Conversione dell'energia solare con i semiconduttori

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Our Research:

Transparent Photoelectrochemical Cells

dyepower

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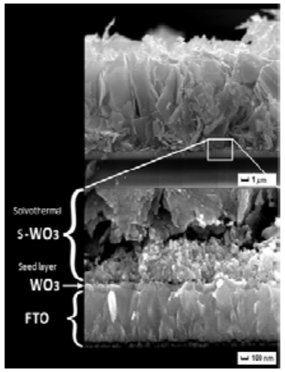
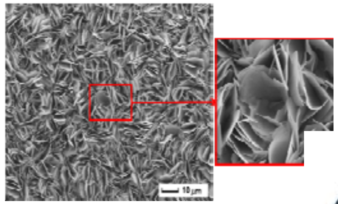
ALMA UNIVERSITAS TAURINENSIS

PERMASTEELISA GROUP

ERG Renew

Photoelectrodes for water splitting, solar fuel production and environmental remediation





HP SOLAR HIGH PERFORMANCE SOLAR DECONTAMINATION

eni

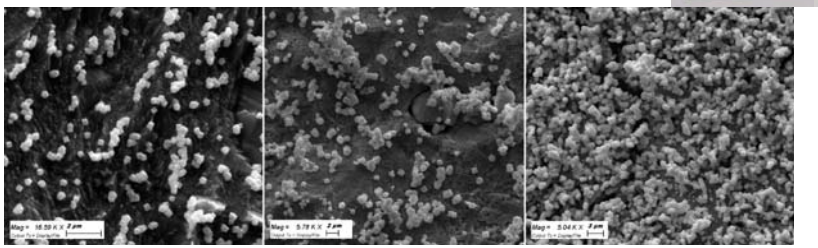
CO2NDOR

COmbined suN-Driven Oxidation and CO_2 Reduction for renewable energy storage

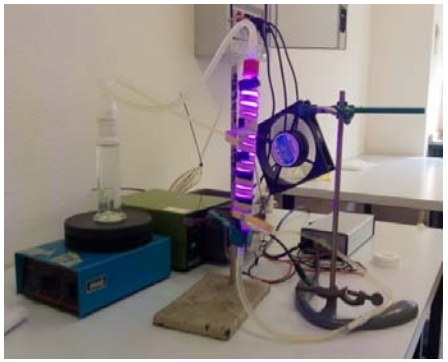
SOREC2

SOLAR ENERGY TO POWER CO_2 REDUCTION TOWARDS C_2 CHEMICALS FOR ENERGY STORAGE

Electrocatalysts for CO_2 reduction



Photocatalysis for pollutant degradation



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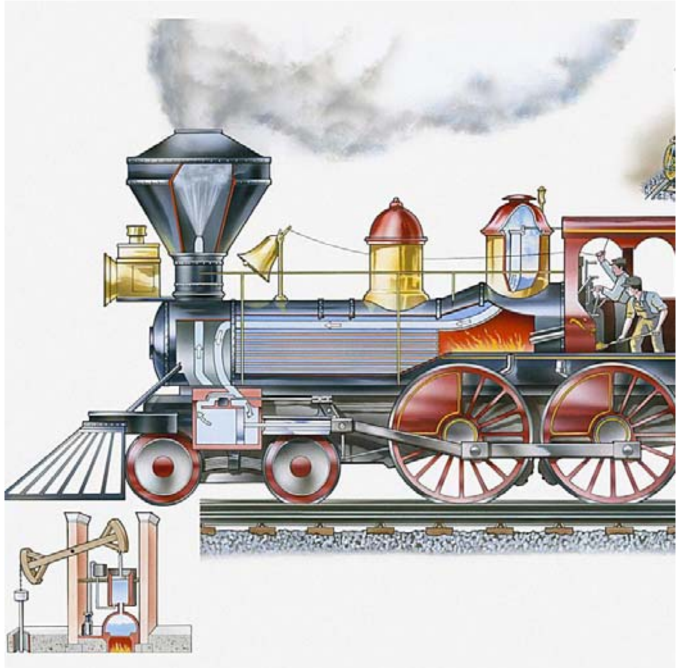
European Regional Development Fund

Marie Curie "Arcadia" (H2020-MSCA-IF 2015)

An energy hungry society vs laws of thermodynamics



First Law: conservation of energy : *ΔU (Internal energy) = ΔL (Work) + ΔQ (Heat)*

Second Law: entropy change in a spontaneous process: $\Delta S_{universe} \geq 0$

TABLE 8.3 Thermochemical Properties of Some Fuels

	Combustion Enthalpy		
Fuel	**kJ/mol**	**kJ/g**	**kJ/mL**
Hydrogen, H_2	−285.8	−141.8	−9.9*
Ethanol, C_2H_5OH	−1367	−29.7	−23.4
Graphite, C	−393.5	−32.8	−72.8
Methane, CH_4	−890.3	−55.5	−30.8*
Methanol, CH_3OH	−726.4	−22.7	−17.9
Octane, C_8H_{18}	−5470	−47.9	−33.6
Toluene, C_7H_8	−3910	−42.8	−36.7

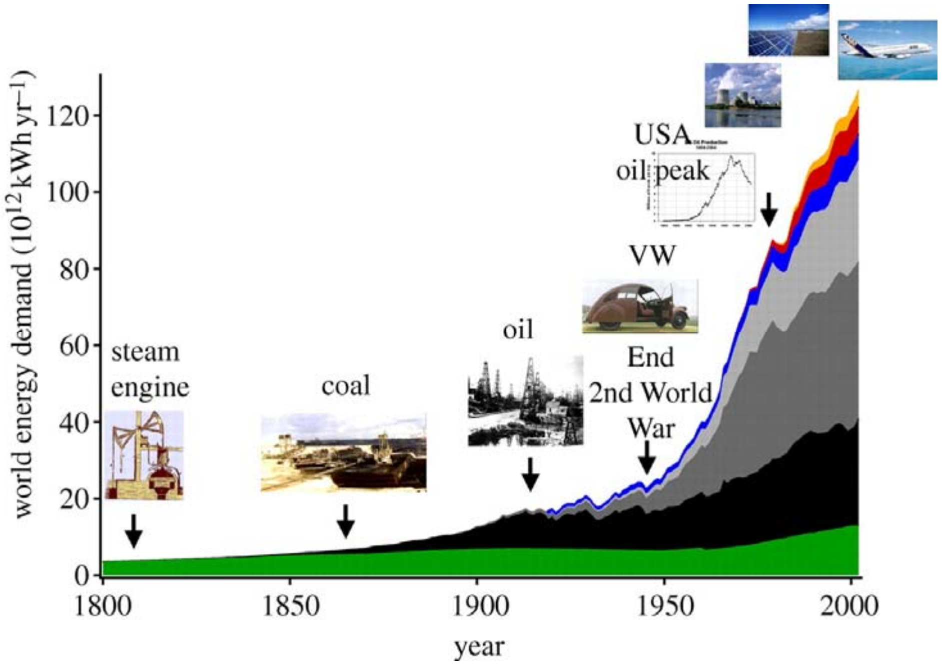
*Calculated for the compressed liquid at 0°C

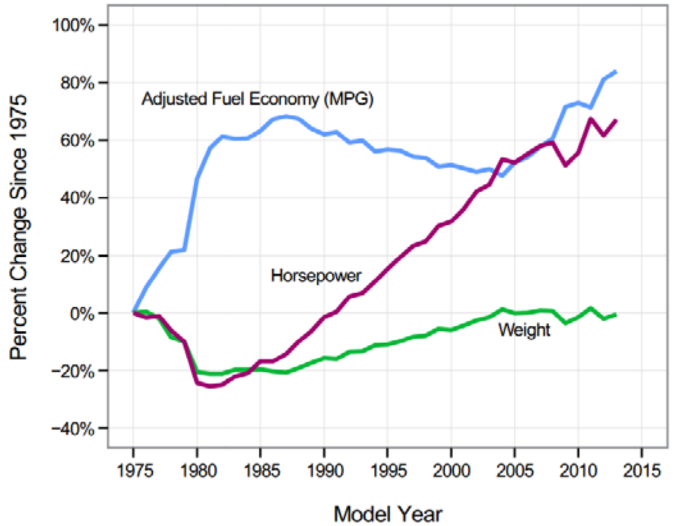
$C + O_2 \longrightarrow CO_2$ + Work + Heat

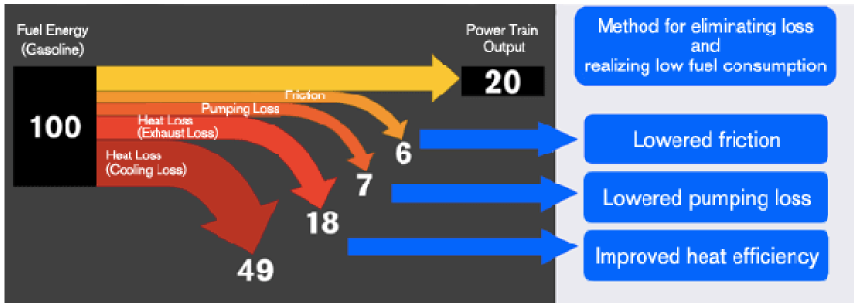
The opposite reaction does not **spontaneously** occur due to second law

Fuels are concentrated forms of internal energy (enthalpy) from which we can extract work and heat to power our society. We extract energy from breaking and forming chemical bonds.

« The energy Efficiency paradox»







PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

Phil. Trans. R. Soc. A (2010) **368**, 3329–3342
doi:10.1098/rsta.2010.0113

Review

Hydrogen: the future energy carrier

By Andreas Züttel*, Arndt Remhof, Andreas Borgschulte and Oliver Friedrichs

Empa Materials Sciences and Technology, Department of Environment, Energy and Mobility, Division of Hydrogen & Energy, CH-8600 Dübendorf, Switzerland

Why Fossil fuels ?

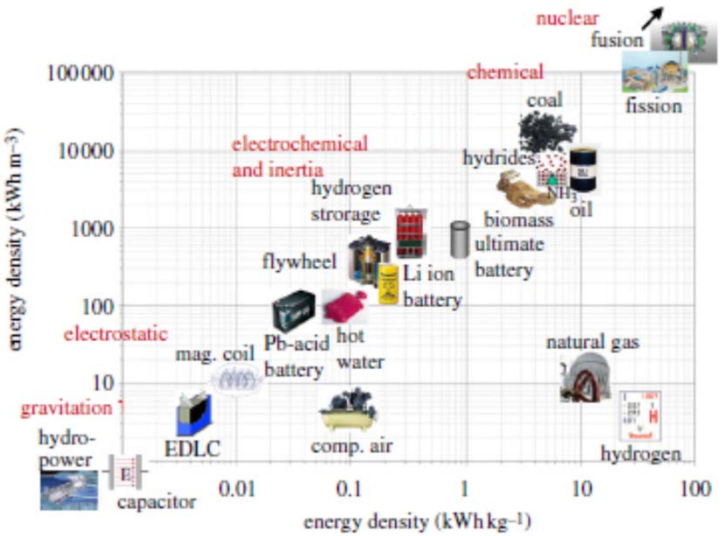
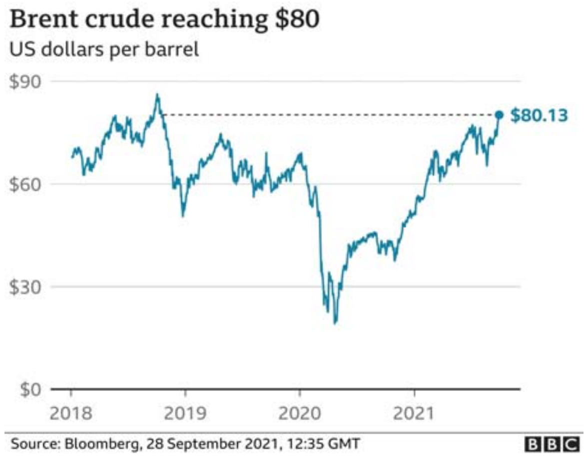
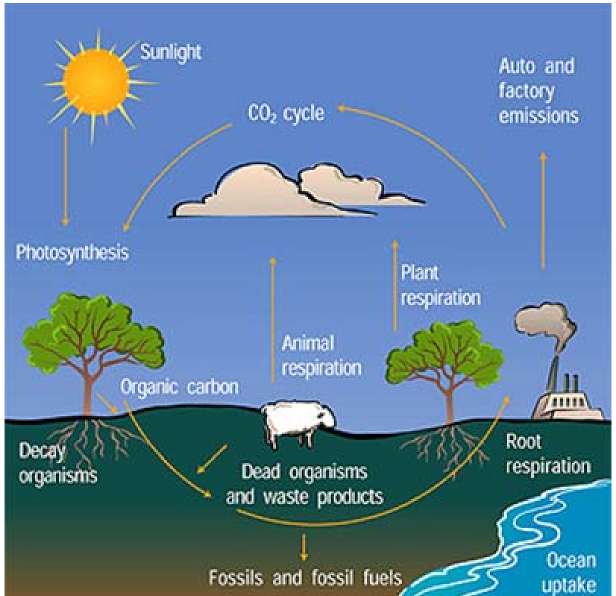
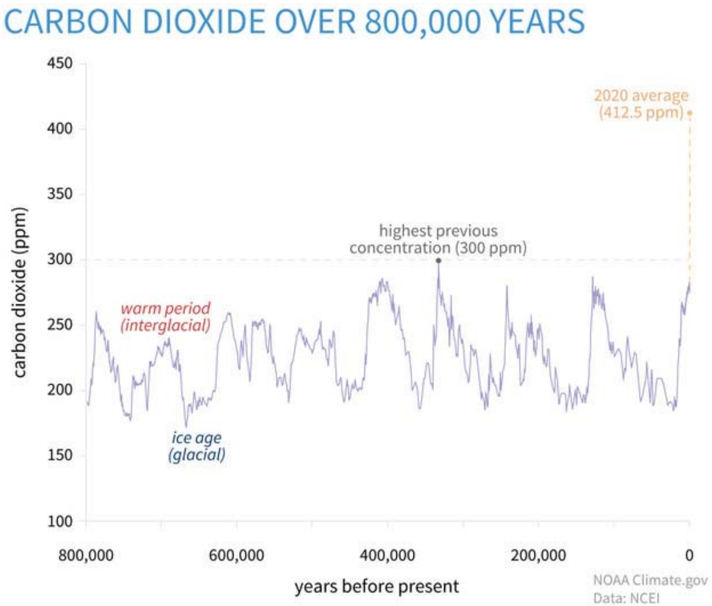


Figure 7. Volumetric versus gravimetric energy density of the most important energy carriers.

