Solar Energy in MIB-Solar

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Department of Materials Science

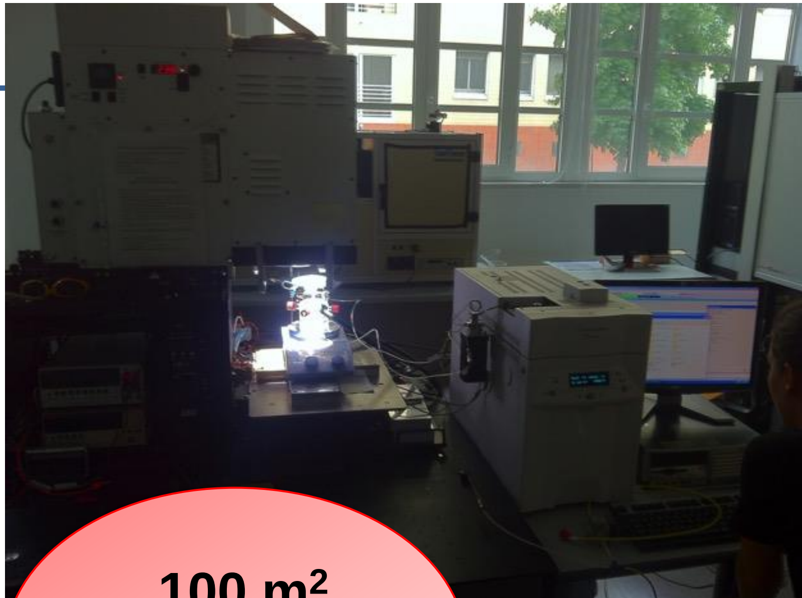
The Jacob Blaustein Center for Scientific Cooperation
The Jacob Blaustein Institutes for Desert Research
Ben-Gurion University of the Negev

Ilse Katz Institute for
Nanoscale Science and Technology

ENEA
Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

Ministry of National infrastructure,
Energy and Water Resources
www.energy.gov.il

MIB-SOLAR clean room



100 m^2
ISO 7
clean room

www.mibsolar.mater.unimib.it

fully equipped synthesis and characterization labs

MIB- SOLAR Facilities

- ✓ Main facilities for the preparation of CIGS and DDSC cells and panels (sputtering system, nitrogen and argon filled glove box, laser scribing machine, titanium hotplates, screen printers, UV-ozone cleaners)
- ✓ main facilities for the full characterization of any solar devices (solar simulators up to 6 x 6 inches, I/V, EQE, light soaking chamber for cell ageing, stability studies, electrochemical impedance spectrometer).
- ✓ fully equipped laboratories for organic synthesis and characterization;
- ✓ fully equipped laboratories for optical , structural and electrochemical investigation (PL ; PLE , ABS, Raman, XRD, EBIC, Hall set-up ..);



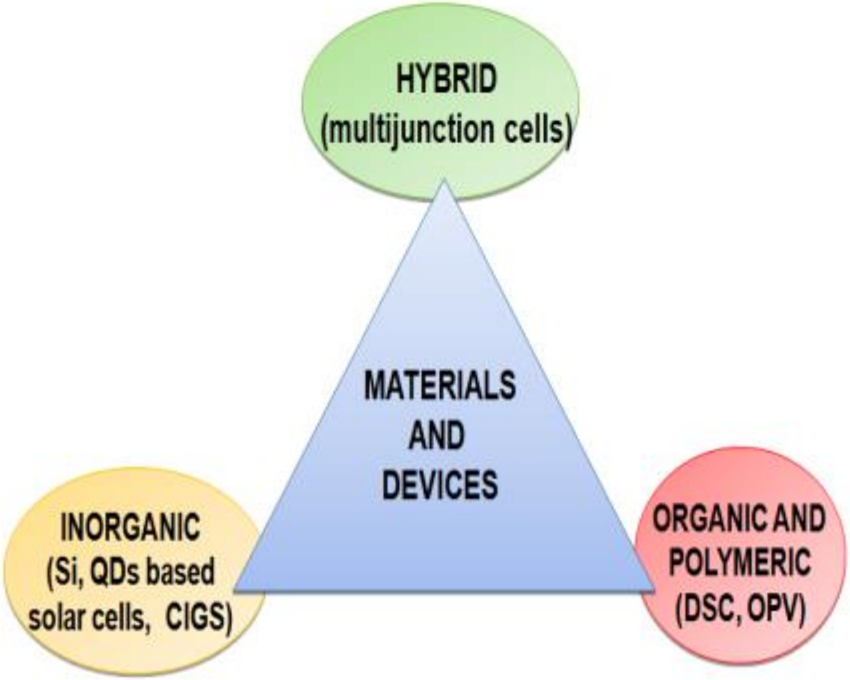




Research lines at MIBSOLAR

- Development of a new deposition procedure to growth Cu(InGa)Se2 thin film solar cells (M.Acciarri, S. Binetti, L. Miglio)
- Kesterite: a new material for thin film solar cells deposited by sputtering and chemical methods (S. Binetti, M.Acciarri)
- Nanocrystalline silicon solar cells (nc-Si:H) (S. Binetti, M. Acciarri, E. Bonera, M. Guzzi)
- Solar Grade Silicon (S. Binetti, M. Acciarri)
- Thin film Si QDs solar cells (M. Acciarri, S. Binetti)
- Light harvesting to increase the efficiency of silicon solar cells: (S. Binetti, M. Acciarri)
- Dye-Sensitized Solar Cells (DSC): Materials and Devicesv(A. Abbotto)
- Small-molecule and polymeric heterojunction solar cells: materials and devices (A. Abbotto, C. M. Mari, R. Ruffo)
- Solar cells of the third generation based thin and individual organic semiconductor crystal film(A. Sassella, A. Papagni, M. Moret, A. Borghesi)
- Panchromatic squaraines for hybrid and organic photovoltaic cells (G. A. Pagani L. Beverina)
- Structure and properties of photoactive materials for catalysis and organic-inorganic solar cells (G. Pacchioni, C. Di Valentin, L. Giordano).
- Computational Science conductivity in nanostructures: ab initio treatment of characteristic processes for the components of organic and hybrid photovoltaic cells(G.P. Brivio).

MIB-SOLAR: Milano-Bicocca Solar Energy Research Center



- Silicon solar cells
- CIGS - CZTS thin film solar cells
- Triple junction solar cells (InGaP/GaAs/Ge)
- Light harvesting, spectrum modification
- Si Quantum dots solar cells

<u>M. Acciarri</u>
S. Binetti

- Organic solar cells
- Dye sensitized solar cells

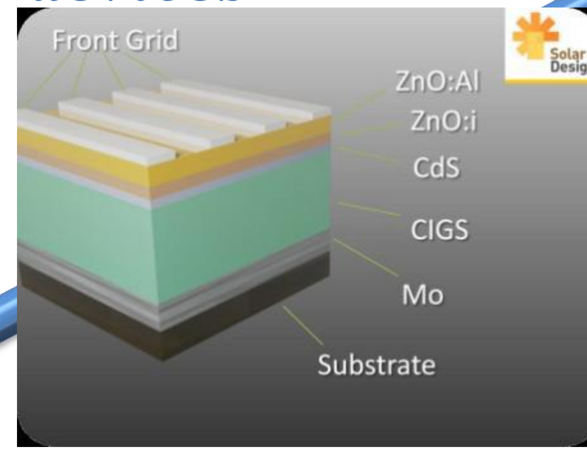
A. Abbotto

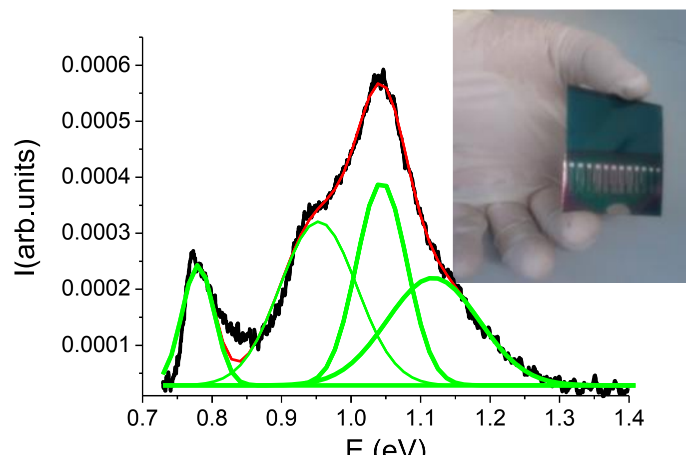
- Modeling and Theoretical activities

The Centre owns its main skills, in the capture and conversion of solar energy from conventional crystalline silicon to new generation inorganic, organic and hybrid thin film devices.

MIB-Solar

Inorganic Photovoltaic devices





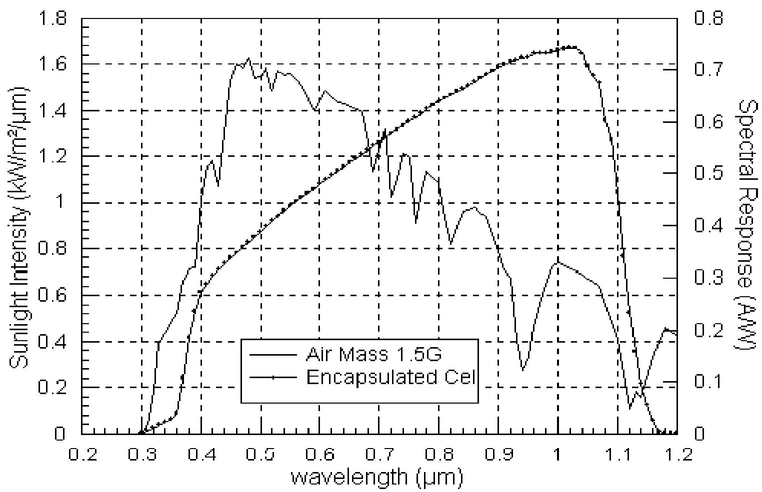
M. Acciarri and S. Binetti group

Research lines: Silicon solar cells

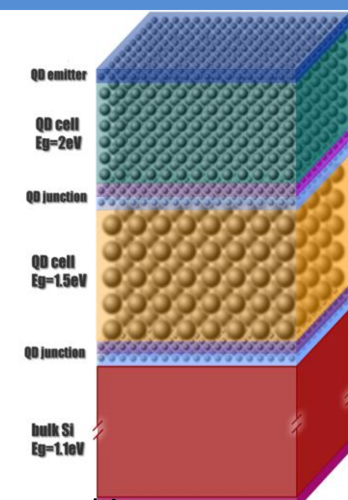
Increase the ratio Efficiency /cost

Use UMG Si

Light harvesting



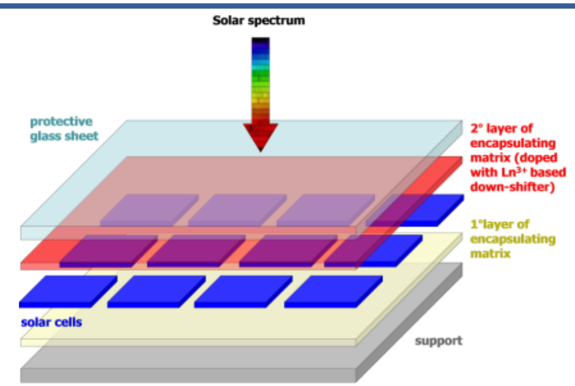
3th generation silicon based solar cells



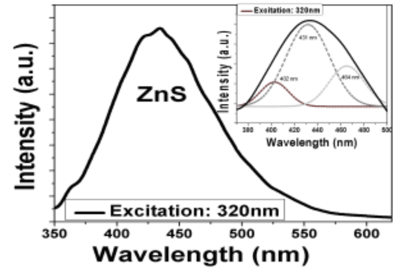
Target 0.20 $/Wp – η = 40 %

Inorganic Photovoltaic materials and devices

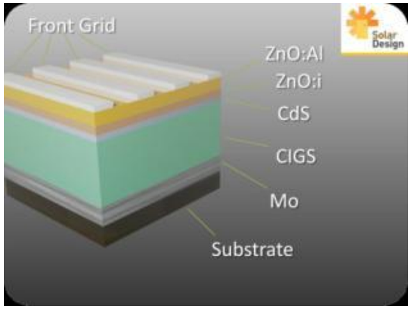
- **c-Silicon solar cells**
  - **Since 1990** involved in EU project on silicon solar cells
  - mc –Si: role of defects (dislocations, grain boundaries)
  - Metallurgical silicon : defect and compensation effect
  - Light harvesting, (EVA doped with Eu complexes)
  - multilayer quantum dots based material



S. Binetti et al. Solar Energy Materials & Solar Cells 130 , 696 (2014)
C.Modanese et al . Prog. Photovolt: Res. Appl. (2013)
S.Binetti et al. International Journal of Photoenergy, ID 249502, 6 pages,(2013)
A.Le Donne et al. J. Appl. Phys. 113, 014903 (2013)
M.Morgano et al. Science of Advanced Materials 3, 388 (2011).
A.Le Donne et al Optical Materials 33, 1012, (2011)
R.Slunjski et al. Solar Energy Materials & Solar Cells 95, 559-563 (2011)
M.Tajima et al. J. Appl. Phys. 110, 043506 (2011)

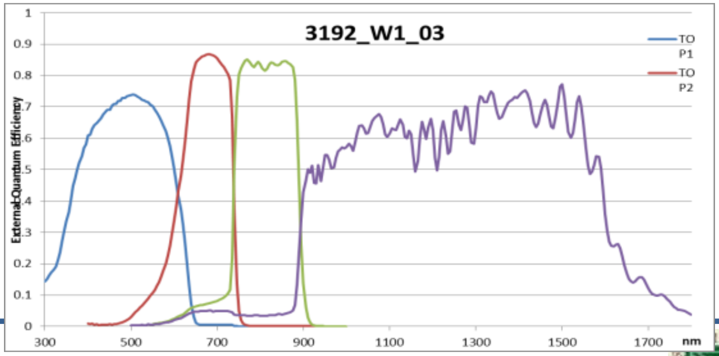


- **Inorganic thin-film technologies**
  - $Cu(In,Ga)Se_2$
  - CZTS



- **III-V based Tandem solar cells**
  - AlInGaP and AlInGaAs for 32% four junction devices for concentration application (CESI Spa)
  - GaAs grown on silicon : chracterization (Pilegrowth s.r.l)

A. Le Donne, et al. Solar Energy Materials & Solar Cells ***94,*** *2002 (2011)*
R.Campesato, et al. Proc. EUPVSEC 2013 (2013)



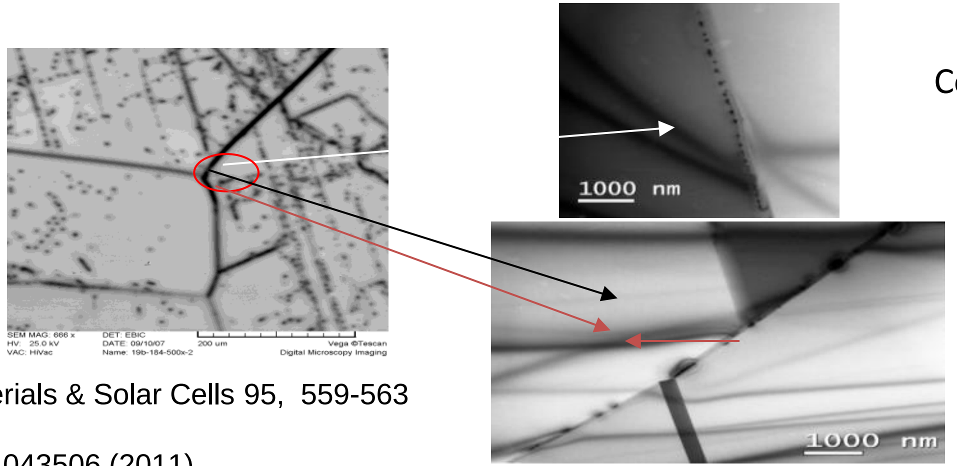
Research lines: Silicon solar cells

Advantages:
- lower cost
- lower energy payback time
- Lower carbon footprint

Drawbacks :
- Low purity

Metallic concentration can be reduced by:

