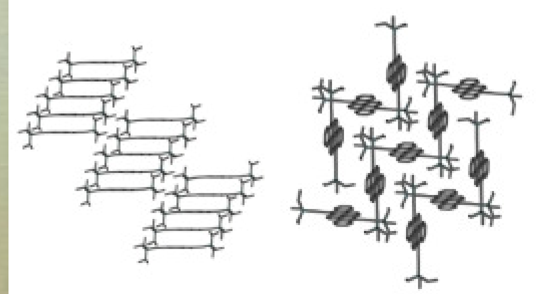
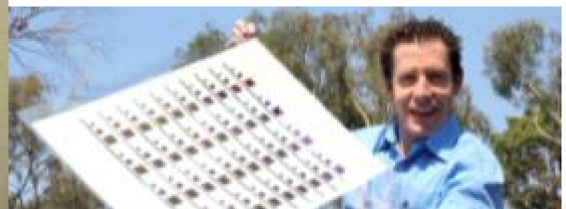




www.csiro.au

Printed Photovoltaics

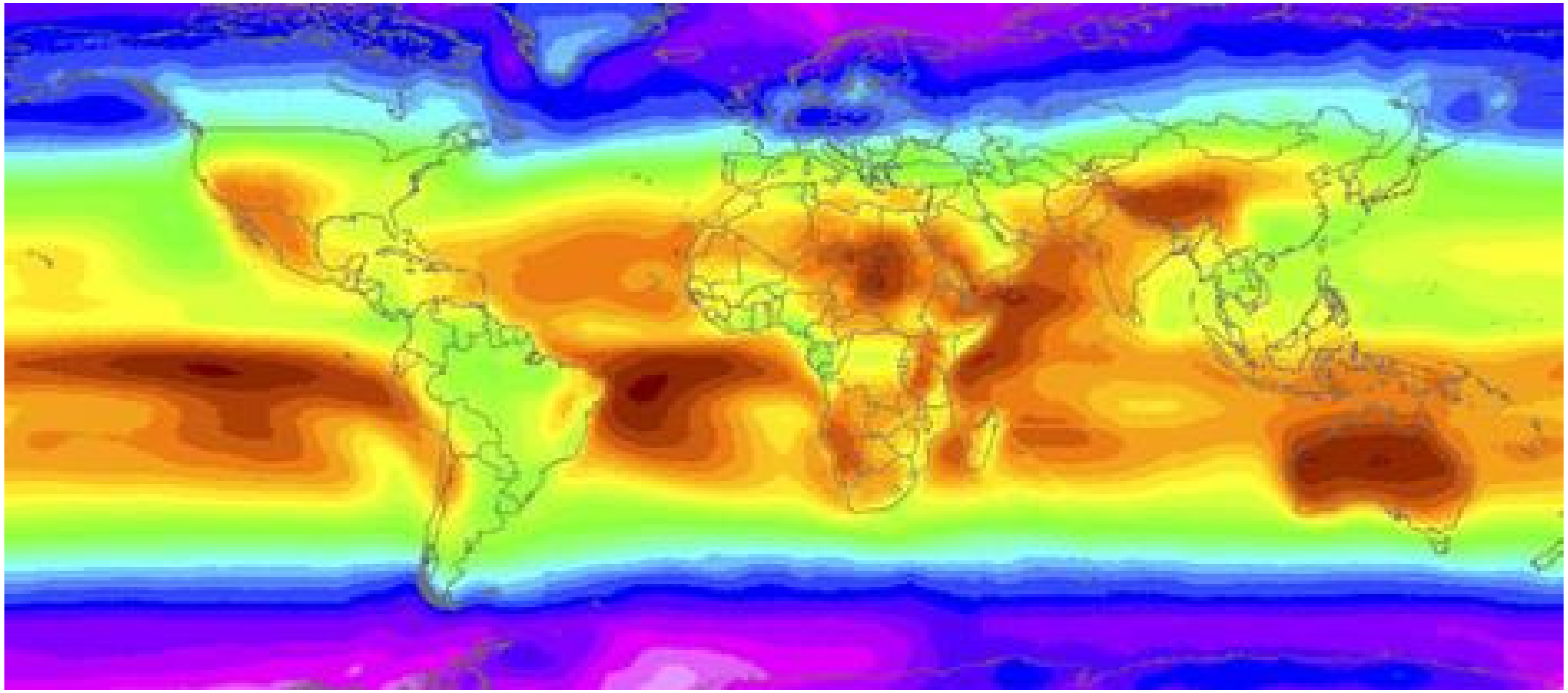
Scott Watkins, Stream Leader – Organic Photovoltaics