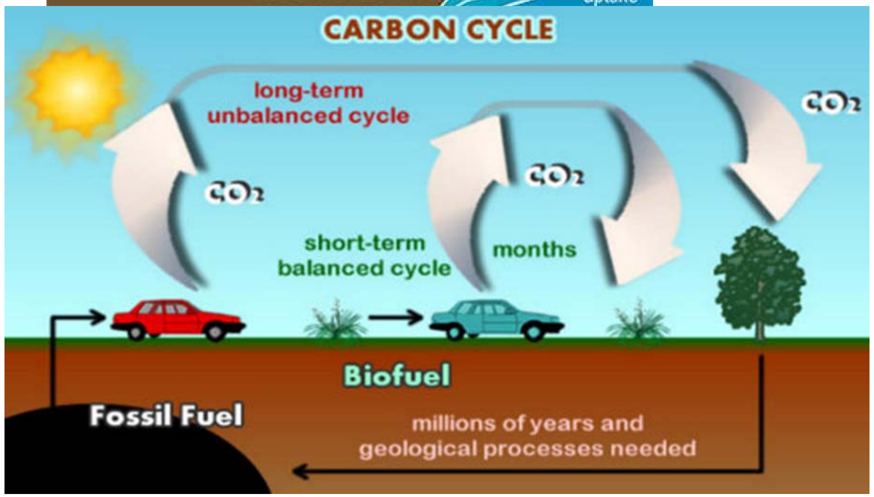


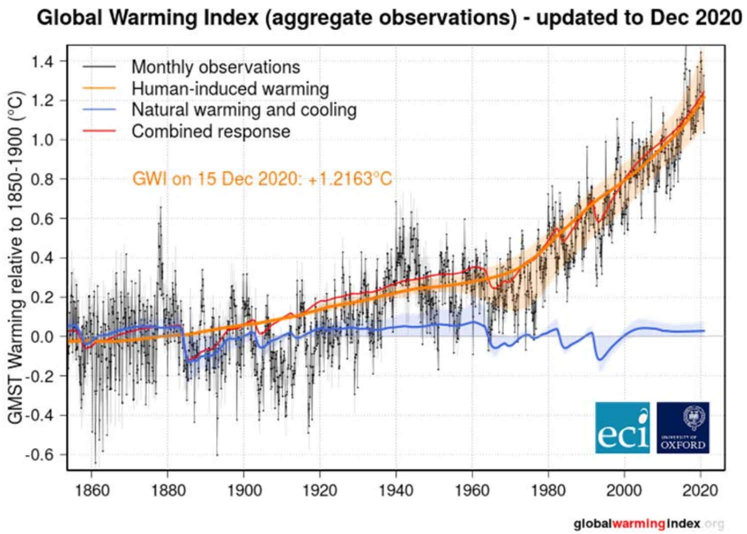
Carbon Cycle



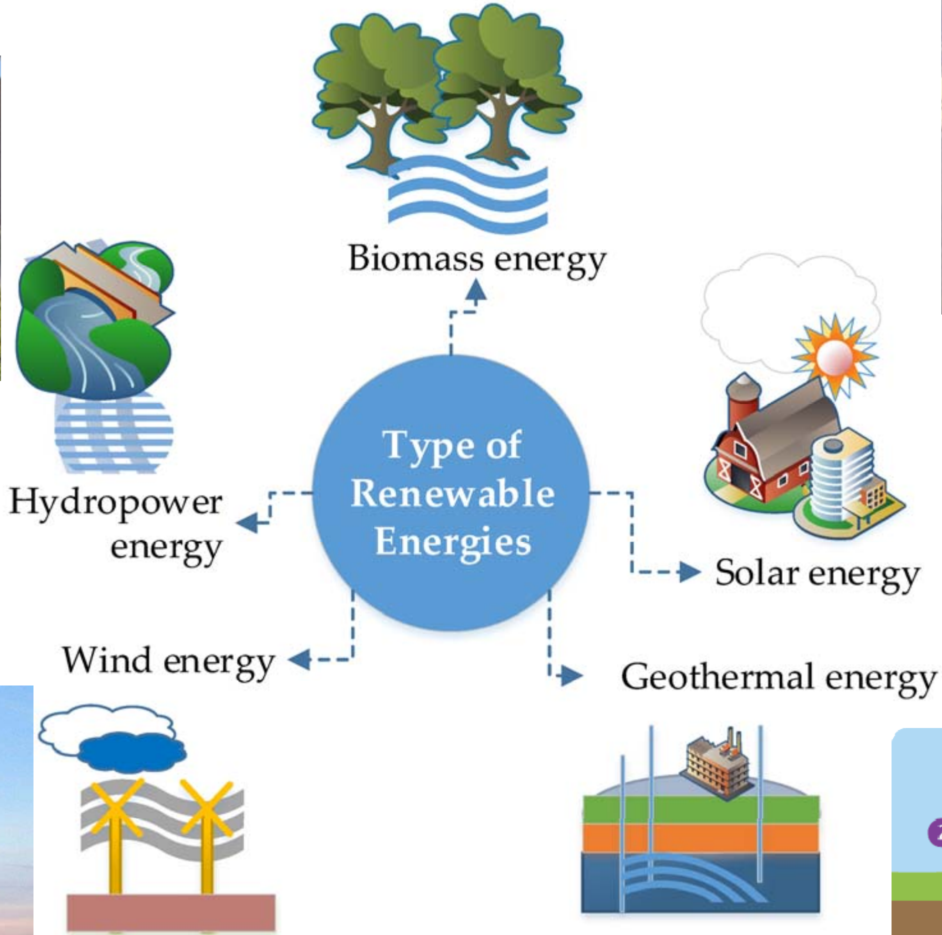


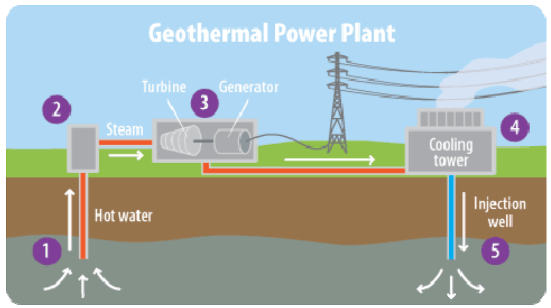
https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide



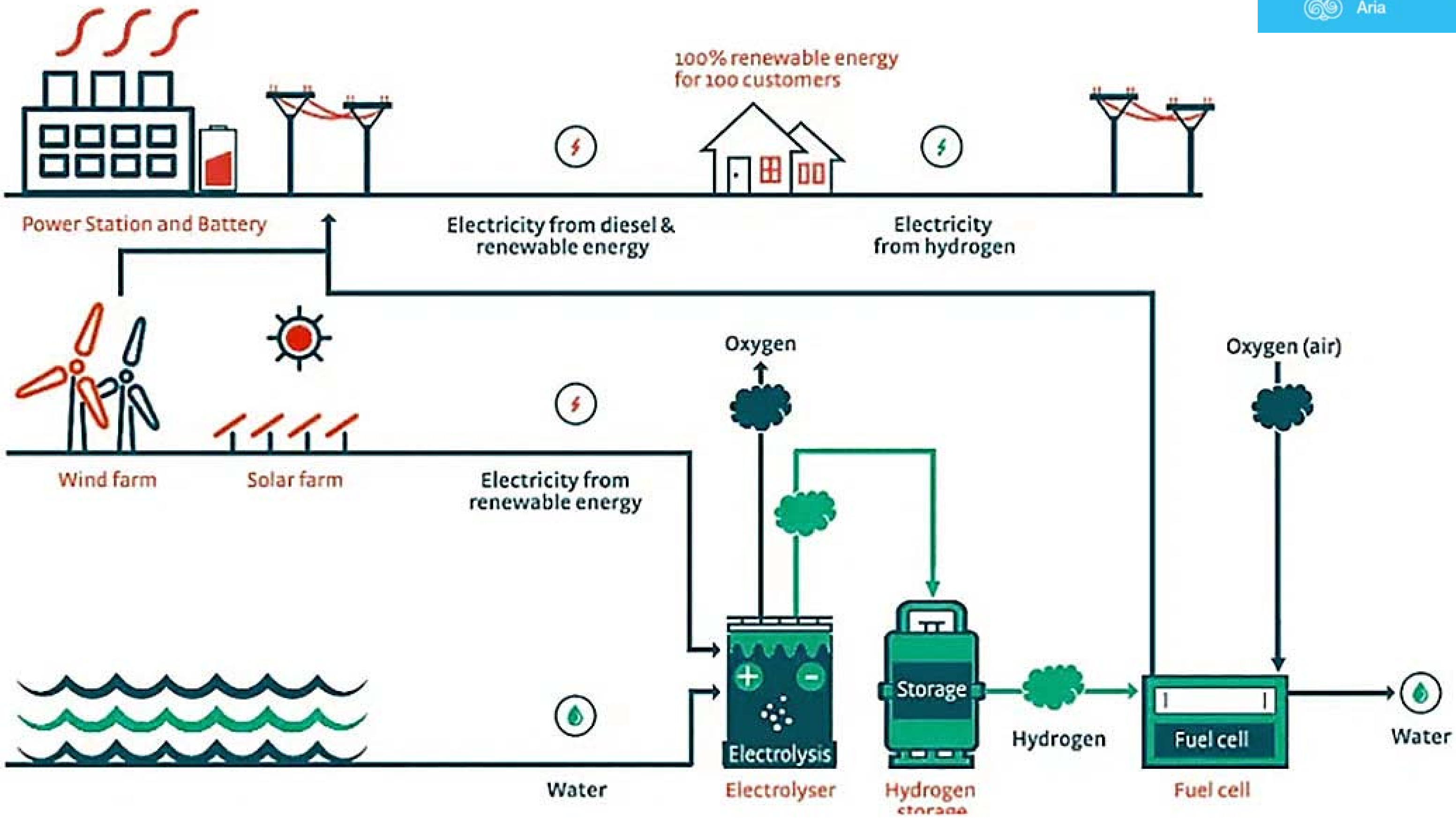


Renewable energies: fast replenishing cycles or continuous supply



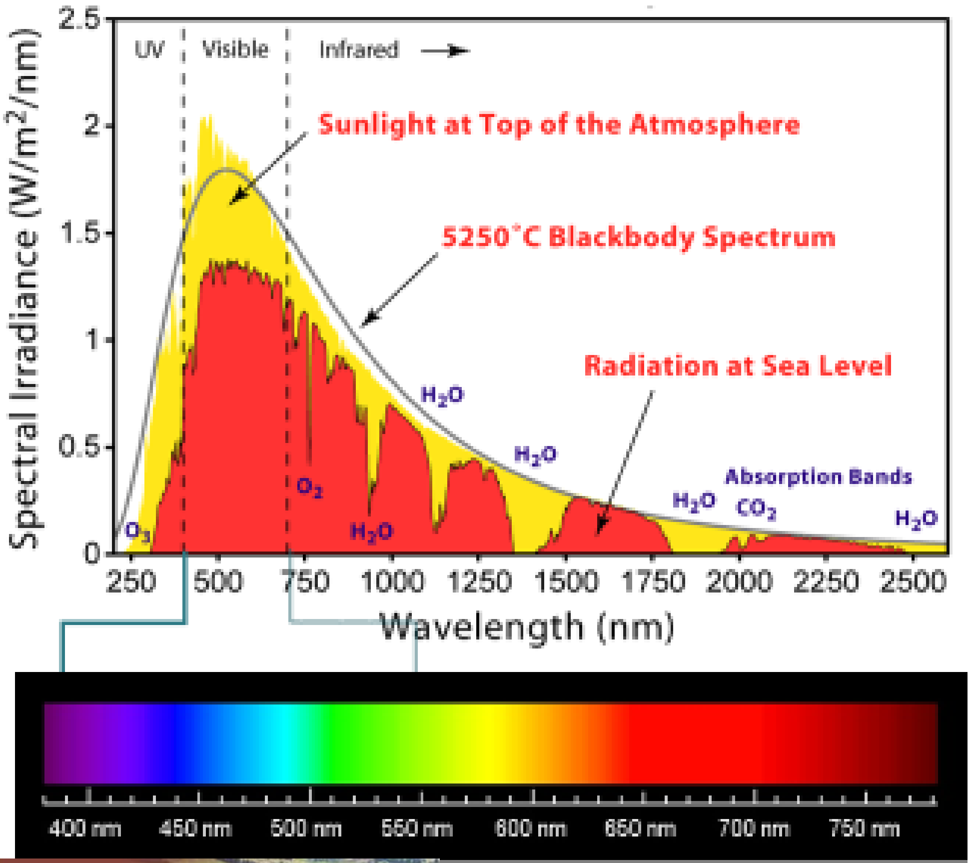


A Sustainable Energy Cycle



https://energyindustryreview.com/power/europe-at-the-top-of-hydrogen-electrolyser-projects/

Solar Energy: is it enough ?



Sunlight exploitation

✓ Solar **thermal:**

Solar energy → **Heat**

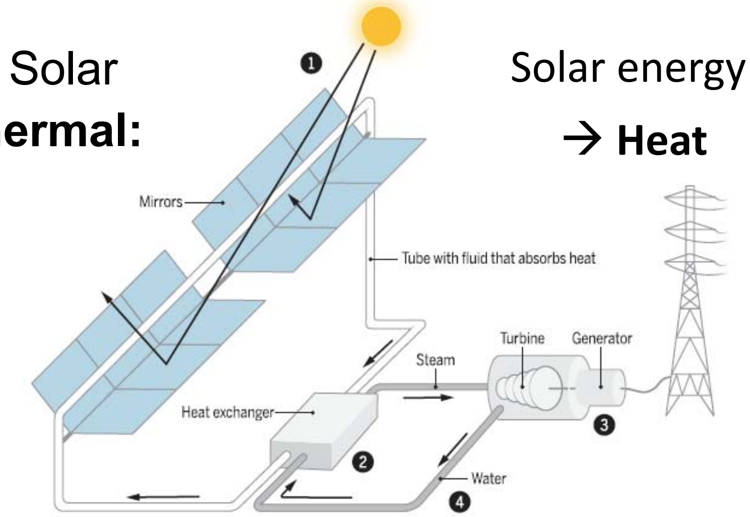
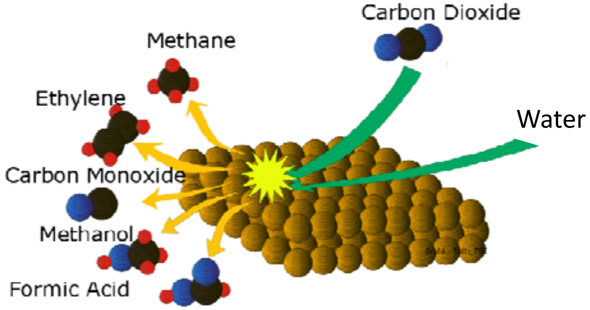


Fig. 4. Schematic of a typical 1D concentrating solar thermal system. The sunlight is focused along one dimension to heat up a thermal fluid—typically, either an oil or a molten salt—which is then passed through a heat exchanger to produce steam that is used in a turbine to produce electricity.

