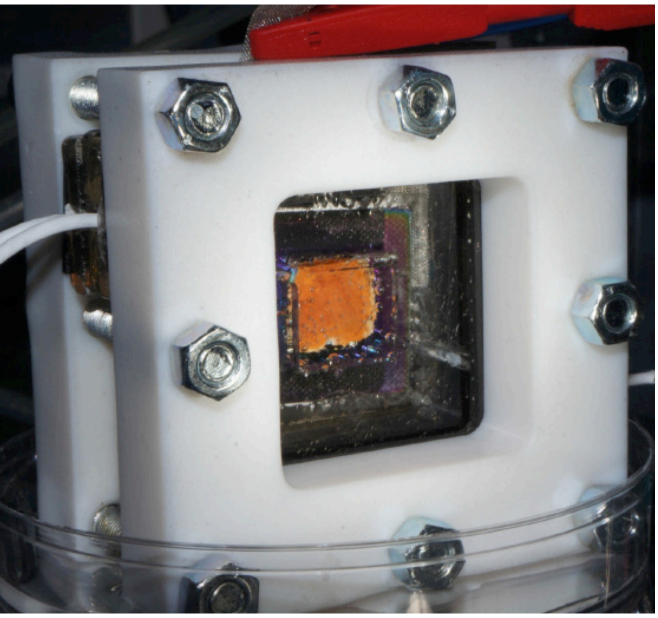
Solar fuels from photons, water and CO_2

*"Since three billions of years ago photosynthetic microorganisms learned how to split water into oxygen and hydrogen, exploiting this last to reduce CO_2 to form the organic molecules of at ambient temperature. The research team of **Professor Guido Saracco** is at work in a series of EC-funded projects to replicate this even more effectively in artificial devices aimed at the intensive production of 'solar fuels'."*

Leaves and algae split water into oxygen and hydrogen at ambient conditions, exploiting sunlight. This is the first, fundamental step of photosynthesis, a crucial phenomenon active on Earth since 3 billion years ago and chiefly responsible for the presence of oxygen in our atmosphere.

Professor Guido Saracco (Fig. 2), Head of the Applied Science and Technology Department at the Politecnico di Torino, recently funded with the world class scientist James Barber (ENI-Italgas prize in 2005 for his studies on the Photosystem II enzyme which governs the water-splitting process in photosynthesis) a new laboratory, the Biosolar Lab, aimed at exploring this natural process and replicating it in artificial high-efficient photo-electrochemical reactors.



In a first European project (Solhydromics; www.solhydromics.com; 2009-2012), funded in the Future and Emerging Technologies area of the Energy Workprogramme, an artificial device to convert solar energy into hydrogen was successfully developed, achieving an overall 1% conversion of solar energy into H_2 chemical energy. A picture of the Solhydromics prototype in operation is provided in Fig. 1.

The device comprises three main components: an anode to carry the PSII-like chemical (a Co-based water splitting catalyst), a cathode to carry another catalyst to reduce protons into hydrogen, and a membrane enabling the transport of both protons and electrons (Fig. 3).

Based on these promising results two new projects (namely ArtipHyction, www.artiphyction.org, funded under the Fuel Cells & Hydrogen JTI initiative, and the Eco^2CO_2, funded in the Nanotechnologies, Materials and Processes section of the 7th EU Framework Programme), both coordinated by Prof. Saracco, have just started in 2012 (Fig. 3).

Left: Fig. 1. The Solhydromics prototype at work. Bubbles of oxygen generated by photochemical water splitting at the anode are visible

The ArtipHyction project aims to offset the Solhydromics limitations by pursuing an efficiency rate of 10% for solar hydrogen generation in a new device characterized by the following features (Fig. 3):

- Water is split at the anode employing a specifically designed electrochemically-tailored catalyst.
- The generated "high energy" electrons are conveyed via a porous electron conducting glass layer (e.g. FTO) to an external wire connection.
- The generated oxygen is removed through the hydrophobic pores of the anode layers; this removal will be facilitated by the waves generated inside an engineered electrode microstructure by pressure fluctuations applied to a water film separating the two electrodes;
- The generated protons are transferred to the cathode with minimum resistance via the water phase sandwiched between the electrodes;
- The reduction of protons will be facilitated by a synthetic hydrogenase-mimetic catalyst on a porous cathode (e.g. FTO);
- Light is absorbed by suitable chromophores at both electrodes to boost (tandem cell).

Conversely, the Eco^2CO_2

project aims at exploiting a photo-electro-chemical (PEC) reactor (Fig. 3) similar to the Solhydromics one to ultimately convert pure CO_2 derived from fermentation processes to produce methanol (with a 6% overall efficiency), as a key intermediate for the production of fine chemicals (fragrances, flavourings, cresol, adhesives,…) integrated with a lignocellulosic biorefinery. A distinct "squared" improvement in the ecological footprint of the envisaged chemical industries will thus be achieved by: i) boosting the potential of lignocellulosic biorefineries by exploiting secondary by-products such as furfurals or lignin; ii) providing a non-negligible contribution to the reduction of CO_2 release into the atmosphere by exploitation of sunlight as an energy source.

This commitment to practical issues, with a view to the eventual application of the ArtipHyction and Eco^2CO_2 devices, is reflected by strong project partnerships, bridging the academic and business sectors, combining scientific rigor of universities and research centres with the knowledge of the commercial marketplace of SMEs and large companies. Such partnerships are listed in the following.

Professor Saracco says the project are looking to the medium-long-term for commercialization. "The ArtipHyction and Eco^2CO_2 technologies and solar fuels will be exploited, but it's not going to happen immediately, possibly within the next 10 years" he acknowledges.

The ArtipHyction partnership:

- Politecnico di Torino
- HySyTech srl
- Commissariat à L'Energie Atomique
- Chemical Process Engineering Research Institute
- Solaronix SA
- Lurederra Foundation for Technical and Social Development
- Tecnologia Navarra de Nanoproductos SL
- Pyrogenesis SA

The Eco^2CO_2 partnership:

- Politecnico di Torino
- Delft University of Technology
- European Research Institute of Catalysis
- Centro Tecnologico de la Quimica de Catalunya
- Chemtex Italia SpA
- Avantium Chemicals BV
- Solaronix SA
- Repsol SA
- Catalonia Institute for Energy Research

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Above: Fig. 2. Prof. Guido Saracco

Below: Fig 3. Sketches of the original devices developed in the Solhydromics project and the new devices under development in the ArtipHyction and Eco2CO2 projects