CSIRO Materials Science and Engineering

CSIRO Future Manufacturing Flagship

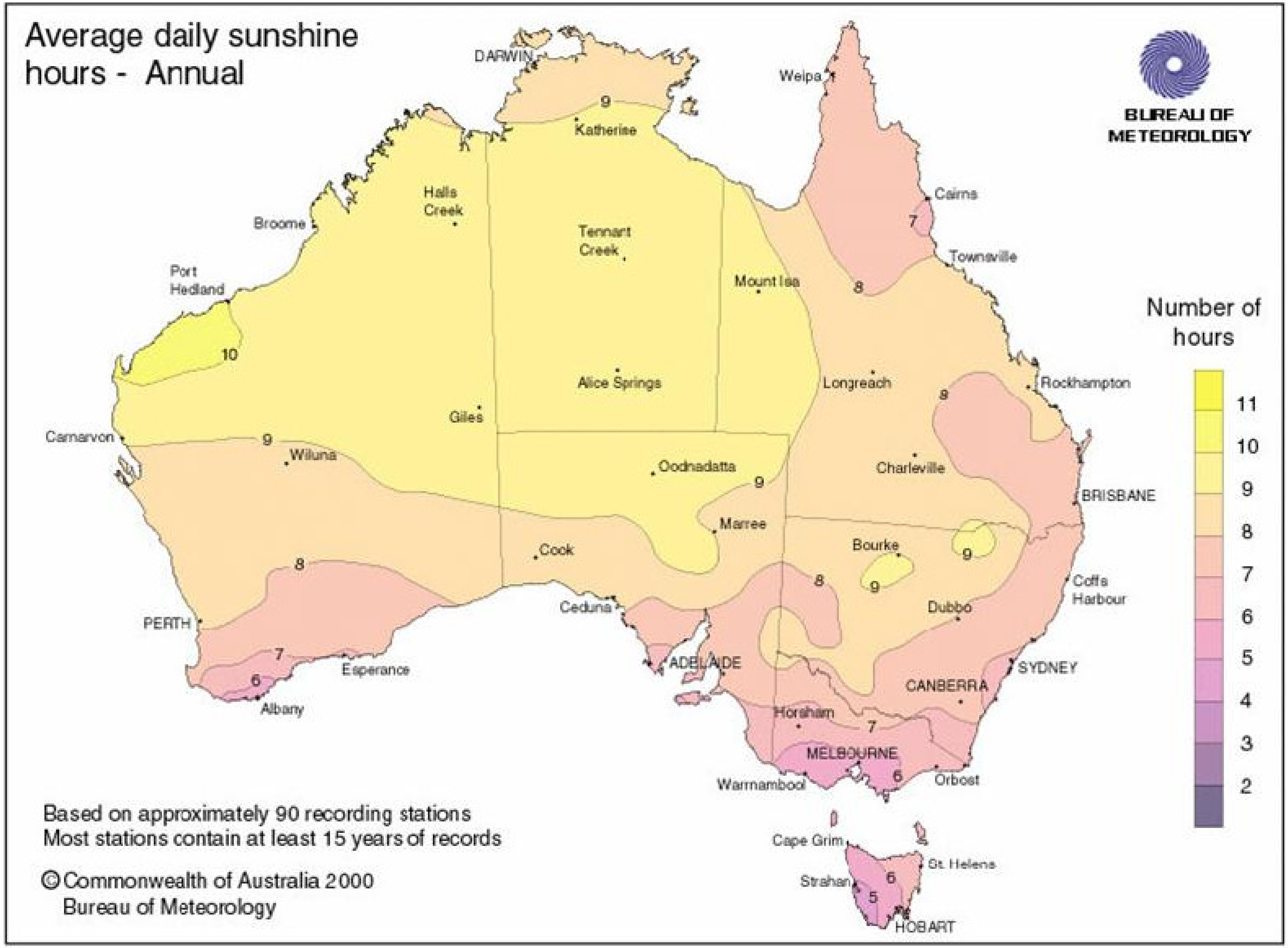
Australia

10-year-average solar insolation at ground level

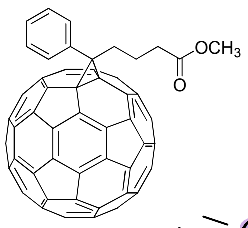


NASA (http://eosweb.larc.nasa.gov/)

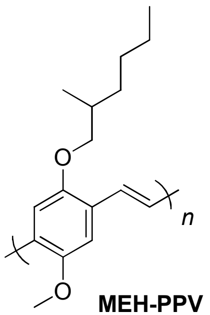
Sunshine in Australia – a natural resource



OPV devices

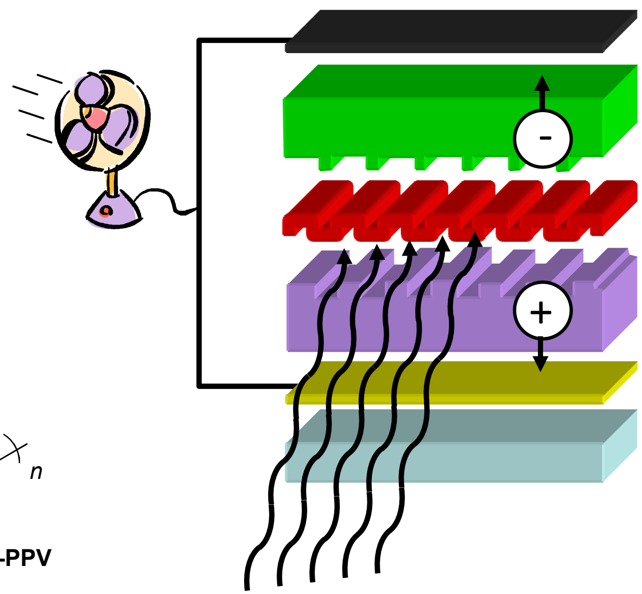


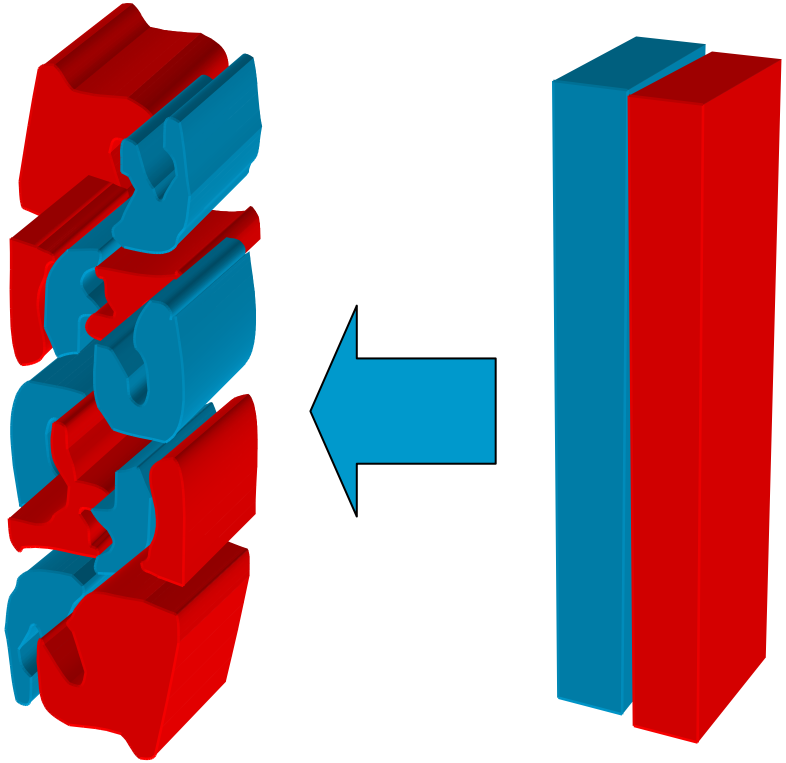
PCBM

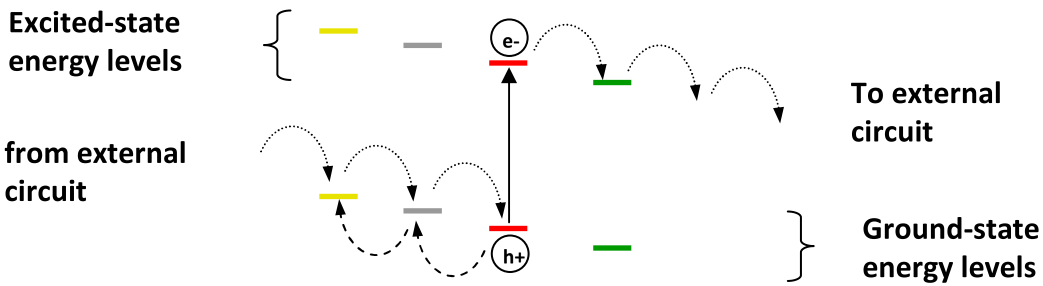


MEH-PPV

Organic Photovoltaic (OPV)

