

PRODUCTION OF SYNTHETIC FUELS: THE DISRUPTIVE TECHNOLOGIES

If the need for synthetic fuels requires the development of the first e-fuels production chains by 2030, using low-carbon hydrogen and electricity [see [focus #3](#)], breakthrough production pathways are also the subject of numerous research efforts. Since not all of these routes rely on the use of electrical energy, the term "synthetic fuels" is more appropriate than "e-fuels," which refers to only a subset of the former. These innovative pathways aim to address several challenges to **maximize the energy yields of synthetic fuels production pathways and lower their production costs**, for instance:

- Directly converting CO₂ using solar energy and low-carbon electricity;
- Selectively converting CO₂ into complex molecules such as hydrocarbons, alcohols (methanol, ethanol, ...), and alkenes (ethylene, propylene, ...);
- Compressing value chains into integrated devices.

To meet these challenges, physico-chemical, biological, and even hybrid approaches are being explored in the research laboratories. The resulting breakthrough technologies are currently at low maturity levels, with TRLs (Technology Readiness Levels) of 4 for the most advanced ones.

Direct conversion of CO₂ requires developing CO₂ electrolysis by using electricity directly to convert it into molecules of interest. Combined with a capture process, **electrocatalytic processes** for the direct conversion of CO₂ provide access to various products, primarily the production of carbon monoxide (CO), synthesis gas (CO+H₂), and formic acid (HCOOH), which are useful intermediates in the chemical and fuel sectors. Another strategy aims to **produce synthetic fuels from solar energy, CO₂, and water**. By using photosynthetic organisms, it is indeed possible to produce oils and other (bio)molecules, for example, through the study, engineering, and cultivation of organisms like microalgae or cyanobacteria. These biological approaches also inspire the development of **photo(electro)catalytic devices**, capable of mimicking the mechanisms of **photosynthesis**

artificially to produce "**solar fuels**" through physico-chemical approaches. Finally, even further upstream, the activation of CO₂ by ionizing radiation and plasmas is also under study.

The transformation of CO₂ requires the use of catalysts, which are molecules and materials capable of converting CO₂ in the presence of solar energy, electricity, or hydrogen. The development of **new catalysts, that are more robust, efficient, selective and recyclable**, is a key challenge in order to improve the performance of synthetic fuels production processes. It is also necessary to develop solid to catalyze the formation of C-H and C-C bonds from CO₂ and hydrogen to **produce more energetic and complex molecules**, such as methanol, ethylene, hydrocarbons, and aromatic compounds. In parallel, **biological pathways** aim to produce various sugars, lipids, or hydrocarbons through the development and use of new strains of photosynthetic or bacterial organisms (methanogens, oleaginous yeasts, etc.).

These scientific and technological breakthroughs are leading to the development of **integrated devices** that foreshadow innovative technological building blocks, through which CO₂ is converted into useful fuels and molecules on **significantly shortened value chains, directly from light or electricity**. To meet the challenge of this integration, R&D on biological and physico-chemical approaches and their hybridization is necessary. These efforts will enable the market introduction of optimized conversion technologies, paving the way for the emergence of a second generation of synthetic fuels production chains in the 2040-2050 timeline.

The various breakthrough approaches are the subject of **R&D projects at CEA and IFPEN**, particularly within the frameworks of **PEPR SPLEEN**, on industry decarbonization, **B-BEST**, on biotechnologies and bioproducts, and **LUMA**, on light-matter interaction, as well as at the European level within the **SUNERGY initiative** (Solar fuels and chemicals).