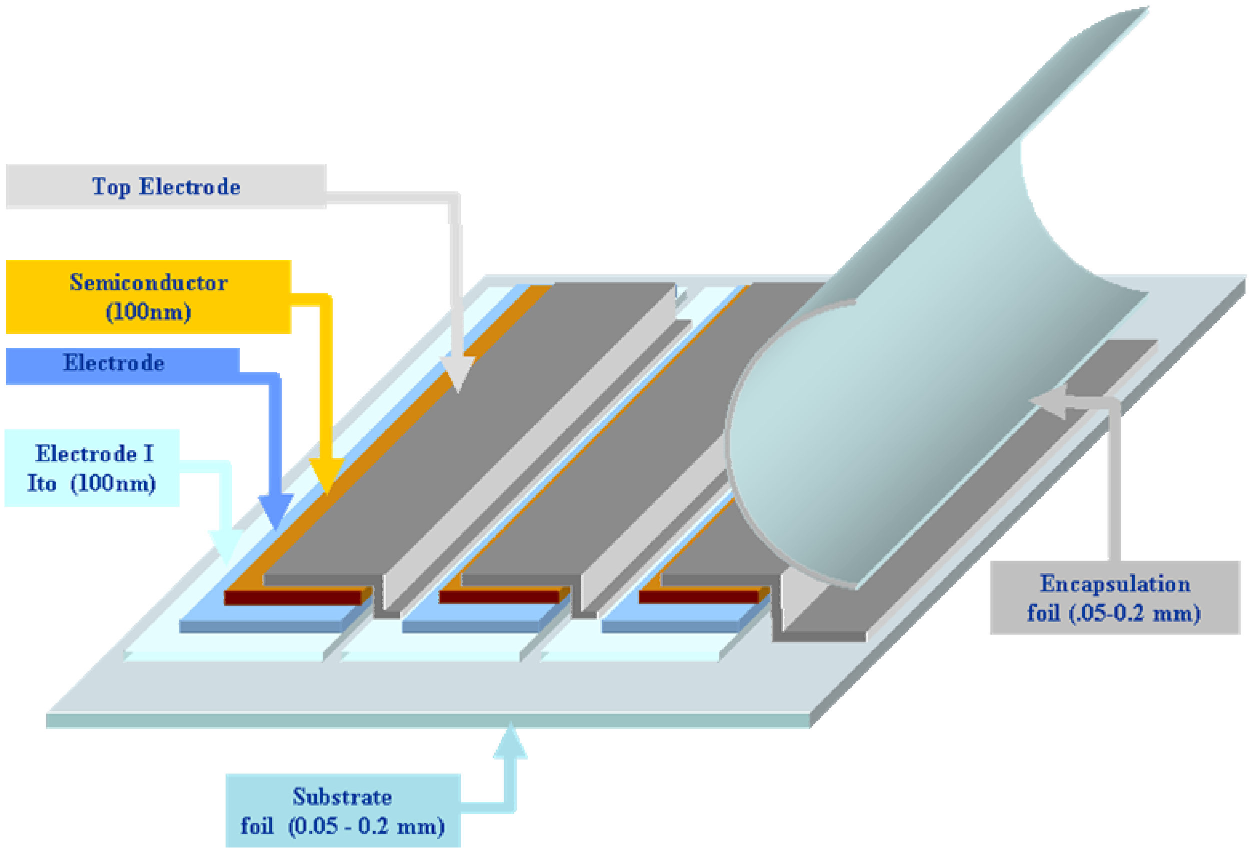
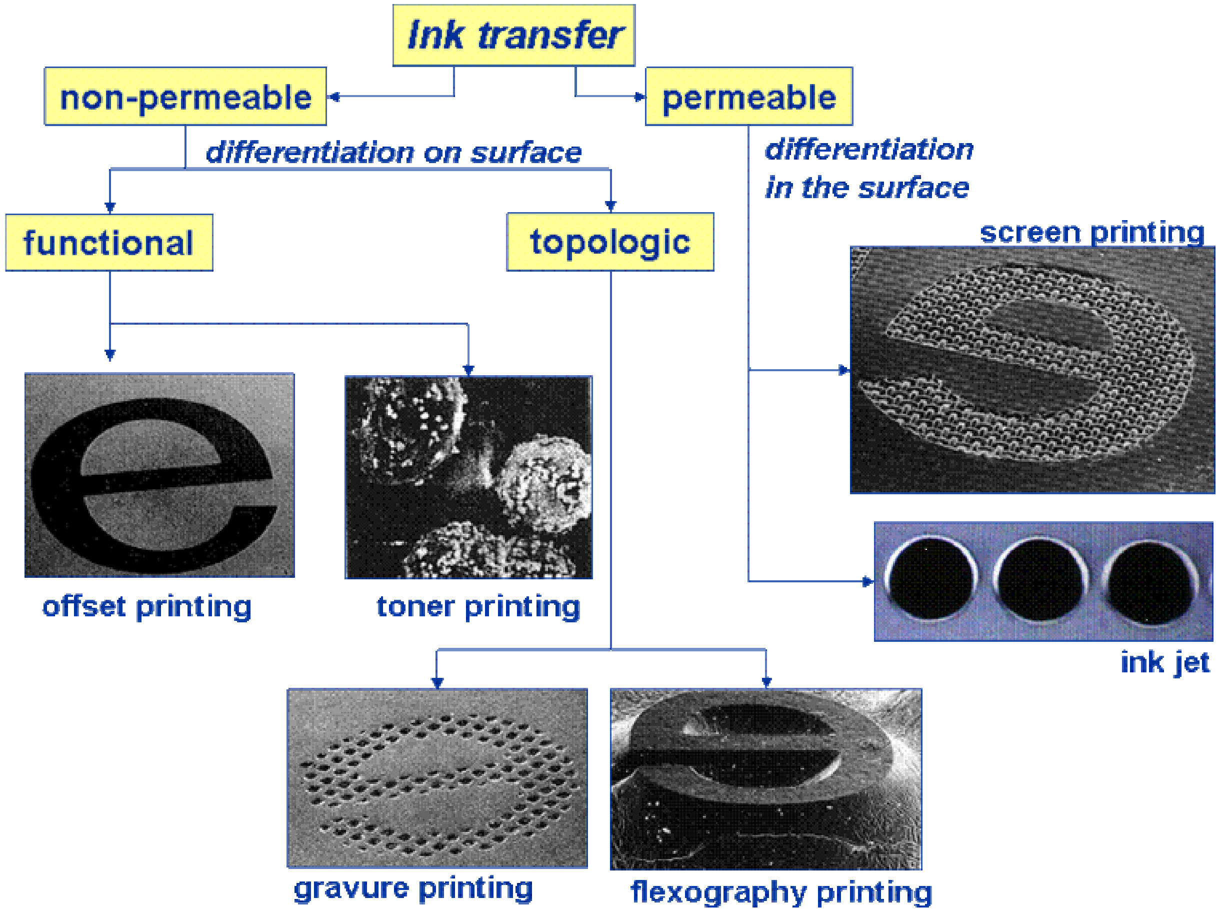
How to print an organic PV module?



