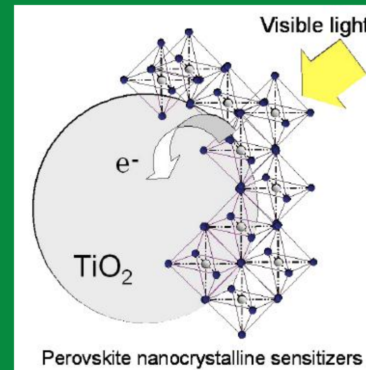
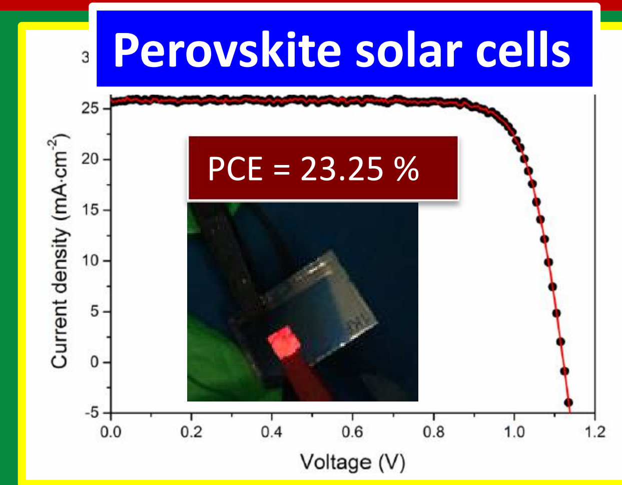
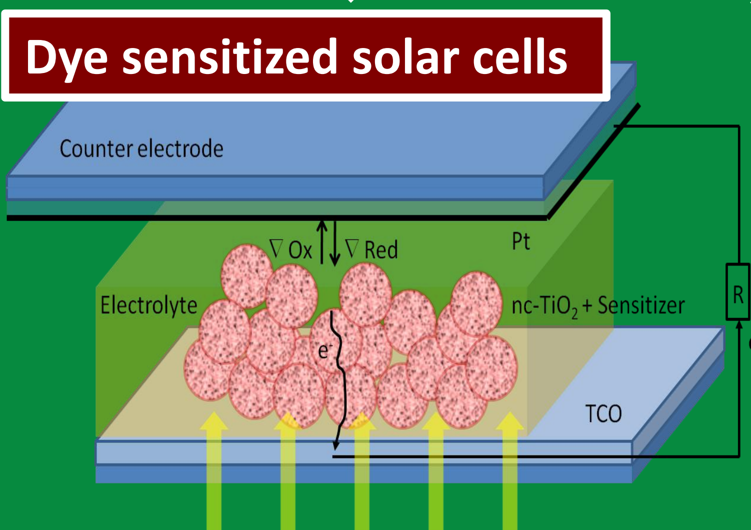
Power from the Sun, Solar Cells that Mimic Photosynthesis

INSPIRATION





EVOLUTION



INNOVATION

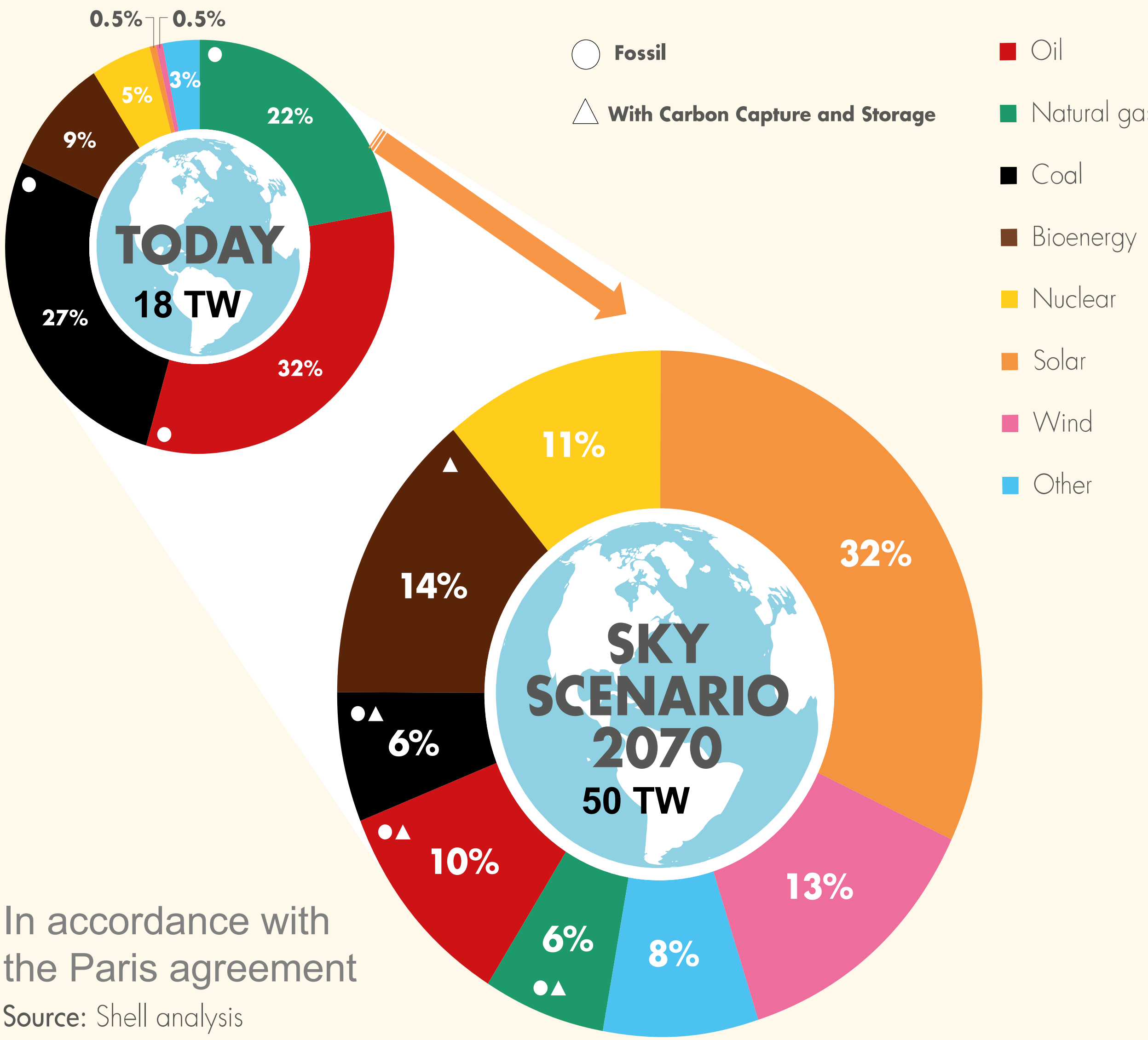
APPLICATION

OUTLINE

- Our motivation, inspiration and research approach
- The advent of molecular photovoltaics and perovskite solar cells
- Architectural applications and commercial deployment.

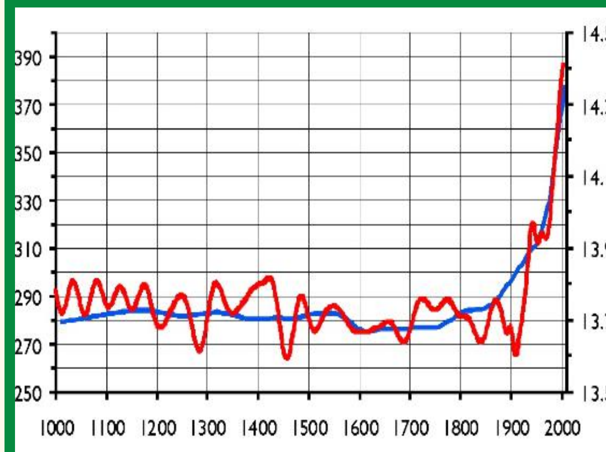
Our Motivation: Respond to the Quest for Renewable + Clean Energy Sources

Climate change and environmental pollution from burning fossil fuels produces planetary emergency