But Internal gettering and metallic precipitates should be avoided



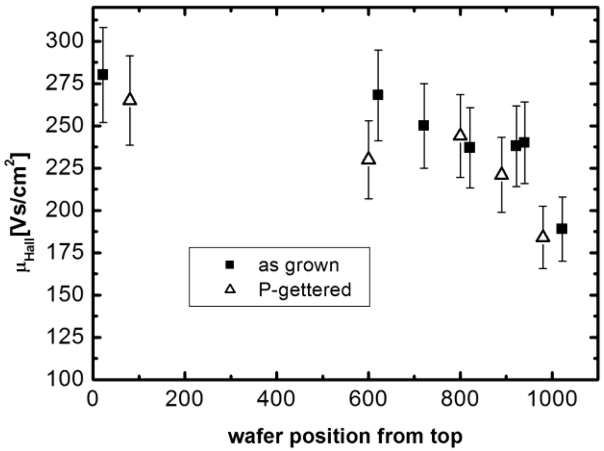
Contaminated with SiO_2

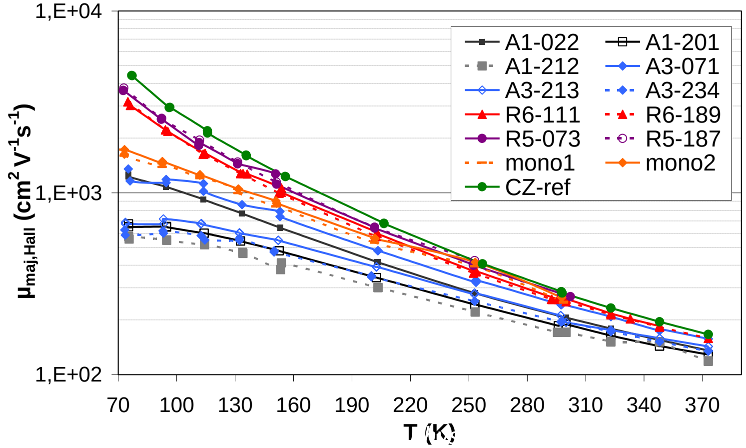
Clean, no EBIC C

Metallic precipitate (Ni, Fe)

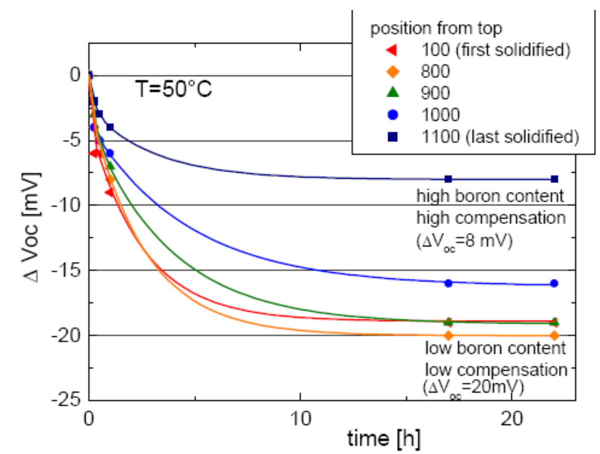
R.Slunjski et al. Solar Energy Materials & Solar Cells 95, 559-563 (2011)
M.Tajima et al. J. Appl. Phys. 110, 043506 (2011)

UMG Silicon solar cells: effect on compensation





➢ *Can lead to carrier lifetime improvements*



➢ Reduction the light induced degradation effect (B-O complexes)

R. Kopecek, S. Binetti , M. Acciarri et al, , Proc. 23rd PVSEC, Valencia, Spain (2008)

S. Binetti, G. Coletti , M.Acciarri IEEE PV 2014

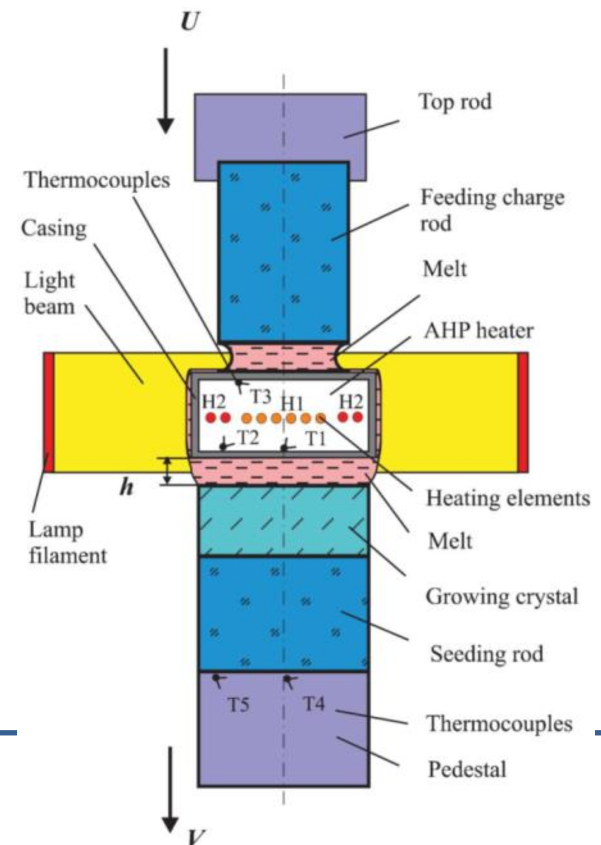
S. Binetti et al. Solar Energy Materials & Solar Cells 130 , 696 (2014)
C.Modanese et al . Prog. Photovolt: Res. Appl. (2013)
S.Binetti et al. International Journal of Photoenergy, ID 249502, 6 pages,(2013)

Silicon sample for PV application grown under reduced melt convection

- Aim is to characterize solar silicon samples grown in microgravity conditions
- (ESA project A0-2009-1051 and Disk Project : a joint Russian- Europe Space Experiments)

Ground-based experiments at University of Freiburg:

Schematics of crystal growth (modified FZ method) in the crucibleless AHP silicon



Advantages :

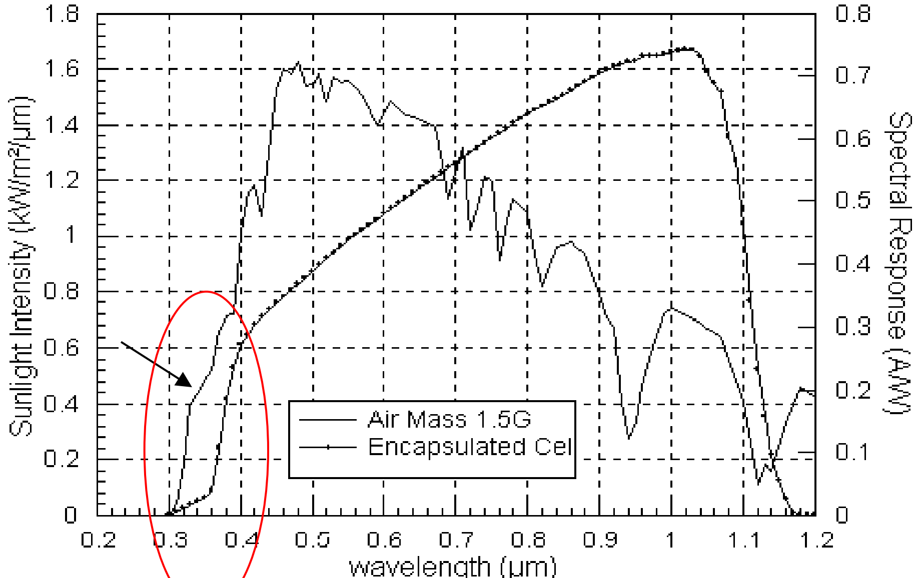
- The melt flow has a laminar characteristic
- close to diffuse regime
- flat shape of the crystallization front

•A. C.Wagner , A.Cröll, M. A.Gonik , H.Hillebrecht, S.Binetti J. of Crystal Growth Vol.401, 762 (2014)

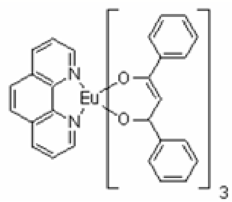
•S. Binetti et al : J. of Crystal Growth (2015) in press

Light harvesting

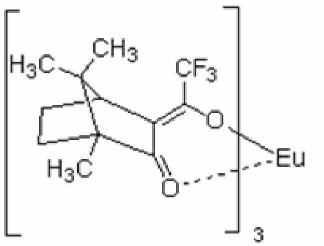
Modify light spectra down converting photons with $E >> E_{gap}$ to photons with energy near the maximum quantum efficiency spectral region on the PV cell



Eu (dbm)$_3$ phen



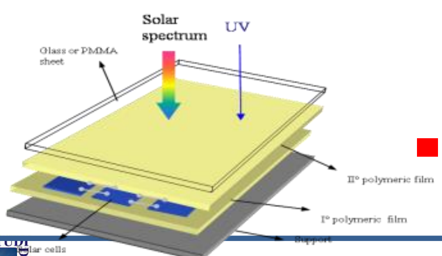
Eu(tfc)3



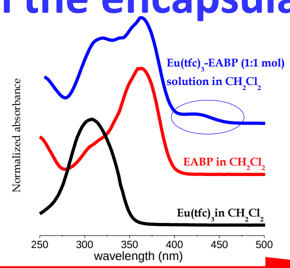
➢ ΔI_{sc} : + 2.7% (relative)

+0,6 % is sufficient to maintain unaffected the Wp price

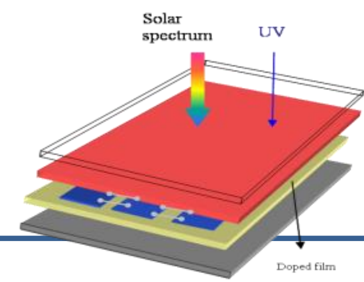
down-shifter dispersed in the encapsulant matrix

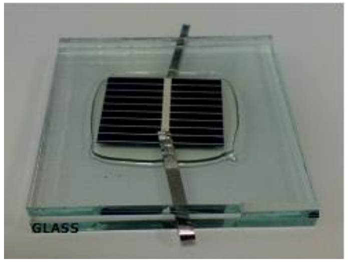


Commercial encasulation scheme for solar modules



Eu3+ Complex



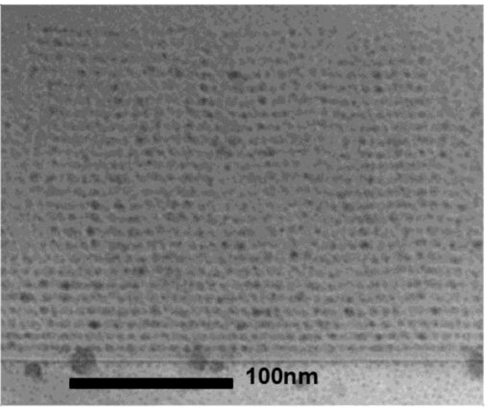


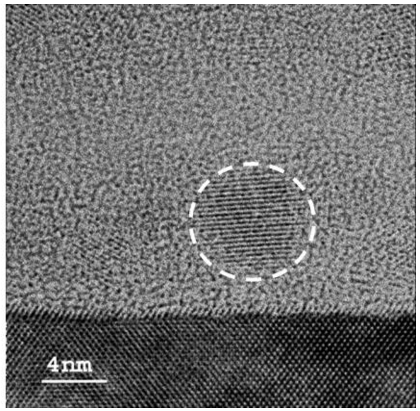
A new material for encapsulation process

Le Donne A, et al. *OPTICAL MATERIALS, vol. 95 (2011), p.1012-1014,*

Si QDs solar cells

The Si QDs were formed by alternate deposition of SiO_2 and silicon-rich SiO*x* with magnetron co-sputtering, followed by high-temperature annealing.





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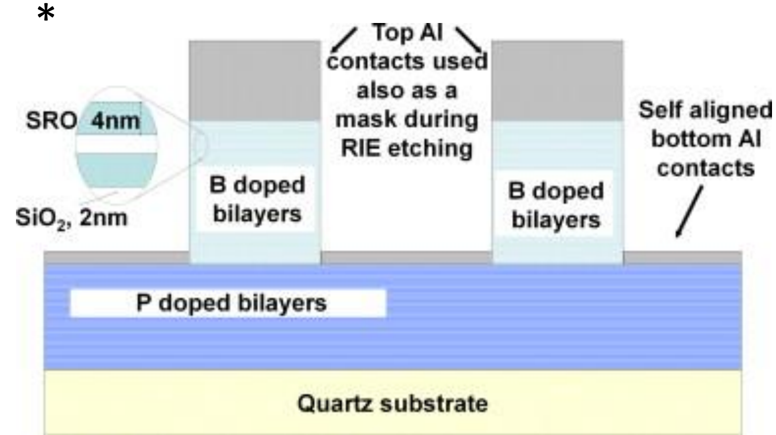
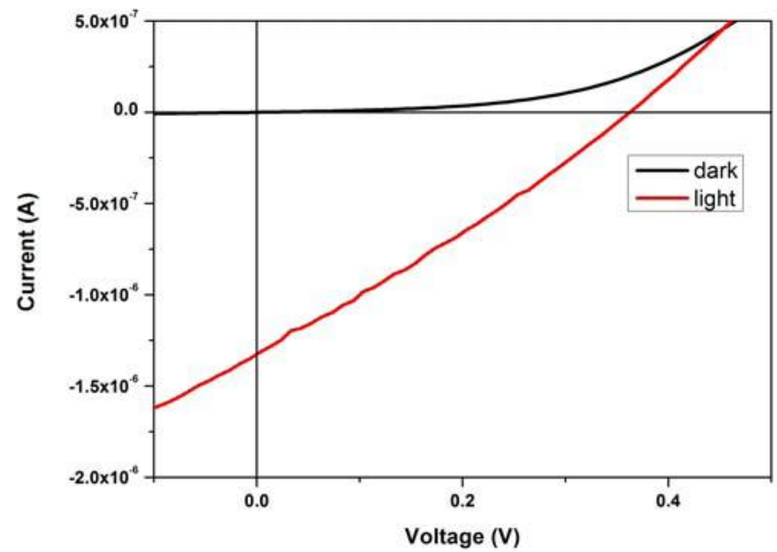


Transport properties, and doping charge collection are crucial



*Iin collaboration with UNSW (Sidney)

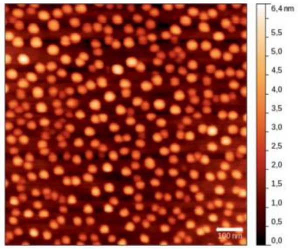
M.Morgano et al. Science of Advanced Materials 3, 388 (2011).

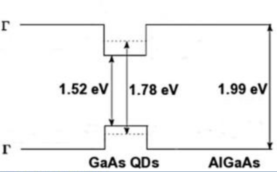
Intermediate band photovoltaic cells

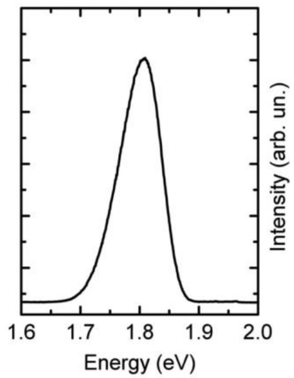
Evidence of two-photon absorption in strain-free quantum dot GaAs/AlGaAs solar cells

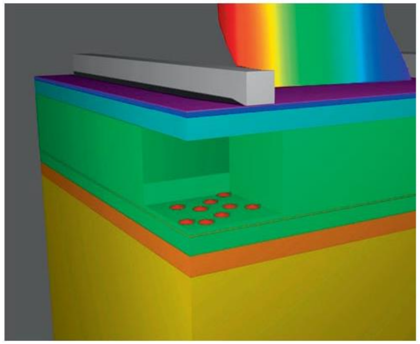
Nanostructured materials grown by Droplet epitaxy (DE), a molecular beam epitaxy variant, due to the absence of strain related defects, the high quality of the interfaces, the good confinement, and the capability to grow high density and large aspect ratio QDs, a perfectlysuited system for the implementation of QD-IBSCs.

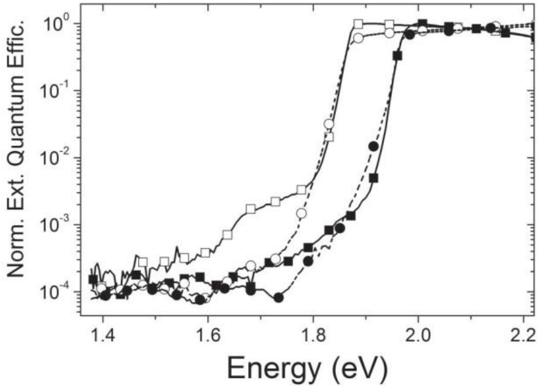
suited system for the implementation of QD-IBSCs.