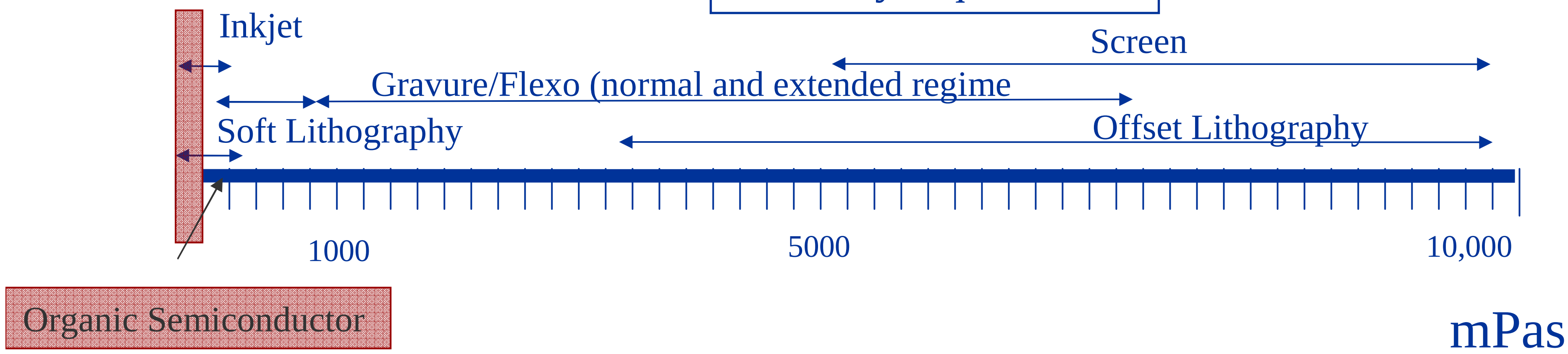
Differentiation of Image Formation by Printing