In accordance with the Paris agreement

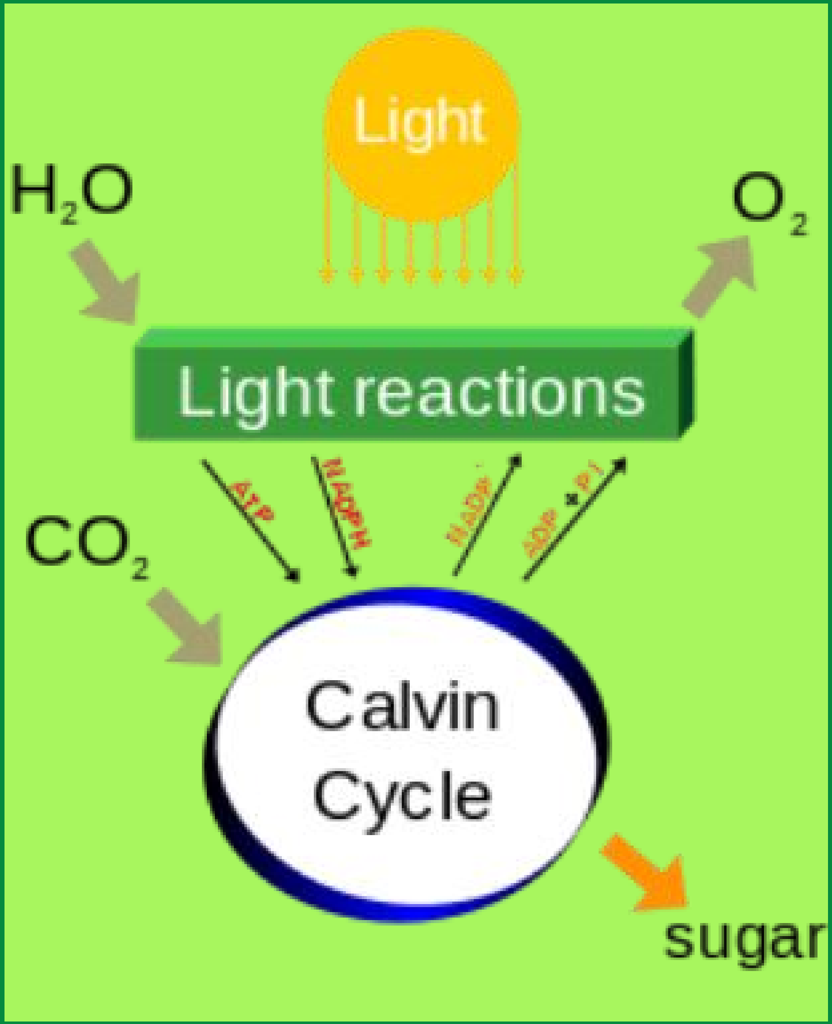
Source: Shell analysis



Climate change

Environmental pollution

PHOTOSYNTHESIS SHOWS THE WAY



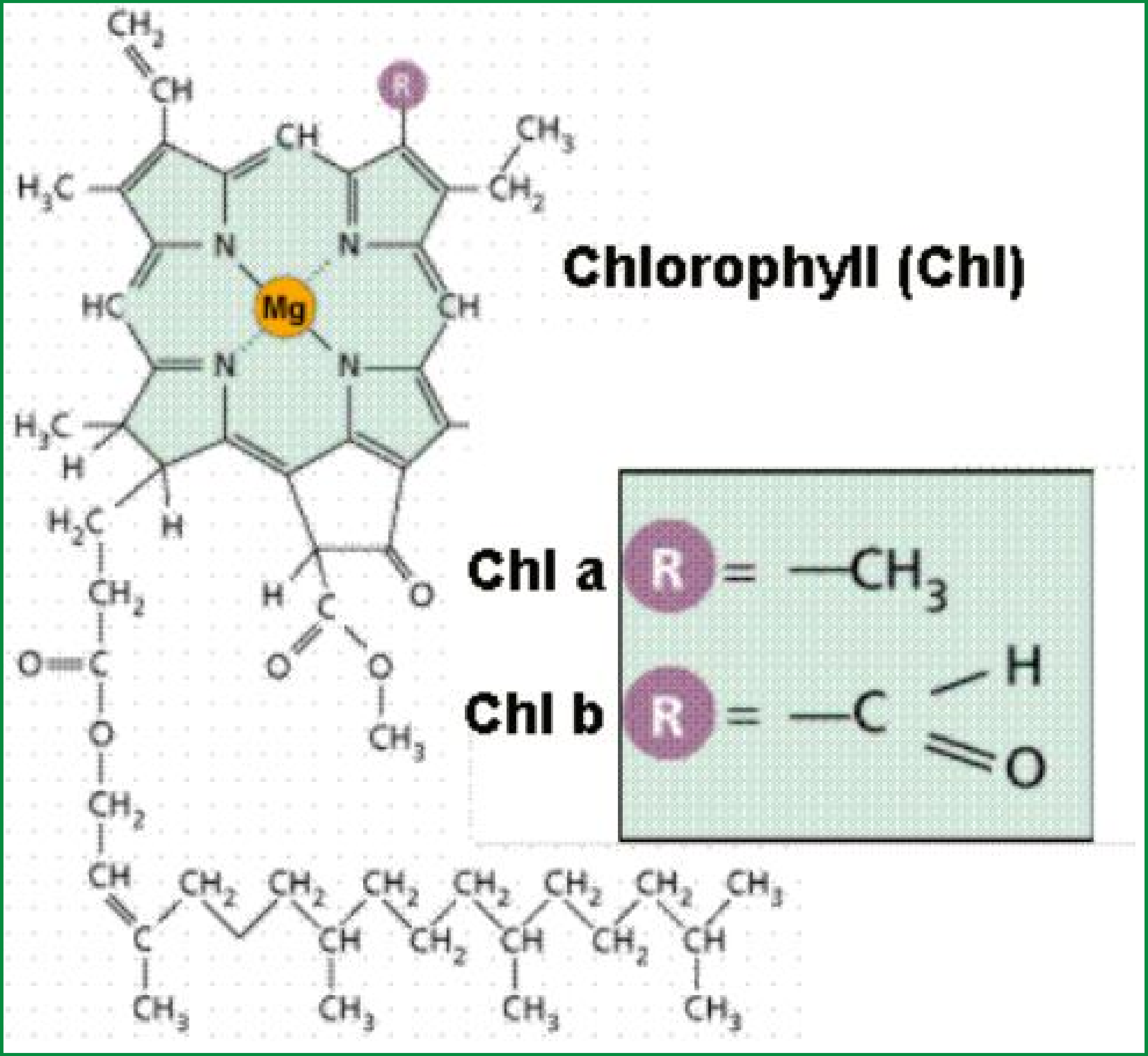
Total solar power
Incident on earth is
178’000 TW

$CO_2 + 2\ H_2O + 8$ photons $\longrightarrow [CH_2O] + O_2$ $\quad \Delta G^* = 477$ KJ/mole

solar power converted to chemical energy stored in biomass is 95 TW

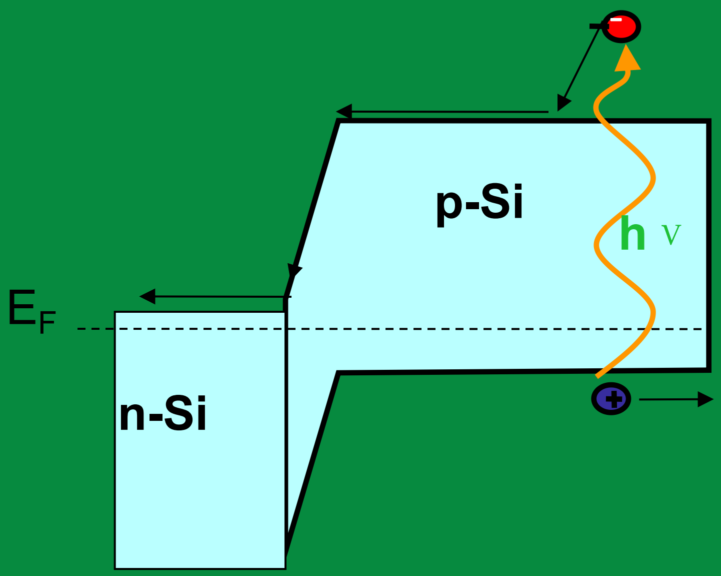
Natural photosynthesis continuously converts 90 TW of solar power to chemical fuels

Photosynthesis uses chlorophyll molecules to harvest sunlight



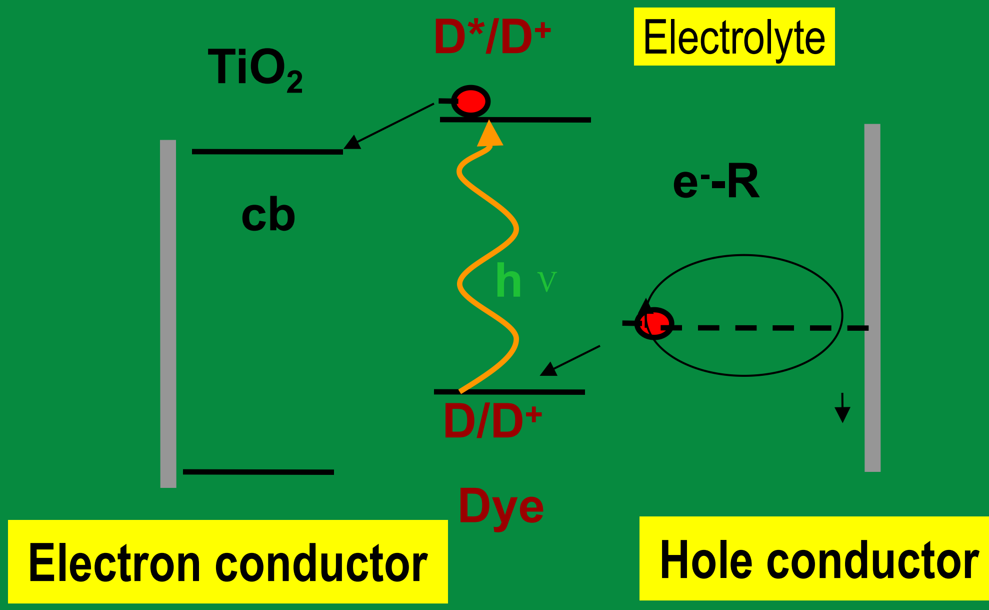
Dye sensitized solar cells are inspired by natural photosynthesis

p-n junction photovoltaic cells



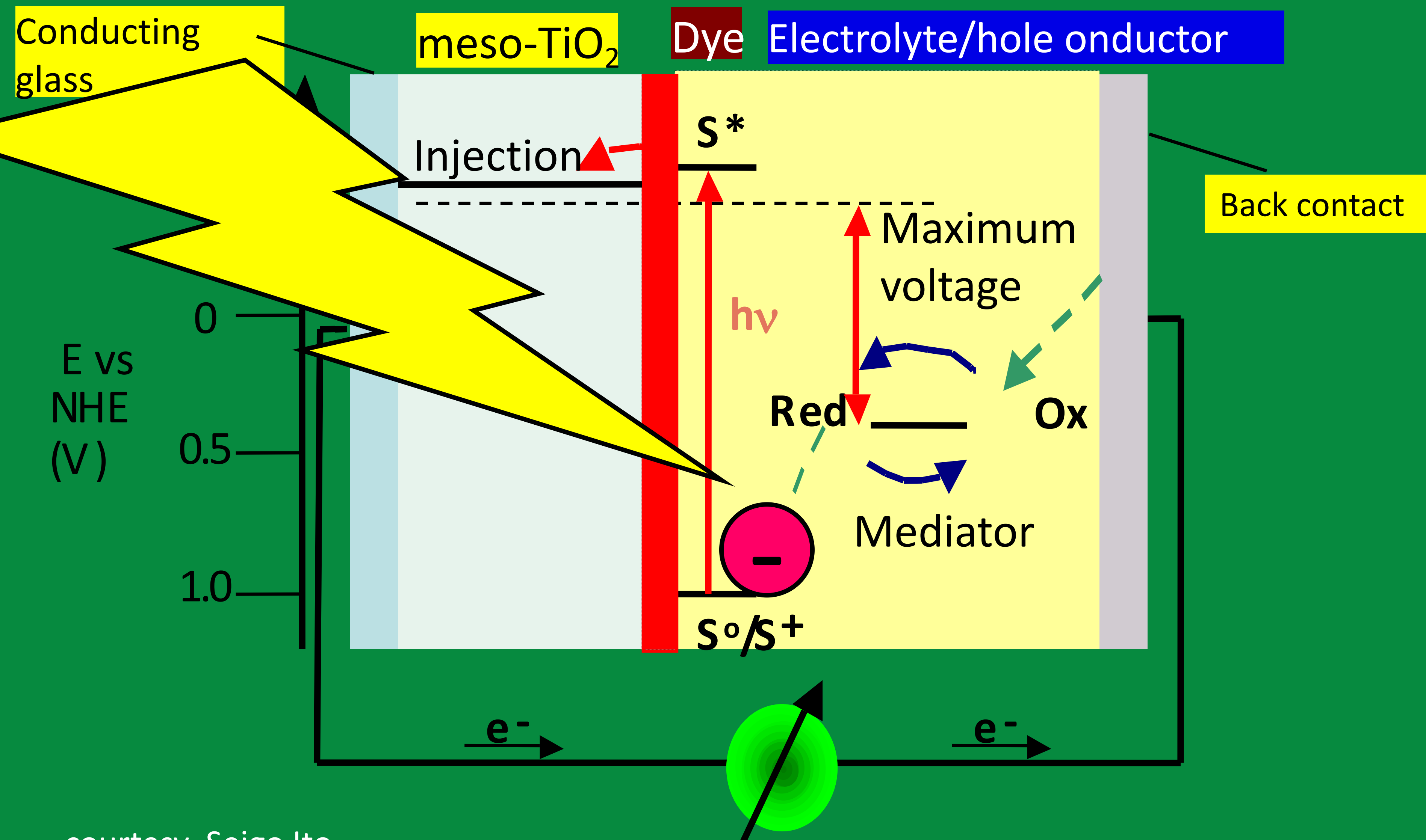
Charge separation by electric field at the p-n junction minority carrier lifetime is a key issue in photoelectric convrsion

dye sensitized solar cells DSC



Charge separation by kinetic competition as in photosynthesis separatiom of light absorption from charge carrier transport

Molecular photovoltaics goes beyond the principle of light absorption via diodes



courtesy Seigo Ito

OUTLINE

- Our motivation, inspiration and research approach
- **The advent of molecular photovoltaics and perovskite solar cells**
- Architectural applications and commercial deployment.