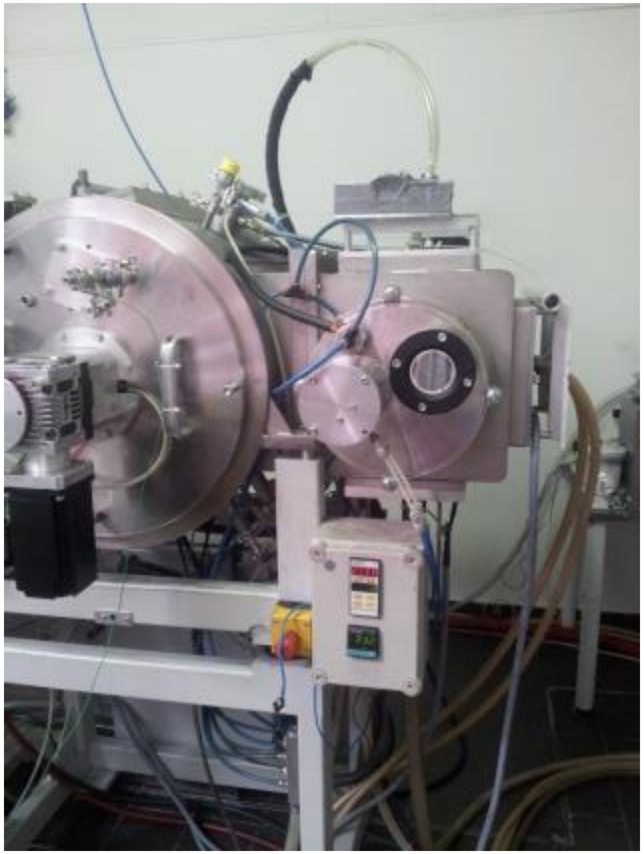






A. Scaccabarozzi et al.: Phys. Status Solidi RRL (2013)

CIGS technology in UNIMIB

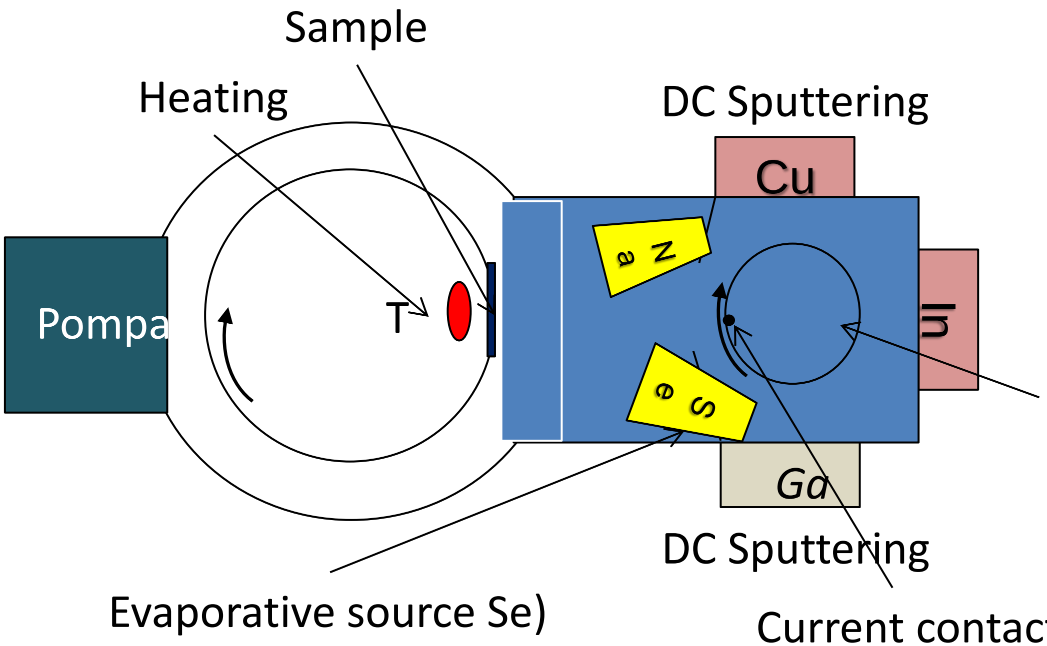


Thanks to the collaboration between the small enterprise Voltasolar S.r.L. e UNIMIB started in 2007, it has been developed an innovative industrial process for the production of the CIGS thin film on flexible substrate

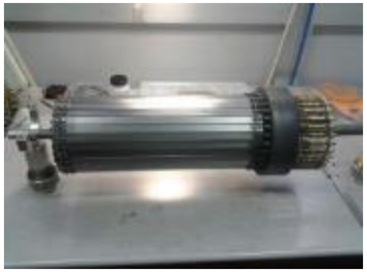
Project SolarDesign (contract no. FP7-NMP-2012-SME-6)
Projects Metadistretti 2008 e 2011 MIUR e Regione Lombardia

CIGS technology in UNIMIB

1. The metal precursors are sputtered on a cylindrical transferring body
2. Metals are then evaporated in Se ambient thanks to a local heating of the graphite elements of the transferring body
3. The process continue since the desiderate thickness is reached.



Cylindrical transferring body

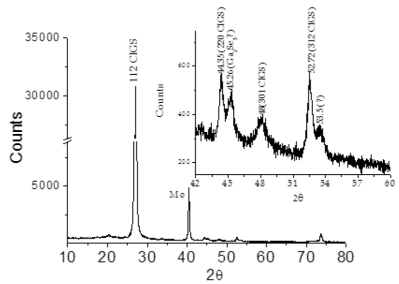


SUBSTRATI:
14 x 11 cm^2 soda lime glss 1 mm
20 x 10 cm^2 Cr stainless steel foil 125 um
20 x 10 cm^2 polyamide 25 um
14 x 11 cm^2 glass foil 125 um

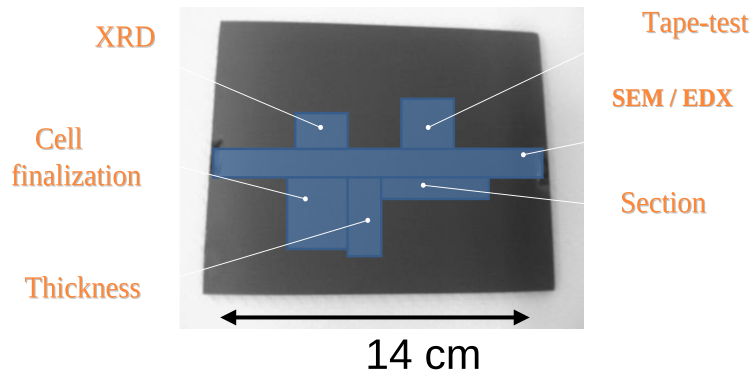
Patent N° EP 13425019.0

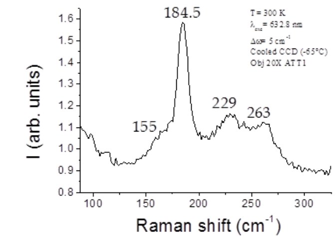
Acciarri et al 2013. PCT European Appl., EP 13425019
S..Binetti,; M. Acciarri et al. Semicond. Sci . Technol. 30 (2015) 105006

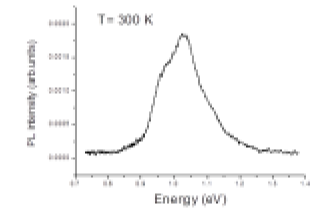
CIGS characterizations



Film di CIGS film



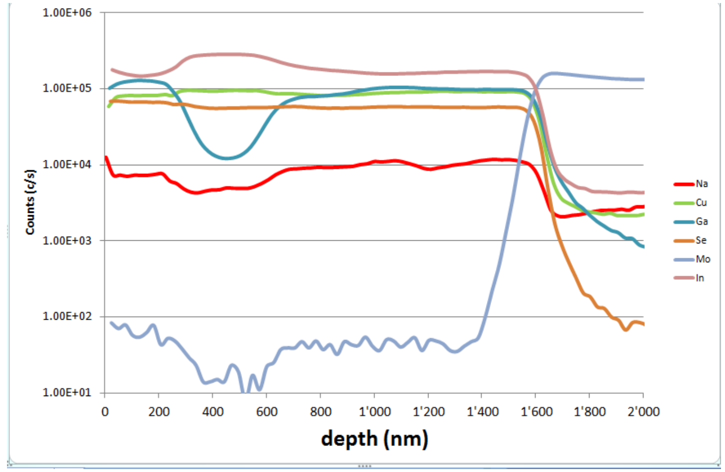




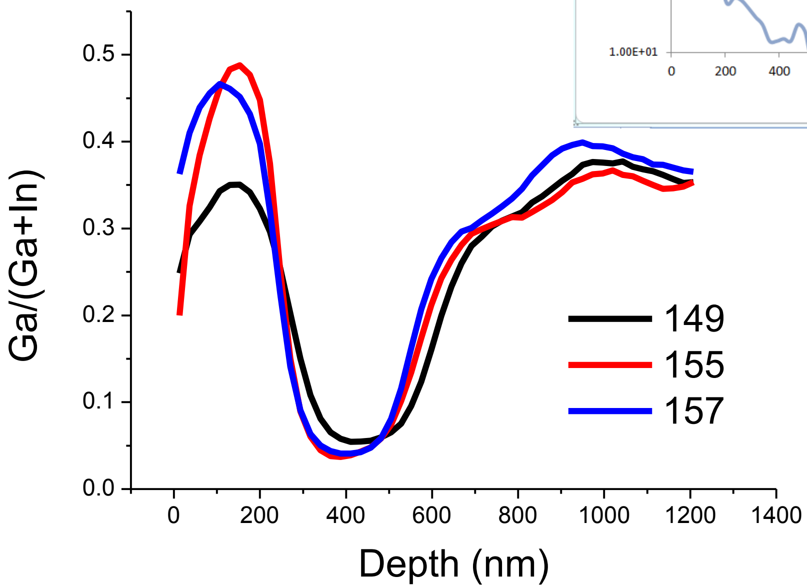
CARATTERIZZAZIONE

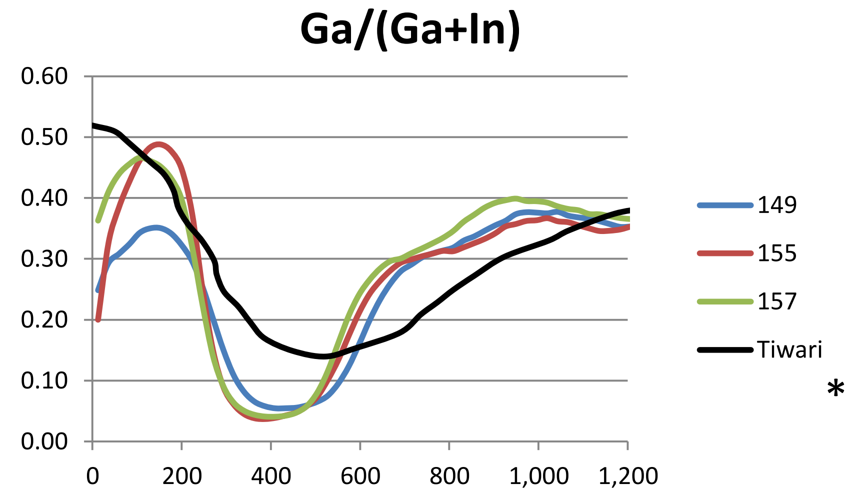
- Scanning electron microscope (SEM) with EDX (morphology and composition)
- XRF (composition)
- *SIMS (University of Trento)* (composition)
- Raman spectroscopy (phase identification)
- Photoluminescence (electrical properties)
- X-ray diffraction (phase identification)
- 4-probes method (resistivity)
- Profilometer (thickness)
- Tape- test (ASTM D 3359-02) (adhesion)

S.I.M.S results *



5.5 keV Cs^+ sputter beam on 200x 200 μm^2





•double grading profile

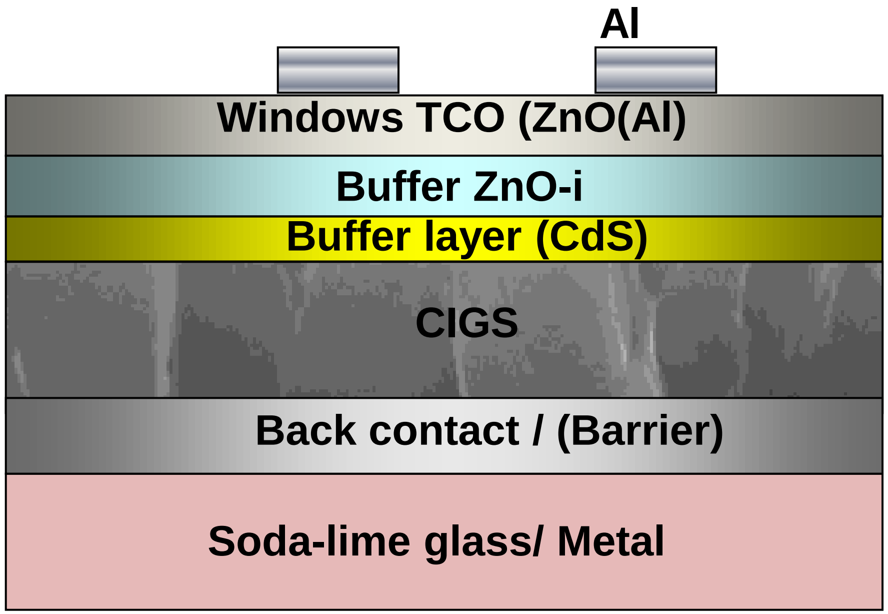
•The “notch” region is less wide, closer to front contact.

• decrease of CGI ratio close to 200 nm

*** Dip di Fisica Università di Padova**

Cell finalization

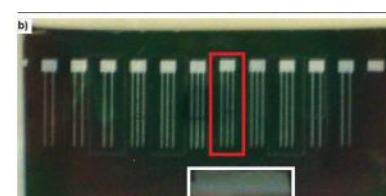
Vacuum | Non vacuum



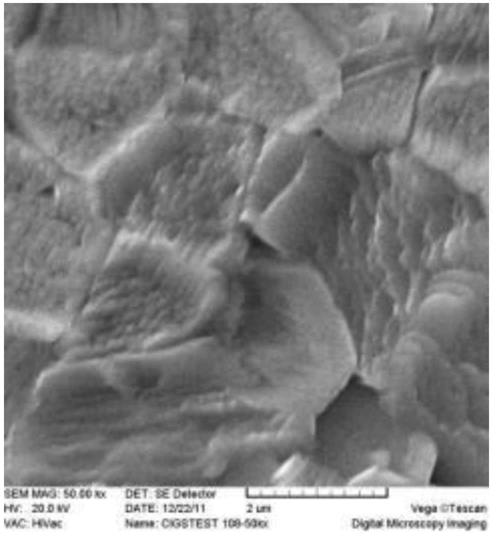
Vacuum process	Layer	Thickness	Non vacuum process
Evaporation	Al	0.4 μm	
	Windows TCO (ZnO(Al))	300-350 nm	
Sputtering	Buffer ZnO-i	80- 100 nm	
	Buffer layer (CdS)	50-70 nm	Chemical Bath Dep.
Sputtering metals + Evaporation Se	CIGS	2-2.5 μm	
Mo sputtering	Back contact / (Barrier)	1 μm	(Sol gel – SiO_x)
	Soda-lime glass/ Metal		