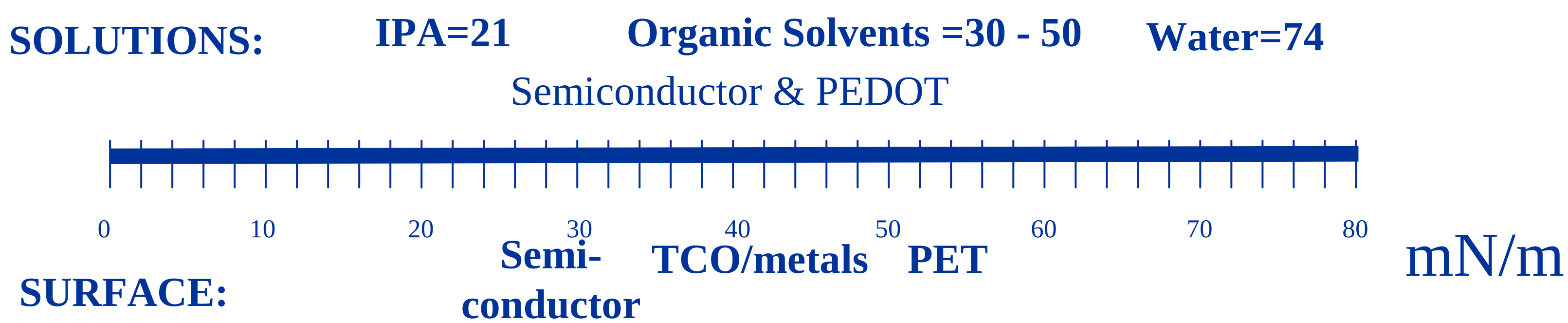
Source: *A. Huebler, Print u Medientechnik, Univ. Chemnitz*