Our JACS paper from year 1985 reported for the first time efficient sensitization of colloidal TiO_2 particles (nanocrystals) and electrodes

J.Am.Chem.Soc., 107, 2988 (1985)

The magic world of nanocrystals

Highly Efficient Sensitization of Titanium Dioxide

Jean Desilvestro, Michael Grätzel,* Ladislav Kavan,[1] and Jacques Moser

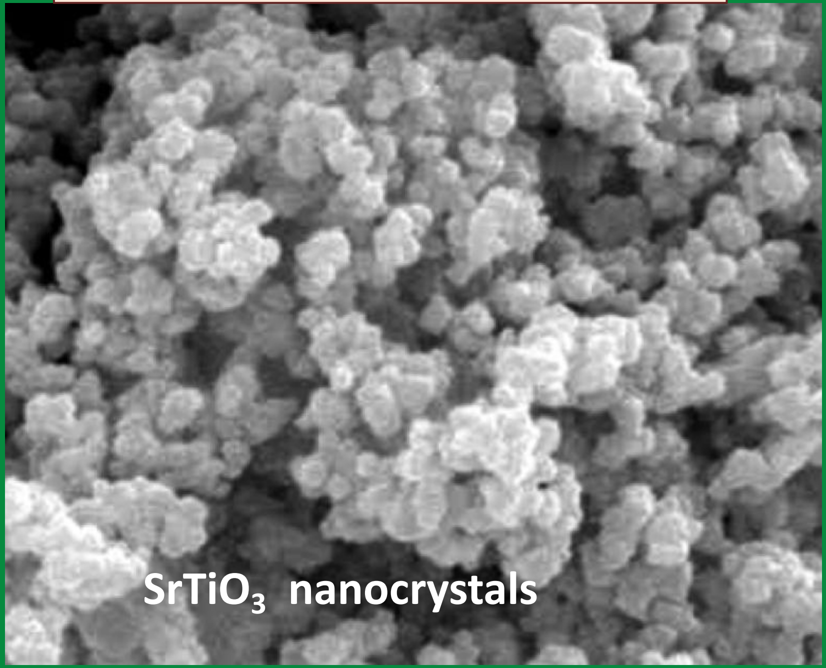
Institut de Chimie Physique
Ecole Polytechnique Fédérale
CH-1015 Lausanne, Switzerland

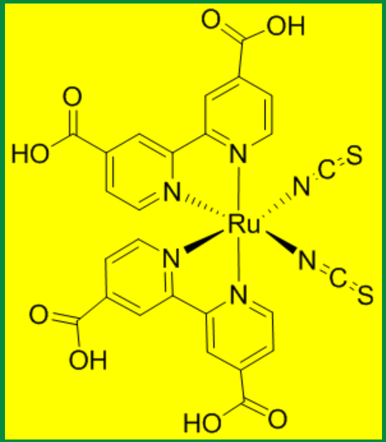
Jan Augustynski

Institut de Chimie Minérale, Analytique et
Appliquée, Université de Genève
CH-1211 Genève, Switzerland

Received December 6, 1984

The photosensitization of wide-bandgap oxide semiconductors is the subject of an intensive investigation, mainly due to its importance for solar energy conversion.[2] Of particular interest is the combination of chromophores such as $Ru(bpy)_3^{2+}$ with TiO_2 or $SrTiO_3$ since this offers the possibility to shift the water cleavage activity of these oxides into the visible.[3] However, the efficiencies achieved so far with such devices have been disappointingly low, mainly due to poor light energy harvesting and small quantum yields for charge injection. We have achieved strikingly high efficiencies in the sensitization of colloidal anatase particles and polycrystalline electrodes using tris(2,2′-bipyridyl-4,4′-dicarboxylate)ruthenium(II) dichloride[4], (1) as a sensitizer.



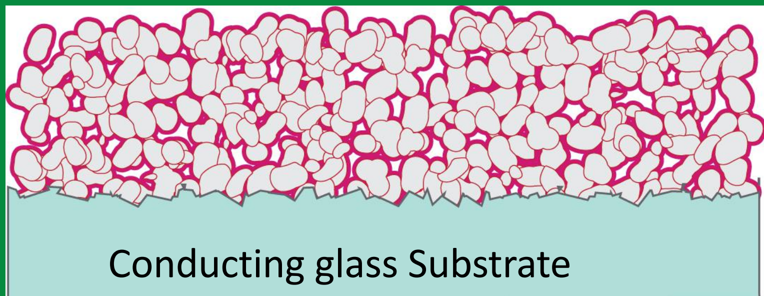


A.Hagfeldt and M. Grätzel, Light Induced Redox Reactions in Nanocrystalline Systems, **Chem. Rev.** 1995, 95 ,49-68.

Replacing the planar electrode by a mesoporous nanoparticle film architecture enabled 10’000 fold enhancement of photocurrent

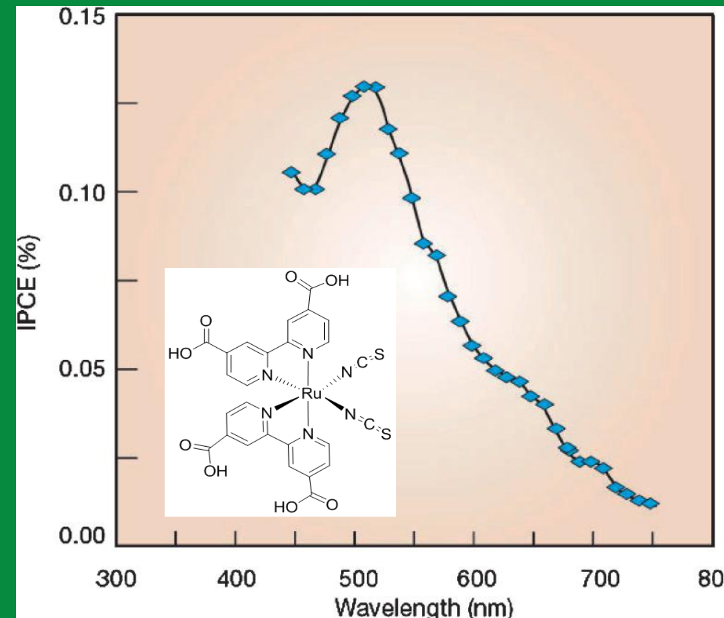
Dye monolayer on planar TiO_2 single crystal

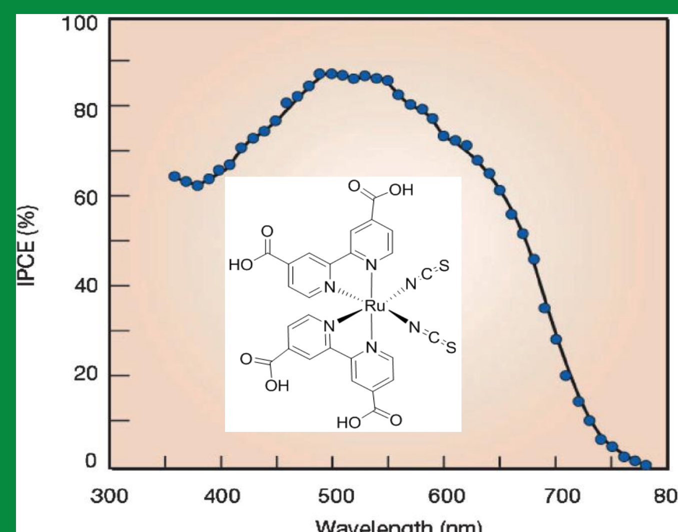
Dye sensitized mesoporous TiO_2 film



External quantum efficiency reaches close to 100 % .

IPCE (EQE) = LHE Φ_{cg} η_{coll}





The first patent application was filed in 1988

The patent protects the use of high surface area three-dimensional mesoporous junctions in photo-conversion systems

Today the DSC patent family has grown to a number over 5000

United States Patent [19] — **Gratzel et al.**

[11] **Patent Number: 4,927,721**

[45] **Date of Patent: May 22, 1990**

[54] **PHOTO-ELECTROCHEMICAL CELL**

[76] Inventors: **Michael Gratzel**, chemin du Marquisat 7a - CH-1050, Sts. Sulpica; **Paul Liska**, chemin des Bossons 47 - CH1018, Lausanne, both of Switzerland

[21] Appl. No.: **255,052**

[22] Filed: **Oct. 7, 1988**

[30] **Foreign Application Priority Data**

Feb. 12, 1988 [CH] Switzerland 00505/88

[51] **Int. Cl.**[5] **H01M 6/36**
[52] **U.S. Cl.** **429/111**
[58] **Field of Search** 429/111

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

53-77188 7/1978 Japan 429/111

OTHER PUBLICATIONS

T. Yoko et al., *Res. Rep. Fac. Eng. Mie Unive.*, vol. 12, pp. 49–64 (1987), English pp. 59–74.
N. Vlachopoulos et al., *Surface Science*, vol. 189/190, pp. 823–831 (1987).
T. Osa et al., *Nature*, vol. 264, pp. 349–350 (1976).
W. D. Clark et al., *J. Am. Chem. Soc.*, vol. 99, No. 14, pp. 4676–4682 (1977).