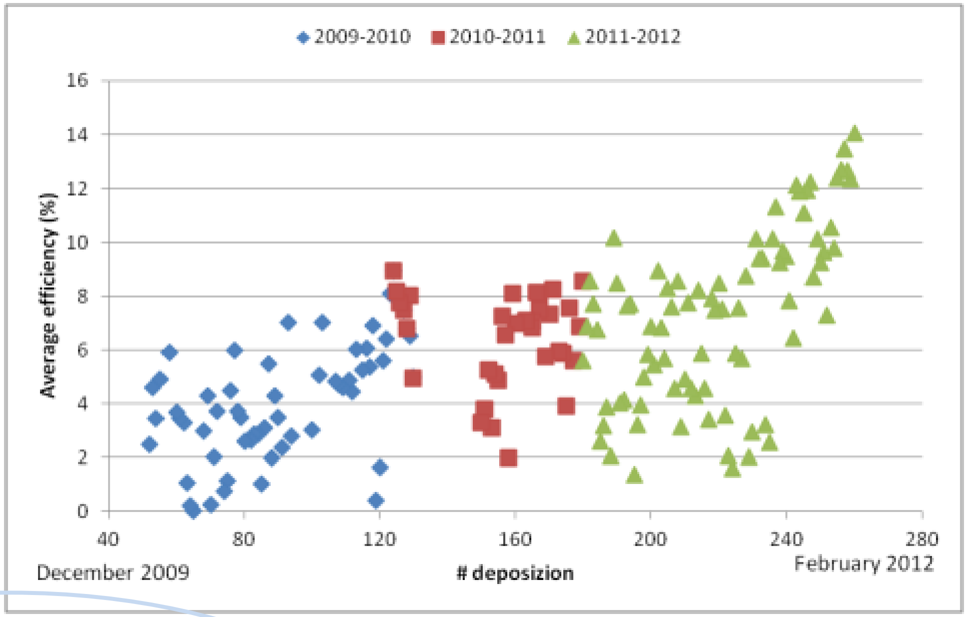
CELL CHARACTERIZATIONS

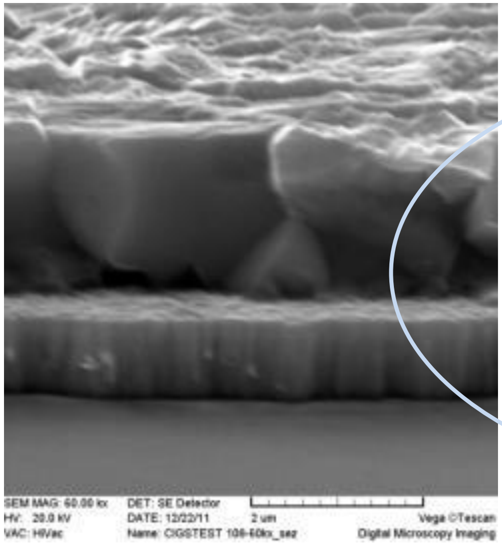
- UV-visible Spectroscopy (CdS,ZnO,ITO optical properties)
- I-V curves (1.5 AM solar simulator) (solar cell properties)
- Scanning electron microscope (section)
- Spectral responce (solar cell properties)
- Electron beam induced current (EBIC) maps (solar cell properties)



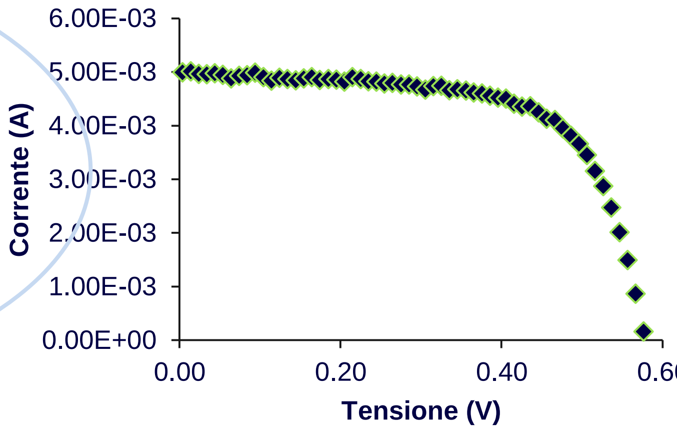
Best result on glass







η [%]:	14.5
Voc [mV]:	**581.71**
FF [%]	72.0
Jsc [mA/cm^2]:	34.572
Area [cm^2]:	0.48
Irrad. mW/cm^2]:	100

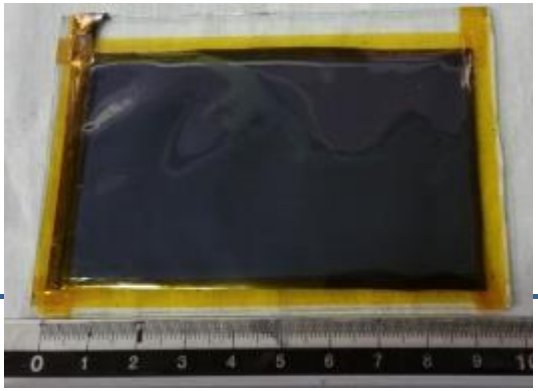


Best results on flexible substrates

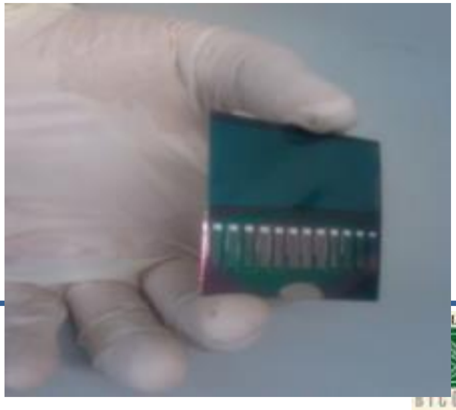
Substrate	Eff (%)	Voc (mV)	Jsc (mA/cm2)	FF (%)	Area cm2
130um glass	9.2	510	27	66	0.15
Stainless steal	13.1	569	34.1	70	0.15
Polyamide	11.7	512	35.6	64.34	0.15

130um glass

Polyamide 25 um



Stainless steal 125 um



From the laboratory to the pilot line

- In 2015, the first pilot line has been installed by Voltasolar in Austria (Sunplugged) and is under testing
- A Roll-to-roll deposition on wide flexible substrates (320 mm) (stainless steal or polyamide)
- Predicted productivity: 1.5-2 MW/y

European Union's Seventh Framework Programme (FP7/2007-2013)

Beyond CIGS solar cells

- Problems:
  - Toxicity (CdS as buffer layer)
  - Material shortage

- Solution:
  - Develop new buffer layers
  - Develop efficient thin-film (TF) photovoltaic (PV) absorbers based on earth-abundant elements!
  - *Cu2M(II)M(IV)S4* chalcogenides using same deposition techniques of CIGS
  - Example: Cu_2ZnSnS_4

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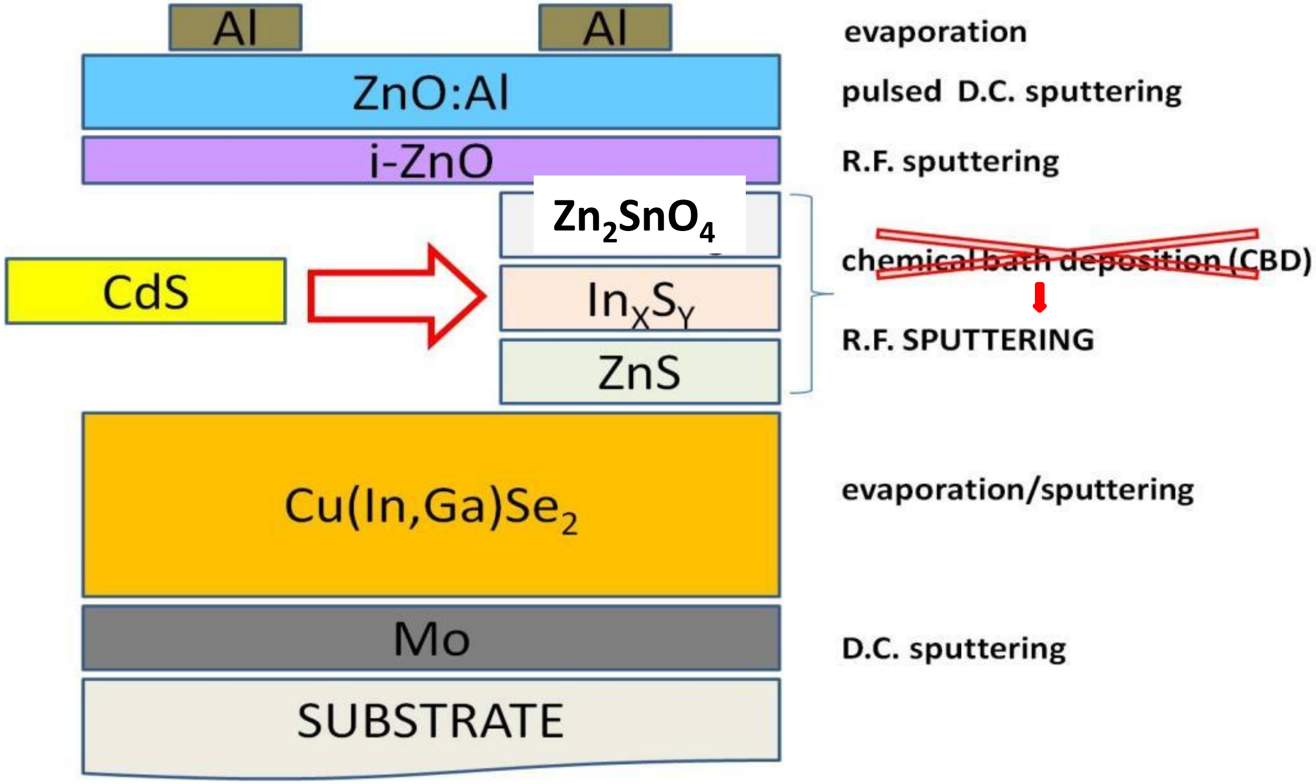
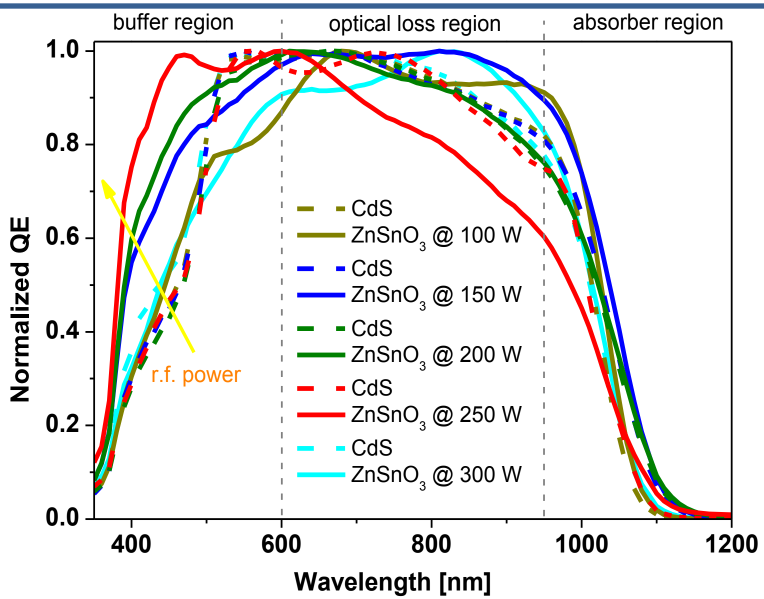
Cd-free alternative buffer layers for Cu(In,Ga)Se2 solar cells



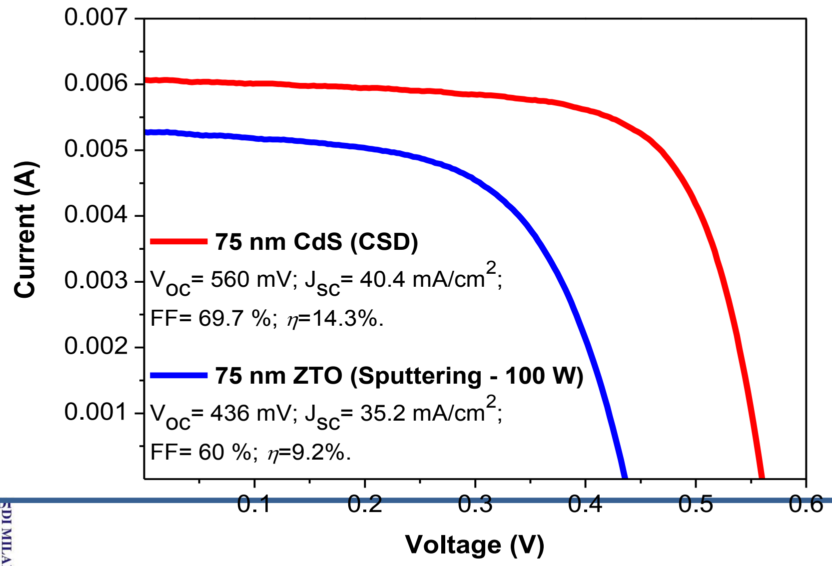
The deposition of the ZTO films was operated both from a ceramic target (75wt% ZnO – 25wt%. SnO_2) and from two metal targets (Zn and Sn) to form a metal bi-layer followed by an oxidation

Mereu R, Le Donne A, Trabattoni S, Acciarri M, Binetti S. JOURNAL OF ALLOYS AND COMPOUNDS, vol. 626, p. 112-117, ISSN: 0925-8388, doi: 10.1016/j.jallcom.2014.11.150

Buffer layer: Zn2SnO4 (c-ZTO)



Size [cm²]	Power [W]	Jsc [mA/cm²]	Isc [mA]	Voc [mV]	FF [%]	Eta [%]
0.15	**100**	**35.2**	**5.3**	**435.7**	**60.0**	**9.2**
0.15	150	34.7	5.2	391.6	55.7	7.6
0.15	200	34.1	5.1	307.9	48.0	5.0
0.15	250	26.0	3.9	198.4	41.8	2.2
0.15	300	28.1	4.2	367.9	53.4	5.5



- *i*-ZnO and AZO front contacts needs to be re-optimized for each new buffer layer

Cu2ZnSnS4 (CZTS) by sputtering

1 . Metal Precursos :

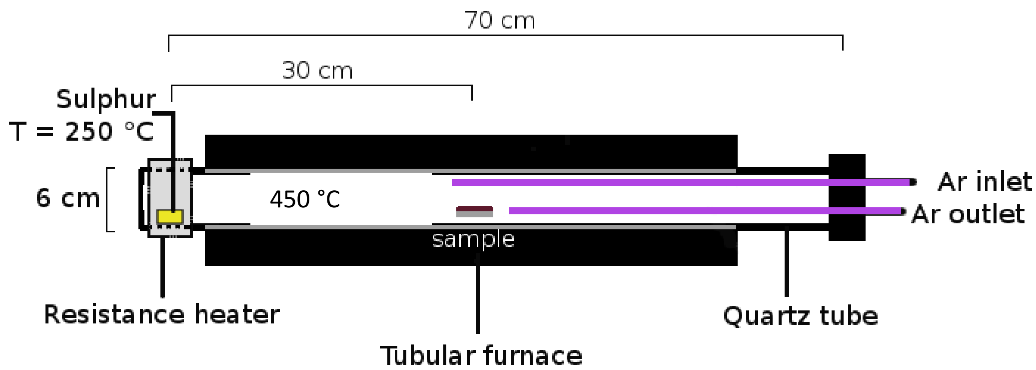
sputtering RF from Cu, Zn, Sn (5N) target on 5x2 cm^2 Mo coated soda lime glasses (SLG)

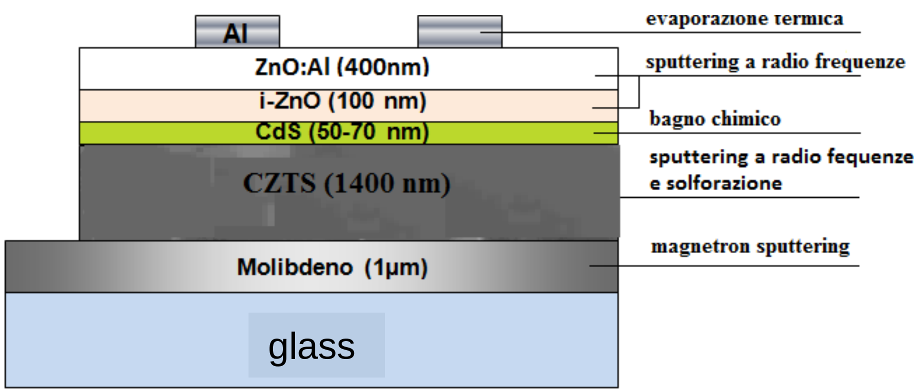
Mo back contact deposited by DC magnetron sputtering (1 µm thick)