Importance of viscosity and surface tension in multiple layer coatings

Viscosity requirements



Surface tensions



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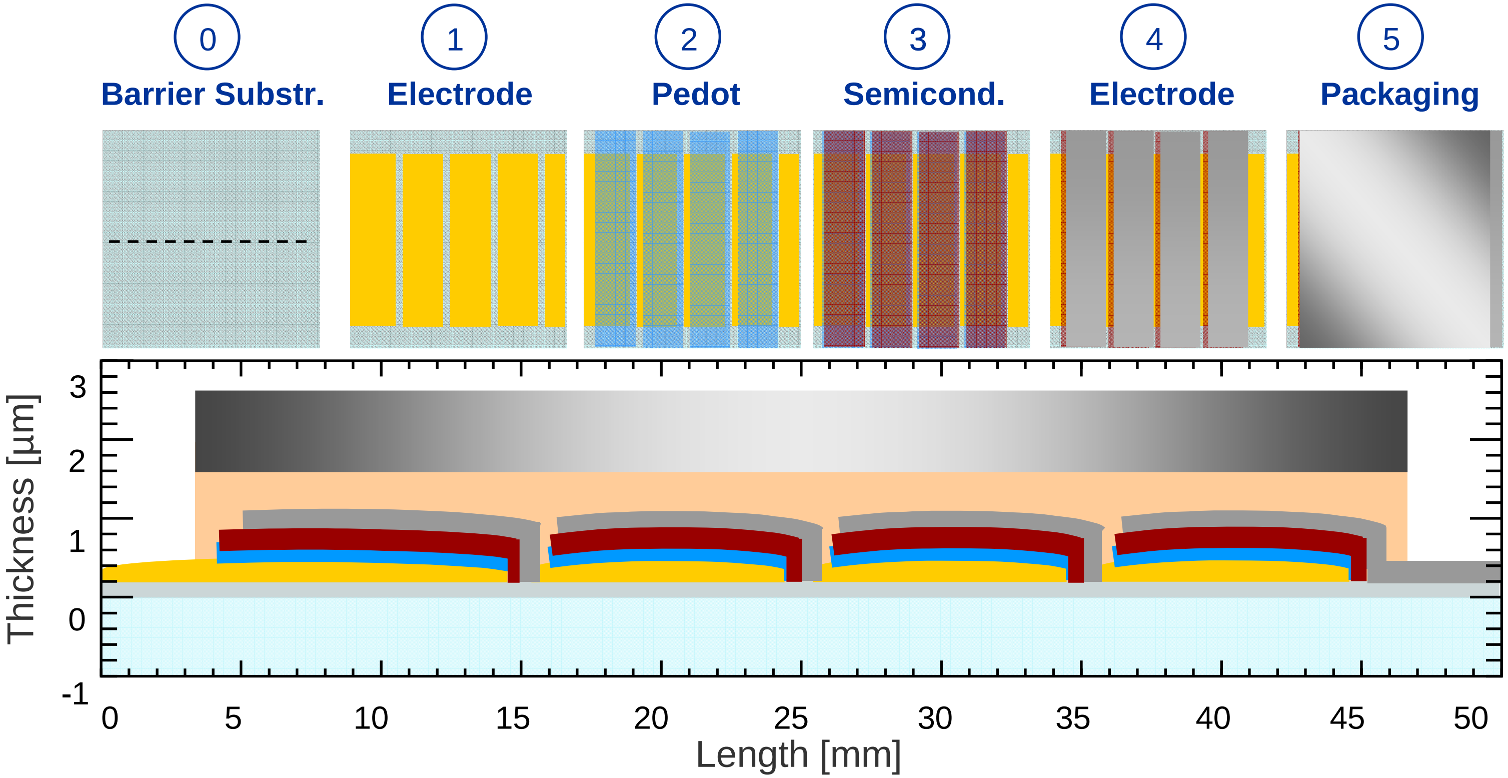
Module stack



Layer Thickness

- Active layer thickness is in the range of 100s nm
- High homogeneity

Resolution requirements

- Guarantee high GFF (> 90)
- Desired in the 100s µm

Registration

- Must prevent shunting
- High GFF – 100 microns req.

Lifetime of flexible solar cells

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Lifetime: Accelerated Aging Testing Capabilities

Equipment	Test	Equipment
Solar Simulator	Pass 1000 hrs under 1 sun, 65 °C	
Dry Ovens	Pass 1000 hrs	
Steady –State Oven Temperature / Humidity	Pass 10… amp heat @ 65° C / 85 % rh	
Thermal Cycling Chamber Temperature / Humidity	3 hrs cycle, -40 ° C to + 80° C	
Light Soaking Chambers Temperature / Humidity / Rain Ultraviolet Light Chamber	According to IEC + IEEE + ASTM standards	 
Flex bending	> 1000 bends over 50 mm roll	