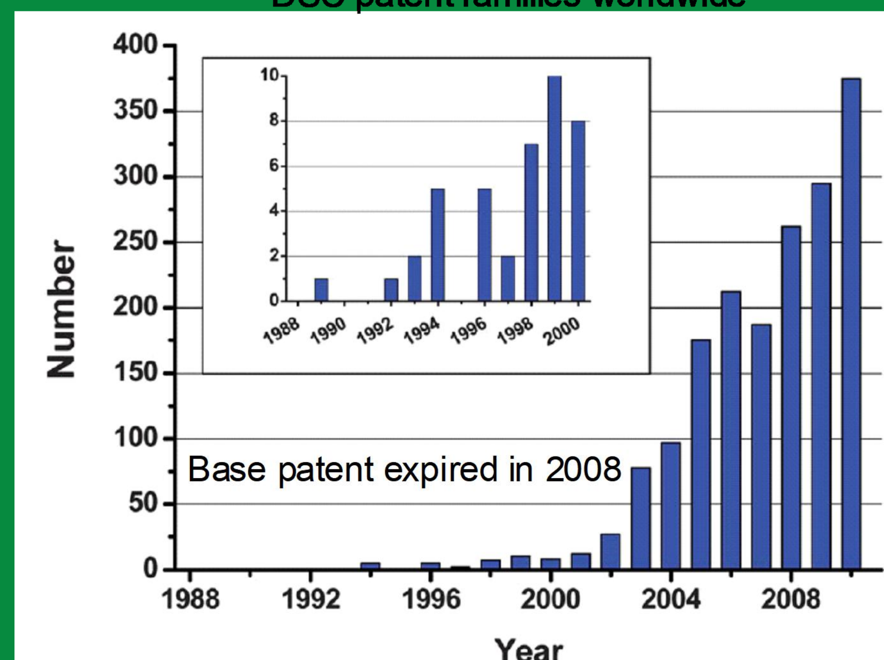
Primary Examiner—Aaron Weisstuch
Attorney, Agent, or Firm—Kenyon and Kenyon

[57] **ABSTRACT**

The regenerative photo-electrochemical cell comprises a polycrystalline metal oxide semiconductor layer having a substantially monomolecular chromophore layer in a surface zone. The surface of the metal oxide semiconductor layer has a roughness factor of more than 20, preferably more than 200. Photo-electrochemical cells having such metal oxide semiconductors have good monochromatic efficiency using redox systems with iodides or bromides.

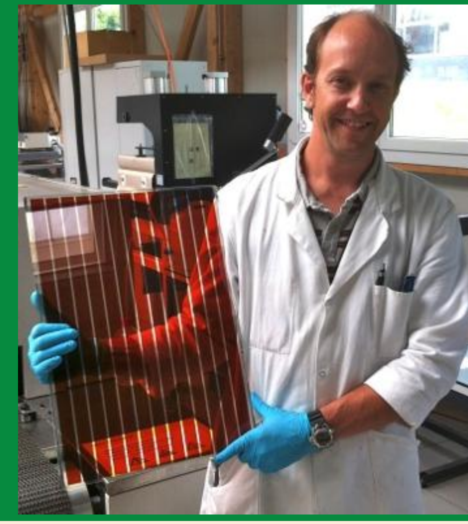
15 Claims, 2 Drawing Sheets

DSC patent families worldwide



From the first prototype to large scale industrial applications

First prototype of a mesoscopic dye sensitized solar cell (DSC) in 1988



2013: Installing first façade: Swisstech Congress Center in Lausanne

Outdoor testing of DSC tiles by 3GSolar in Jerusalem 2005- 2008

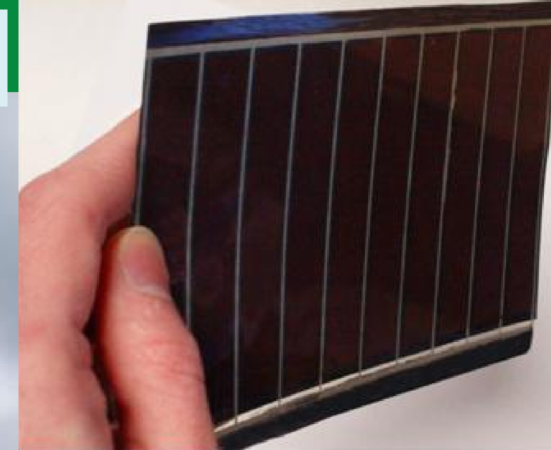
Roll to roll production of flexible DSCs started in 2007