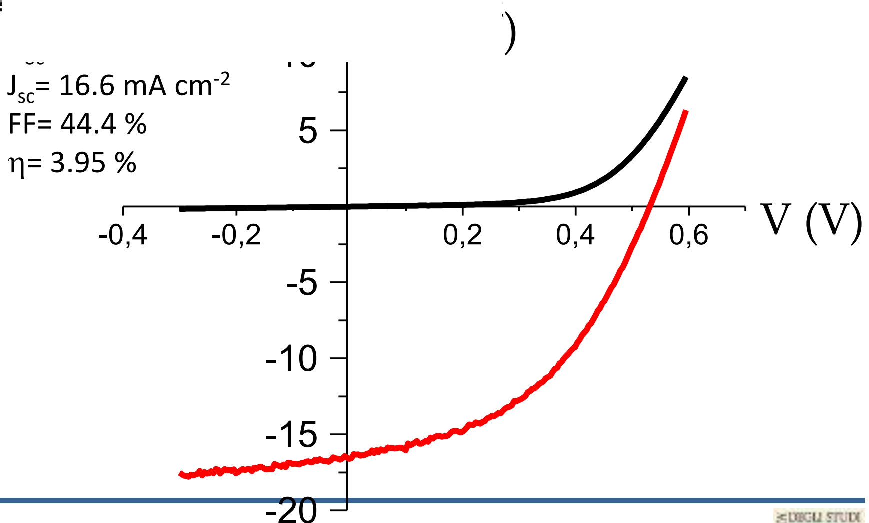
Working pressure

2 . Sulphurization process

- 0.5 – 0.2 g of S in graphite crucible @ 250 °C in
- Ar flow = 30-40 cm^3/min
- T= 550 °C







S. Marchionna, P. Garattini, A. Le Donne, M. Acciarri, S. Tombolato & S. Binetti Thin Solid Films **542**, 114–118 (2013)
A. Le Donne S. Marchionna, P. Garattini, R.A. Mereu, M. Acciarri & S. Binetti International J.of Photonergy submitted (2015)

CZTS by chemical method

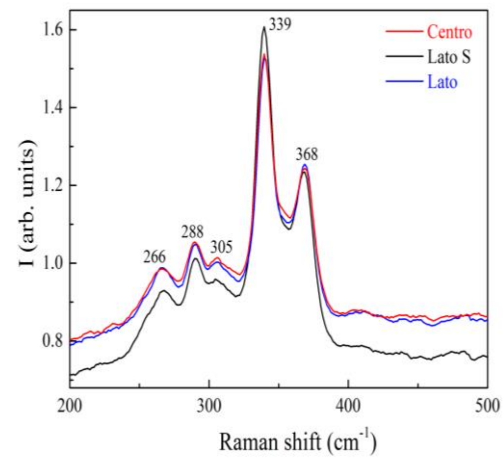
CZTS absorber layer via drop casting

Reagents	Solvents
$(CH_3COO)_2Cu \cdot H_2O$ – 0.05 M	CH_3OH (90%)
$(CH_3COO)_2Zn \cdot 2H_2O$ – 0.025 M	$OHCH_2CH_2OH$ (10%)
$SnCl_2 \cdot 2H_2O$ – 0.025 M	+ PVA (0.50 ml)
H_2NCSNH_2 – 0.11 M	

Annealing

1 . $SC(NH_2)_{2\,(l)} \xrightarrow{180\text{-}200\,°C} NH_2CN_{(l)} + H_2S_{(g)}$

2. @ 450 °C in S_2 → Poliammide



S. Tombolato, et al . Proceedings of 29th EUPSEC pp. 1829-1931 (2014)

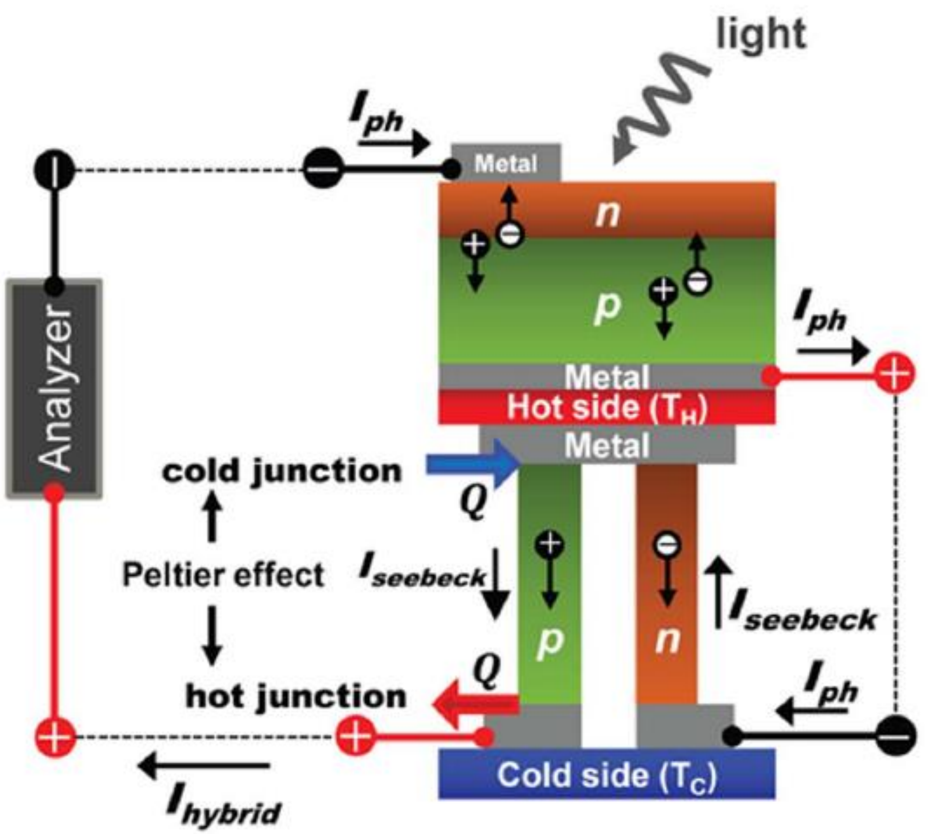
Problems

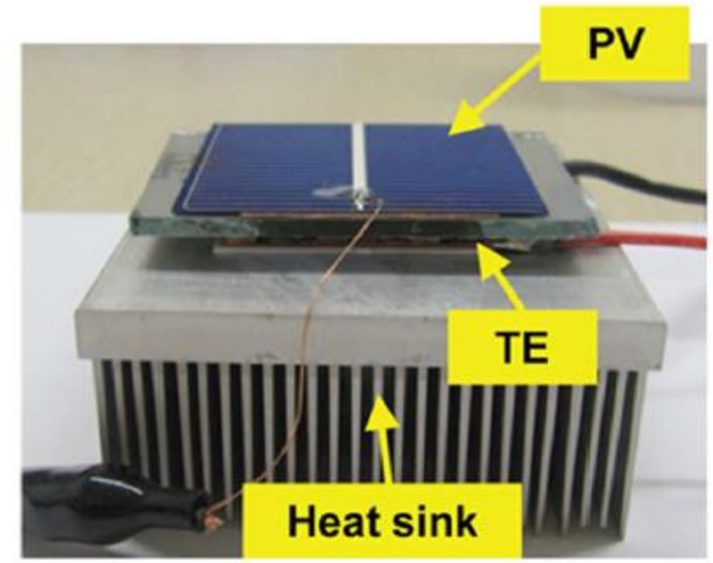
- Spurius phases
- High rugosity
- $\eta < 1$ %

Project “Grande Rilevanza -Energy and Environment- “Nuovi materiali con basso impatto ambientale per la fabbricazione di celle solari a film sottile” – Protocollo Esecutivo ITALIA-EGITTO

•M. Boshta, S. Binetti, A. Le Donne, M. Gomaa, M. Acciarri (2016): *A chemical deposition process for low-cost CZTS solar cell on flexiblesubstrates*, Materials Technology published online June 2016

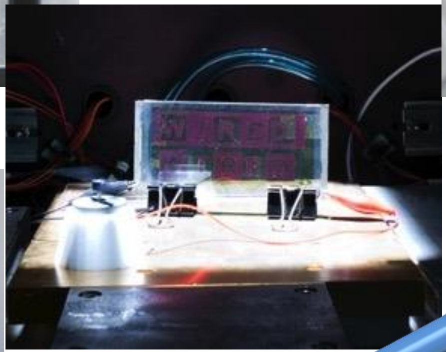
Thermoelectric Heat Recovery in Single Junction Solar Cells

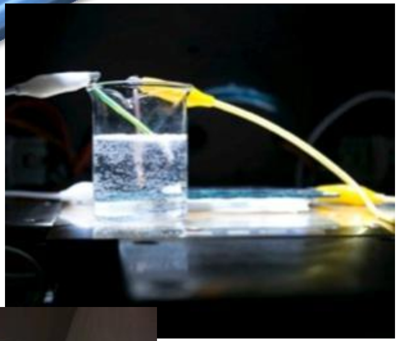


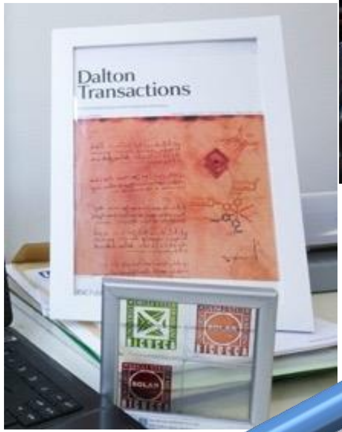


B Lorenzi, M Acciarri, D Narducci *Conditions for beneficial coupling of thermoelectric and photovoltaic devices* Journal of Materials Research, (2015) 1-7

3rd Gen PV devices (DSSC, OPV, PSC)







3rd Gen Solar fuels

DSSC Overview

PHOTOSENSITIZERS:

I. Polypyridine and polyquinoline complexes (Ru^{II}, Ir^{III})
II. Cyclometalated complexes
III. Porphyrins
IV. Metal-free organic dyes
V. p-Type dyes
VI. Perovskites (PSC)

ELECTROLYTES:

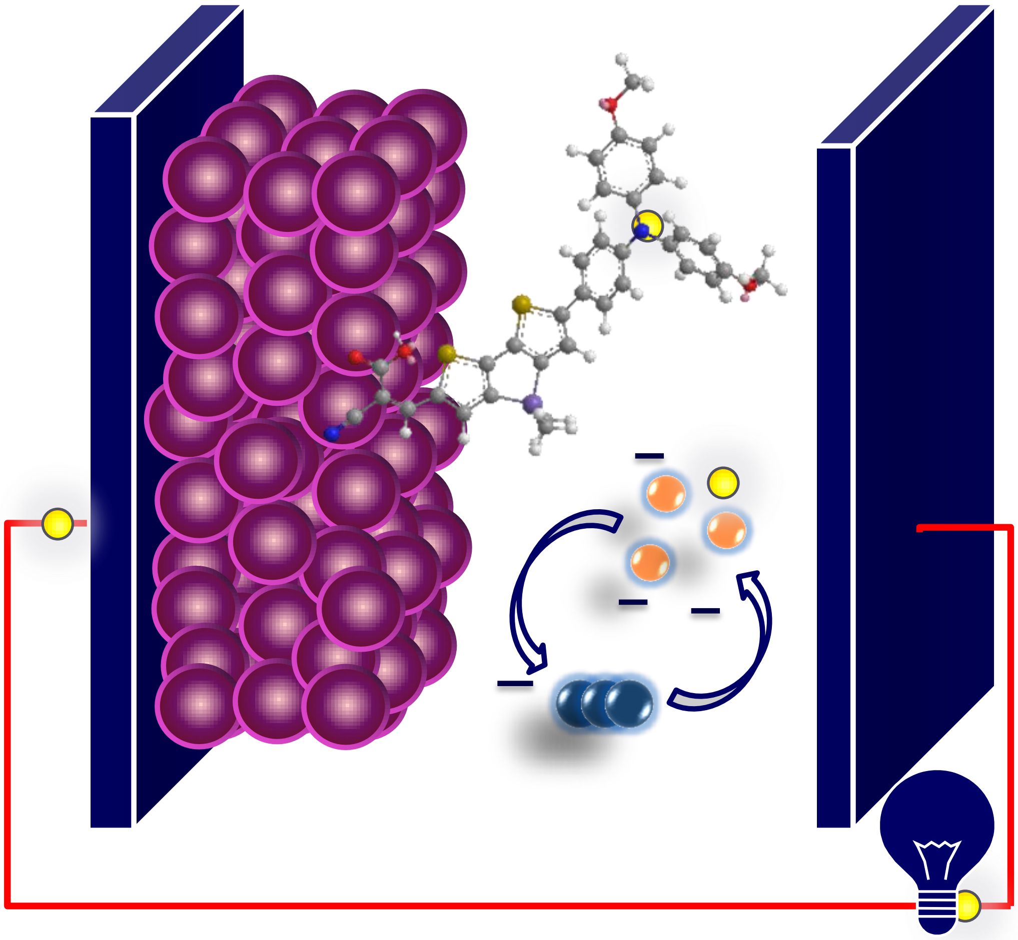
1. Iodine-free electrolytes
2. Quasi solid-state electrolytes

TiO_2:

1. Hierarchical nanostructures
2. Dye-uptaking

DEVICE

1. Fabrication and Characterization
2. Cells and Modules
3. Hybrid technologies (Si-CIGS-DSSC-perovskites)

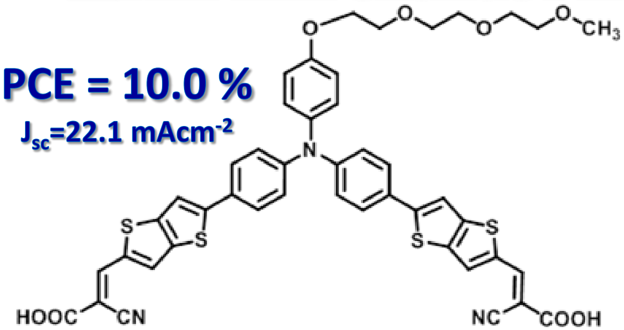


MULTIBRANCHED DYES:
enhanced photocurrent

METAL-FREE ORGANIC DYES

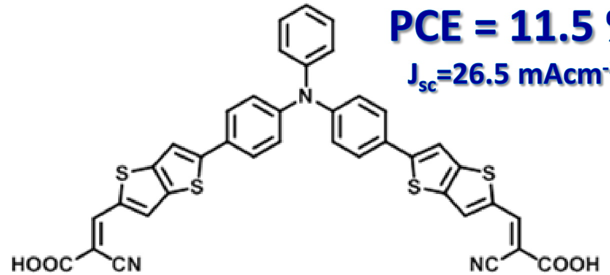
In collaboration with

PCE = 10.0 %
J_{sc}=22.1 mAcm^{-2}



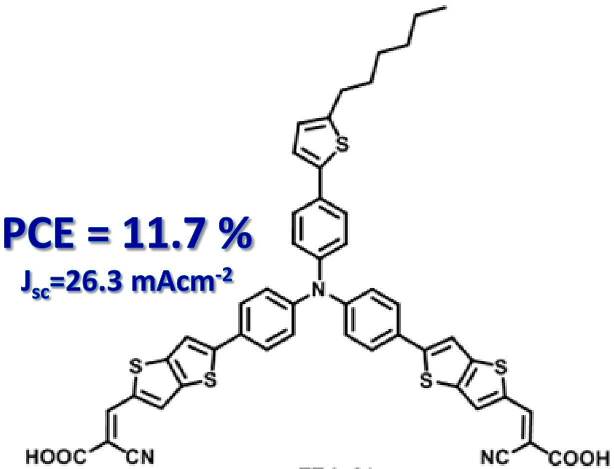
TT-a-03

PCE = 11.5 %
J_{sc}=26.5 mAcm^{-2}

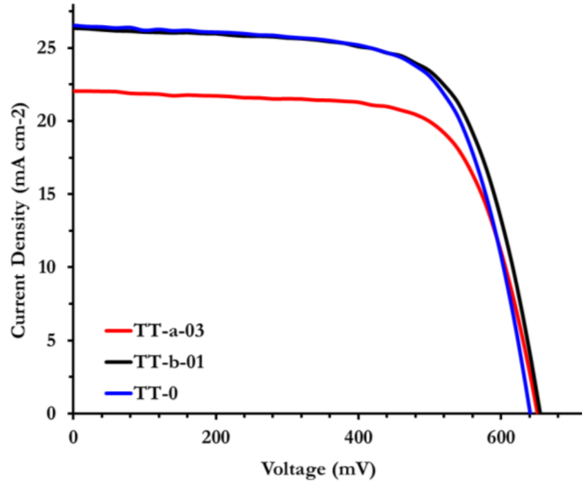


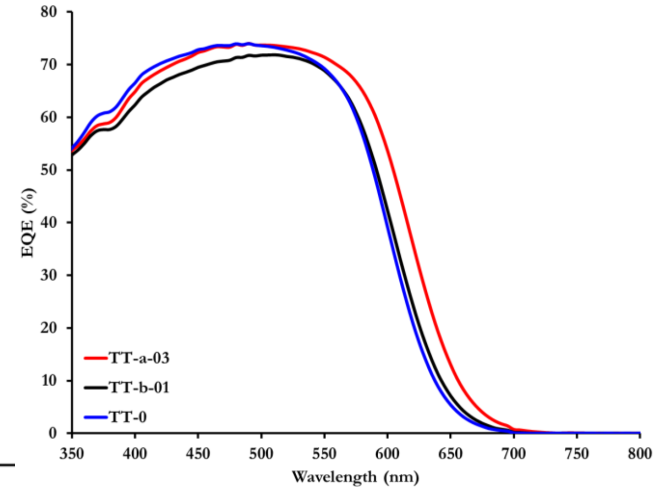
TT-0

PCE = 11.7 %
J_{sc}=26.3 mAcm^{-2}



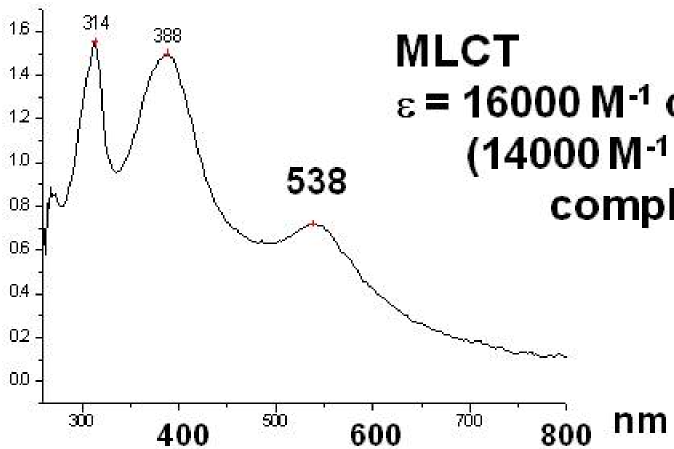
TT-b-01





Abbotto, Acciarri, Biagini, Binetti, *PCT Int. Appl*. **2014**, WO 2014053626 A1 20140410.