✓ Photovoltaics:

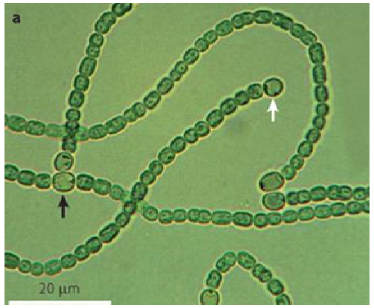
Solar energy → **Electricity**

✓ Solar **fuels** (hydrogen, value-added products):

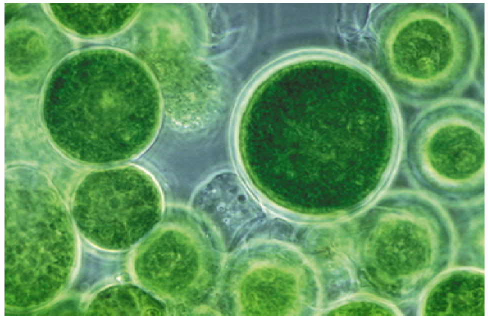


Solar energy → **Chemical Energy**

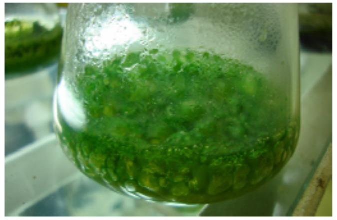
Natural Photosynthesis: nature's way to solar harversting

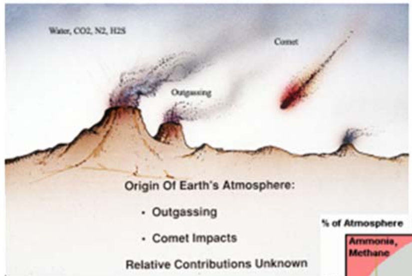


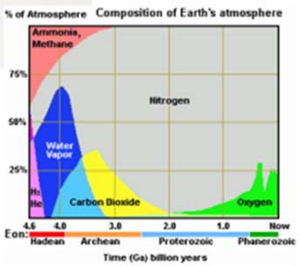
Cyanobacteria

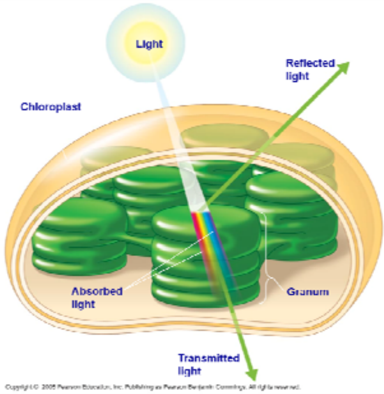


Chlorella sp.

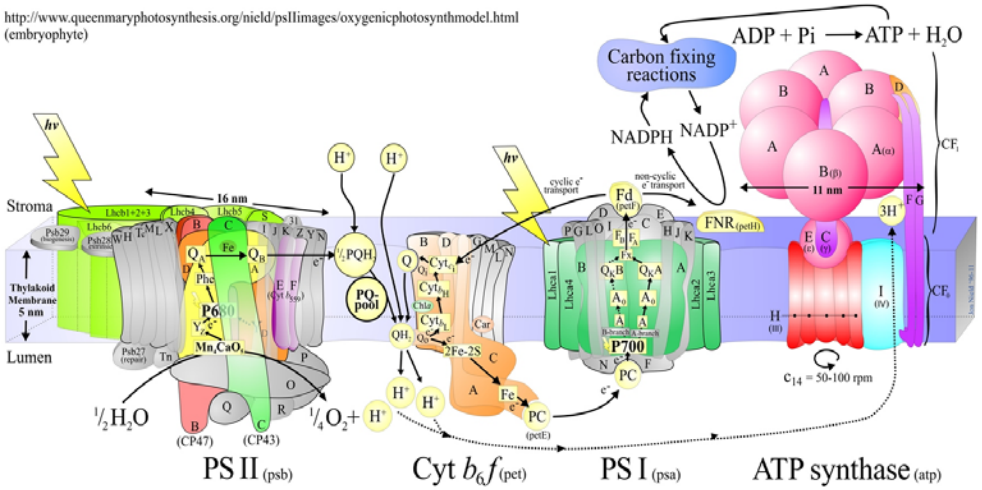


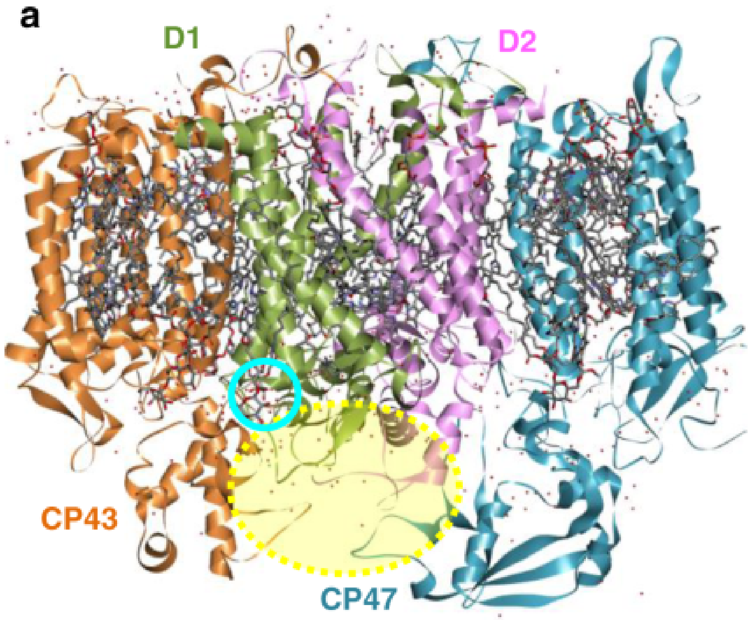


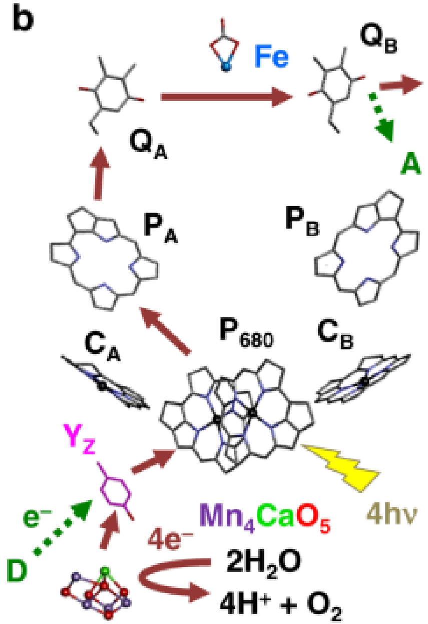


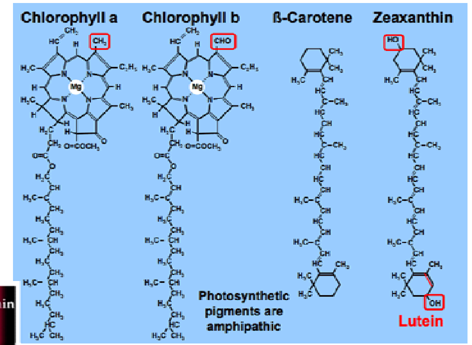


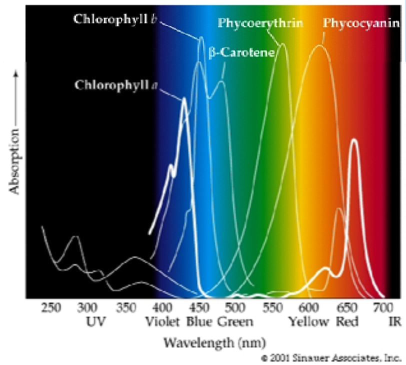
Natural Photosynthesis: molecular view











ARTICLE

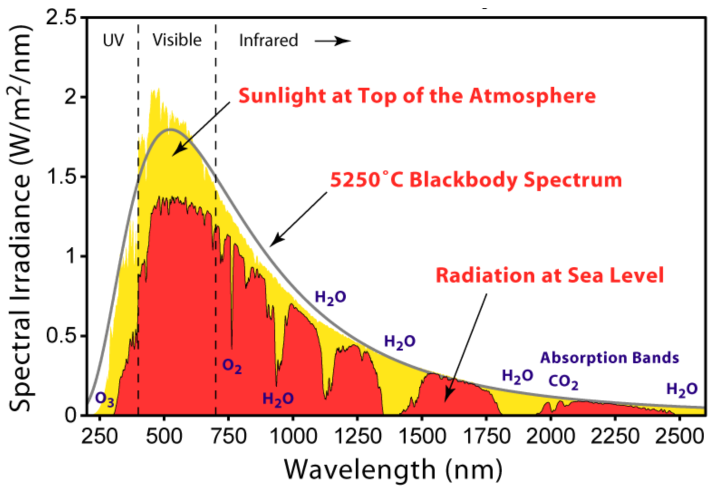
https://doi.org/10.1038/s41467-020-19852-0 OPEN

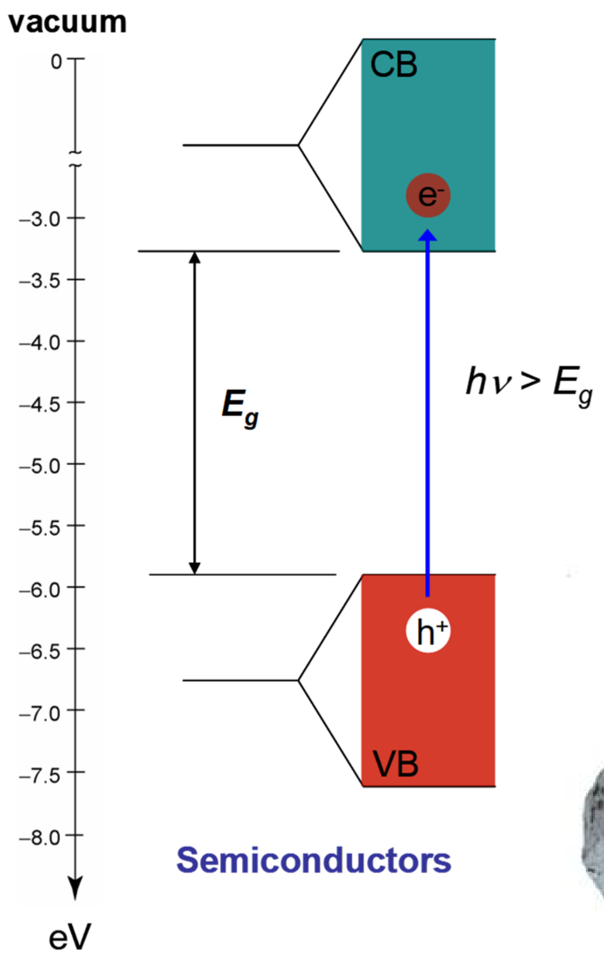
Light-driven formation of manganese oxide by today's photosystem II supports evolutionarily ancient manganese-oxidizing photosynthesis

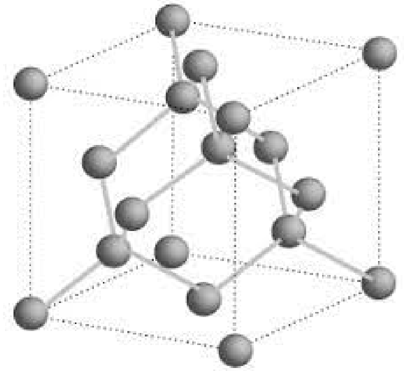
Petko Chernev[1,3], Sophie Fischer[1], Jutta Hoffmann[1], Nicholas Oliver[1], Ricardo Assunção[1], Boram Yu[1], Robert L. Burnap[2], Ivelina Zaharieva[1], Dennis J. Nürnberg[1], Michael Haumann[1] & Holger Dau[1]

«Artificial» harvesting of solar light with semiconductors

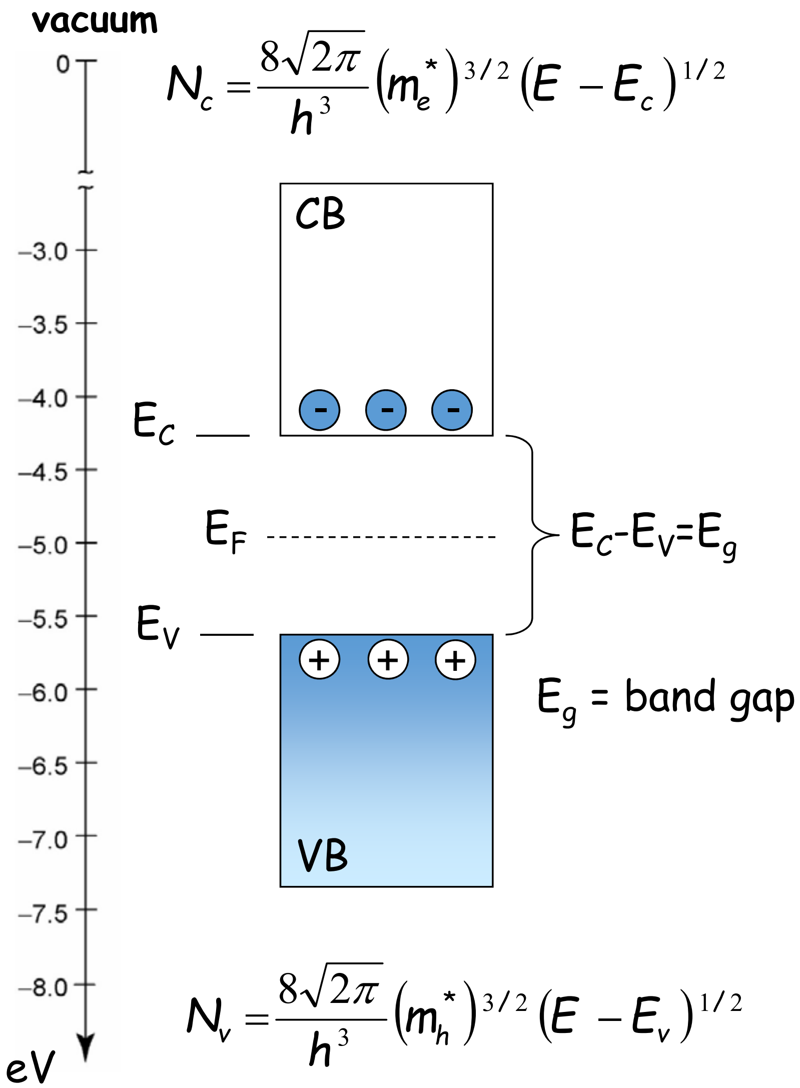
By using suitable catalyzers, it should be possible to transform the mixture of water and carbon dioxide into oxygen and methane, or to cause other endo-energetic processes.