QCell Solar back pack

Scale up to mass production from 2008 to 2011

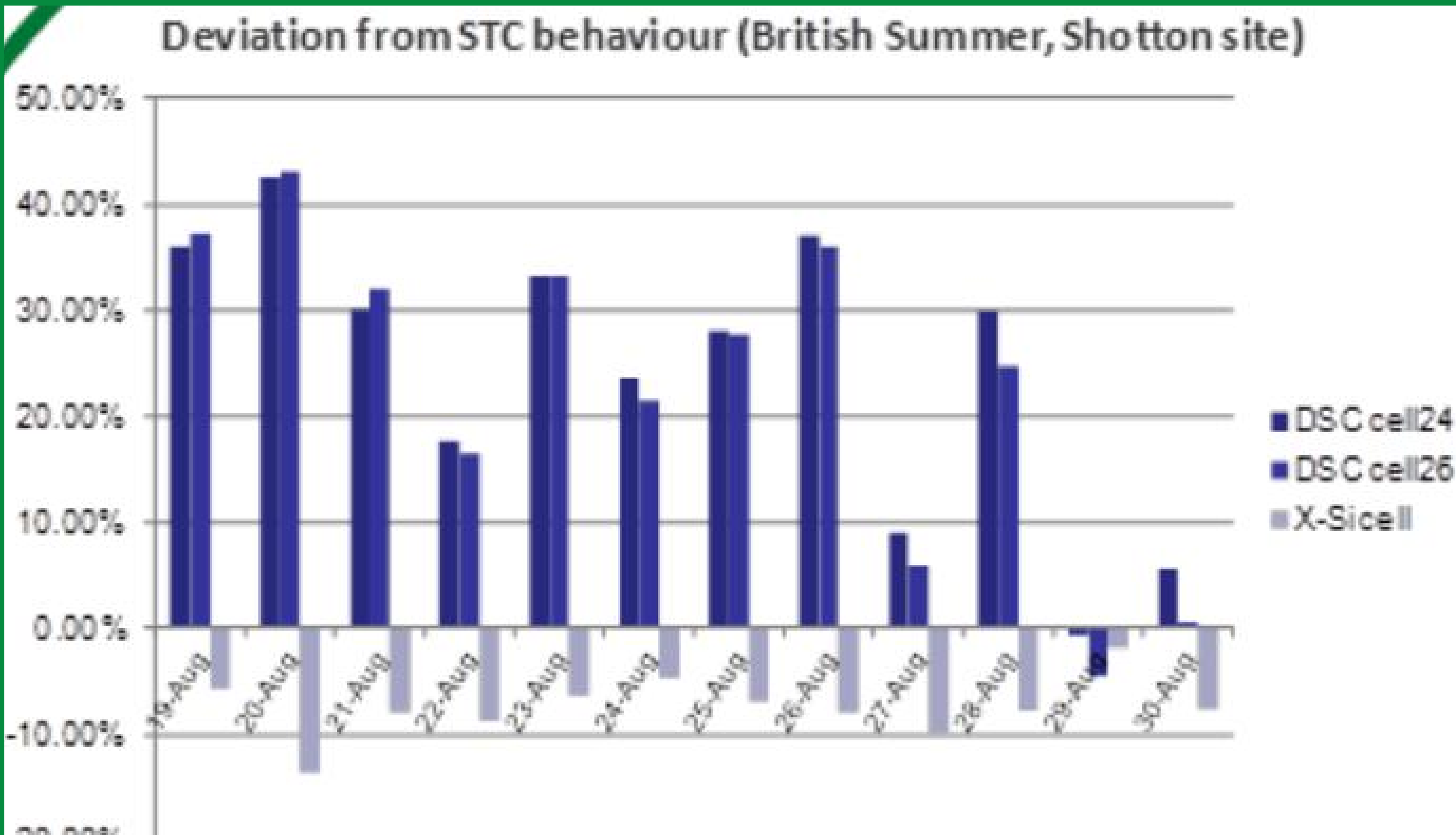
DSC Solar Steel Roofing Project DYESOL

TATA

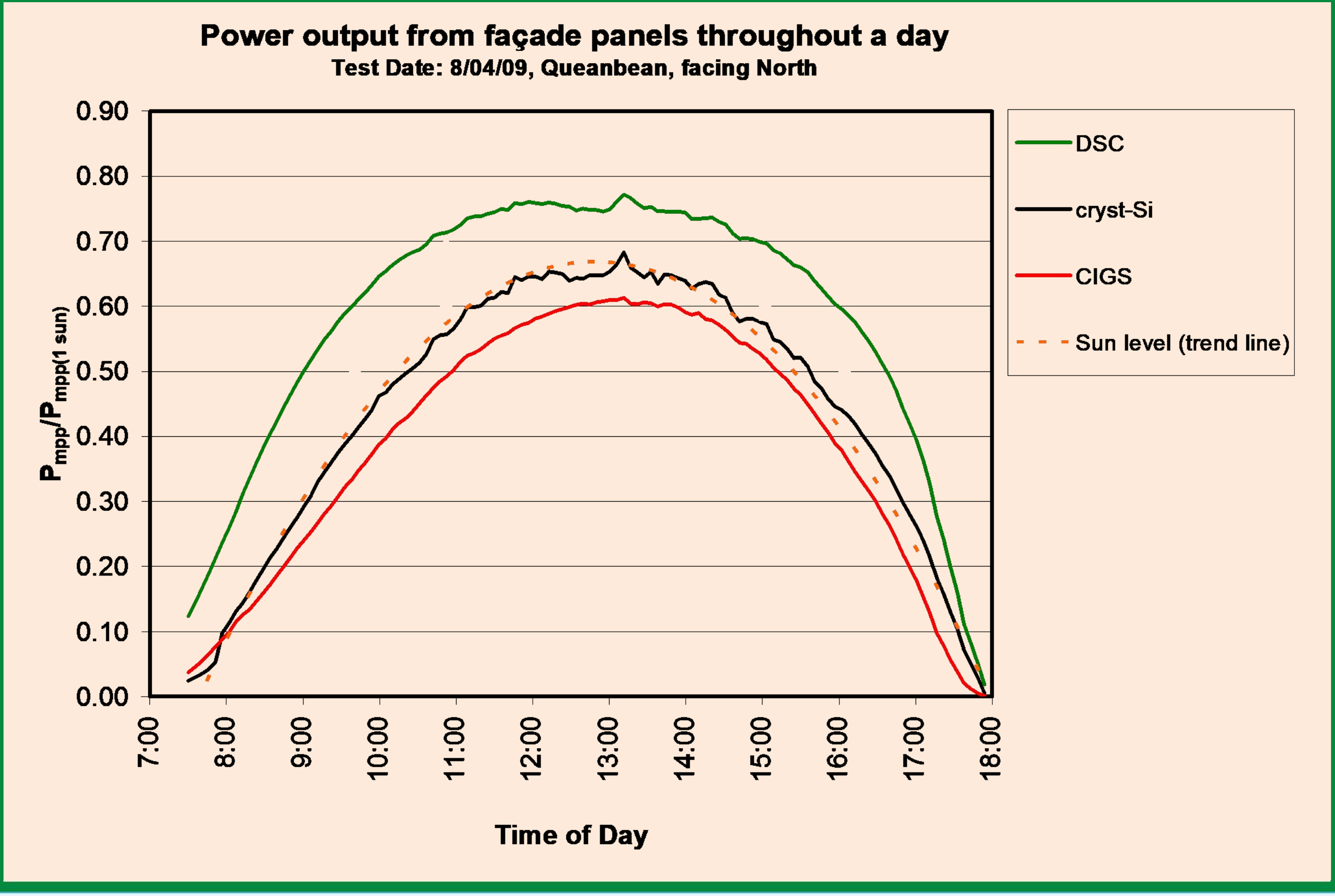


Shotton, Wales UK

Outdoor tests in Shotten,Wales reveal advantages of Dye sensitized Cells



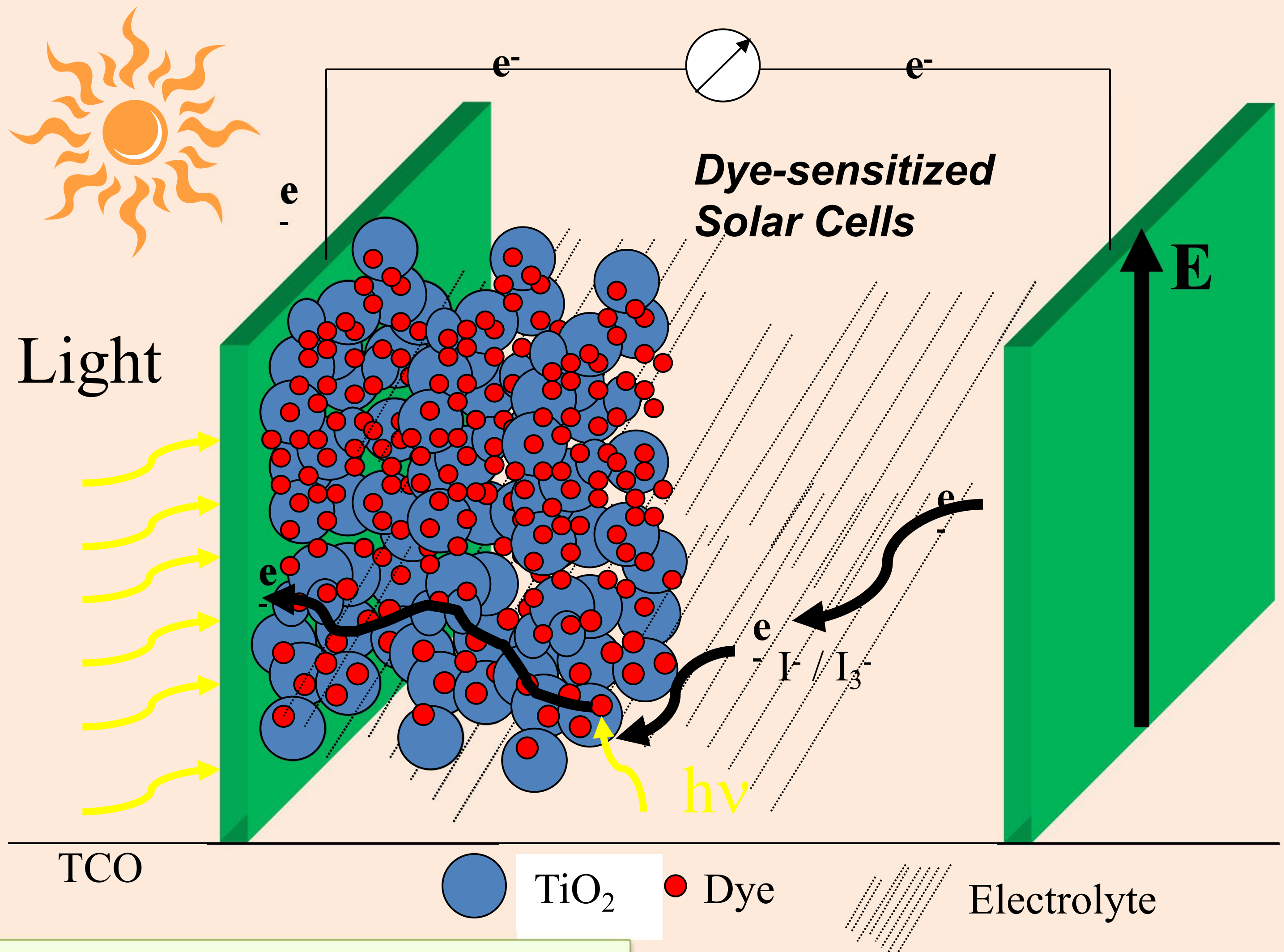
Higher Energy collection efficiency of DSC in façade application provides advantage over competition



- Significantly higher output in the morning and evening hours
- In façade orientation: **+75%** (or higher)relative energy output every day due to better light harvesting of the DSC at low incident light angles.

DYESOL

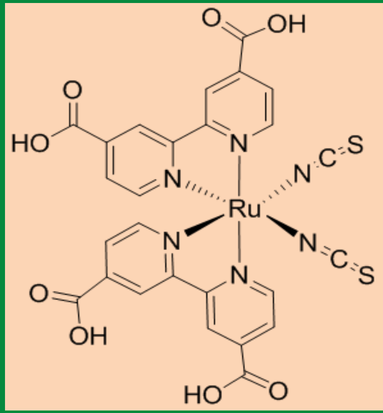
Typical architecture of a mesoscopic dye sensitized solar cell



Nature, 1991, 353, 7377.
J. Phys. Chem, 1990, 94, 8720.

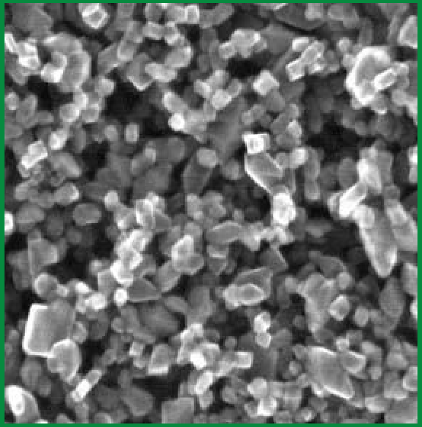
The three key ingredients of dye sensitized solar cells

Sensitizing Dye



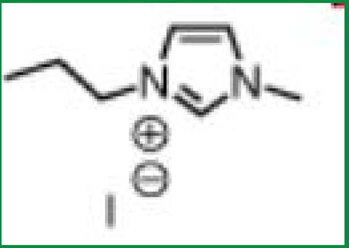
Chemical Structure of N3 Dye

Titania Nanoparticles



20 nm Titania nanoparticles

Electrolyte



Ionic liquid
Iodide/tri-iodide
redox couple

1991 Publication in Nature introduces first photovoltaic cell with a 3D mesoscopic junction archtectture

A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films

Brian O'Regan* & Michael Grätzel†

Institute of Physical Chemistry, Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland

THE large-scale use of photovoltaic devices for electricity generation is prohibitively expensive at present: generation from existing commercial devices costs about ten times more than conventional methods[1]. Here we describe a photovoltaic cell, created from low- to medium-purity materials through low-cost processes, which exhibits a commercially realistic energy-conversion efficiency. The device is based on a 10-μm-thick, optically transparent film of titanium dioxide particles a few nanometres in size, coated with a monolayer of a charge-transfer dye to sensitize the film for light harvesting. Because of the high surface area of the semiconductor film and the ideal spectral characteristics of the dye, the device harvests a high proportion of the incident solar energy flux (46%) and shows exceptionally high efficiencies for the conversion of incident photons to electrical current (more than 80%). The overall light-to-electric energy conversion yield is 7.1–7.9% in simulated solar light and 12% in diffuse daylight. The large current densities (greater than 12 mA cm^{-2}) and exceptional stability (sustaining at least five million turnovers without decomposition), as well as the low cost, make practical applications feasible.

* Present address: Department of Chemistry, University of Washington, Seattle, Washington 98195, USA.

† To whom correspondence should be addressed.

nature International weekly journal of science

1991

Cited > 20’000 times

nature International weekly journal of science
550 | NATURE | VOL 514 | 30 OCTOBER 2014

The most highly cited research of all times

Rank: **90** Citations: **12,873**

A low-cost, high-efficiency solar-cell based on dye-sensitized colloidal TiO2 films.

O'Regan, B. & Grätzel, M.

Nature **353**, 737–740 (1991).

As off January 21 ,2017 the paper has received 17176 citations (ISI-Web of Science=

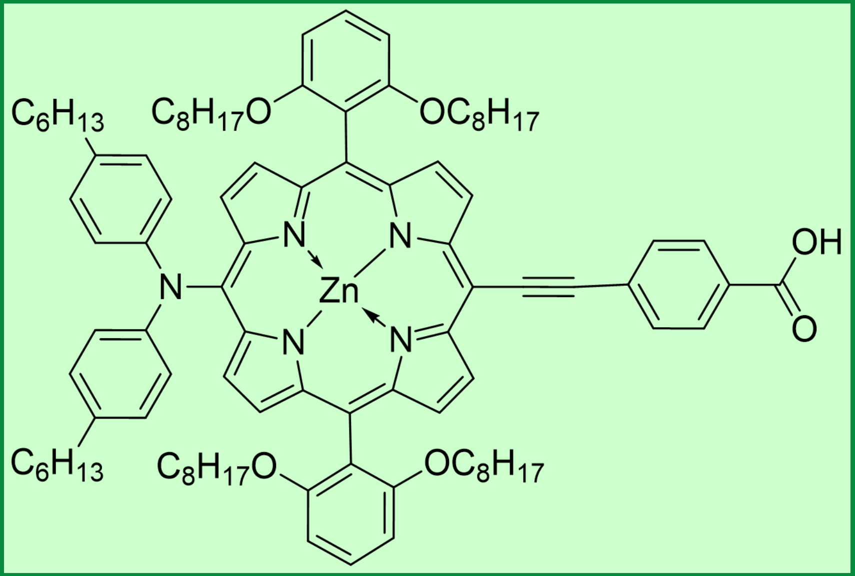
Porphyrin-Sensitized Solar Cells with Cobalt (II/III)–Based Redox Electrolyte Exceed 12 Percent Efficiency