Independently verified by ECN

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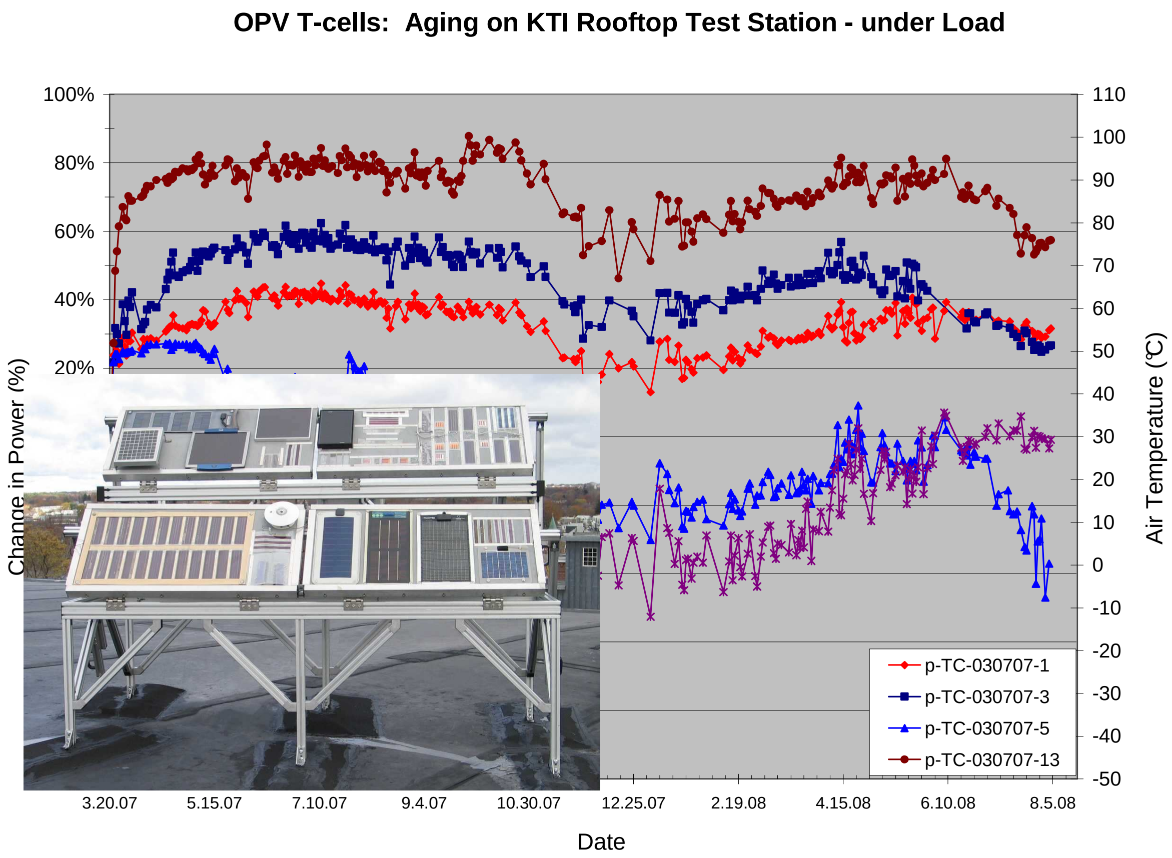
Lifetime: Outdoor degradation of OPV cells

- Roof top stability > 1.5 years and ongoing.
- Expected product lifetime 3 – 5 years.
- 5 – 10 yrs lifetime expected after 2010



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Markets, Applications & Products

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The OEA Roadmap for OPV

- Gen 1 & Gen 2 prototypes and products commercialization started in 2008 & 2009
- All R&D focus needs to be put on accelerating the time lines for Gen 3 and Gen 4 products

Product Generations:

Generation	Product description	Market	General Availability
Gen1	Small, lower efficiency, flexible PV	consumer electronic	2008
Gen2	Robust, but low efficiency PV	outdoor recreational application	2009
Gen3	Large, increased efficiency	off-grid buildings; façade	2015
Gen4	Large, high efficiency OPV	roof top grid connected (residential)	2020