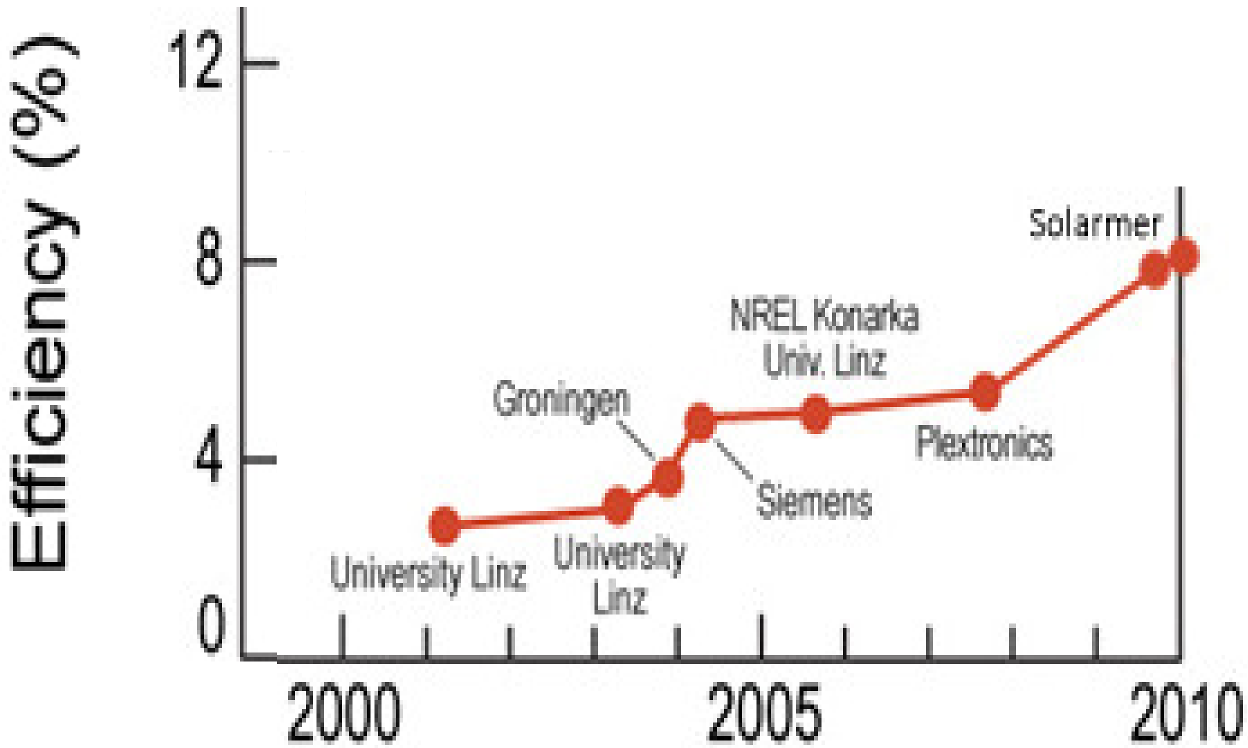






Printed Solar Cells

Organic Photovoltaics (OPVs) - Efficiencies

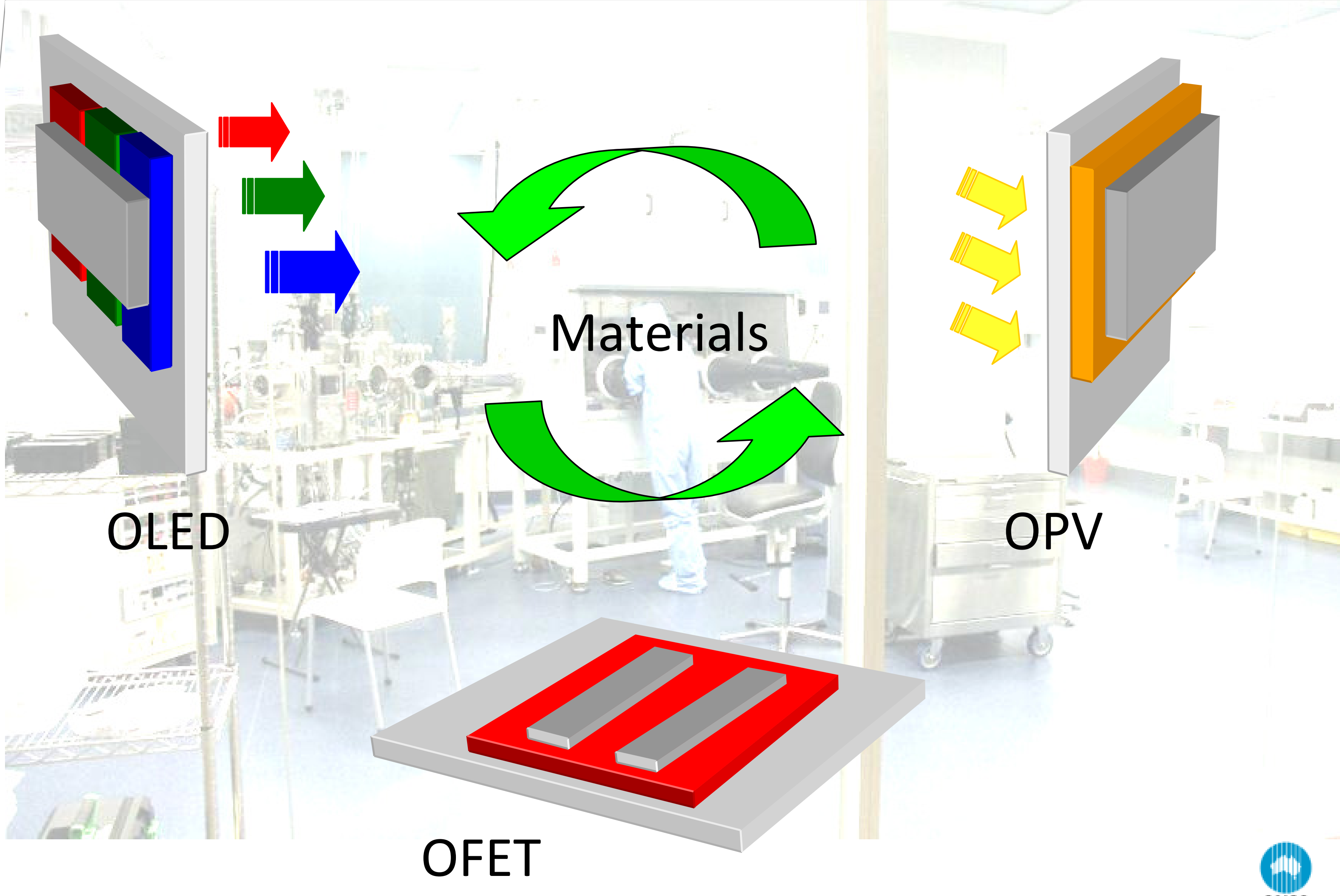


But, gap to other technologies is not as great as this suggests as excitonic solar cells are more efficient in the morning and evening.

A 1 W_p excitonic module can generate upto 25% more power over a whole day than a 1 $W_p$inorganic module