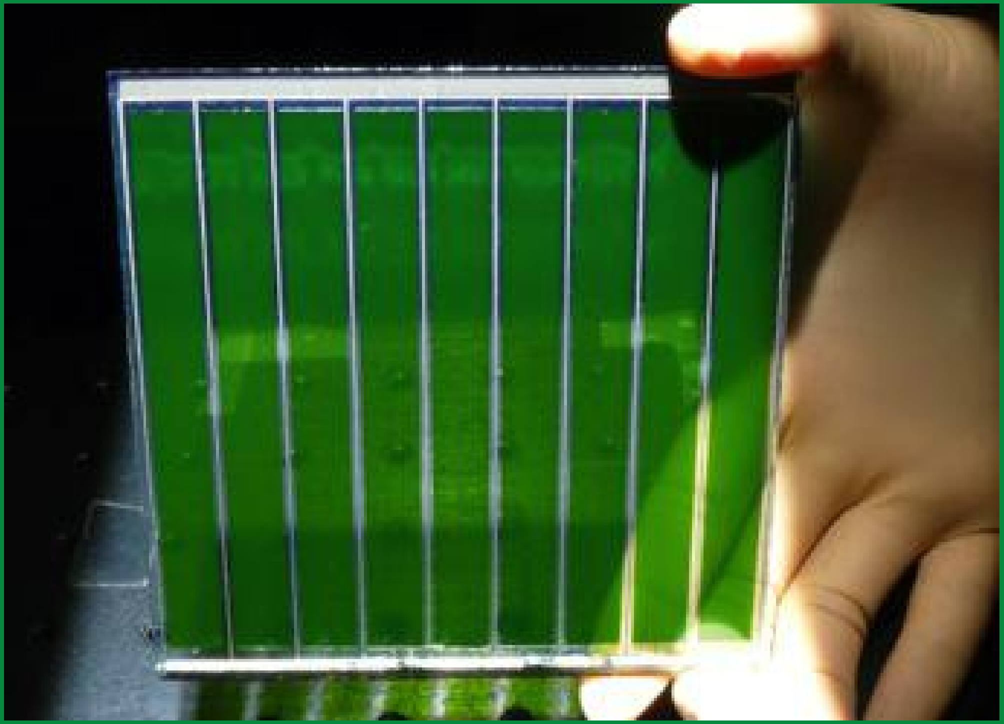
Aswani Yella,[1] Hsuan-Wei Lee,[2] Hoi Nok Tsao,[1] Chenyi Yi,[1] Aravind Kumar Chandiran,[1] Md.Khaja Nazeeruddin,[1] Eric Wei-Guang Diau,[3] Chen-Yu Yeh,[2] Shaik M Zakeeruddin,[1] Michael Grätzel[1]*

over 3600 citations

Science AAAS

Science 2011, **334**, 629 – 634.





ECTRIC POWER PRODUCING GREEN NOISE BARRIER INSTALLED AT THE MOTORWAY BETWEEN BERN AND ZURICH

Electric car charging station powered by green panels

Bridge at lake Geneva in Lausanne

Private home in Basel Switzerland

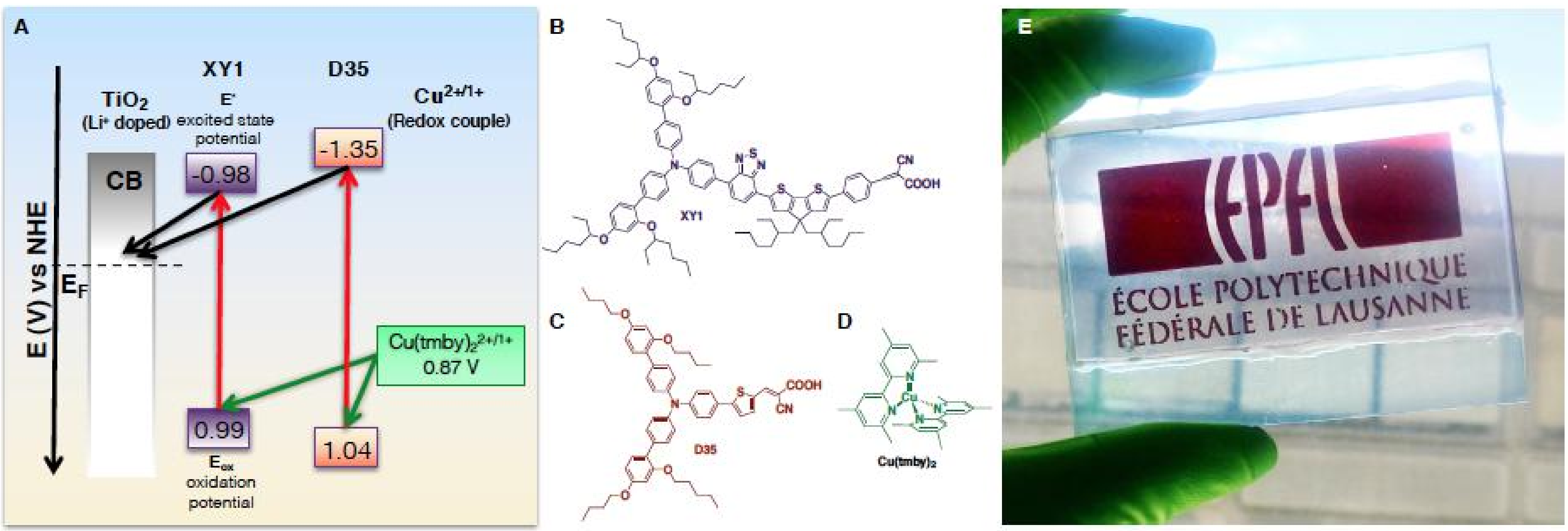
nature photonics

ARTICLES

PUBLISHED ONLINE: 1 MAY 2017 | DOI: 10.1038/NPHOTON.2017.60

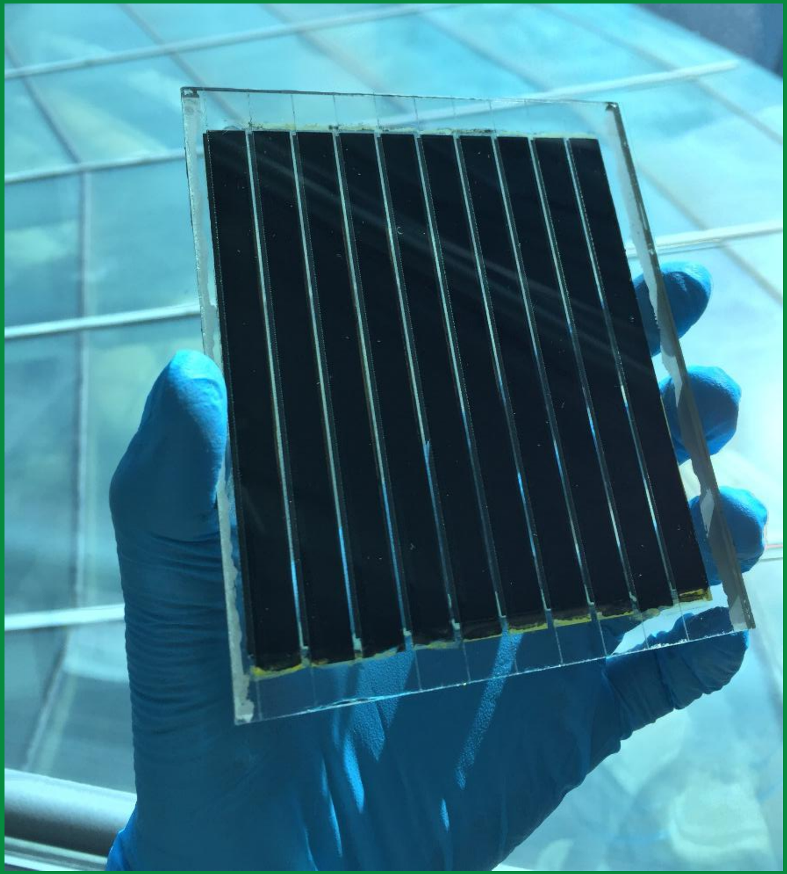
Dye-sensitized solar cells for efficient power generation under ambient lighting

Marina Freitag[1†], Joël Teuscher[2], Yasemin Saygili[1], Xiaoyu Zhang[3], Fabrizio Giordano[4], Paul Liska[4], Jianli Hua[3], Shaik M. Zakeeruddin[4], Jacques-E. Moser[2], Michael Grätzel[4*] and Anders Hagfeldt[1*]



PERVOSKITE PV EMERGED FROM DYE SENSITIZED SOLAR CELLS

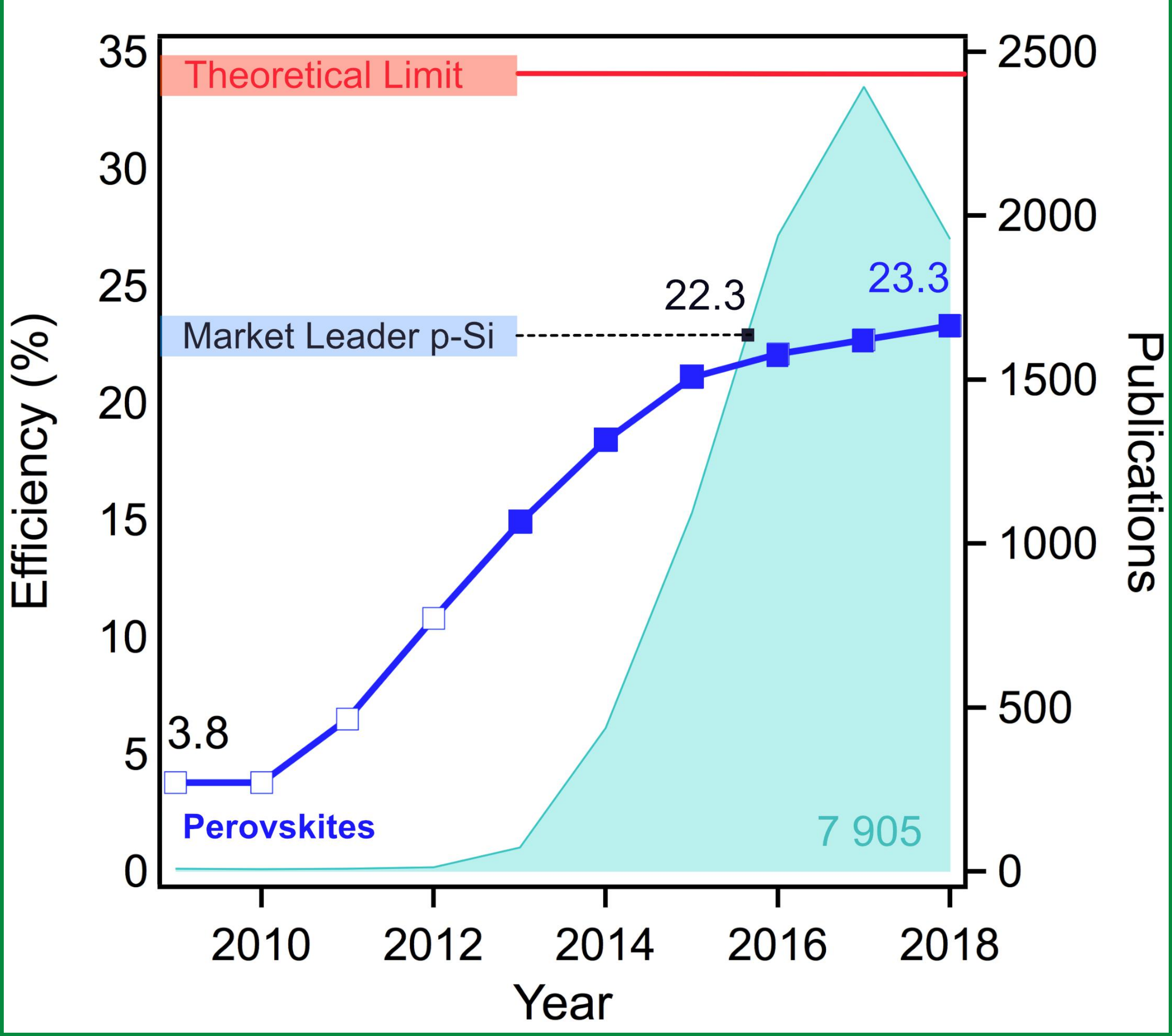
Dye sensitized solar cell (DSC) → Perovskite solar cell (PSC)