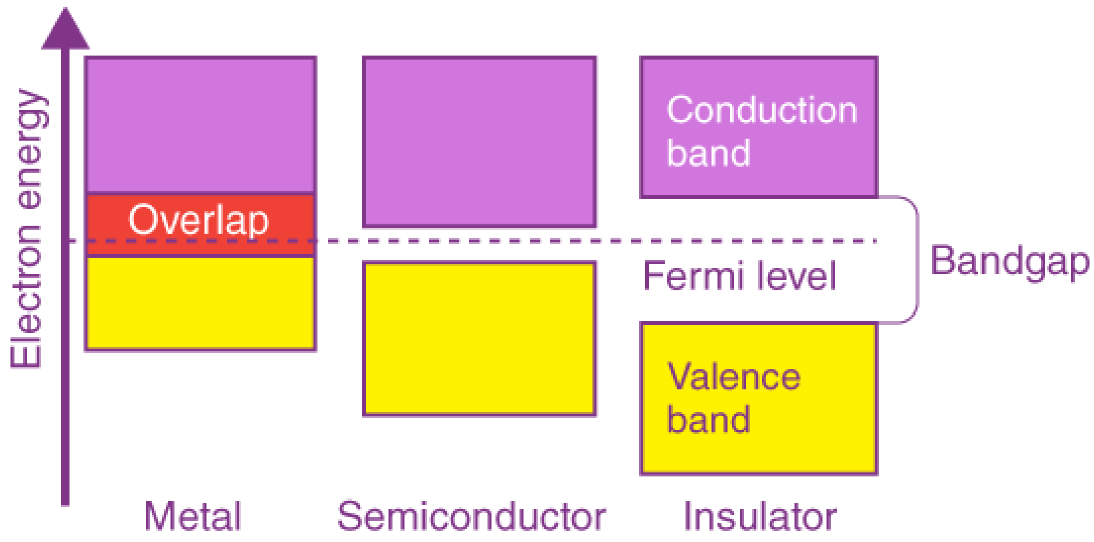


Some details about the band structure of solids



$$N_c = \frac{8\sqrt{2\pi}}{h^3}(m_e^*)^{3/2}(E - E_c)^{1/2}$$

$$N_v = \frac{8\sqrt{2\pi}}{h^3}(m_h^*)^{3/2}(E - E_v)^{1/2}$$



How to produce Silicon

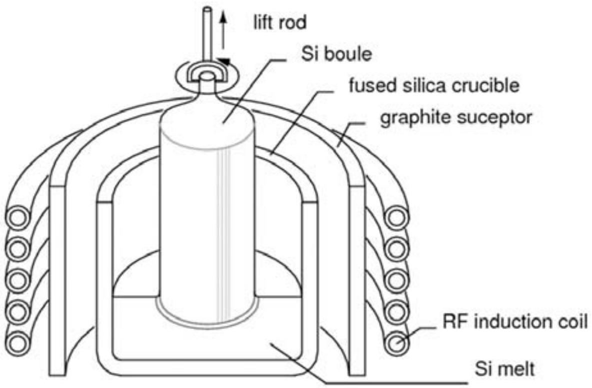
$$SiO_2 + C \longrightarrow CO_2 + Si$$

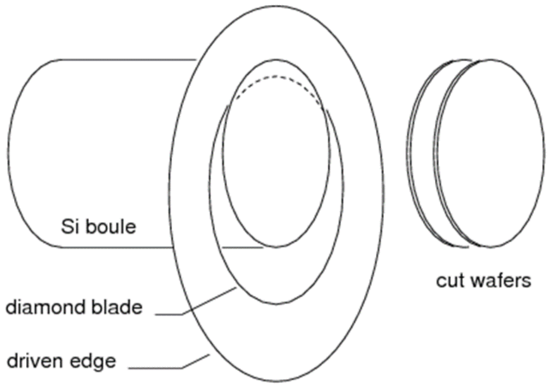
Purificazione tramite formazione di $SiCl_4$ o $HSiCl_3$ e successiva riduzione con idrogeno o metalli ultrapuri

Es : $Si + 3\ HCl \longrightarrow HSiCl_3 + H_2$

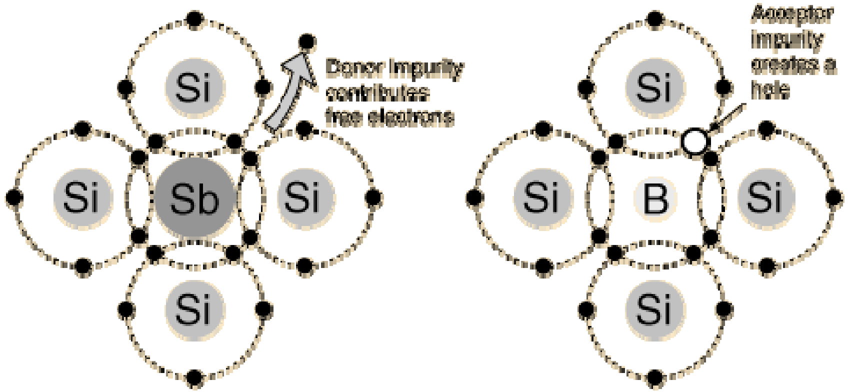
$HSiCl_3 + H_2 \longrightarrow Si + 3\ HCl$

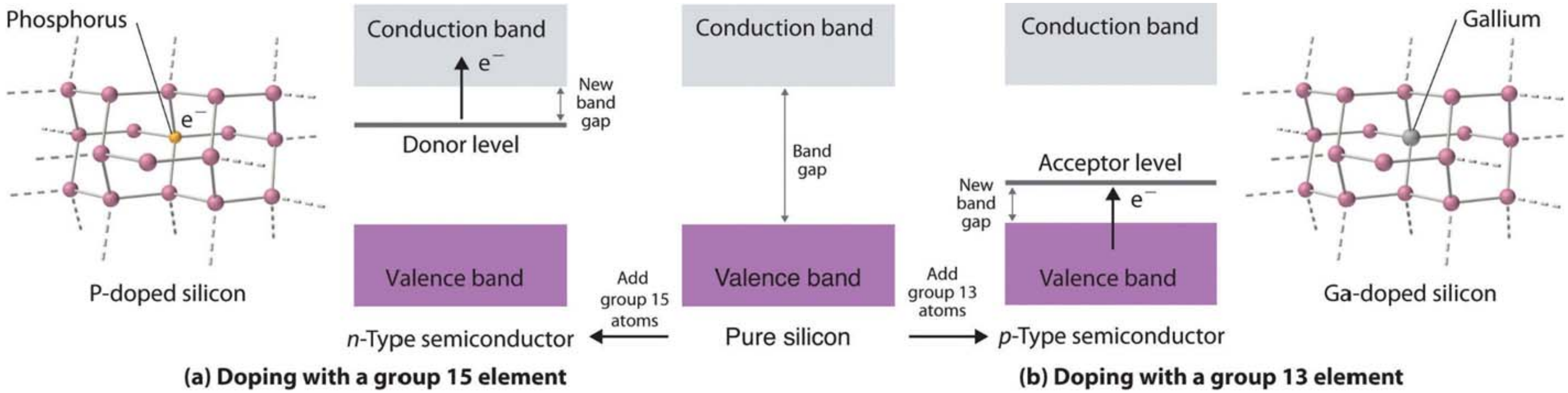
Successiva purificazione per ricristallizzazione da Si fuso i.e. Czochralsky





Doping

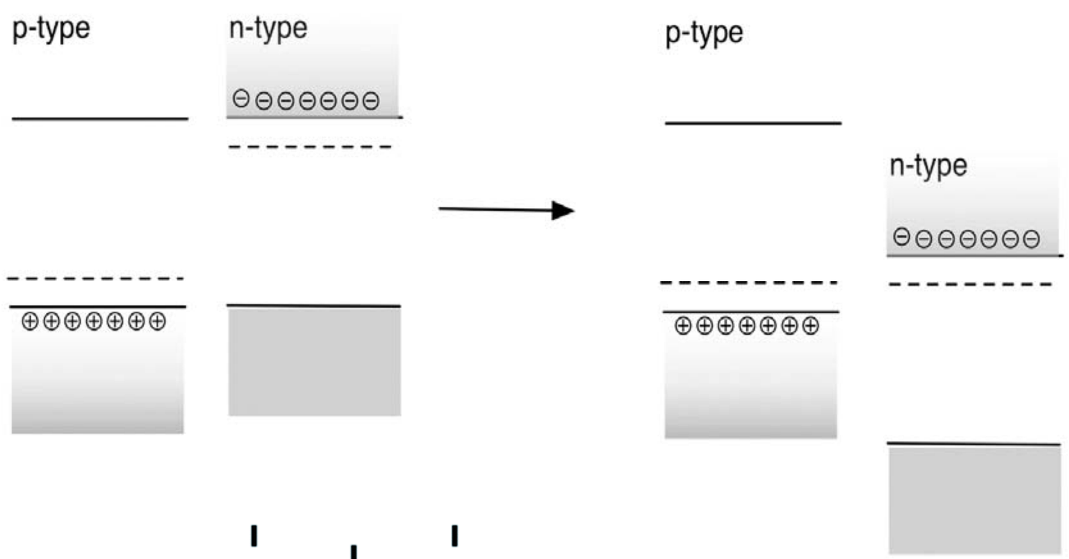


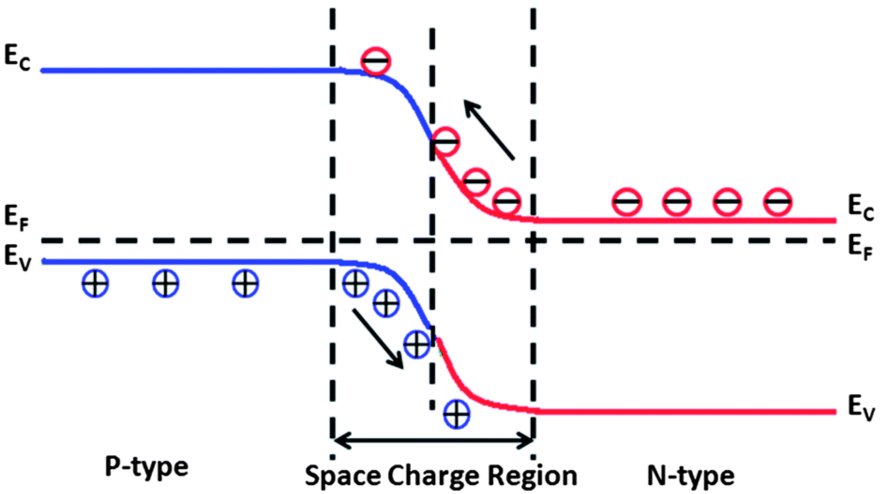


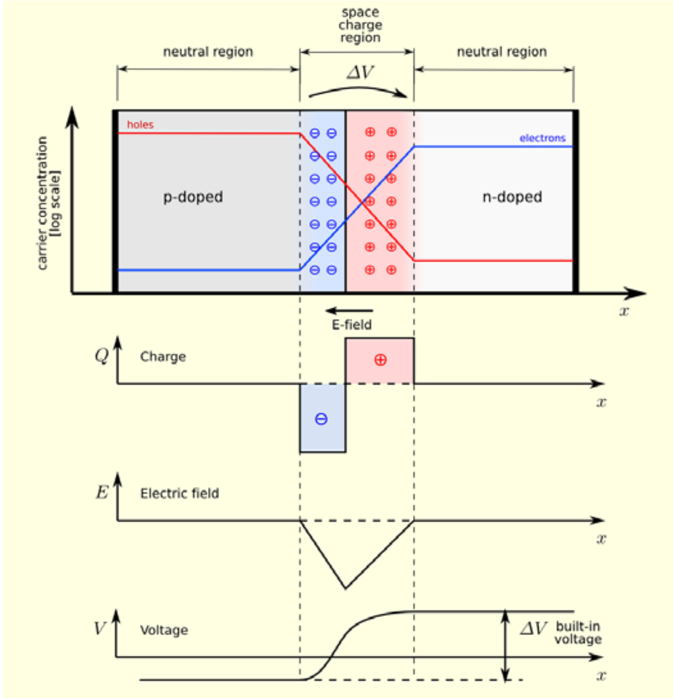
$$\varepsilon_F^n = \frac{\varepsilon_C + \varepsilon_D}{2} + kT\ln\frac{N_D}{2N_C}$$

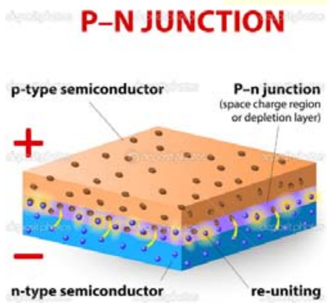
$$\varepsilon_F^p = \frac{\varepsilon_V + \varepsilon_A}{2} - kT\ln\frac{N_A}{2N_V}$$