Printed Electronics at CSIRO

CSIRO: Organic Electronics



CSIRO

Acknowledgements

Chemists, Materials Scientists and Physicists from 20 different countries

Printing: Noel Clark and Jo Ramamurthy

Spray Coating: Doojin Vak

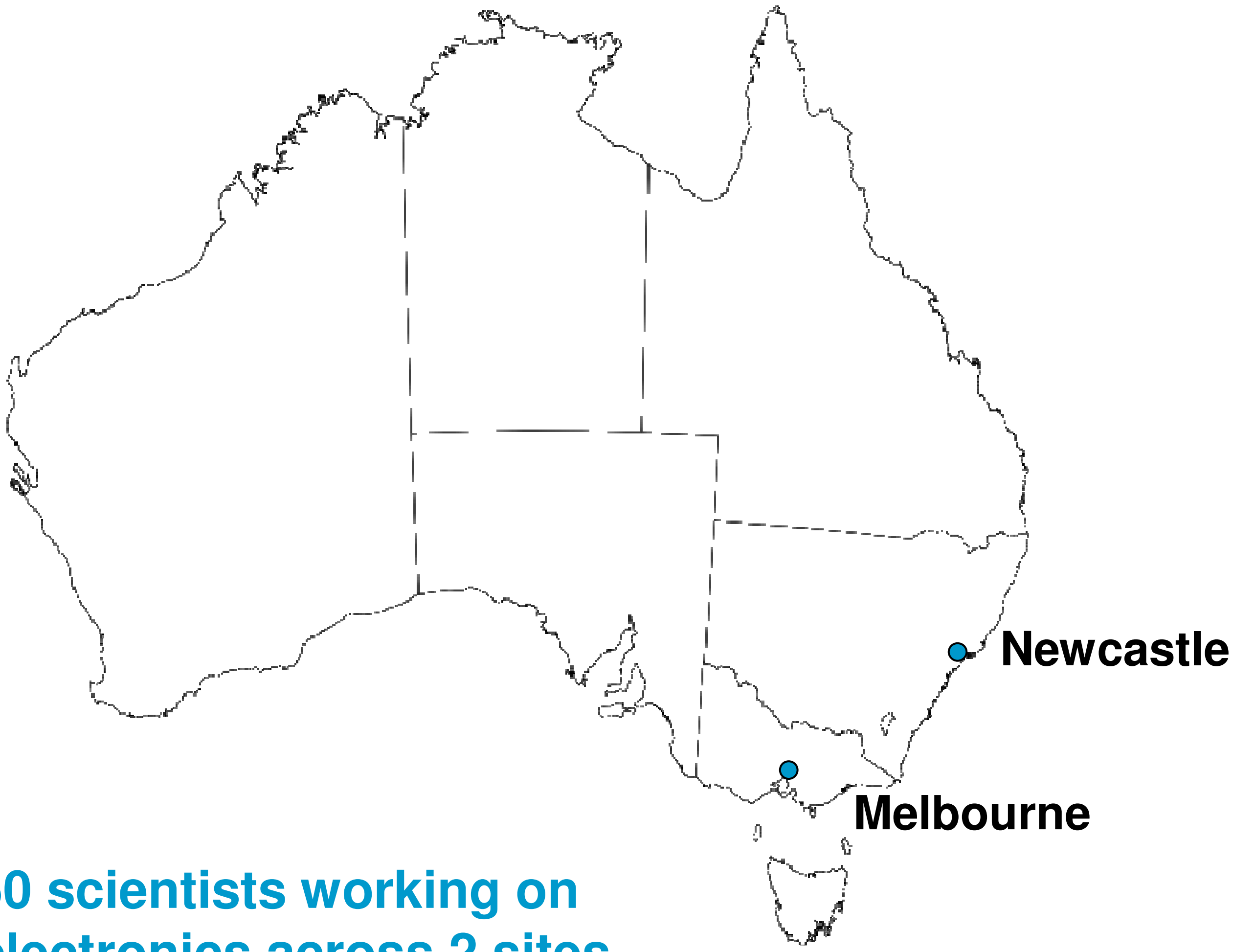
Testing and Modules: Chris Fell, Peter Phillips, Tim Nagle, Kerry Burke, Doojin Vak

Gerry Wilson and Prof Andrew Holmes

Funding: CSIRO, VICOSC, ICOS

CSIRO

Organic Electronics at CSIRO



Around 50 scientists working on organic electronics across 2 sites, Melbourne and Newcastle

Organic Electronics in Australia

Close collaboration between CSIRO and University groups in Australia and internationally.

CSIRO

THE UNIVERSITY OF MELBOURNE

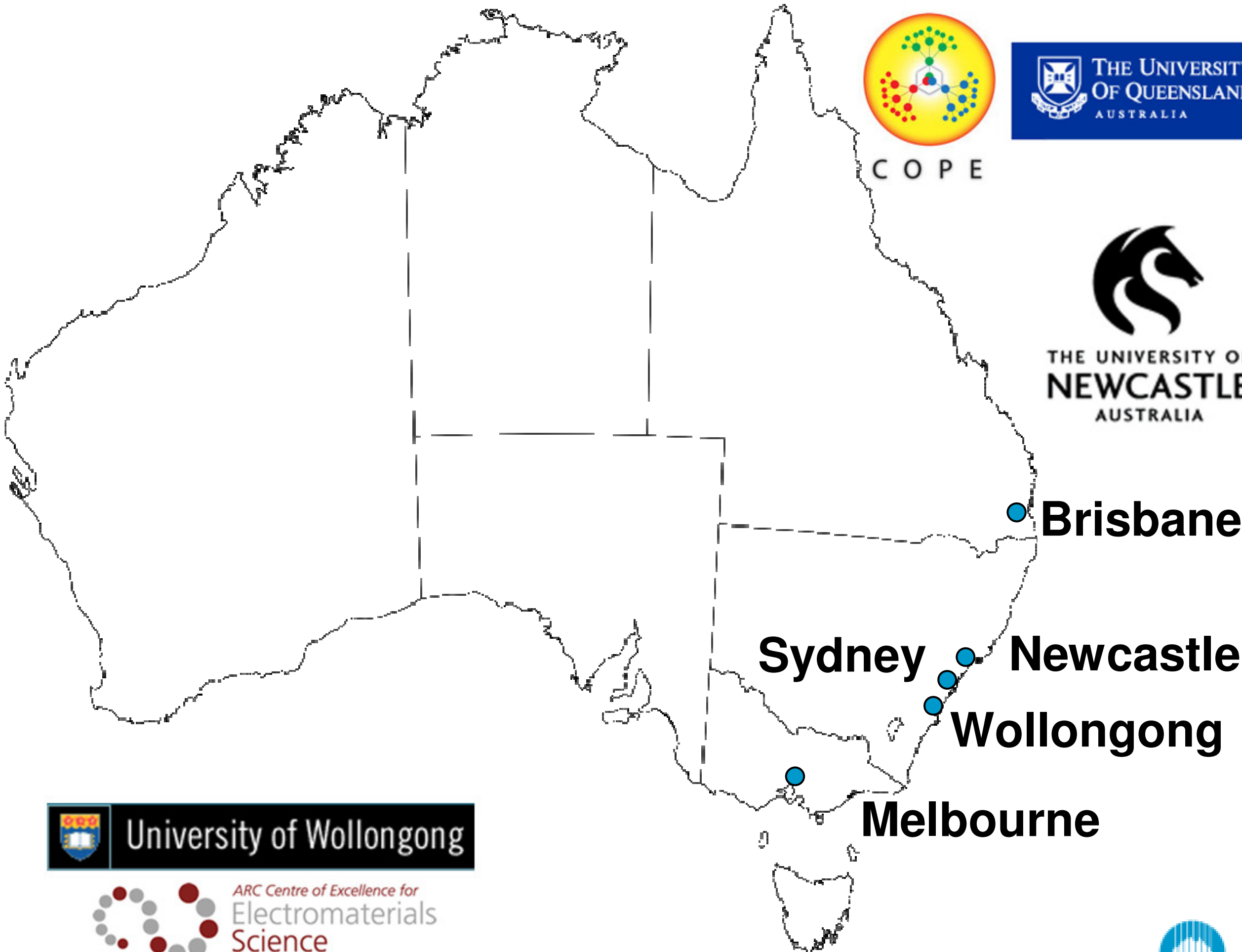
MONASH University

ARC Centre of Excellence for Electromaterials Science

The University of Sydney

University of Wollongong

ARC Centre of Excellence for Electromaterials Science



C O P E

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

CSIRO

Organic Electronics in Europe

VDMA - Organic Electronics Association

Organic Electronics Association (OE-A)

oe-a
Organic Electronics Association

- Working Group within VDMA
  - The German Engineering Federation
- Founded in December 2004
- Private non-profit organization (financed by membership fees)
- International key industry association for organic electronics
- Our members represent the entire organic electronics value chain
  - component & material suppliers
  - equipment & tool suppliers
  - producers / system integrators
  - end-users
  - R & D institutes