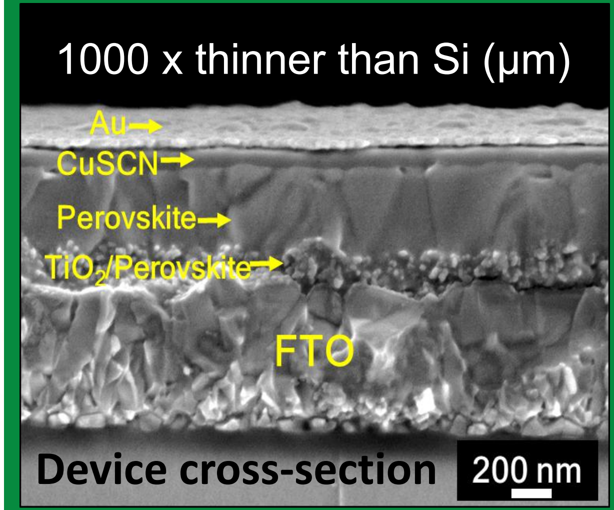


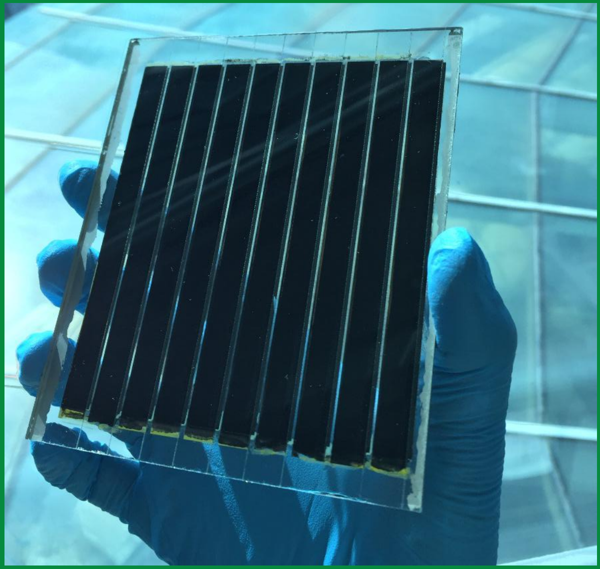
courtesy Sony corporation

Courtesy NTU SIngapore

Metal Halide Perovskites are a Revolutionary Renewable Energy Source



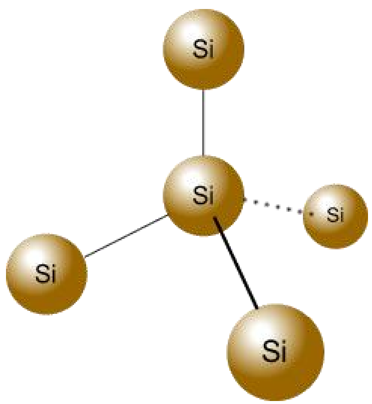




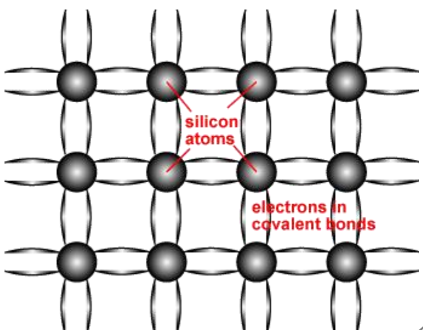
Scopus Analysis (Sep 2018)

Optoelectronic & Structural Complexity: Challenges & Opportunities

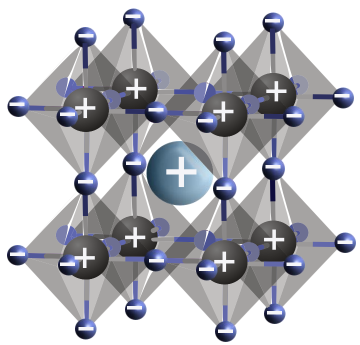
Si Solar Cells



covalent and electronic



Perovskite Solar Cells

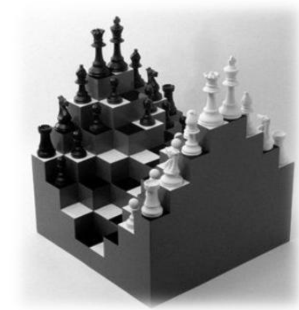


AMX_3

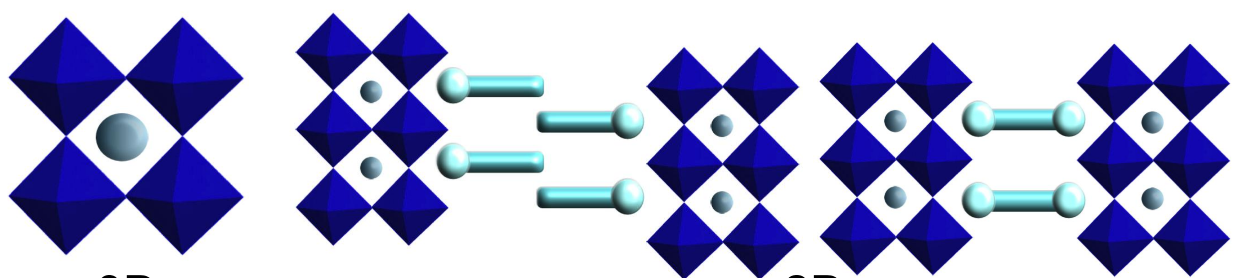
$X^- = I^-, Br^-, Cl^-$

$M^{2+} = Pb^{2+}, Sn^{2+}$

$A^+ = Cs^+, FA^+, MA^+, GUA^+$

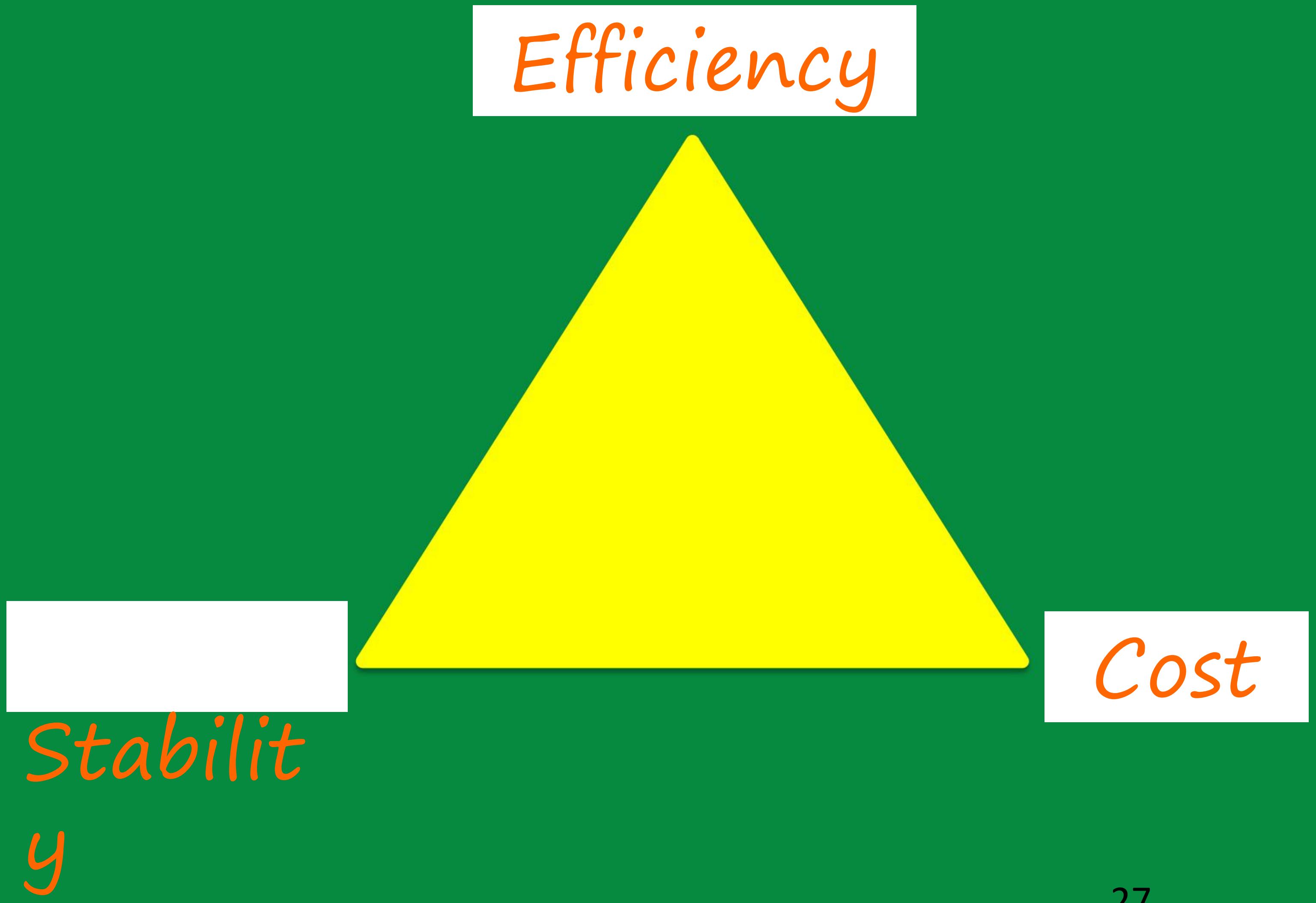


mixed ionic-electronic **hybrid organic-inorganic** **multidimensional**



3D 2D

The “Golden Triangle” of photovoltaics



OUTLINE

- Our motivation, inspiration and research approach
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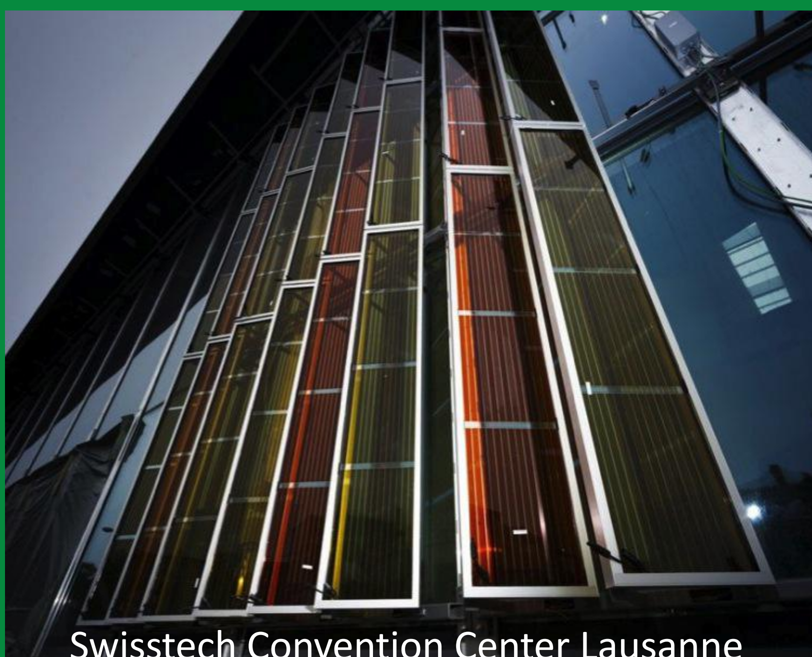
Graz Science tower