Schottky Barrier at n-p junction: the «engine» of the solar cell

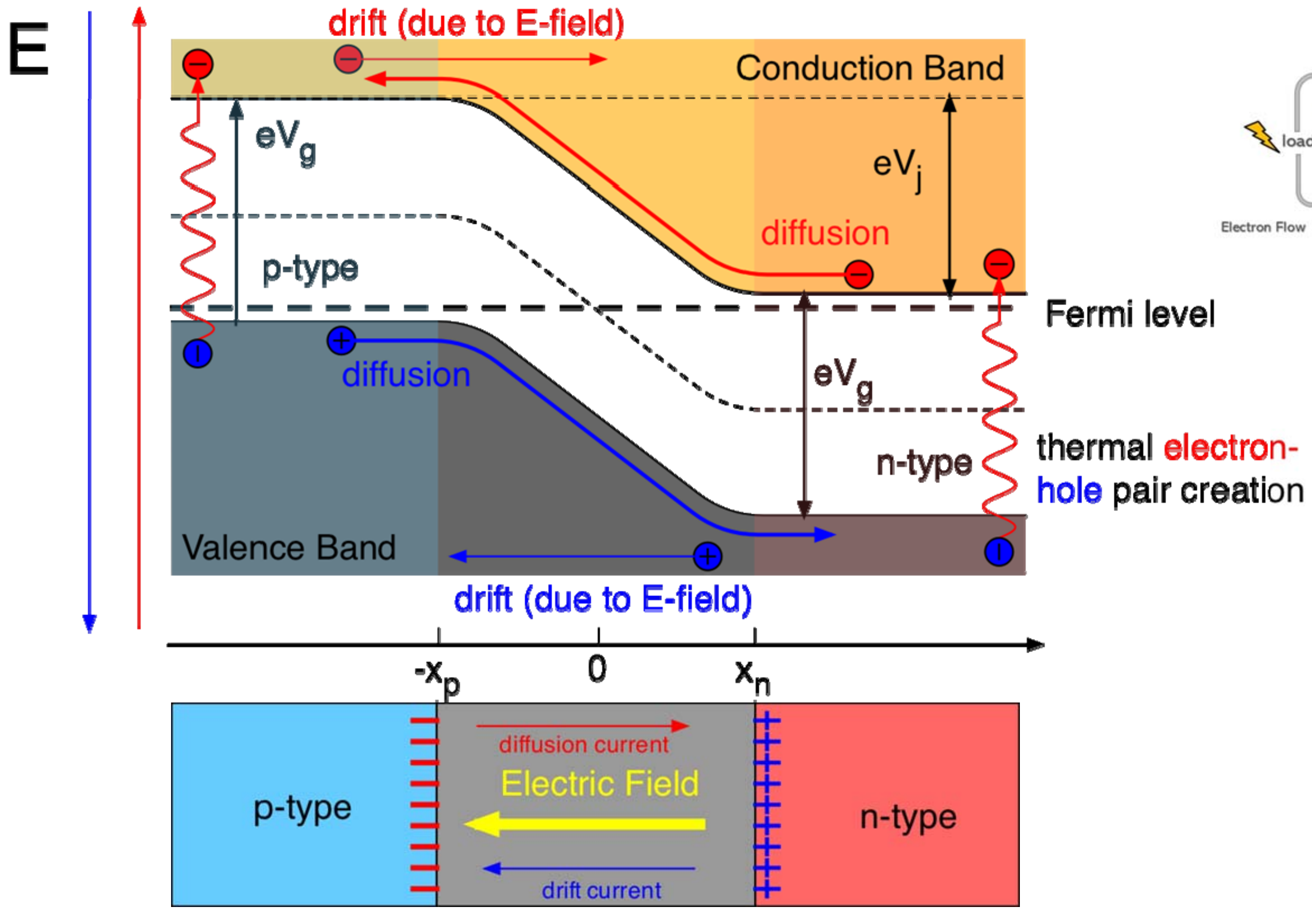


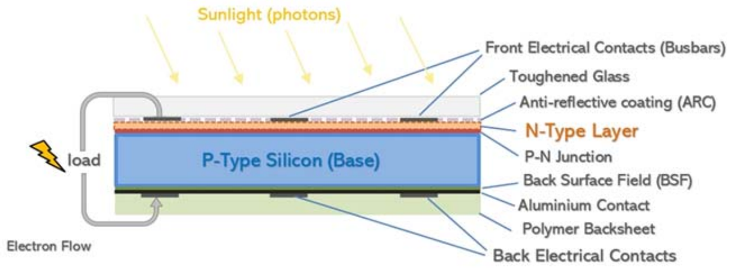


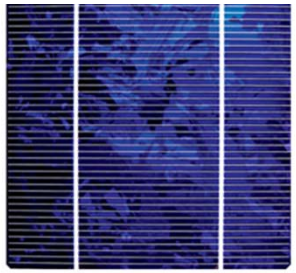


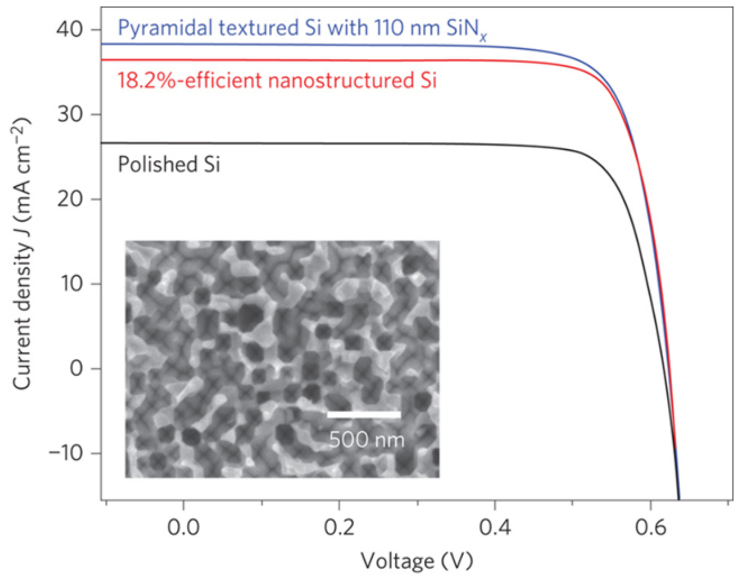


n-p junction as a solar cell (photodiode)

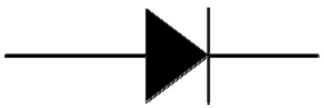




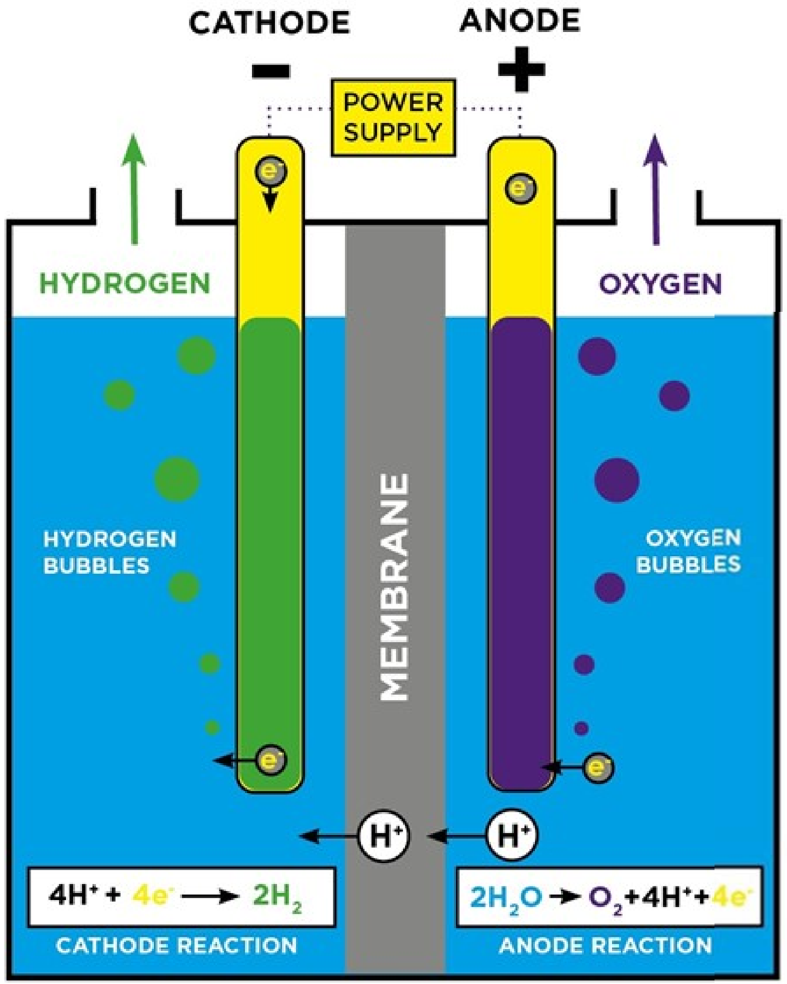




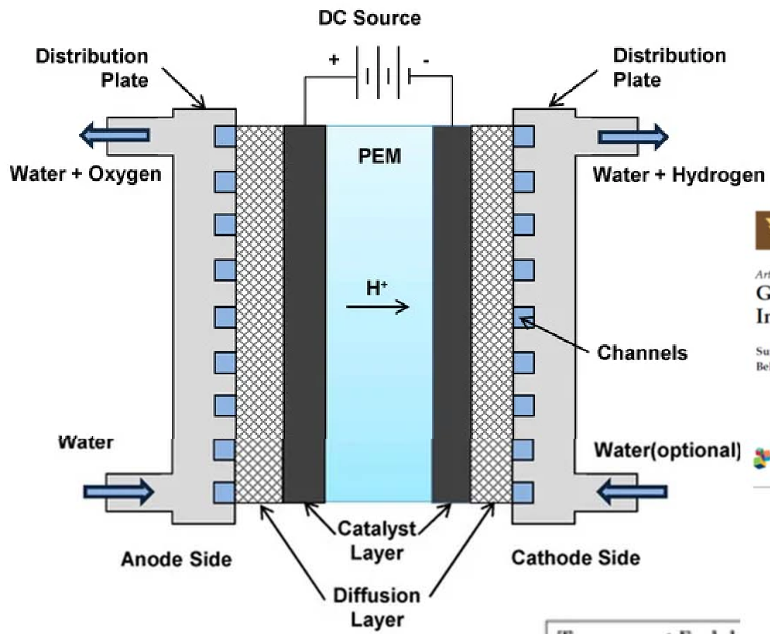
Schematic of pn-junction



Water Electrolysis and Electrolysers



https://www.tfphydrogen.com/markets/water-electrolysers



energies MDPI

Article

Generic Dynamical Model of PEM Electrolyser under Intermittent Sources

Sumit Sood [1,*], Om Prakash [1], Mahdi Boukerdja [1], Jean-Yves Dieulot [1], Belkacem Ould-Bouamama [1], Mathieu Bressel [2] and Anne-Lise Gehin [1]

frontiers in Energy Research
ORIGINAL RESEARCH

Optimisation of Mass Transport Parameters in a Polymer Electrolyte Membrane Electrolyser Using Factorial Design-of-Experiment

*Jude O. Majasan, Jason I. S. Cho, Maximilian Maier, Paul R. Shearing and Dan J. L. Brett**

Electrochemical Innovation Lab, Department of Chemical Engineering, University College London, London, United Kingdom

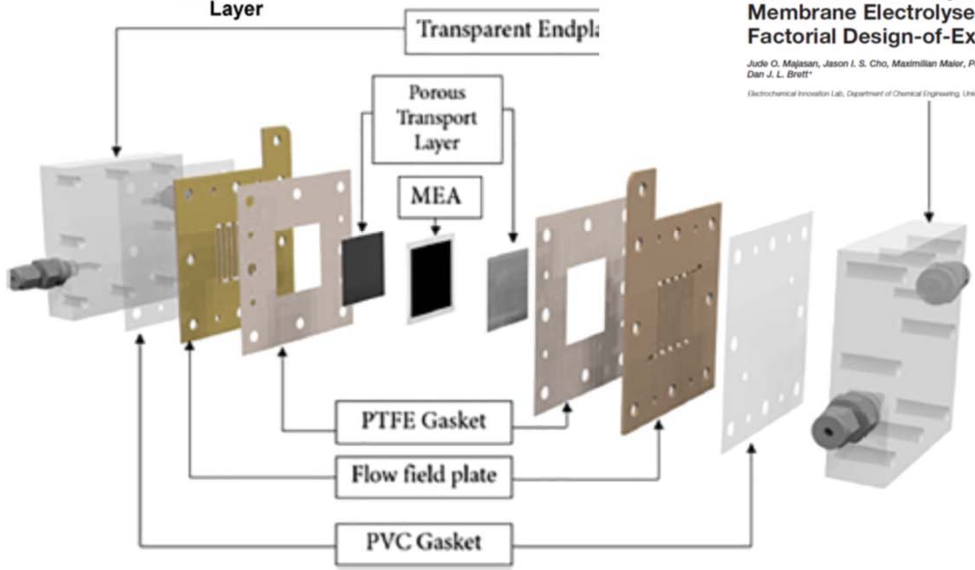
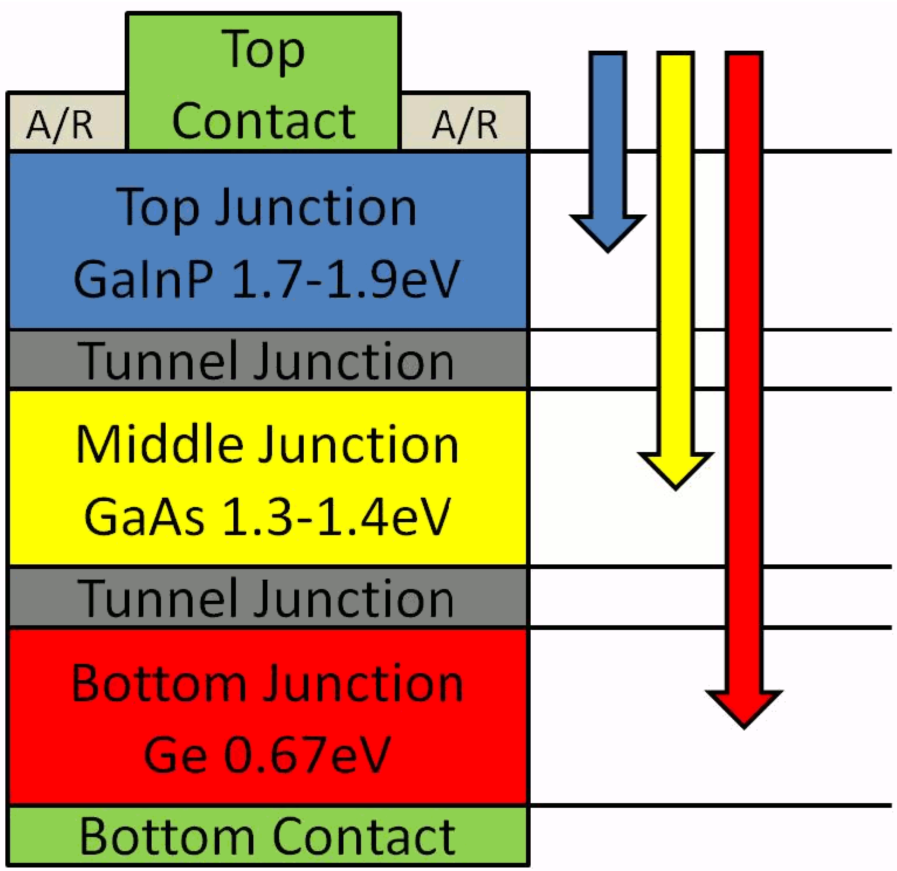
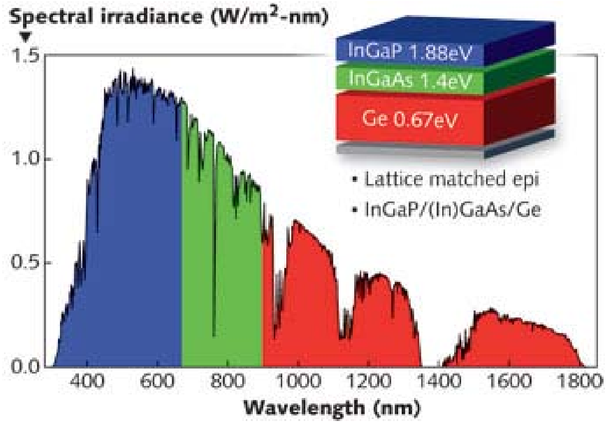
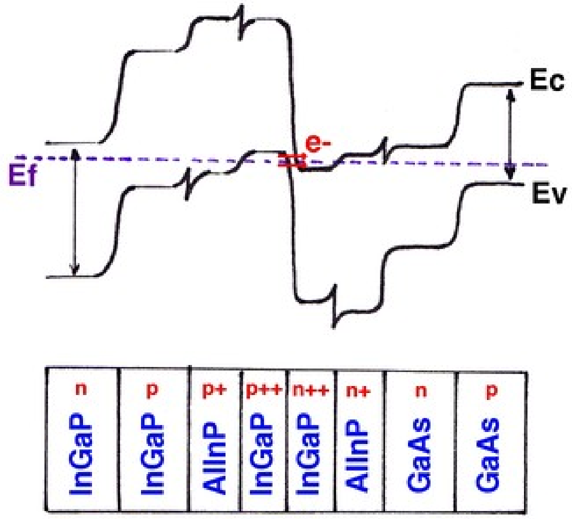