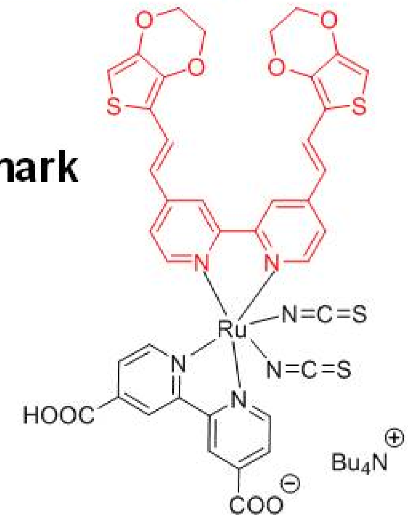
DSSC record EQE with Ru(II) dyes

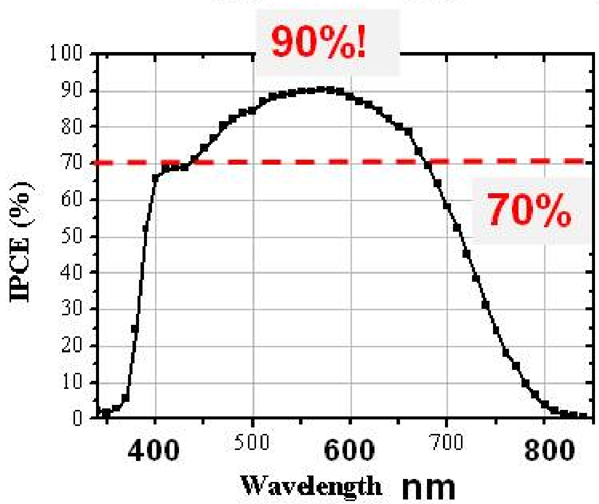


MLCT

ε = 16000 M^{-1} cm^{-1}

(14000 M^{-1} cm^{-1} in benchmark complex)





EXTERNAL QUANTUM EFFICIENCY

$$\frac{\text{electrons out}}{\text{photons in}}$$

(benchmark dye: max 87%)

Abbotto et al. *Chem. Commun.* **2008**

Branched organic dyes: evolution

EurJOC European Journal of Organic Chemistry

MICROREVIEW

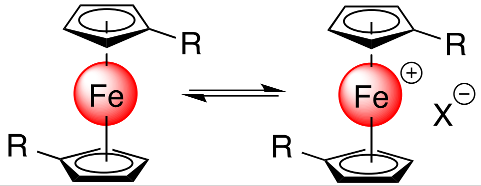
DOI: 10.1002/ejoc.201402422

Multi-Branched Multi-Anchoring Metal-Free Dyes for Dye-Sensitized Solar Cells

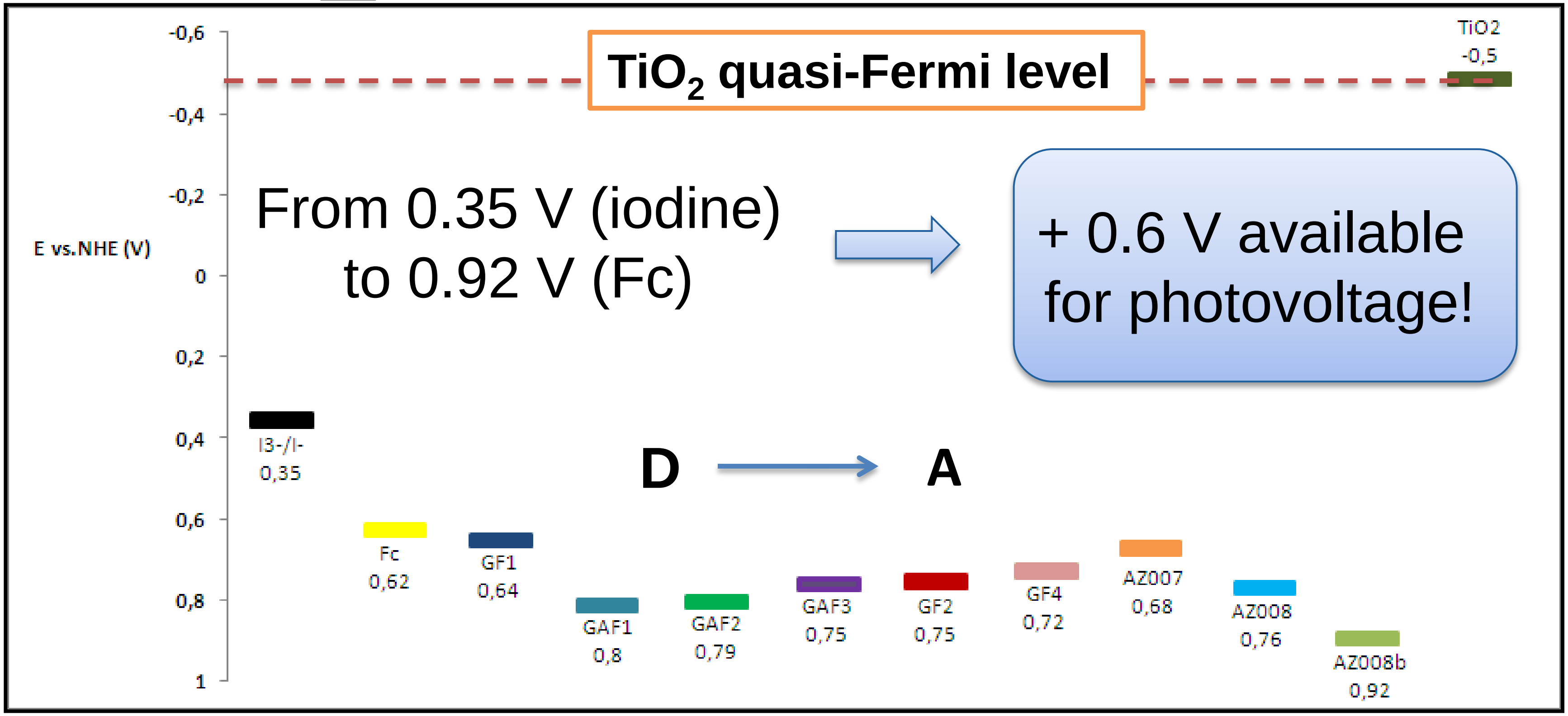
Norberto Manfredi,*[a] Bianca Cecconi,[a] and Alessandro Abbotto*[a]

Keywords: Solar cells / Dyes/Pigments / Sensitizers / Energy conversion / Photochemistry

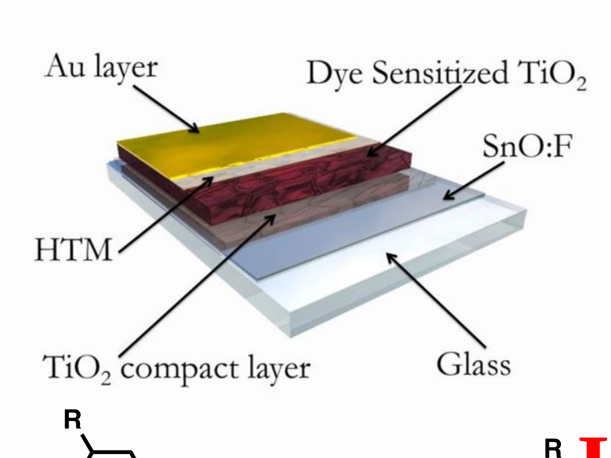
Iodine-free electrolyte



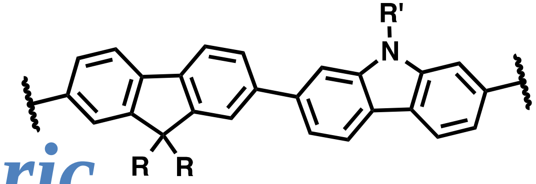
Redox potentials

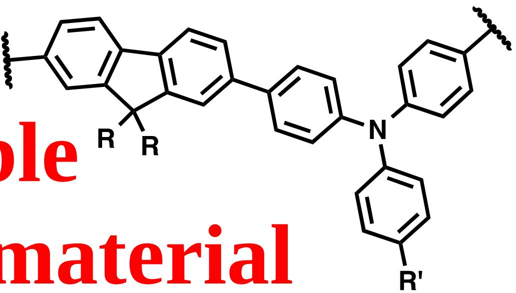


ssDSSC and PSC



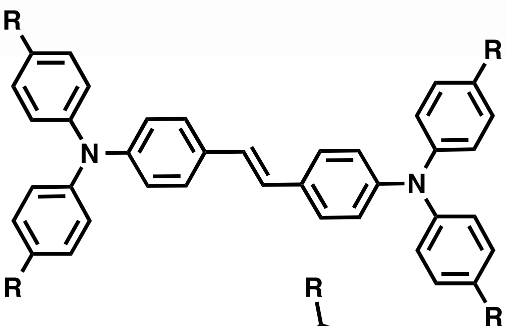
polymeric



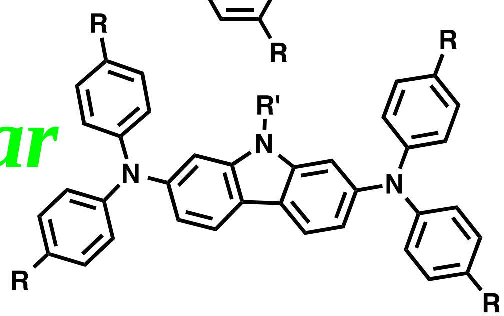


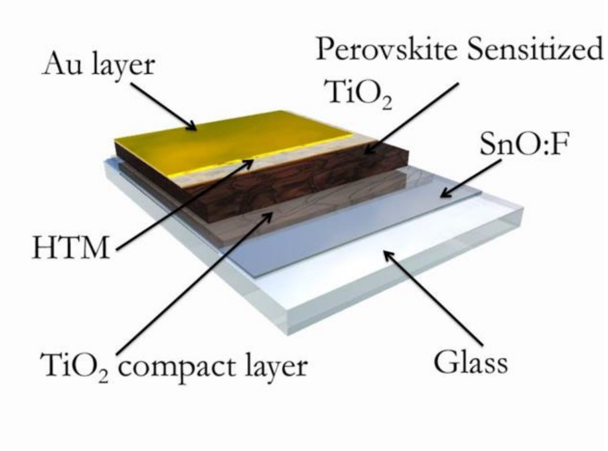
Novel air-stable

Hole transporting material



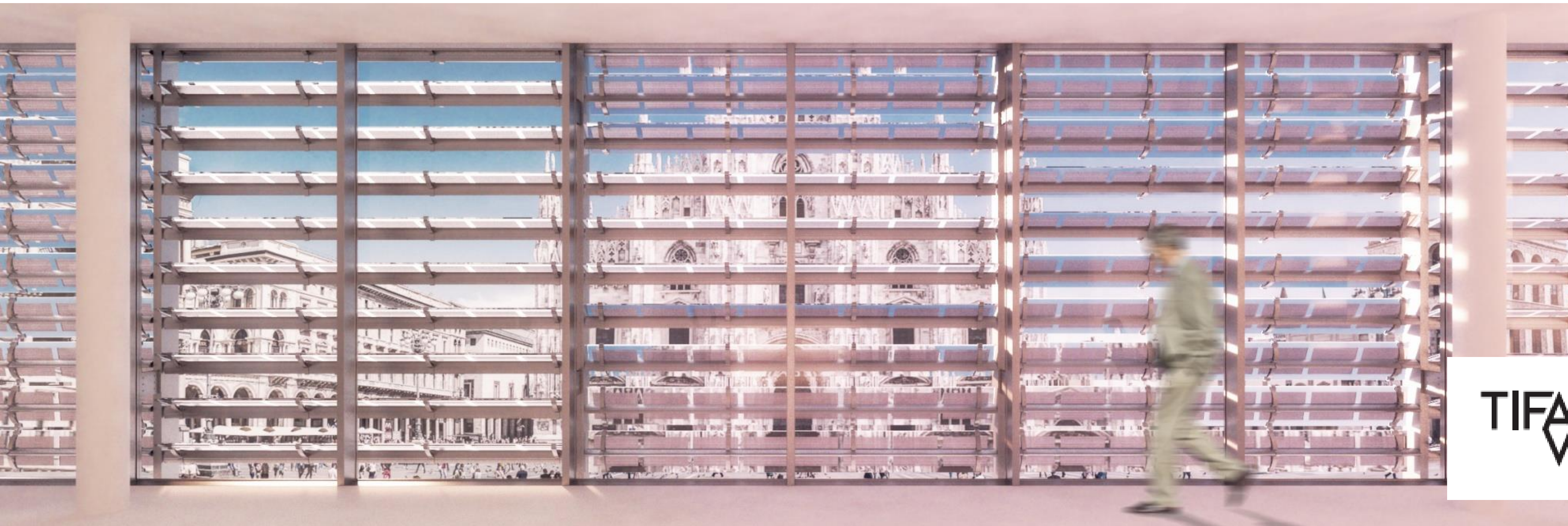
molecular



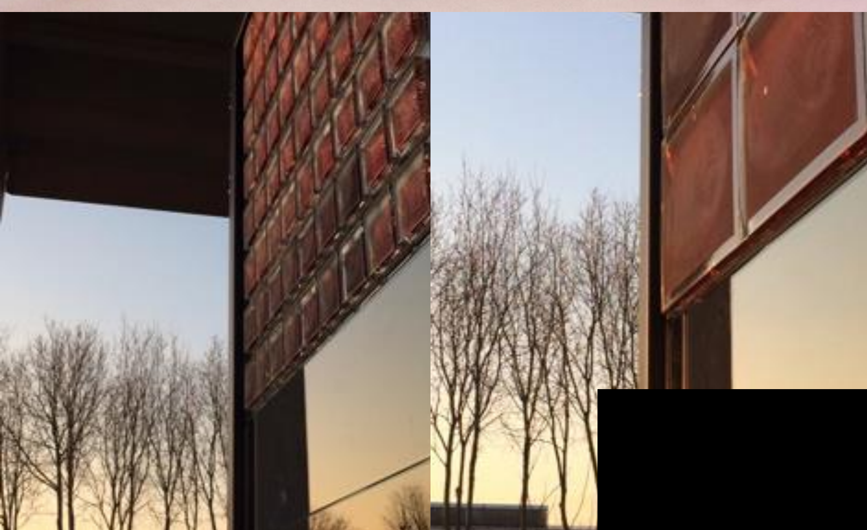


Building-integration PV (BIPV)