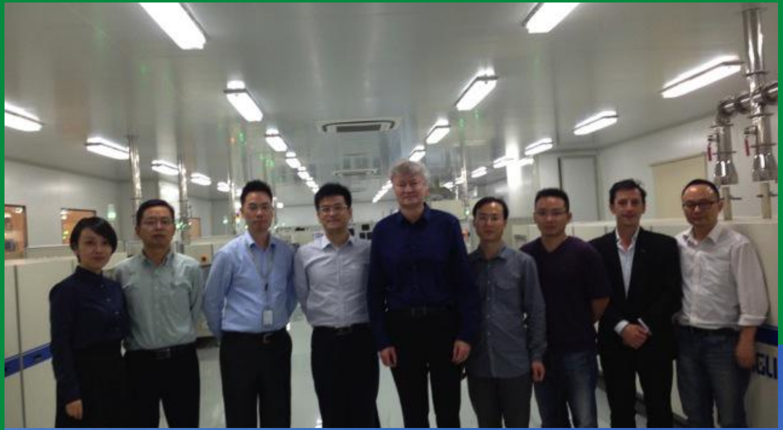


Swisstech Convention Center Lausanne

DSC 모듈 건물입면 설치

Dr. Shen Hujiang, project manager for DSC deployement supervises PV curtain installation on buildings in Shanghai China

Since 1928
SICCAS



MASS PRODUCTION OF DYE SENSITIZED SOLAR CELLS IN CHINA

1991年，瑞士科学家格兰泽尔教授将纳米技术引入太阳能电池的制备工艺，染料敏化太阳能电池由此发明。染料敏化太阳能电池（Dye Sensitized Solar Cell，简称 DSSC）是模仿光合作用原理研制的一种新型太阳能电池，能耗低、无毒、无污染、环境友好。“看到上海硅酸盐所的研究者们努力开发出 DSSC 生产技术，并向工业技术转化，我感到非常荣幸。”染料敏化电池的发明者、瑞士联邦理工大学教授格兰泽尔也在签约现场发来视频祝贺。

ENERGY

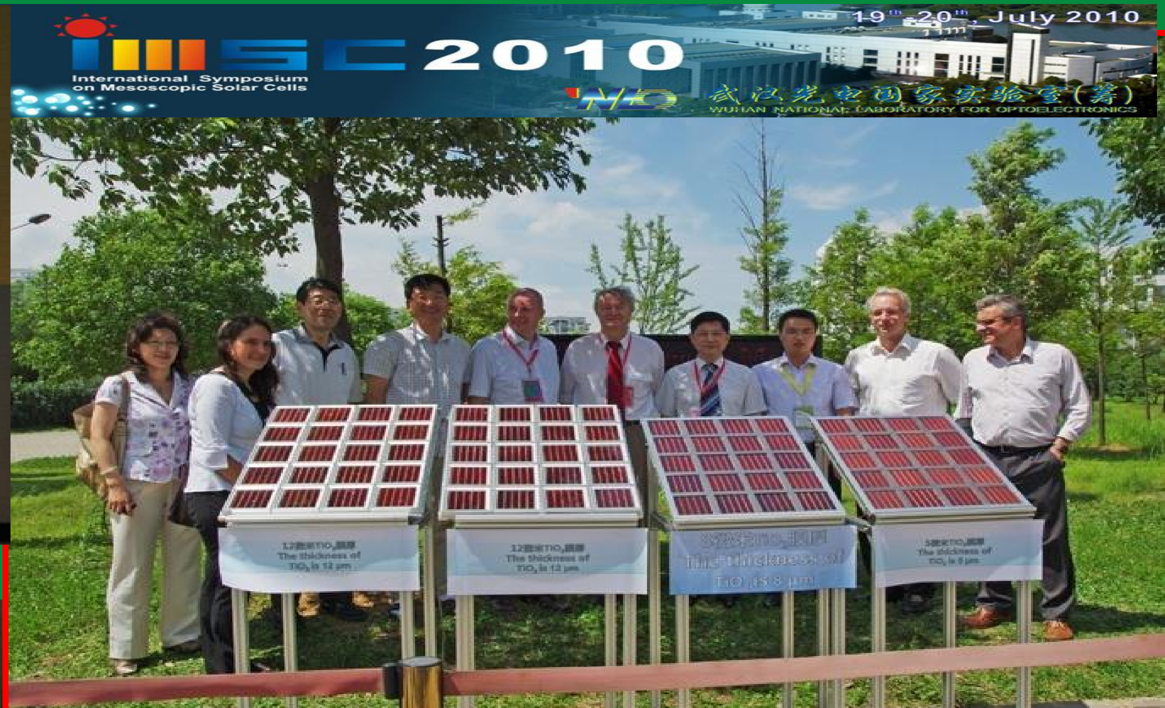
Advanced solar cells ready for production

Third-generation design abandons silicon, mimics photosynthesis for high performance

“The third generation (solar cell) is able to work even indoors or on cloudy days or when the sunshine slants through.”

Liu Yan, senior official from the Shanghai Institute of Ceramics

inauguration of the Michael Graetzel Center (MGC) for mesoscopic solar Cells at the Optoelectronic Laboratory, HUST, Wuhan   in July 2010

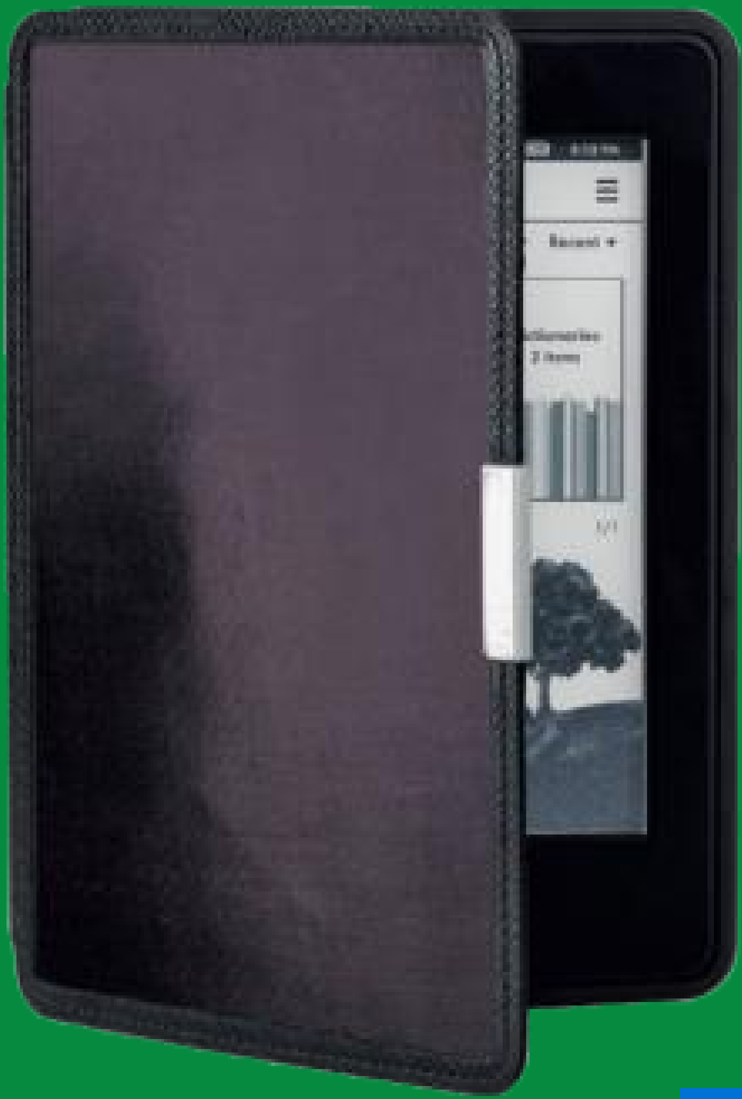


MGC
太阳能电池研究中心
格兰泽尔介观太阳能电池研究中心
Michael Grätzel Center for Mesoscopic Solar Cells

July 2010

Battery-free display powered by dye sensitized solar cells

E-READER POWERED BY MOLECULAR PHOTOVOLTAICS



E-reader with eternal life.

The Swedish company EXEGER has developed the prototype pictured here through seamless integration of the world's best indoor solar cell. The product has eternal life in standard indoor illumination alone.

http://www.exeger.com/

EXEGER manufactures dye-sensitized solar cells

EXEGER ,STOCKHOLM IS HIRING TO MEET INCREASED MARKET DEMAND

We are very grateful for financial support from

- Swiss CTI , CCEM-CH
- Swiss National Science Foundation, Swiss Energy Office
- Horizon 2020 European Joule Projects: GOTSOLAR
- European Research Council: Adv. Research Grant MESOLIGHT
- The Balzan Prize Foundation
- Marie Curie Actions
- Industrial Partners

GOT SOLAR

Funded by the Horizon 2020 Framework Programme of the European Union

Global Energy
The International energy prize

مدينة الملك عبدالعزيز
للعلوم والتقنية KACST

Eric and Sheila Samson Prime Minister's Prize for Innovation in Alternative Fuels for Transportation

MILLENNIUM TECHNOLOGY PRIZE

Technology for humanity

BALZAN

Fuel Choices Initiative
Prime Minister's Office


EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Anzère, Valais Switzerland group skiing day