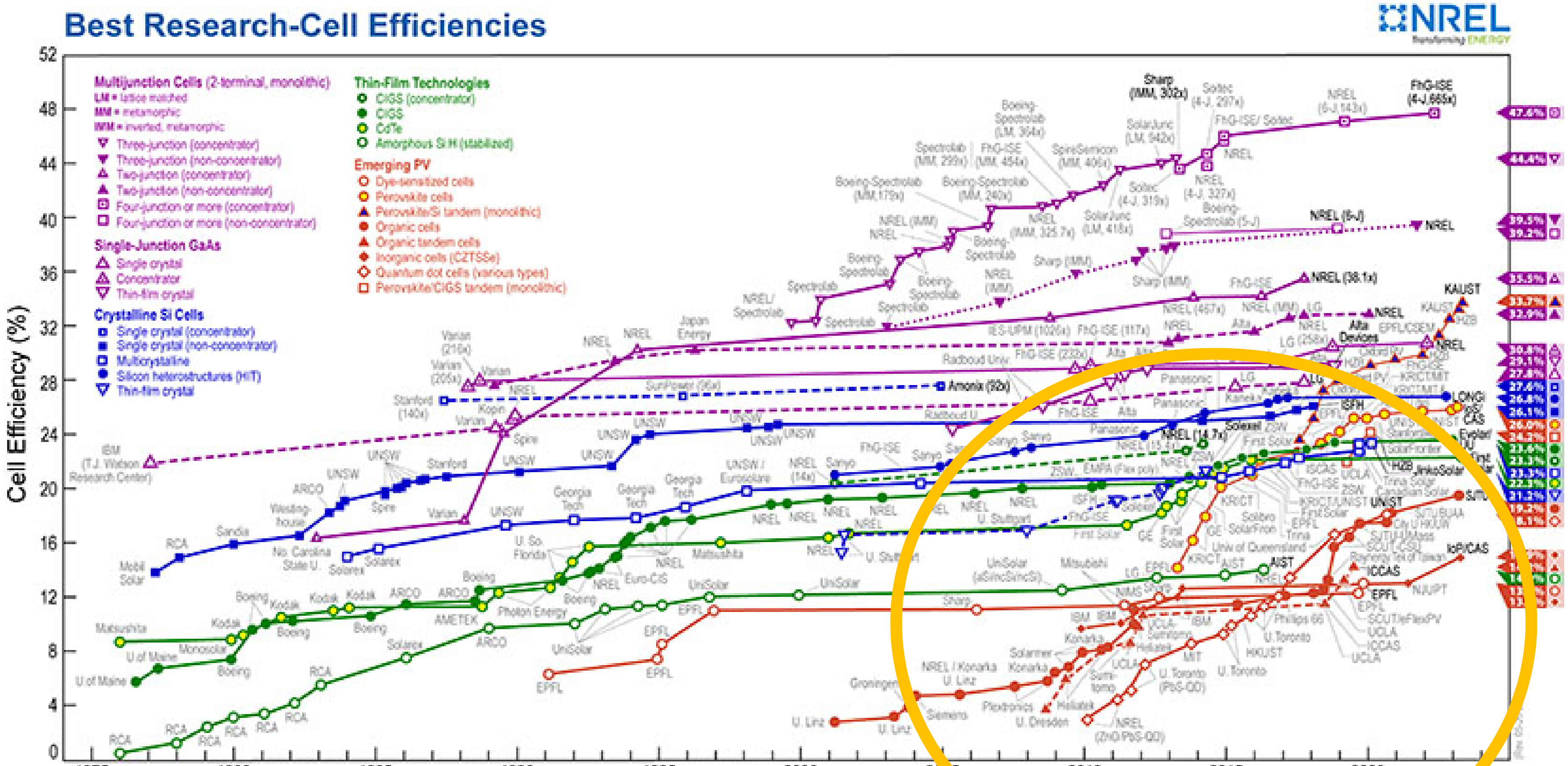
FIGURE 1 | Schematic of the PEMWE cell used for the study.

Optimizing efficiciency: Multijunction Solar Cells





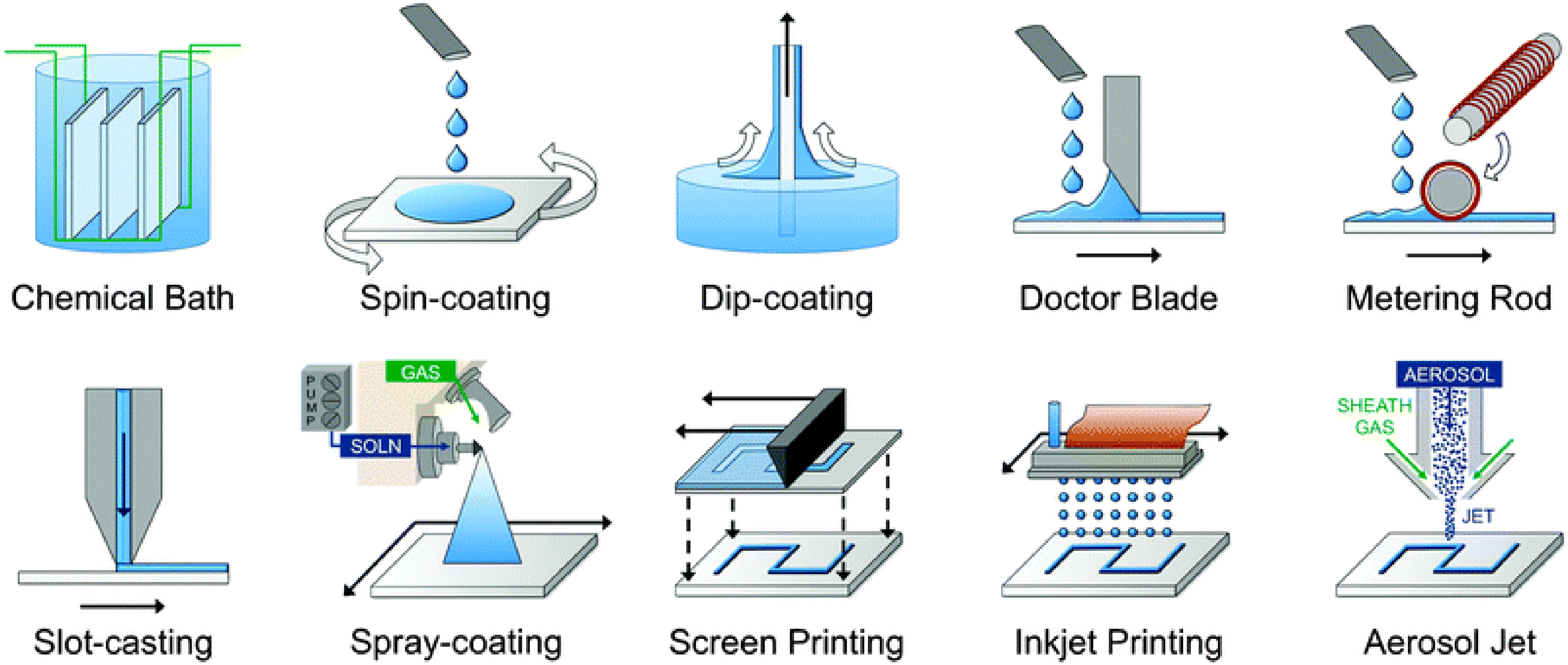



Best Research-Cell Efficiencies
NREL
Cell Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells
Perovskite/Si tandem (monolithic)
Organic cells
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells (various types)
Perovskite/CIGS tandem (monolithic)
47.6%
44.4%
39.5%
39.2%
35.5%
33.7%
32.9%
1975
1980
1985
1990
1995
2000
2015
2020


Terra
Fuoco
Acqua
Aria

Semiconductor preparation at Unife: search for scalable wet routes

✓ **Deposition of sol–gel colloidal suspensions or precursors’ solutions**



Chem. Soc. Rev. **2011**, *40*, 5406

Nanostructured Materials

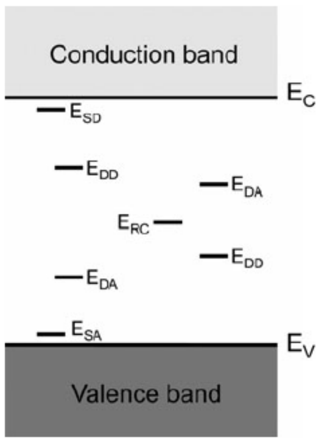
GOOD PROPERTIES

- Active Surface
- low T, wet routes available
- Diffusion Length

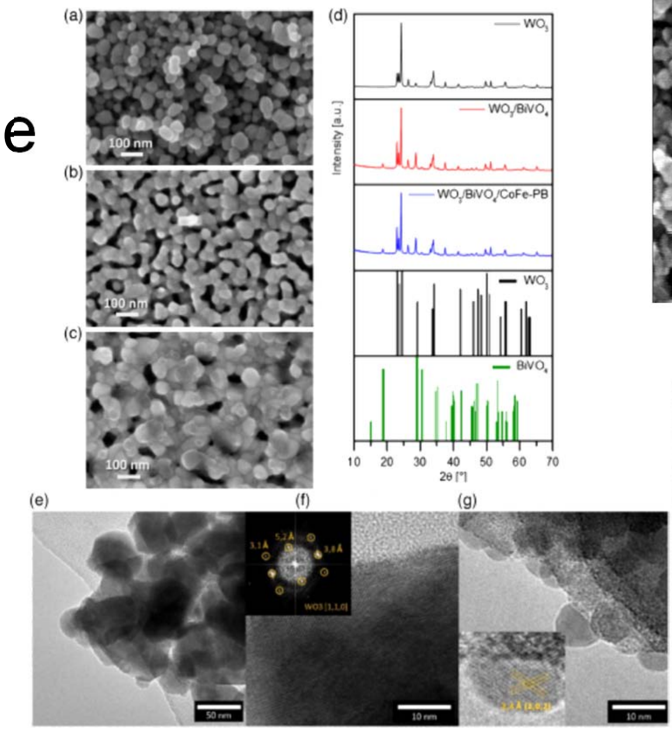
Drawbacks

•Defects/SS

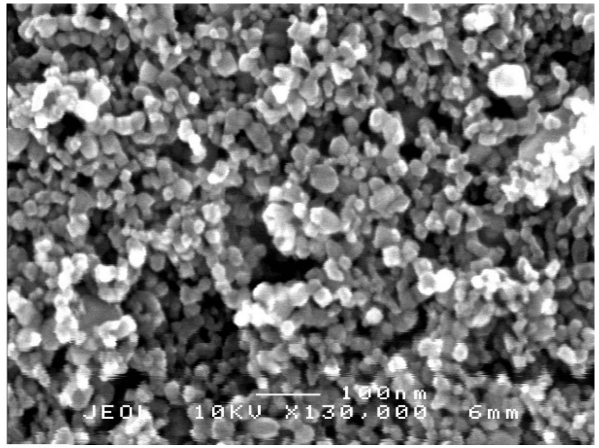
•Traps



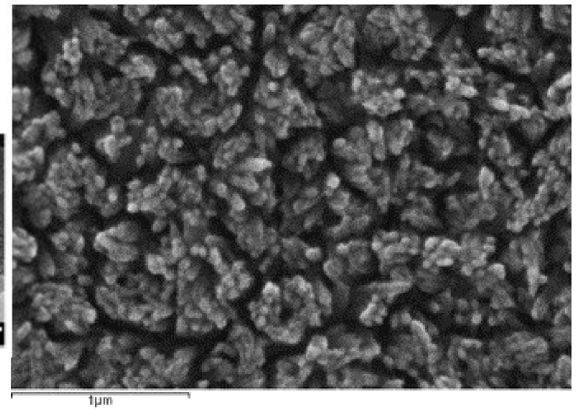
$BiVO_4/WO_3$



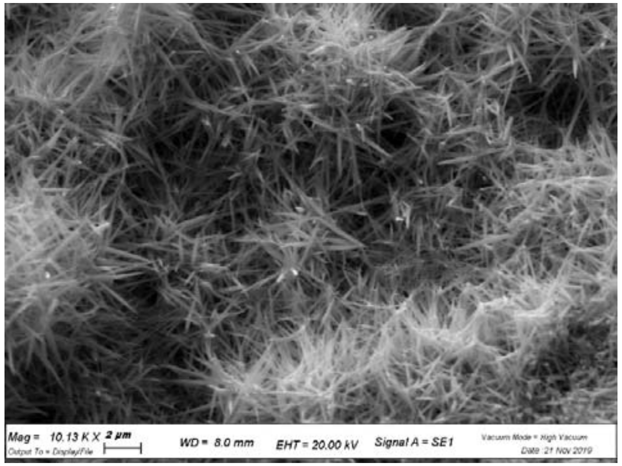
Sol-gel TiO_2



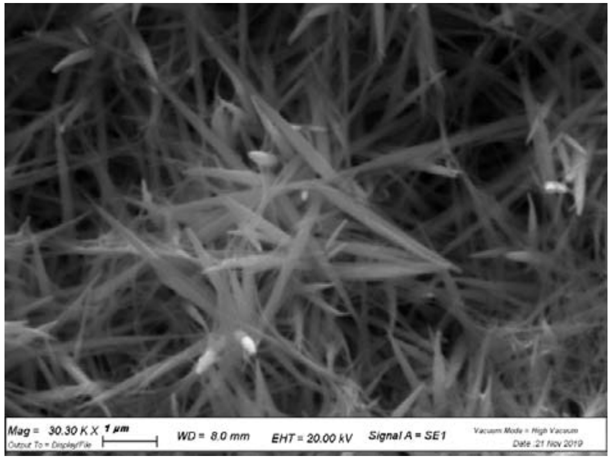
Fe_2O_3 nanorods



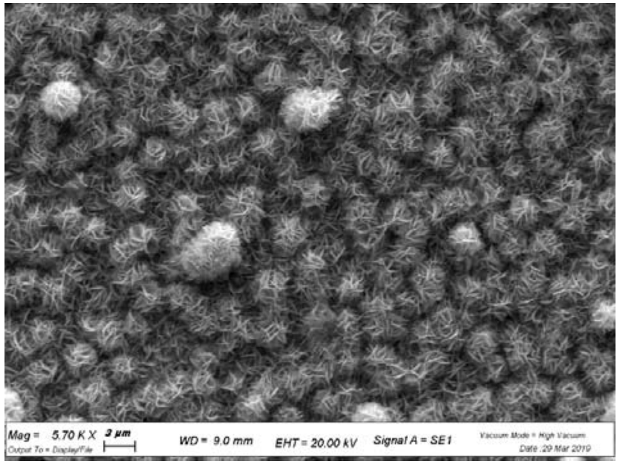
WO_3 nano-morphologies from hydrothermal-Solvothermal Routes