VDMA

CSIRO

VICOSC
Victorian Organic Solar Cell Consortium

MONASH University
ARC Centre of Excellence for Electromaterials Science
CSIRO
THE UNIVERSITY OF MELBOURNE
SECURENCY INTERNATIONAL PTY LTD
BLUESCOPE STEEL
innovia FILMS
BOSCH Invented for life

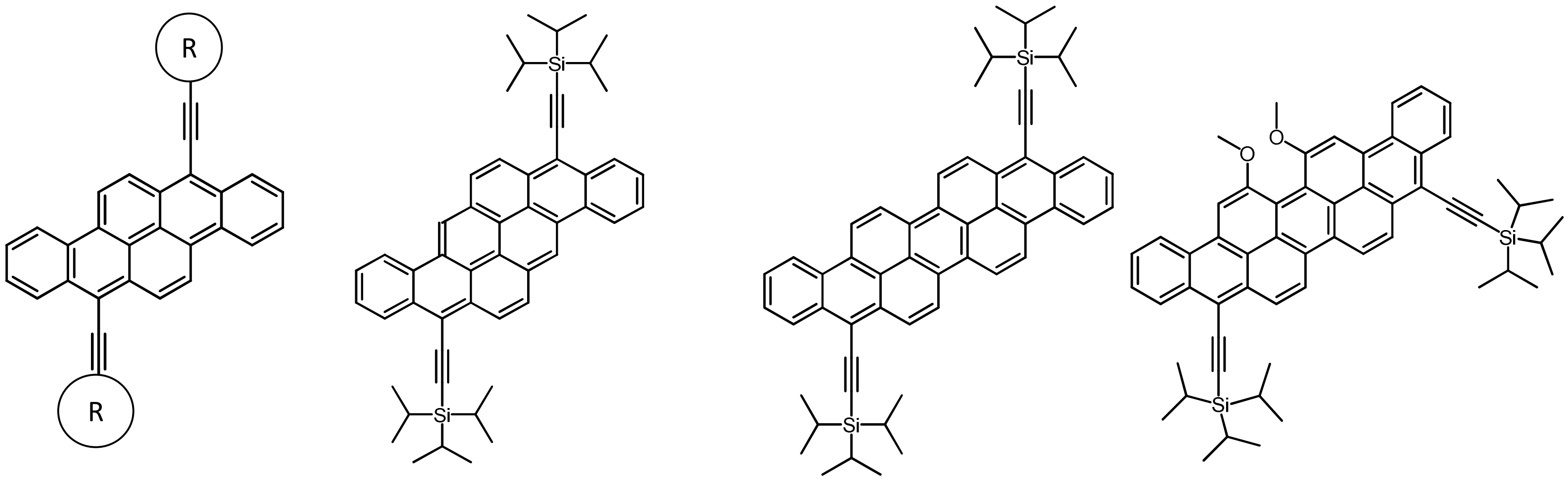
Funding from the State Government of Victoria and the Australian Solar Institute

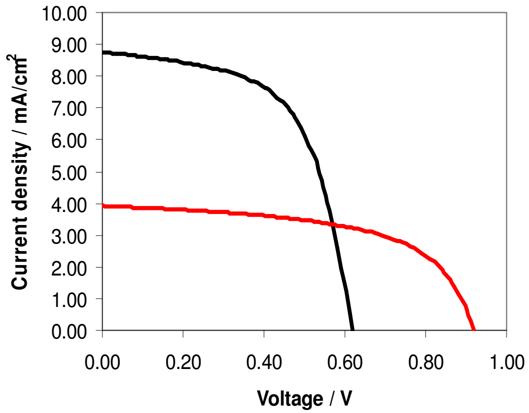
Working on new materials, new device architectures, printing processes and device lifetime and testing.
Both **bulk heterojunction** and **solid-state dye sensitised solar cells**.

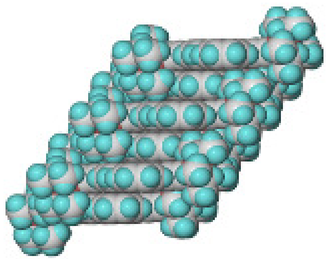
Science Highlights
- Materials

Small molecules

>40 representatives of >5 families of new PAH templates, some examples:



