EERA European Energy Research Alliance

AMPEA Advanced Materials and Processes for Energy Applications

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Renewing efforts to demonstrate carbon capture and storage (CCS) in the EU and developing sustainable solutions for carbon capture and use (CCU)

This input paper deals with the aspect of carbon capture and use as discussed in the above-mentioned issue paper. In the issue paper, it is stated that "*Also other CO_2 utilisation options could help improving the economic case for CO_2 capture, but further research & innovation activities are necessary for them to have a chance to make a meaningful contribution to our greenhouse gas reduction objectives and should therefore be intensified.*" We discuss this aspect in the frame of power to chemical technologies with a specific focus on an emerging energy technology, "*Artificial photosynthesis*" or "*Solar Fuels Generation*". This topic falls under two themes of the SET Plan Integrated Roadmap, namely:

→ **Theme 11**: *Carbon capture, CO_2 utilisation and storage technologies*,

→ **Theme 13**: *Developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport mix*.

Power to chemicals technologies in general consist in the transformation of electrical energy into chemical energy carriers (hydrogen and methanol being two examples). These carriers have a high energy density and can be stored to balance variations in solar irradiation over both daily and yearly cycles. Once the energy is transformed into chemicals (chemical processes using micro-structured reactors, electro-chemical processes), many usages are open: it includes re-electrification by using fuel cells, mobility (hydrogen or synthetic fuels) or production of higher value chemicals like methane, methanol, ethene, particularly when using co-valorization of anthropogenic CO_2, which also help in the decarbonization of the chemical sector. This quite broad topic embeds chemical processes, electrochemical transformation (*e.g.* H_2O and CO_2 co-electrolysis), direct processes such as artificial photosynthesis and the related materials made of sustainable and non-critical raw materials.

Artificial photosynthesis corresponds to the production of solar fuels by converting solar energy, CO_2 and water in a direct process into high-energy and high-value chemical compounds. These compounds can be used as solar fuel or as a feedstock (hydrocarbons) for the chemical industry. Starting from concentrated CO_2 sources, *e.g.* obtained from fossil fuel plants, it allows producing carbon containing precursors such as methanol, methane or ethene[i,ii]. Ethene, presently produced in large quantities from fossil fuels, is the building block for a vast range of chemicals from plastics to antifreeze solutions and solvents. Thus, with the input of solar energy, artificial photosynthesis promises to provide carbon neutral fuel production, as well as feedstock to replace fossil sources.

Artificial photosynthesis is a cross-disciplinary field that brings together the expertise of chemists, physicists, biologists, material scientists and engineers and feeds on the combined synergy between theory and experiment. It can be used to produce hydrogen by photoelectrochemical water splitting, but also to synthesize hydrocarbons from concentrated CO_2 and water. To lower the presently observed high overvoltages for CO_2 reduction - about 3V at current densities of ~100mA/cm^2 - new catalysts and new photoelectrochemical cell design is in demand, in order to compete with a price of 1000€/t.

Artificial photosynthesis can be efficient, with a theoretical energy conversion efficiency limit above 40% for a tandem light absorber.[iii] This is much better than current biomass production (1-2% for the best crops), and it does not compete for land area with food production. Therefore, solar fuels by artificial photosynthesis can be much more energy efficient than biofuel production by conversion of biomass from agriculture, forestry and waste products. At the same time, fuels are much easier to store than electricity. Therefore, it is important to note that solar fuel production by artificial photosynthesis is the only envisaged renewable energy technology that does not target electricity or biomass.[iv]

Artificial photosynthesis was identified in Theme 13 of the SET Plan integrated roadmap as one emerging energy technology that needs an advanced research programme. Even more important is the synthesis of hydrocarbons from concentrated CO_2 using alternative energy sources, i.e. the conversion of light energy into chemical bonds. Along this line, such a programme was indeed proposed in order to bring this field, presently at TRL of 1-2 to 4-5 in 6 years (see *Heading 7: Keeping technology options open* in Annex I, part II in the SET plan integrated roadmap). Priority research that would be developed in this advanced research programme would focus on the design of molecules, advanced solid state materials and hybrid systems together with specific processes for artificial photosynthesis energy conversion and production of solar fuels exhibiting: flexibility of solar fuel device designs, energy transformation and fuel production efficiency, long-term stability and affordability (taking into account issues such critical raw materials for the development of dedicated catalysts). Presently, European enterprises such as SIEMENS are working on the development of catalysts and devices to convert CO_2 into hydrocarbons.

We are convinced that in the frame of carbon capture and use, artificial photosynthesis is a promising way of giving added value to concentrated CO_2 sources, provided a suitable advanced research programme allows pushing this technology to the required TRL levels for the generation of hydrocarbons as industrial feedstock.

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[i] A. Thapper *et al.*: "*Artificial photosynthesis for solar fuels – an evolving research field within AMPEA, a joint programme of the European Energy Research Alliance*", *Green* 2013, **3**, 43-57 (DOI 10.1515/green-2013-0007).

[ii] A.J. Morris, G.J. Meyer and E. Fujita: "*Molecular Approaches to the Photocatalytic Reduction of Carbon Dioxide for Solar Fuels*" *Acc Chem Res.* 2009;**42**(12):1983–94.

[iii] M.C. Hanna and A. J. Nozik, J. Appl. Phys. 2006, **100**, 074510.

[iv] R.E.H. Sims,et al.; in *Climate Change 2007* (the 4th Assessment Report of IPCC 2007).