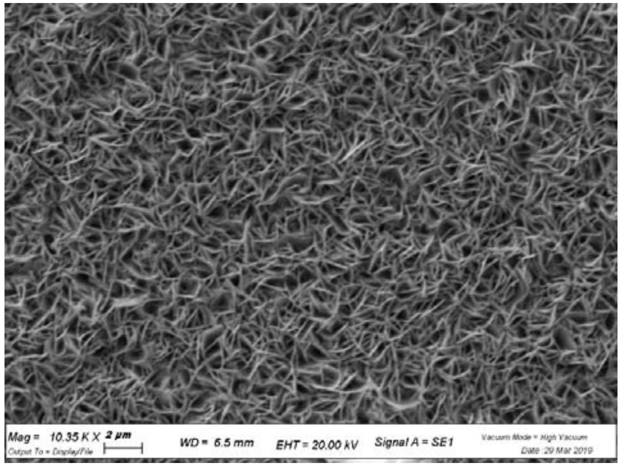


Nano Flakes



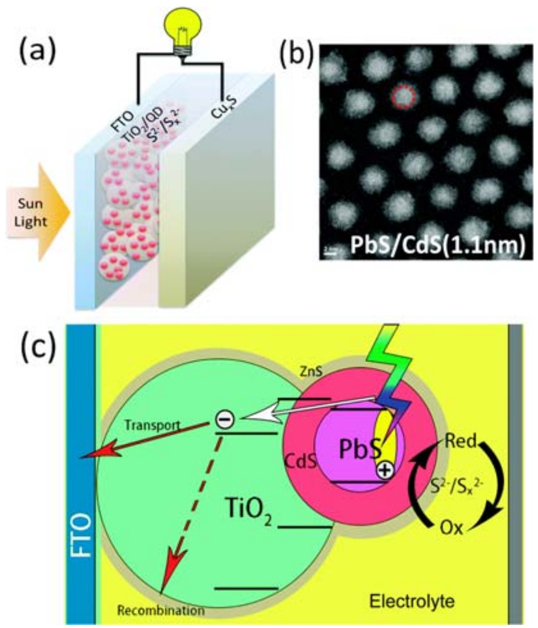
Nano Fiber Sheets

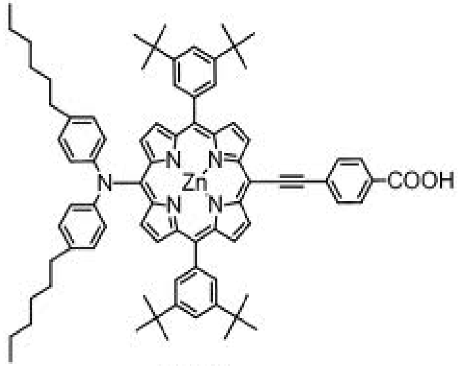




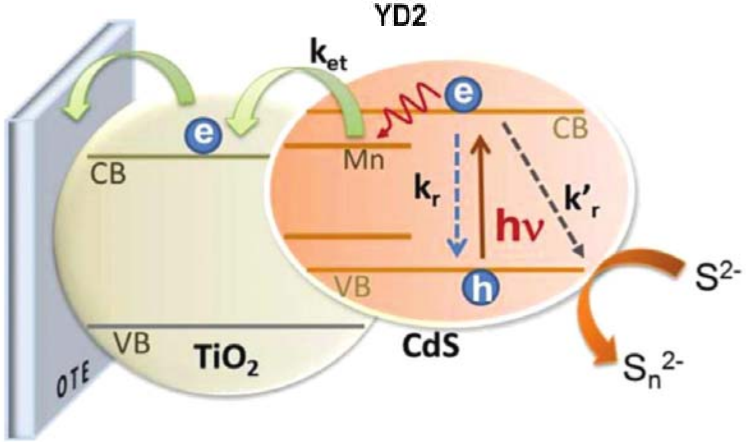
Research at Unife: Spectral Sensitization

Light Absorption and Charge separation are originated by photoactive surface bound species. The wide band gap semiconductor acts as a phyisical support and as a conductor for majority carriers. Surface bound species can be either other semiconductors (e.g. Quantum dots) or molecular species.

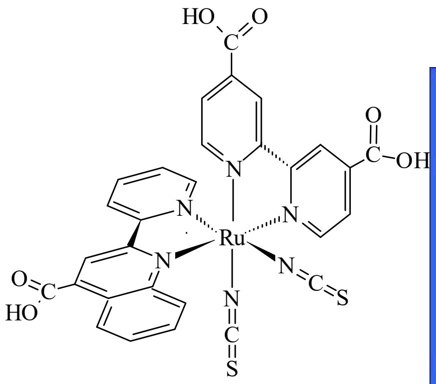


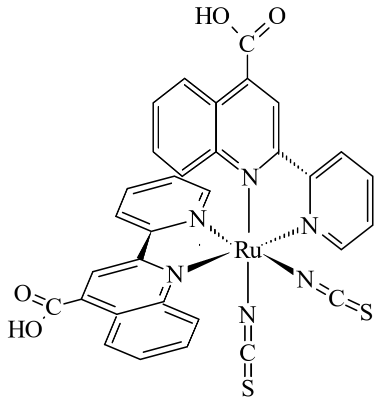


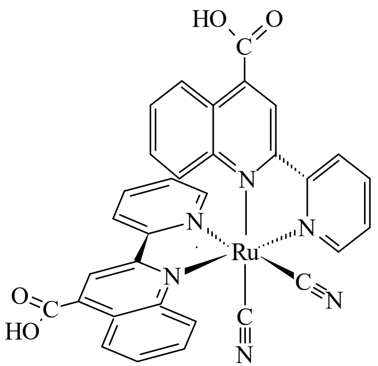
YD2

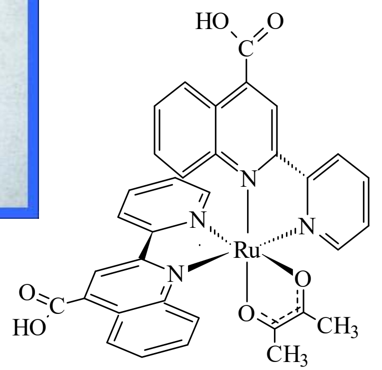


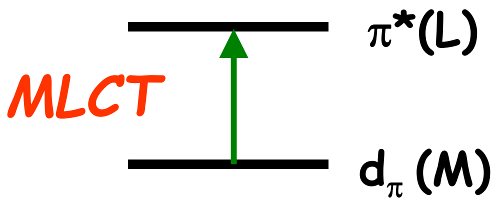
Chromatic versatility of metal based dyes





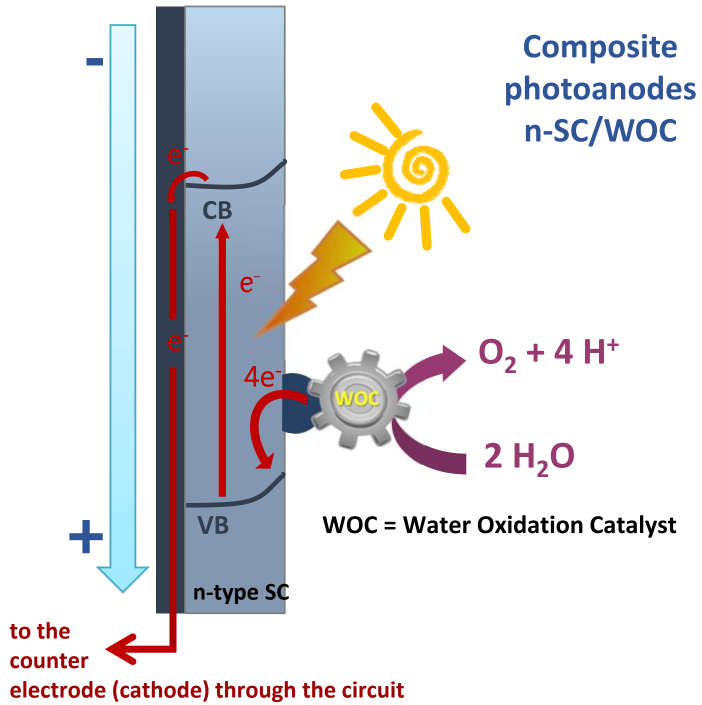


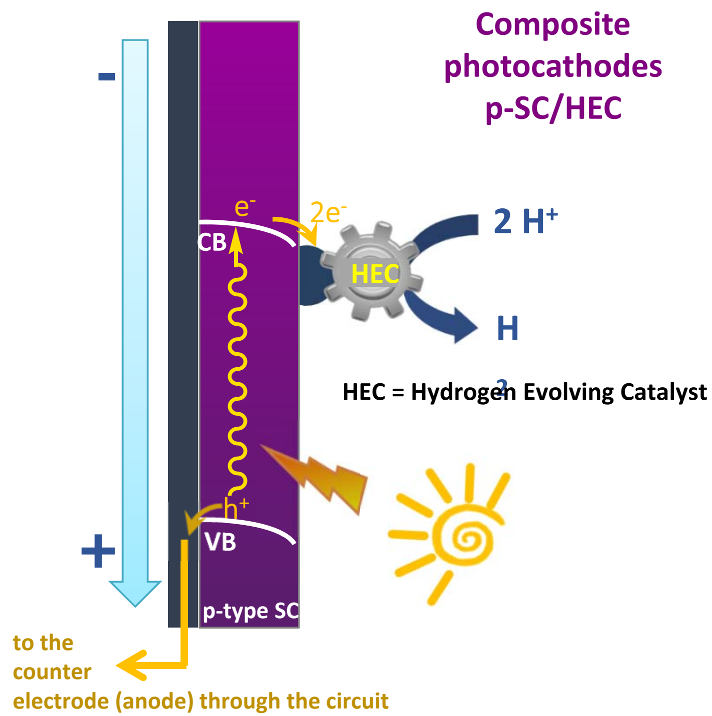




Tuning the surface properties with “catalytic” layers

- Catalytic layers as SCs overcoatings





Some tandem PEC configurations

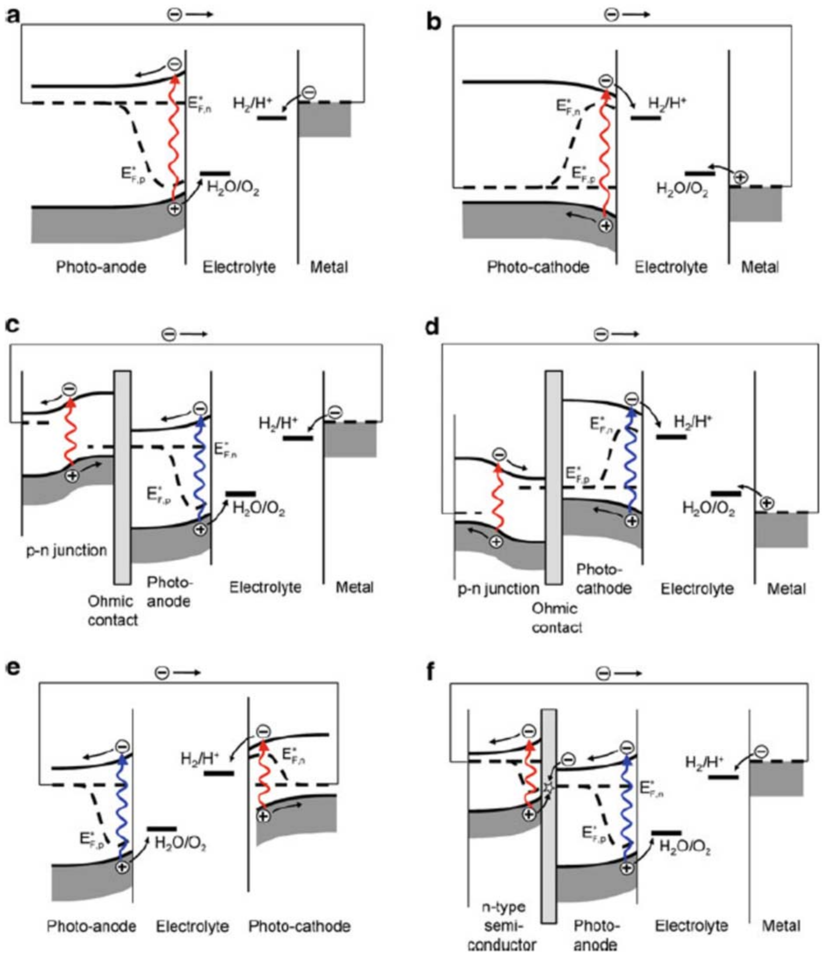


Fig. 2.25 Examples of possible PEC configurations under illumination. *Top row*: Standard single-semiconductor devices based on a photoanode (a) or photocathode (b) with a metal counter electrode. *Middle row*: Monolithic devices based on a photoanode (c) or photocathode (d) biased with an integrated p–n junction. *Bottom row*: p–n junction photoelectrochemical device (e), and an n–n heterojunction PEC device based on a photoanode deposited on top of a second n-type semiconductor that "boosts" the energy of the electrons (f)

nature photonics LETTERS
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Highly efficient water splitting by a dual-absorber tandem cell

Jeremie Brillet[1], Jun-Ho Yum[1], Maurin Cornuz[1], Takashi Hisatomi[1], Renata Solarska[2], Jan Augustynski[2], Michael Graetzel[1] and Kevin Sivula[1]*

"Water splitters fabricated using triple-junction amorphous silicon1,2 or III–V3 semiconductors have demonstrated reasonable efficiencies, but at high cost and high device complexity"

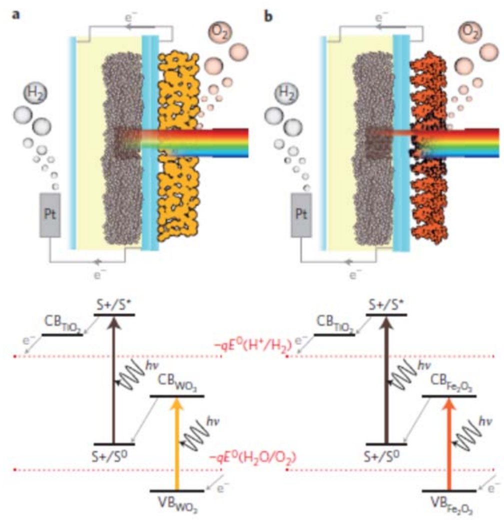
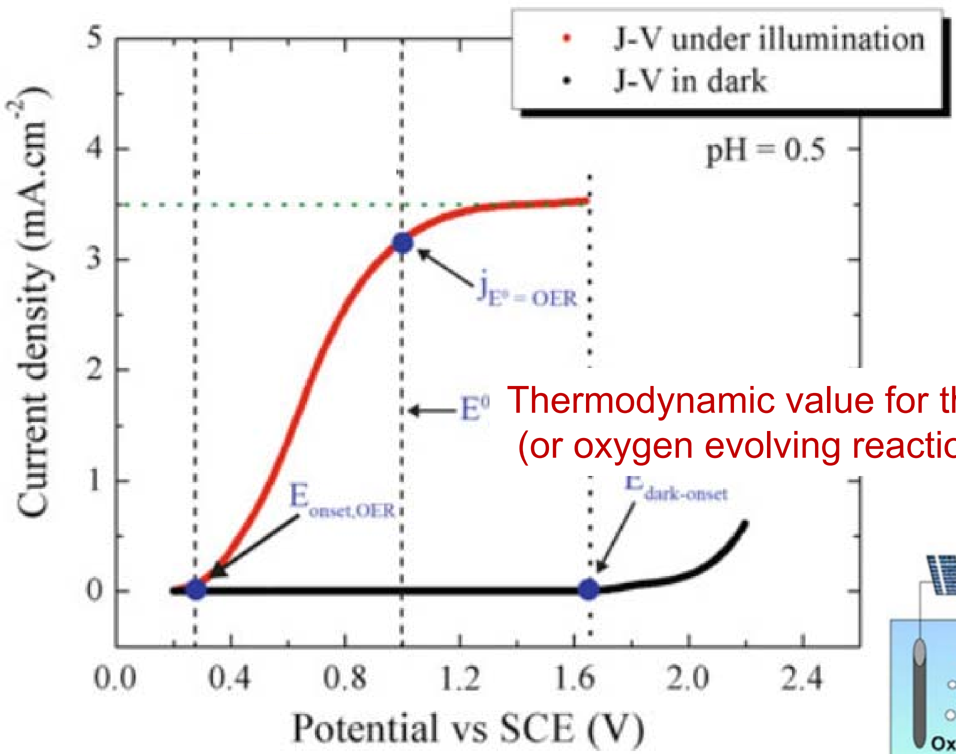
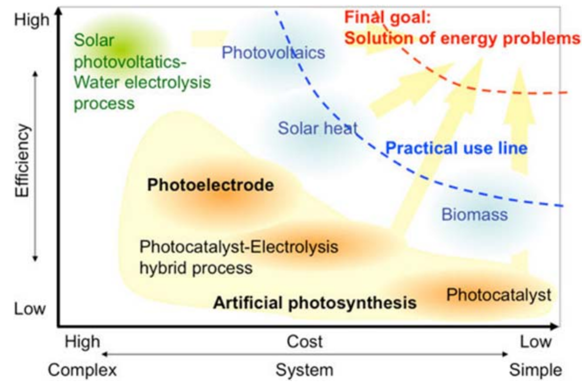


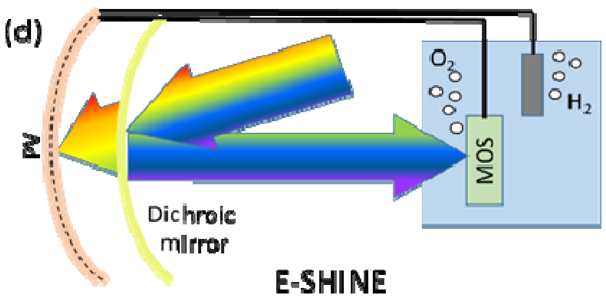
Figure 1 | General schemes and energy diagrams for a photoanode/DSC D4 tandem cell. a, WO_3 tandem cell. **b**, Fe_2O_3 tandem cell. Red dotted lines indicate the reduction and oxidation potentials of water.