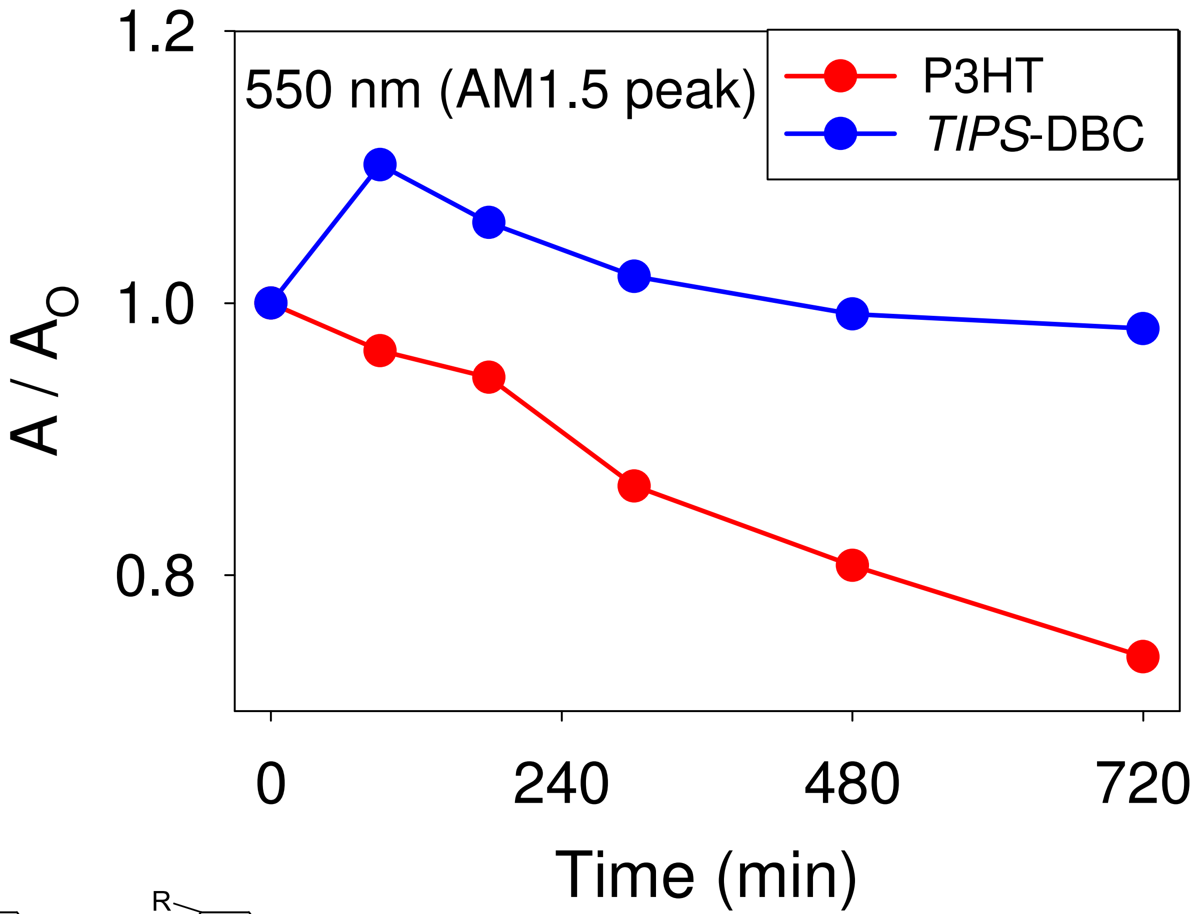


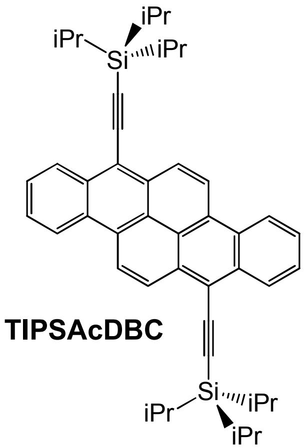


	P3HT/PCBM	DBC/PCBM
% eff.	3.1	2.25
V_{OC}	0.65	0.92
I_{SC}	8.7	3.9

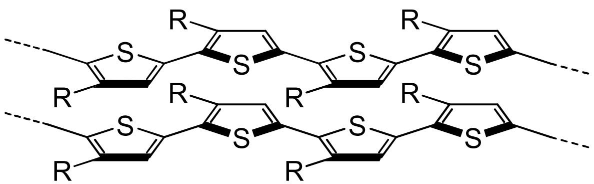
Winzenberg, Watkins *et al.*, *Chem. Mat.*, 2009, 5701

Photostability of CSIRO materials





TIPSAcDBC



P3HT

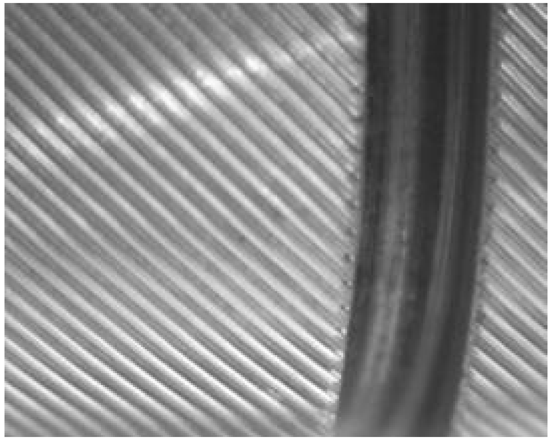
Scale-up

50g batches, packaged, safety-assessed

Printing and coating

Reverse gravure printing

Mini-Labo Printer

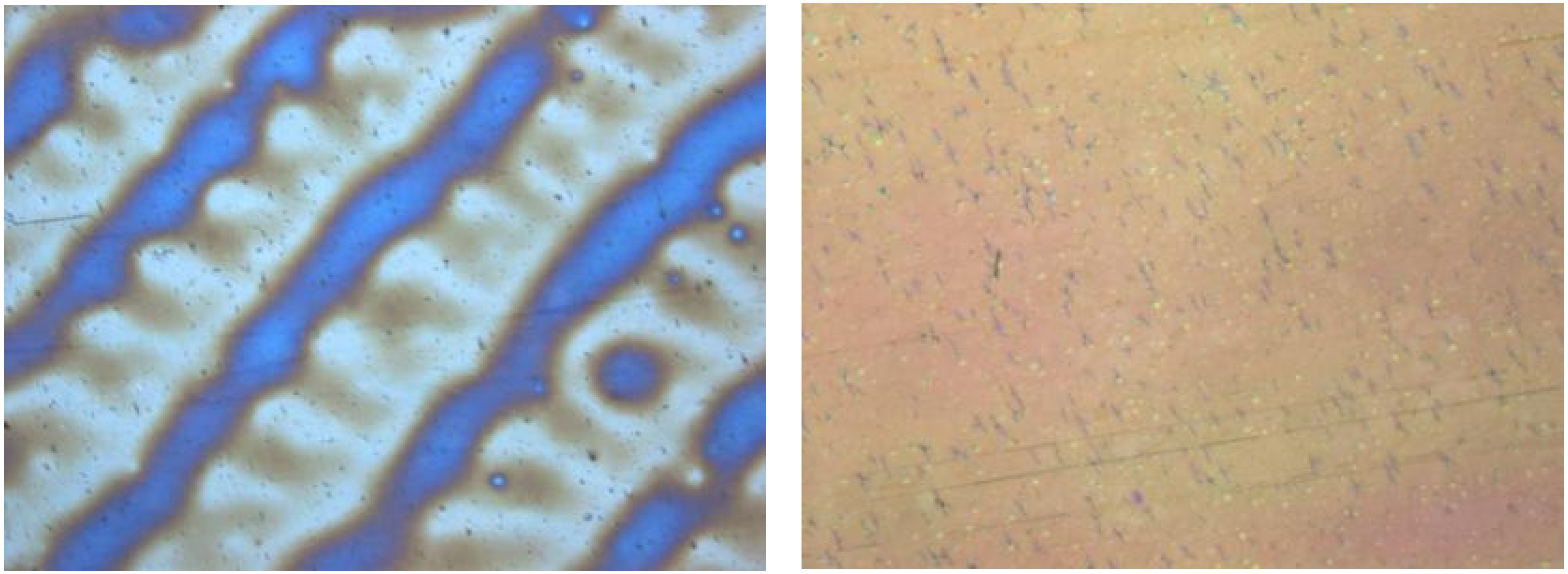


- **Reverse-gravure or microgravure**
- **120-mm wide substrate**
- **50 mL ink required**

See also: Tobjork *et al.*, *Mater. Res. Soc. Symp. Proc*. 1091-AA05-45 (2008)

Reverse gravure printing

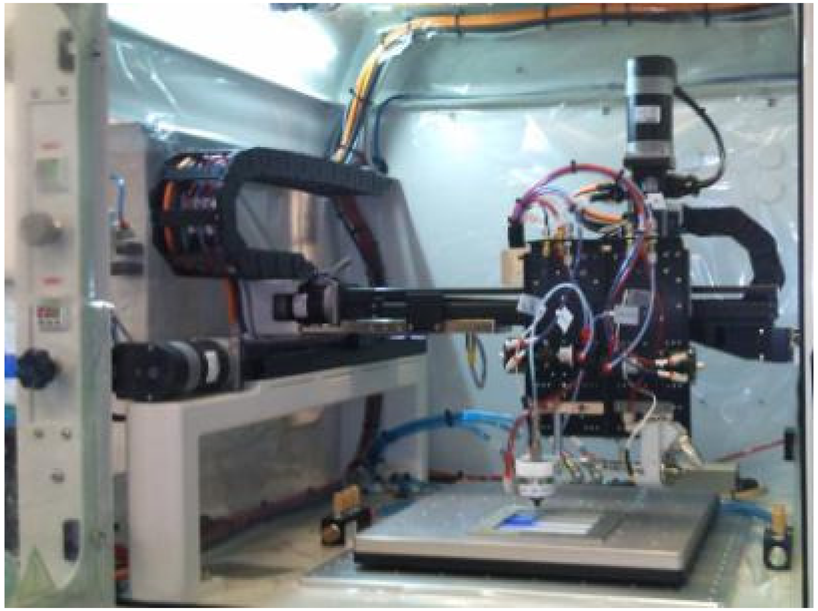
- **Cylinder rotates against substrate direction**
- **Continuous film applied**
- **Coating weight controlled by cylinder speed**
- **Results are encouraging on fully printed devices**



Gravure (left) and Reverse Gravure (right) PEDOT-PSS on ITO-PET (x5 magnification)

Spray deposition: Laboratory systems

Air-brush fed with syringe pump



Sono-Tek spray deposition equipment at UoM

Includes collaboration with
Karlsruhe Institute of Technology

Industrial-scale printing

Pilot-scale production trials continue with gravure printing at Securency's R&D line