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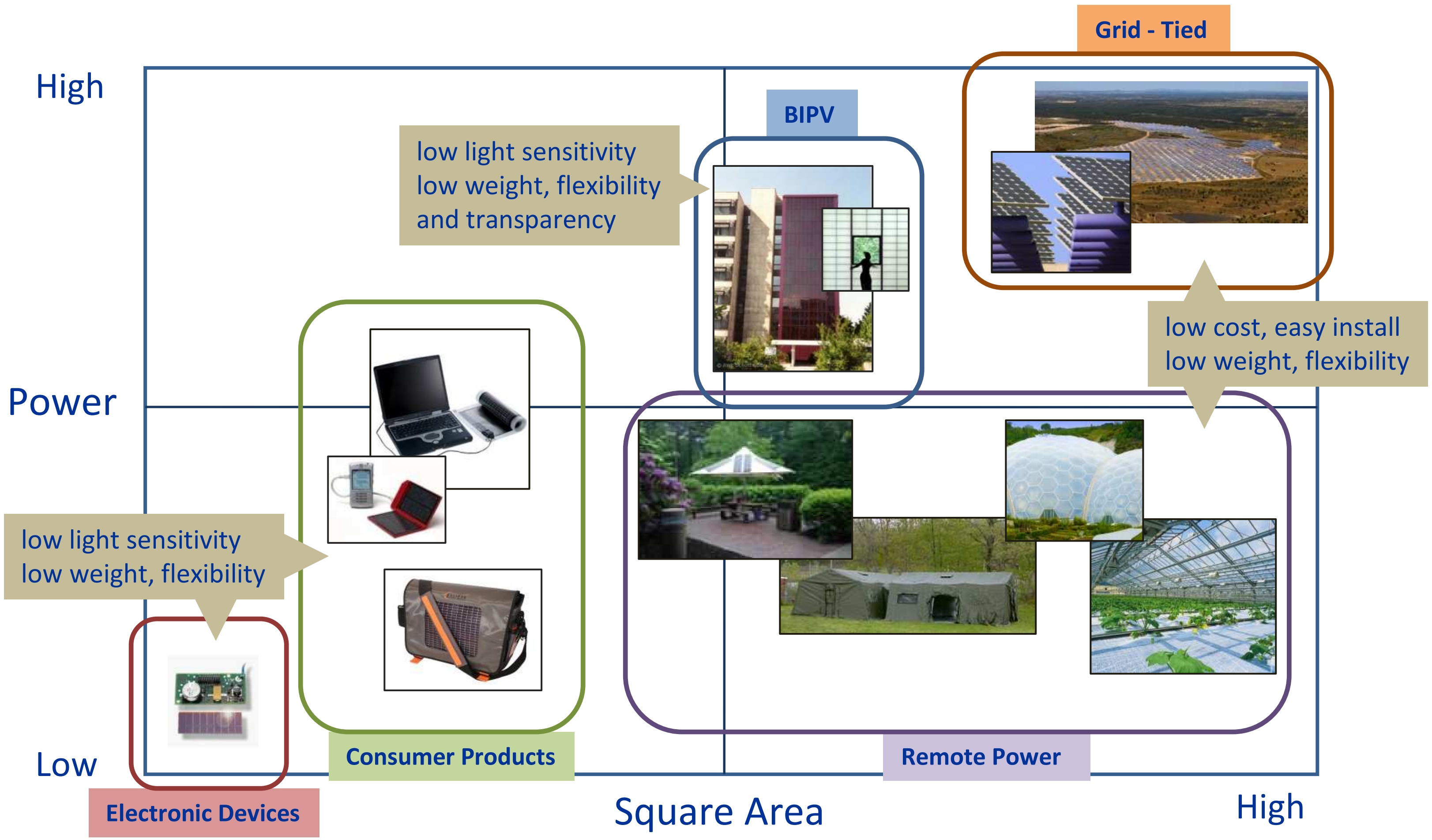
Power Plastic® Market Opportunities



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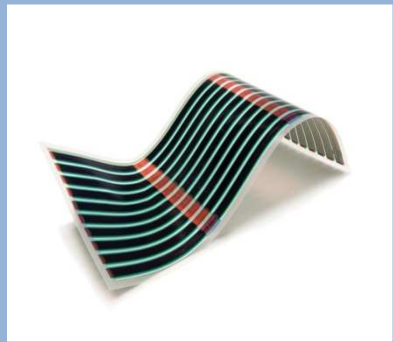
Summary - Solar Cell Advantages

Cost

$\$50/m^2$ BOM achievable
Translates to \$1 watt @ 5% eff.

Lifetime

3 to 5 years - plastic encapsulate



Power to Weight

85 mW / gram

Form Factor

2 inch diameter roll flexibility
Transparent metal grids possible
Color variability (red, green, blue)

Efficiency

Good performance in low light
> 6 % NREL certification

Environmental

Organic, no toxic heavy metals
Recyclable including silver ink
Low energy manufacturing process

KONARKA®