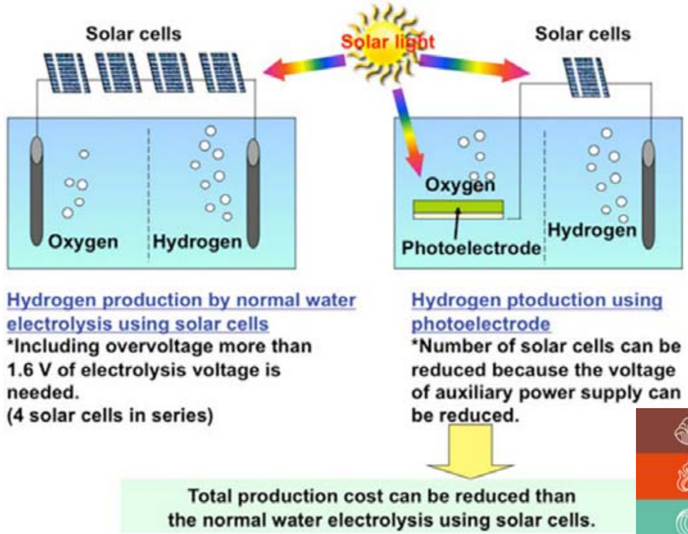
Typical n-type PEC Current/Voltage characteristic: **voltage saving with respect to conventional electrolysis**



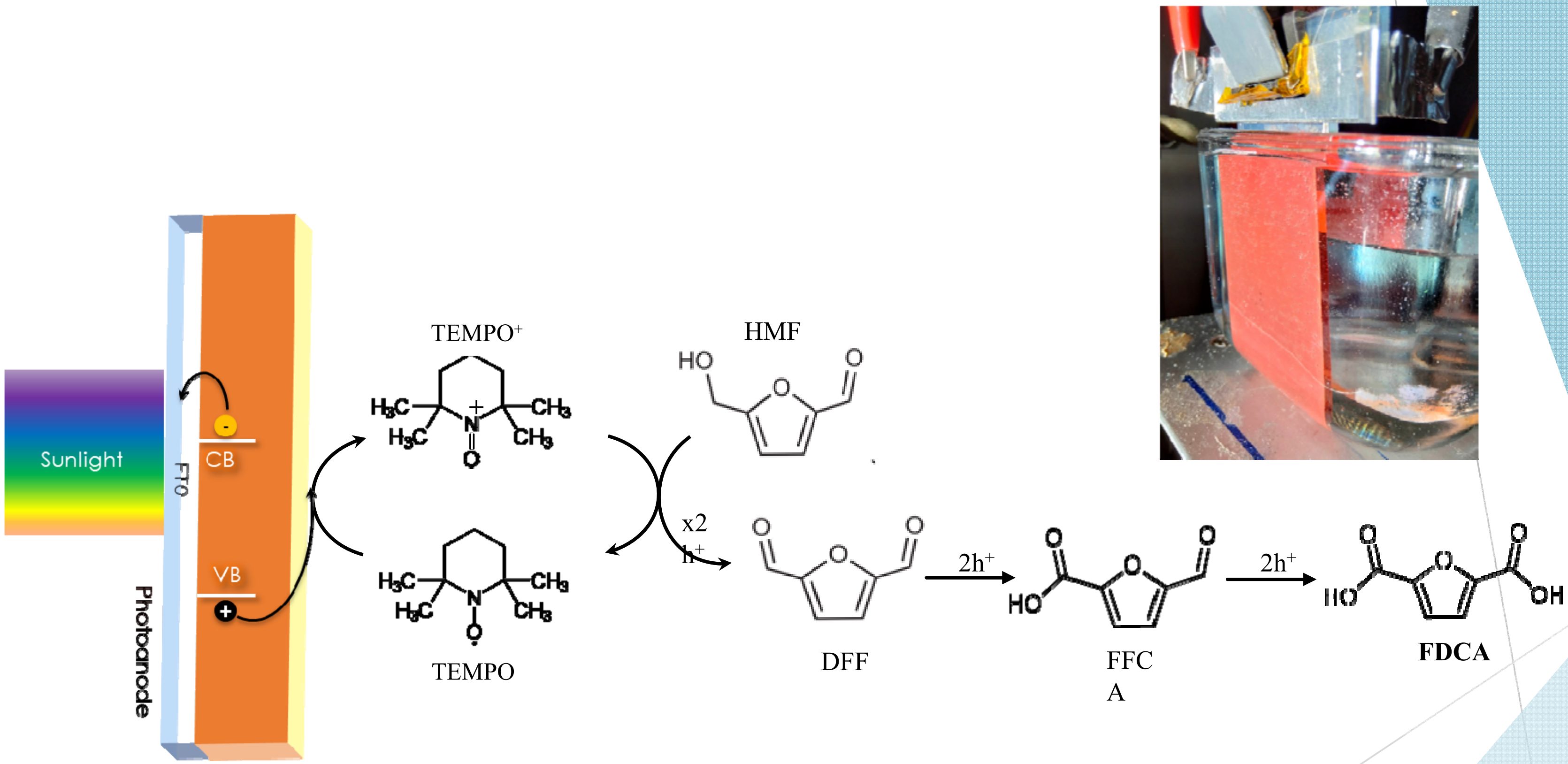
Thermodynamic value for the water oxidation
(or oxygen evolving reaction, OER) at pH 0.5, vs SCE





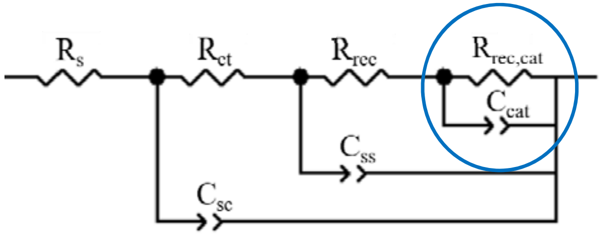


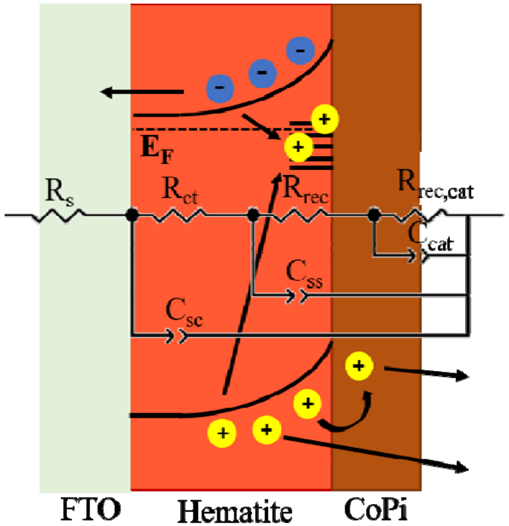
CONDOR research: Hematite photoanodes for Biomass oxidation: from HMF to FDCA



Kawde, A. et al., *Catalysts* 2021, 11, 969

Electrochemical Impedance Spectroscopy of Hematite with CoPi catalyst





Additional mesh to account for charge transfer through the CoPi layer.
Holes trapped in Hema's SS are transferred to the CoPi layer, which subsequently transfers them to the electrolyte

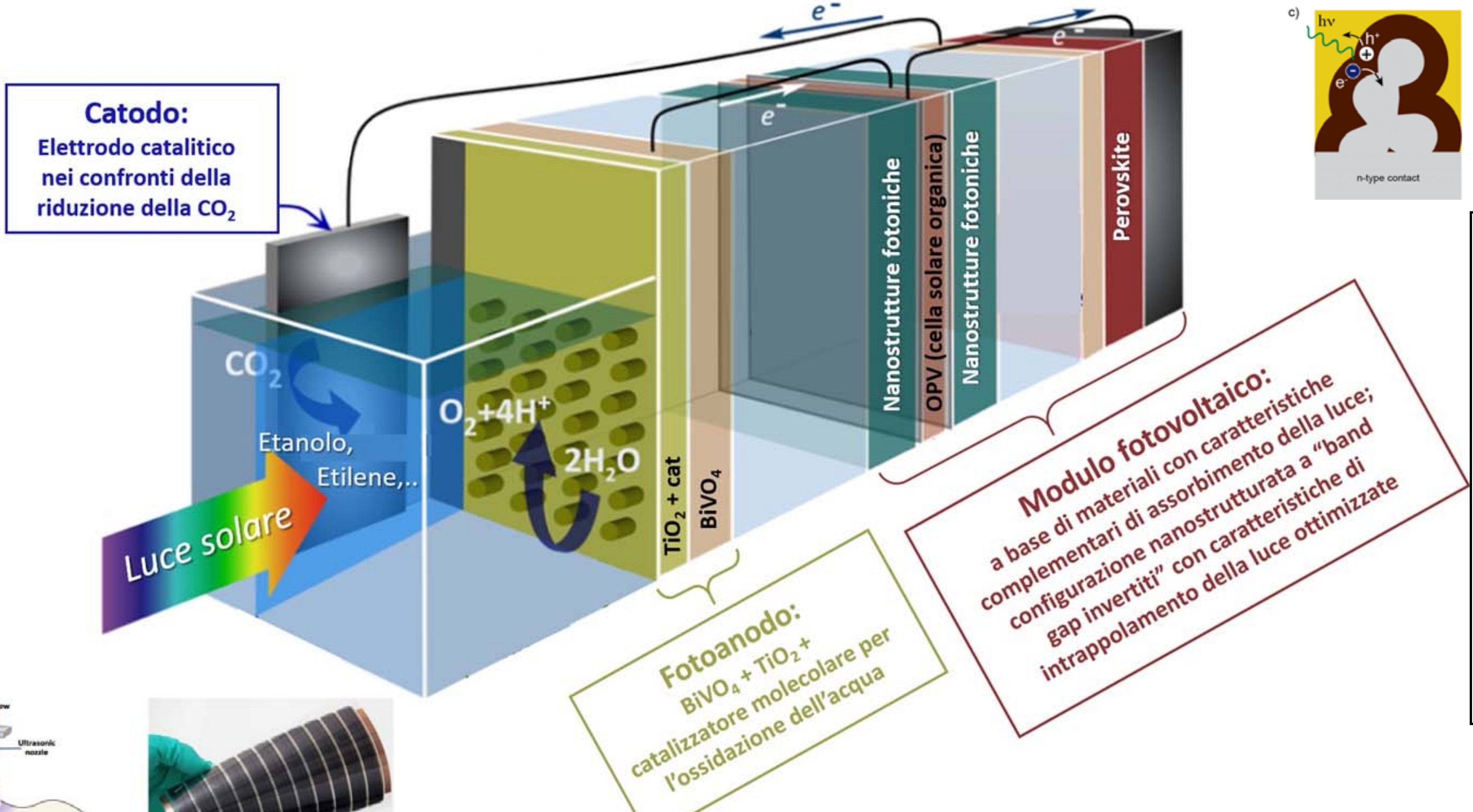
Rrec,cat = recombination resistance through CoPi
Ccat = capacitance associated to CoPi

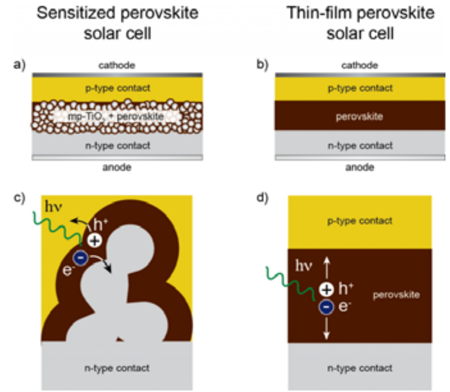
$R_{tot} = R_s + R_{ct} + R_{rec} + R_{rec,cat}$

$R_s = R_{series}$
$R_{ct} = R_{charge\ transfer}$
$R_{rec} = R_{recombination}$
$R_{rec,cat} = R_{recombination\ from\ cat}$

$C_{sc} = C_{space\ charge}$
$C_{ss} = C_{surface\text{-}states}$
$C_{cat} = C_{catalyst}$

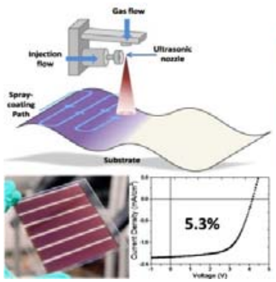
Integrated Cells for Solar Fuels

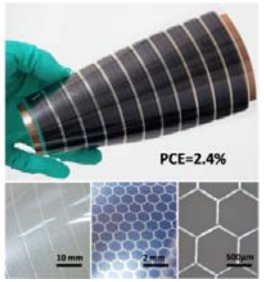




SOREC2
SOLAR ENERGY TO POWER CO_2 REDUCTION TOWARDS C_2 CHEMICALS FOR ENERGY STORAGE

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Grant Agreement n. 101084326





General Remarks

Some emerging «low cost» technologies are becoming viable competitors of conventional PV junctions, and their efficiency are further rapidly growing.

PEC represent the most direct pathway to exploit low cost materials for storing solar energy into chemical energy, or to exploit solar power for environmental remediation processes.

Some materials, particularly metal oxides, are cheap, easy to produce and display stability under photoanodic conditions in water based electrolytes. They enjoy suitable energetics to drive demanding electrochemical reactions and to harvest a sizable portion of the solar spectrum.

The thermodynamic efficiency limit to the STH of many semiconductors is still far from being achieved. Fundamental research is still needed to understand the optimization of the interfaces, minimize recombinative losses, improve the light management, but results are being achieved and progresses being made made.

Photo(electro)chemical People