Printed Inorganic Devices

New processes for proven materials

CSIRO has recently developed a process for producing highly efficient solution processed, inorganic solar cells

Vacuum deposited CdTe and CIGS cells are commercially available, with module efficiencies of 10-15%

Reports of solution processed laboratory devices in the literature are limited to device power conversion efficiencies of around 5% or they require explosive solvents (hydrazine) in gloveboxes

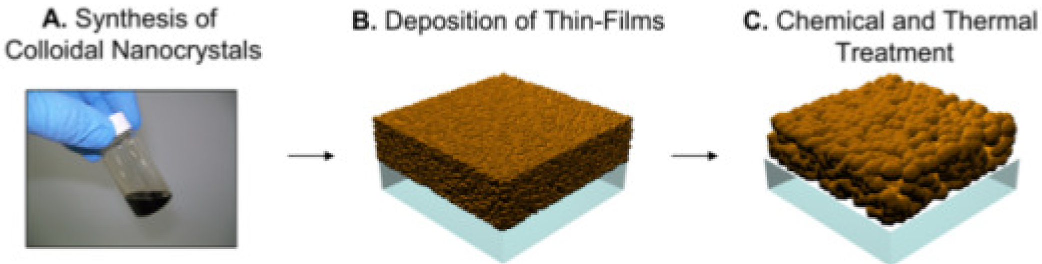
Jacek Jasieniak and Brandon MacDonald

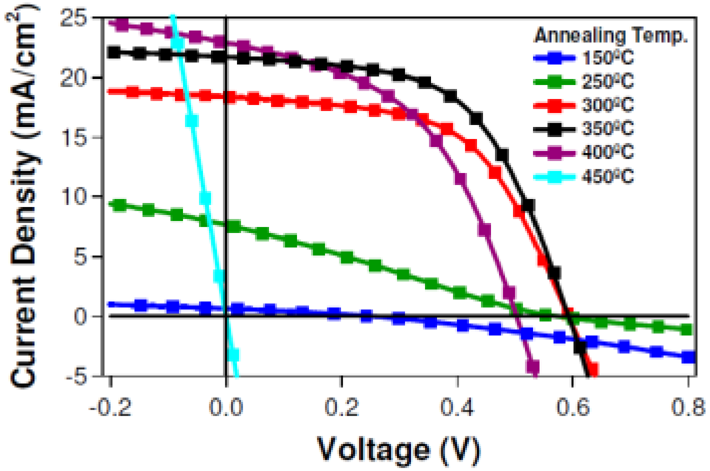
New processes for proven materials

CSIRO has recently developed a process for producing highly efficient solution processed, inorganic solar cells

Our process reproducibly delivers device power conversion efficiencies of 8% with hero devices >10%

All deposition and annealing of semiconductors is from **solution** and in **air**





Jacek Jasieniak and Brandon MacDonald

Outdoor Testing

Durability testing

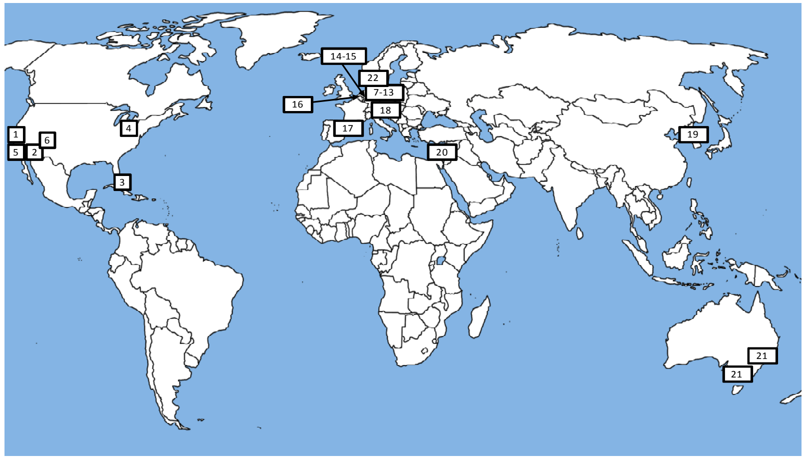
An inter-laboratory stability study of roll-to-roll coated flexible polymer solar modules

Suren A. Gevorgyan,[1] Andrew J. Medford,[1] Eva Bundgaard,[1] Subarna B. Sapkota,[2] Hans-Frieder Schleiermacher,[2] Birger Zimmermann,[2] Uli Würfel,[2] Amine Chafiq,[3] Monica Lira-Cantu,[3] Thomas Swonke,[4] Michael Wagner,[4] Christoph J. Brabec,[4] Olivier Haillant,[5] Eszter Voroshazi,[6,7] Tom Aernouts,[6] Roland Steim,[8] Jens A. Hauch,[8] Andreas Elschner,[9] Michael Pannone,[10] Min Xiao,[10] Anthony Langzettel,[10] Darin Laird,[10] Matthew T. Lloyd,[11] Thomas Rath,[12,13] Eugen Maier,[13,14] Gregor Trimmel,[12,13] Martin Hermenau,[15] Torben Menke,[15] Karl Leo,[15] Roland Rösch,[16] Marco Seeland,[16] Harald Hoppe,[16] Timothy J. Nagle,[17] Kerry B. Burke,[17] Christopher J. Fell,[17] Doojin Vak,[18] Th. Birendra Singh,[18] Scott E. Watkins,[18] Yulia Galagan,[19] Assaf Manor,[20] Eugene A. Katz,[20,21] Taehee Kim[22], Kyungkon Kim[22] Paul M. Sommeling,[23] Wiljan J. H. Verhees,[23] Sjoerd C. Veenstra,[23] Moritz Riede,[24,15] M. Greyson Christoforo,[24] Travis Currier,[25] Vishal Shrotriya,[25] Gregor Schwartz,[26] and Frederik C. Krebs[1,*]

