Written on 03 April 2025 5 minutes of reading

Economic outlook

Issues and Foresight

Biofuels and e-fuels

SYNTHETIC FUELS: CHALLENGES AND OPPORTUNITIES

Focus n°5

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 CO_2 using solar energy and low-carbon electricity;
- Selectively converting CO_2 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 CO_2 requires developing CO_2 electrolysis by using electricity directly to convert it into molecules of interest. Combined with a capture process, **electrocatalytic processes** for the direct conversion of CO_2 provide access to various products, primarily the production of carbon monoxide (CO), synthesis gas ($CO+H_2$), and formic acid (HCOOH), which are useful intermediates in the chemical and fuel sectors. Another strategy aims to **produce synthetic fuels from solar energy**, CO_2, 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 CO_2 requires the use of catalysts, which are molecules and materials capable of converting CO_2 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 CO_2 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 CO_2 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).

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LES BRÈVES

ADEME: French energy transition agency (www.ademe.fr)
ANCRE: French National Alliance of Coordination of Research for Energy (www.allianceenergie.fr)
CBAM: Carbon Border Adjustment Mechanism
CCS: Carbon Capture and Storage
CCU: Carbon Capture and Utilization
COP: Conference of the Parties
DAC: Direct Air Capture
DME: DiMethyl Ether
EU: European Union
EU-ETS: EU Emissions Trading System
FuelEU: European law for shipping decarbonization (Fit for 55)
HTE: High Temperature Electrolysis
ICAO: International Civil Aviation Organization (www.icao.int)
ICM: Industrial Carbon Management
ICR: Industrial Carbon Removal
IEA: International Energy Agency (www.iea.org)
IPCC: Intergovernmental Panel on Climate Change (www.ipcc.ch)
LCA: Life Cycle Analysis
Mtoe: Millions tons of oil equivalent
NZE: Net Zero Emission by 2050 (IEA scenario)
PEM: Proton Exchange Membrane
PEPR: French Priority Research Programs and Equipments
Power-to-X: Approach consisting of transforming electricity into a chemical carrier such as an e-fuel or an e-molecule
RED: Renewable Energy Directive
ReFuelEU: European law for aviation decarbonization (Fit for 55)
R&D: Research & Development
R&I: Research & Innovation
RWGS: Reverse Water Gas Shift reaction
SAF: Sustainable Aviation Fuels
SGPE: French General Secretariat for Ecological Planning
SMF: Sustainable Maritime Fuels
TIRUERT: French incentive tax relating to the use of renewable energy in transport
TRL: Technology Readiness Level

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