Integrated Photovoltaic Glass Tiles for Innovative Architectural Applications



TIFAIN



INDUSTRIA e INNOVAZIONE

ENERGYGLASS SOLAR & GLASS ARCHITECTURE

FLAME SPRAY

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

POLITECNICO MILANO

iit ISTITUTO ITALIANO DI TECNOLOGIA

UNIONE EUROPEA

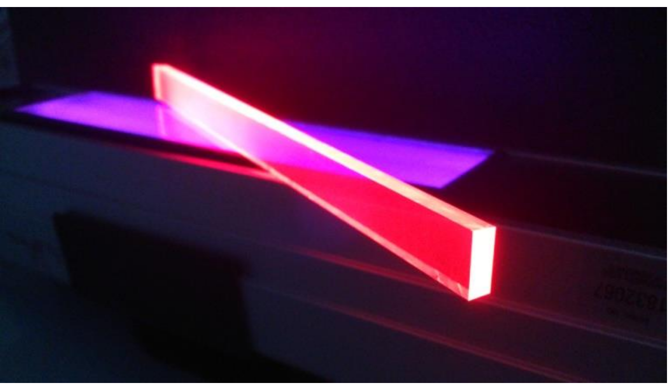
Ministero dell'Istruzione dell'Università e della Ricerca

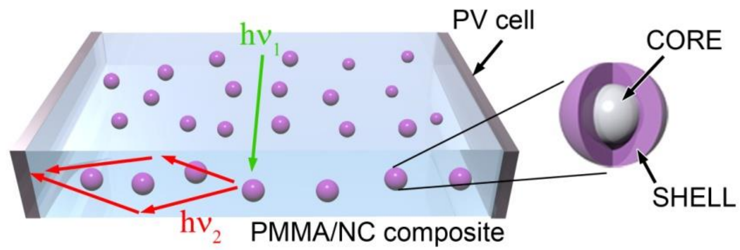
RegioneLombardia

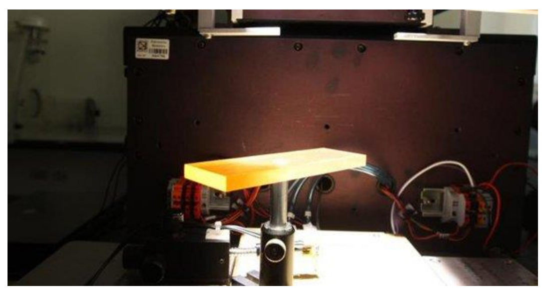
Luminescent solar concentrators

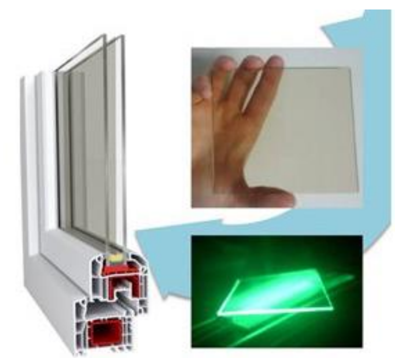
Prof. F. Meinardi and S. Brovelli group.

‘Stokes-shift-engineered’ CdSe/CdS quantum dots with giant shells (giant quantum dots) were used to realize luminescent solar concentrators without reabsorption losses for device dimensions up to tens of centimetres.



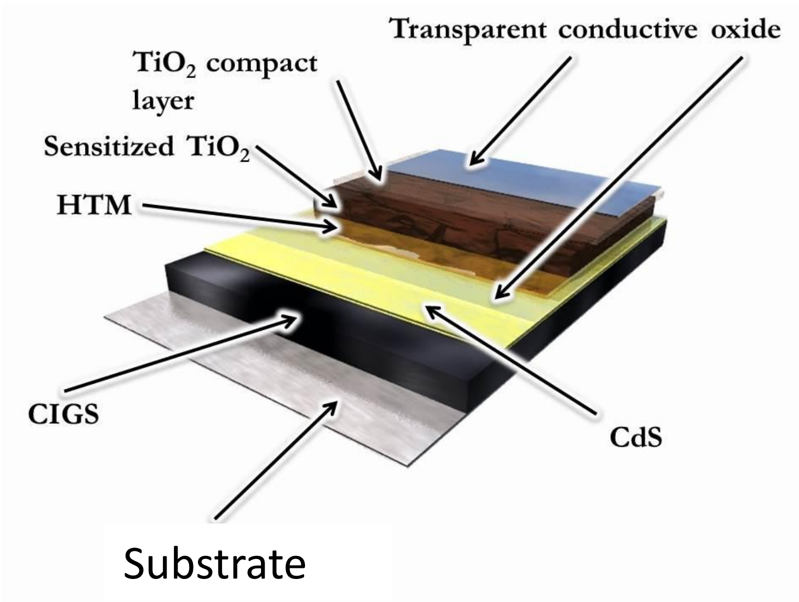




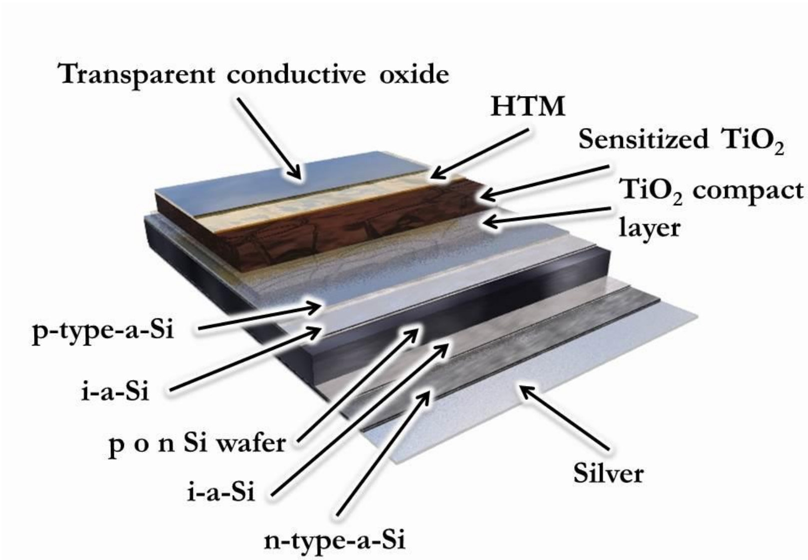


Study of these luminescent solar concentrators yields optical efficiencies >10% and an effective concentration factor of 4.4. These results demonstrate the significant promise of Stokes-shift-engineered quantum dots for large-area luminescent solar concentrators.

ss-Hybrid technologies



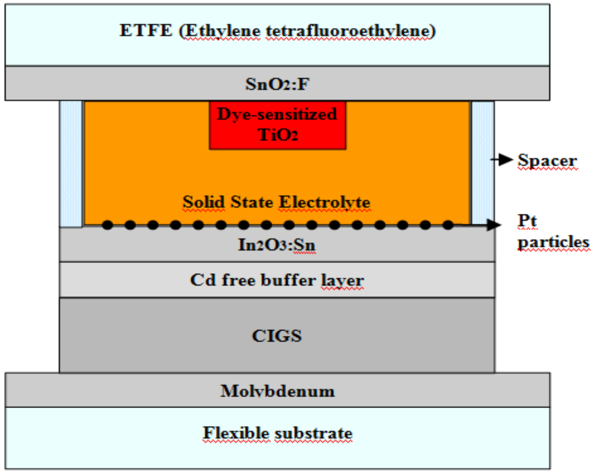
Monolithic solid state devices

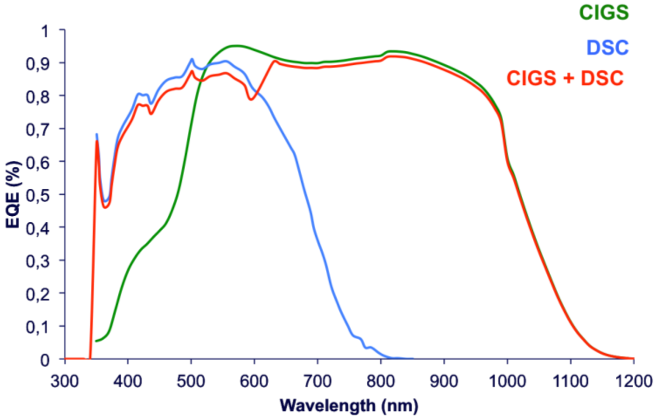


Target

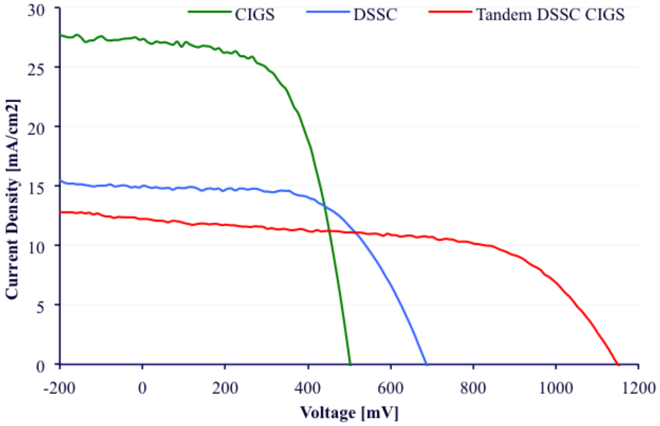
- ***moderate scenario*** $\eta=17\%$
- ***optimistic scenario*** $\eta=21\%$

Hybrid technologies





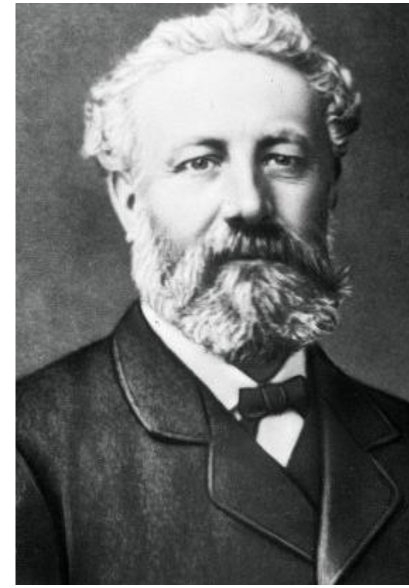
Type	PCE (%)
DSC	6.0
CIGS	7.1
DSC/CIGS	***8.4***



TOWARD HYDROGEN ECONOMY: SOLAR FUELS (?)

“water will be the coal of the future”

Jules Verne
The Mysterious Island
1874



TOWARD A LOW-CARBON SOCIETY

European
Commission

Forward the artificial photosynthesis

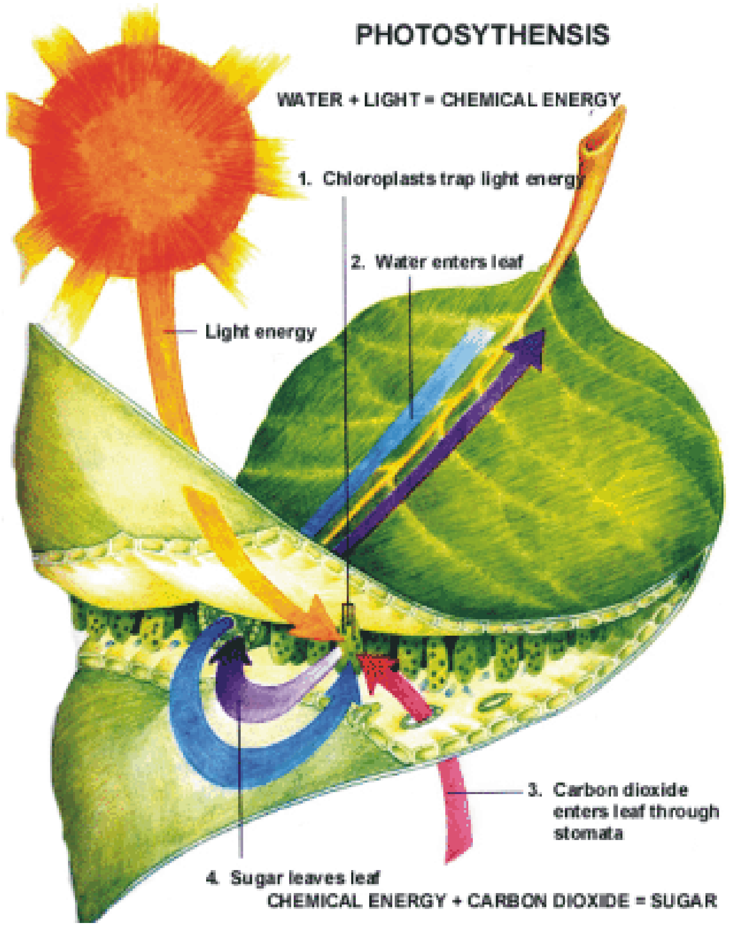
Natural photosynthesis

$$H_2O \xrightarrow{h\nu} \text{"}H_2\text{"} + 1/2\ O_2$$

CO_2 → carbohydrates

Artificial photosynthesis

$$H_2O \xrightarrow{h\nu} H_2 + 1/2\ O_2$$



The chemical challenge:
High transformation efficiency from electron to hydrogen

Clean sources of Water Splitting

2-step

1-step

ARTIFICIAL PHOTOSYNTHESIS

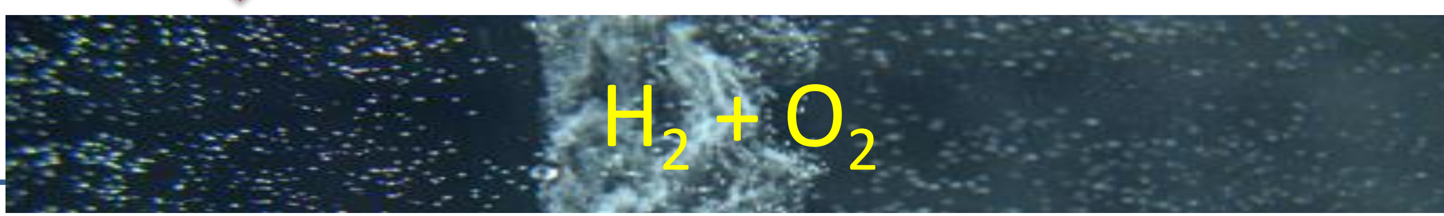
electrical power

integrated device
(PEC, photocatalysis)

too expensive!

PV-driven electrolysis

cheaper but low currents!