[1] Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
[2] Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstrasse 2, D-79110 Freiburg, Germany
[3] Centre d'investigació en Nanociència i Nanotecnologia (CIN2, CSIC). Laboratory of Nanostructured Materials for Photovoltaic Energy. ETSE, Campus UAB, Edifici Q, 2nd Floor. E-08193. Bellaterra (Barcelona), Spain
[4] Bavarian Center for Applied Energy Research, Am Weichselgarten 7, D-91058 Erlangen, Germany
[5] Atlas Material Testing Technology, Vogelsberstrasse 22, 63859 Linsengericht-Altenhasslau
[6] IMEC VZW. – Organic Photovoltaics, Kapeldreef 75, B-3001 Leuven, Belgium
[7] Katholieke Universiteit Leuven, ESAT, Kasteelpark Arenberg 10, B-3001 Leuven, Belgium
[8] Konarka Technologies GmbH, Landgrabenstr. 94, 90443 Nürnberg, Germany
[9] H.C. Starck Clevios GmbH, Chempark Leverkusen Build. B202, D-51368 Leverkusen, Germany
[10] Plextronics, Inc., 2180 William Pitt Way, Pittsburgh, PA 15238, USA
[11] National Renewable Energy Laboratory, Golden, Colorado, 80401, USA
[12] Christian Doppler Laboratory for Nanocomposite Solar Cells, Graz University of Technology, Stremayrgasse 9, 8010 Graz, Austria
[13] Institute for Chemistry and Technology of Materials, Graz University of Technology, Stremayrgasse 9, 8010 Graz, Austria
[14] Polymer Competence Center Leoben GmbH, Roseggerstrasse 12, 8700 Leoben, Austria
[15] Institut fuer Angewandte Photophysik, Technische Universitaet Dresden, George-Baehr-Straße 1, 01062 Dresden, Germany
[16] Institute of Physics, Ilmenau University of Technology, Weimarer Str. 32, D-98693 Ilmenau, Germany
[17] CSIRO Future Manufacturing Flagship and CSIRO Energy Technology, 10 Murray Dwyer Circuit, Mayfield West, NSW, 2304, Australia
[18] CSIRO Future Manufacturing Flagship and CSIRO Materials Science and Engineering, Ian Wark Laboratory, Clayton, VIC, 3168, Australia
[19] Holst Centre, PO Box 8550, 5605 KN Eindhoven, the Netherlands
[20] Dept. of Solar Energy and Environmental Physics, J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boker Campus 84990, Israel
[21] The Ilse Katz Institute for Nanoscale Science and Technology, Ben-Gurion University of the Negev, Beersheva 84105, Israel
[22] Solar Cell Center, Korea Institute of Science and Technology, P.O. Box 131,Cheongryang, Seoul 136-791, Korea
[23] Energy Research Centre of the Netherlands (ECN), P.O. Box 1, 1755 ZG Petten, the Netherlands
[24] Department of Electrical Engineering, Stanford University, Stanford, California, CA-94305, USA
[25] Solarmer Energy, Inc., 3445 Fletcher Avenue, El Monte, CA 91731 USA
[26] Heliatek GmbH, Treidlerstr. 3, 01139 Dresden, Germany

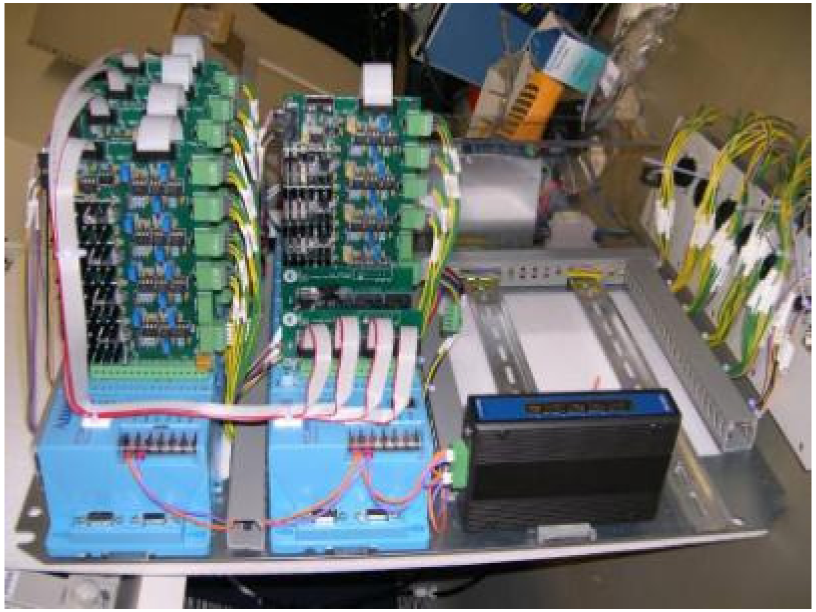
e-mail : frkr@risoe.dtu.dk

Prof. Frederik Krebs
Riso, Denmark



27 sites around the world
CSIRO provided two, Newcastle and Melbourne

OSCAR – Organic Solar Cell Assessment Rig



- Outdoor testing of modules with temperature and irradiance data, 20 modules on 5 faces of a cube
- Temperature stable electronics
- Devices are current driven – an algorithm scans current to determine device parameters

OSCAR

- So far, our 10 × 10 cm devices are running at 1-2% PCE
- Common irradiances in Melbourne: 1200 W/m^2 (top) and still 750 W/m^2 on the south face

CSIRO

The challenge and opportunities

Challenge - Scale

Calculations to produce 100MW of power. Assume average solar insolation is 200W/m^2.

100MW = 1e8 W, therefore 1e8/200 = 5e5 m2 required

Assuming the cells have 5% efficiency this requires 5e5 x 20 = 1e7 m2

Assuming cells are printed on substrate that is 1m wide this requires 1e7 m or **10,000 km of film -** this is 0.25 times around the Earth.

A printing firm can print at speeds of upto **400m / minute**

Doing 8 hrs a day, it would take **52 working days** to produce 10,000 km of film.

The films are typically 100-200nm thick. Allowing for deposition loses the production requirements have been estimated to be 0.1g/m2.

1e7 m (at 1m wide) needs 1e7 x 0.1g = 1e6 g = 1000 kg = 1 tonne of polymer.

So, 100 MW of power needs: 10,000km of a 1m wide film, 1 tonne of polymer

As a comparison, the **global production of polystyrene is around 20 million tonnes per annum**.

CSIRO

Opportunity - Markets

The total PV market (~$40 bn p.a.) is dwarfed by the display market.

Large-size LCD (> 10 inch) is ~$70bn p.a.

Every large display manufacturer has active OPV research

The development of OPVs is therefore an opportunity to leverage the size and expertise of ***traditional electronics*** to grow the new field of ***printed electronics***.

Challenge - Roadmap

Parameter	Generation 1	Generation 2	Generation 3	Generation 4
Market Application	Portable consumer electronics	Outdoor recreation	BIPV Off-grid power	Residential roof top grid connected. Utility power generation
Expected Timing	2010	2011	2014+	2016+
Product features	Flexible Low weight modules	Flexible Low weight modules	Low weight modules	Low weight modules
Lifetime (yrs)	1-2	3-5	5-10	10+
Efficiency (%)	Lower: 3%	Moderate: 5%	Moderate: 5%	Higher: 10-20%

OE-A Roadmap Working Group

Value Proposition for OPVs

- Inherently inexpensive manufacturing technology – thin films and low-cost deposition
- Huge diversity in materials – chemistry solutions
- Demonstrated significant lifetimes and rapidly improving efficiencies

- Applications will be portable then building integrated then large scale

- Technology will be advanced by the electronics/display industry as opposed to the energy industry
- Size and diversity of the electronics/display market is an extremely significant advantage for OPVs

CSIRO

Summary

CSIRO is leading OPV research in Australia into new materials and printing processes

Does the SKA *need* OPVs?
Probably not.

Does the SKA represent an opportunity for a targeted, high profile application of OPVs that will give the field momentum and in turn catalyse the growth of printed electronics?
Definitely!

OPVs and the SKA - a tremendous opportunity for Printed Electronics in Australia and Germany

CSIRO

CSIRO Materials Science and Engineering
Dr Scott Watkins
Stream Leader – Organic Photovoltaics

Phone: 03 9545 2618
Email: scott.watkins@csiro.au
Web: www.csiro.au

Costs – bottom-up

- Estimated manufacturing cost for purely organic solar cells will range between \$50 and \$140/m^2.
- Under the assumption of 5% efficiency, this leads to a module cost of between \$1.00 and \$2.83/W_p.
- Under the assumption of a 5-year lifetime, this leads to a levelized cost of electricity (LEC) of between 49¢ and 85¢/kWh.
- In order to achieve a more competitive COE of about 7¢/kWh, we would need to increase efficiency to 15% and lifetime to between 15–20 years.

Joseph Kalowekamo, Erin Baker, *Solar Energy*, **2009**, 1224

CSIRO