Towards artificial photosynthesis

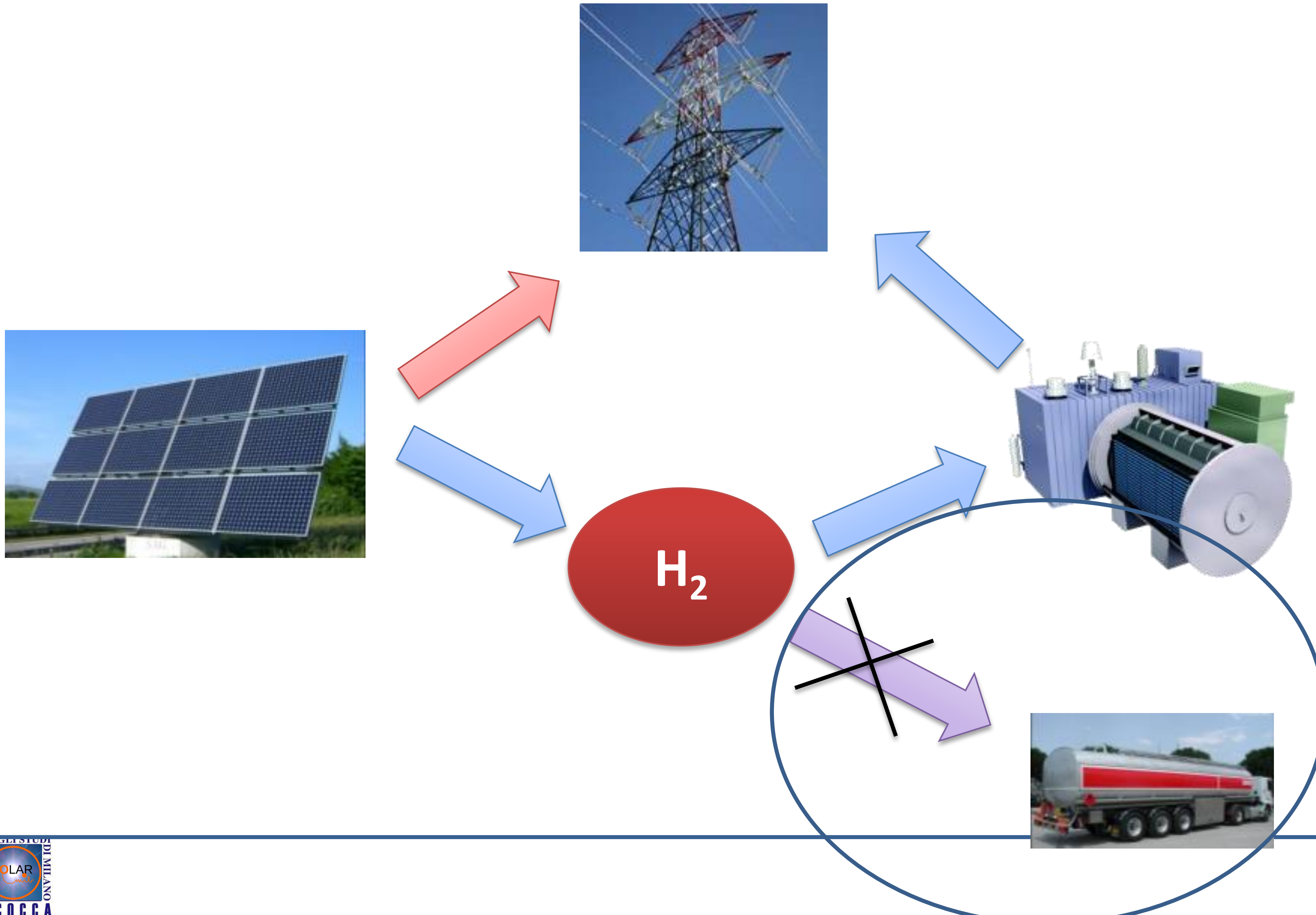
Dye-Sensitized Solar Cells

Water electrolysis through DSC

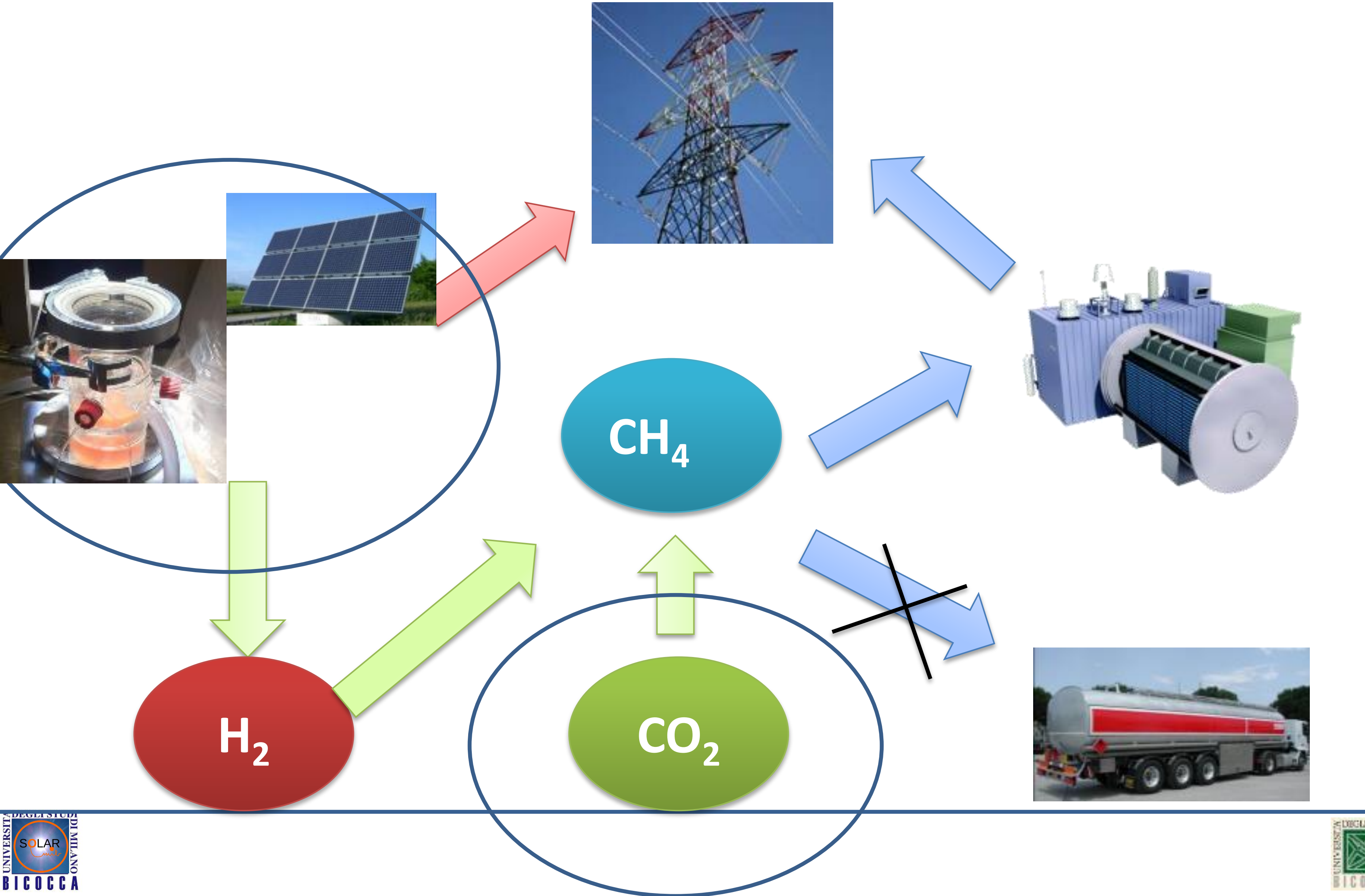
Water Splitting with Solar Energy

Thanks to Prof. S. Abbotto

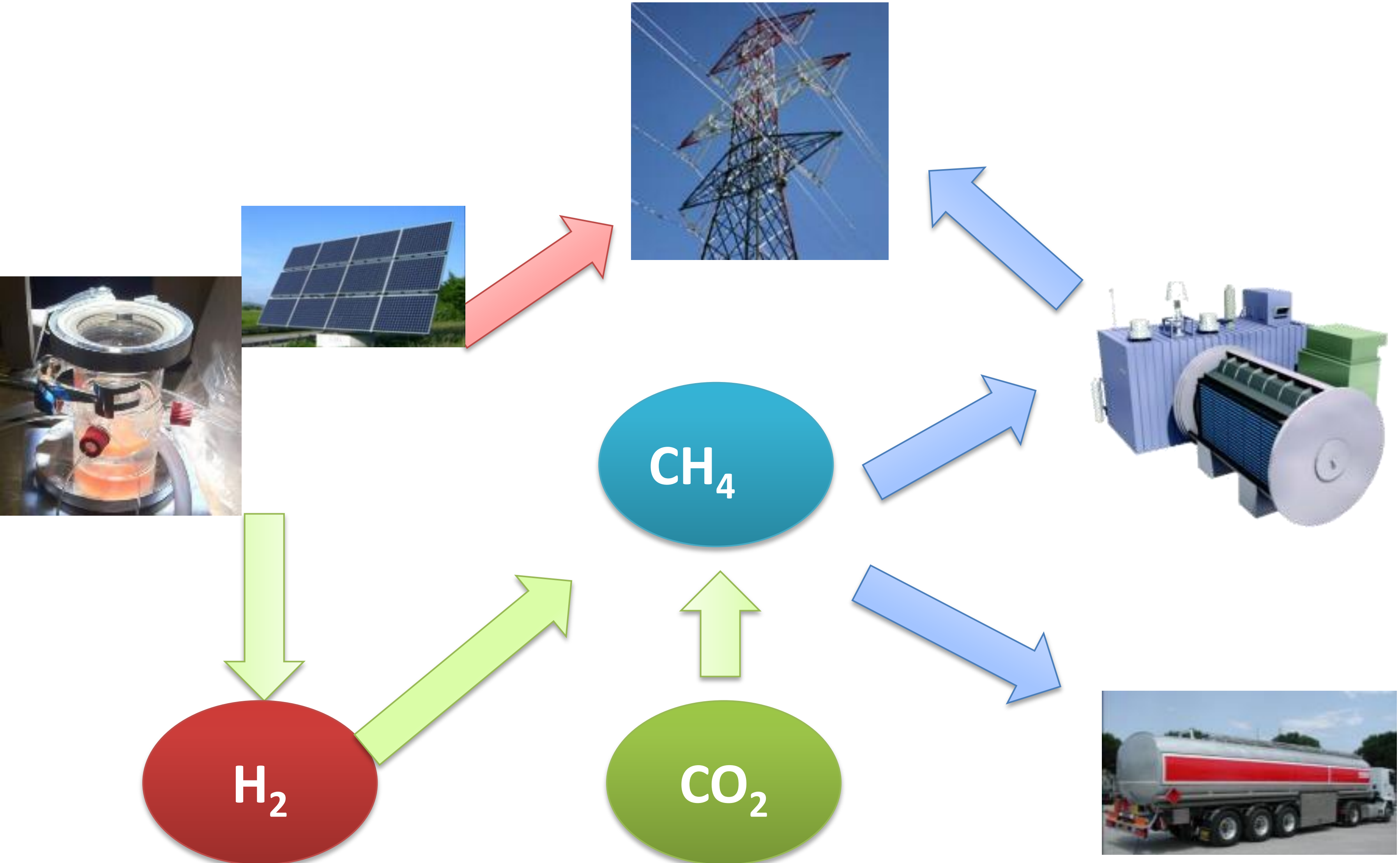
Energy store



Energy store

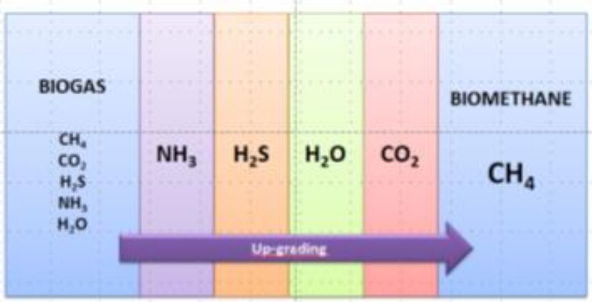


Energy store



Upgrading technologies

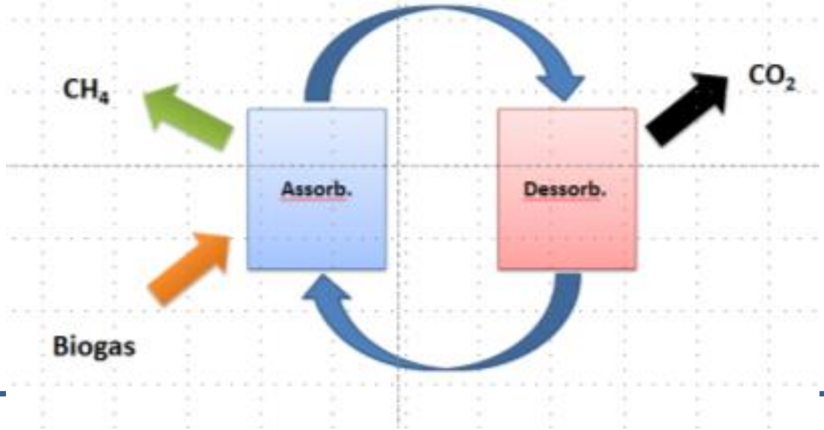
- Upgrading of **biogas** or landfill gas to **bio-methane** is defined as removal of carbon dioxide from the biogas.
- This will result in an increased energy density since the concentration of methane is increased to up to 95%.
- Several technologies for biogas upgrading are commercially available and others are at the pilot or demonstration level.



Smart upgrading

Principal phases of our process:

- absorption CO_2 in the **solvent** in the cold column
- Solvent heating for the CO2 release (temperature below75°C)
- CO_2 collection and solvent regeneration in the hot stripping
- Solvent cooling
- Solvent reintroduction in the cold absorption column



Solvent based on Ionic liquid
- no toxic
- low cost

2016: Industrial production plant under pianification

Lab scale 1 m^3/h
2012

pilot scale 100 m^3/h
2014

Pre-Industrial scale
2015

Presso CEM Ambiente Cavenago (MB)

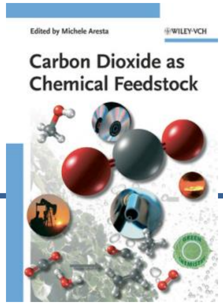
Biomethane and CO2: energy storage and "sequestration"

- Biogas produced through anaerobic digestion is often used as a source of combined heat and power (CHP).

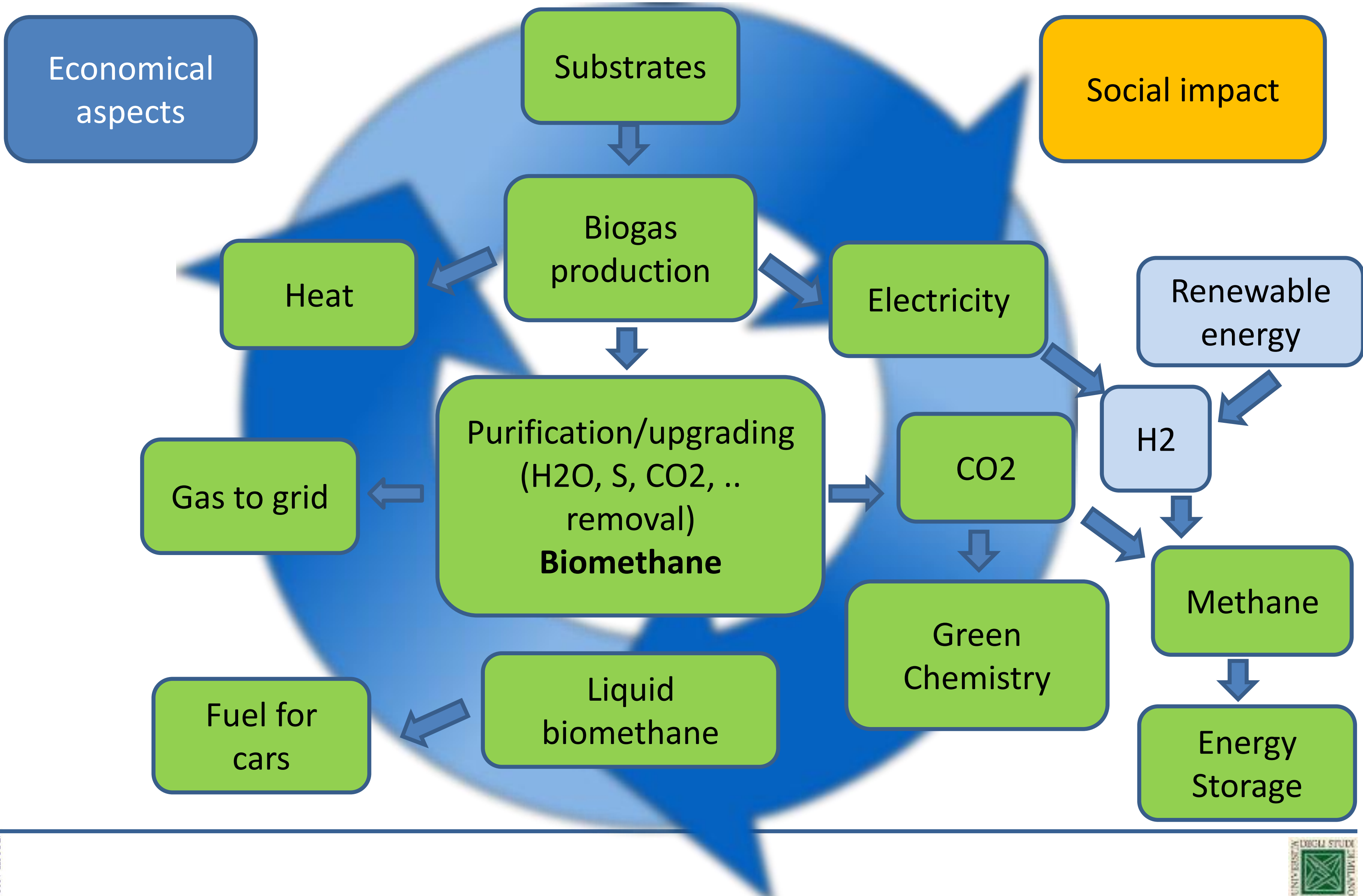
- **For use as a transport fuel** as well as **for natural gas grid injection**, biogas must be cleaned and upgraded to typically greater than 97% methane content (then known as biomethane).

- Another advantage is that the biomethane can be used to generate electricity in combined cycle gas turbines that can produce electricity from methane with efficiency above 60%.

- CO_2 can be easily accumulated … and CO_2 **is ready to go as a fuel and chemical feedstock** (Electrolysis, Artificial leaves, catalytic water splitting, CO_2 reduction, Biotechnology)



Biogas an example of Circular Economy



Photovoltaics could become an important source of energy, but this won't happen by chance.

Thanks

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