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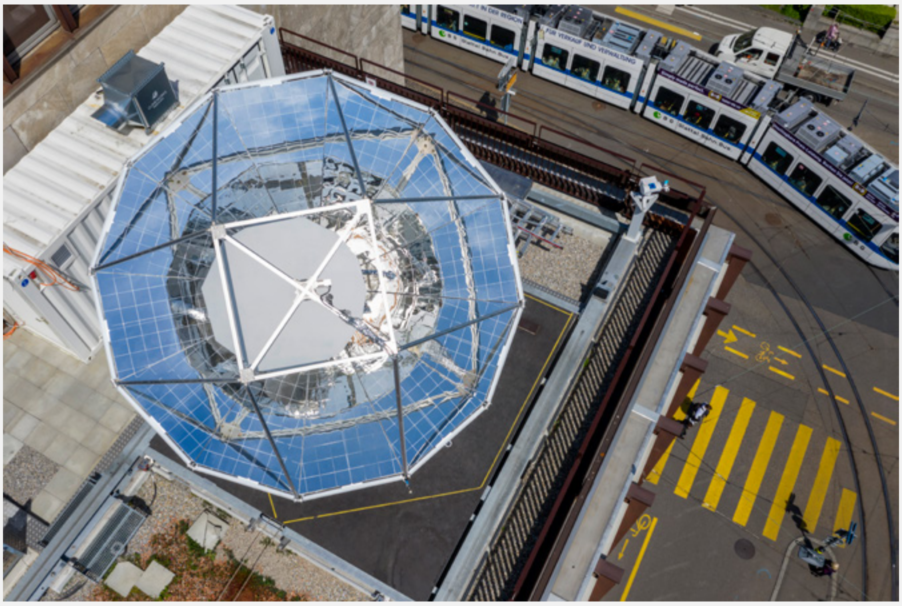
Solar fuels: Energy from thin air

An innovative process developed by ETH researchers makes it possible to extract CO_2 and water directly from ambient air and transform them into carbon-neutral transportation fuels. A solar mini-refinery mounted on the roof of ETH Machine Laboratory demonstrates the technology, which can particularly contribute to sustainable aviation.

The successful operation of the solar demonstration plant represents a crucial milestone towards the production of carbon-neutral synthetic fuels.



The research plant is located on the roof of the ETH building on Sonneggstrasse

On a sunny day and if they are lucky, passers-by might notice what looks like a large satellite dish unfolding on the roof of the ETH Machine Laboratory. What they are seeing, in fact, is a small refinery that is able to produce liquid hydrocarbon fuels from two ingredients: sunlight and ambient air. Although this demonstrator produces only small quantities, it serves as a technological proof and represents a crucial milestone towards large-scale production of sustainable fuels.

Hydrocarbon fuels burn in an exothermic reaction with oxygen, releasing heat and discharging CO_2 and water vapour into the atmosphere. "Our process literally reverses the combustion process by capturing both discharged elements from air and using solar heat to convert them back into hydrocarbon fuels," says Prof. Aldo Steinfeld, Head of the Professorship of Renewable Energy Carriers. "These are carbon-neutral fuels because their combustion releases only as much CO_2 as was removed from the air for their production."

Process chain to solar fuels
The thermochemical process chain involves three stages. Firstly, CO_2 and water are extracted from ambient air in an adsorption-desorption process. Secondly, both components are then fed into a solar reactor at the focus of a high-flux solar concentrator, which delivers concentrated sunlight at a radiative flux intensity of 3,000 suns and creates heat at temperatures of 1,500 °C. At the heart of the solar reactor is a porous ceramic structure made from ceria (CeO_2) that enables an oxidation-reduction (redox) cycle. Ceria is firstly reduced, releasing oxygen, and then re-oxidized with CO_2 and water, forming syngas – a specific mixture of H_2 and CO_2. The initial state of ceria is restored, and the cycle can begin again. Finally, in the third stage of the process chain, syngas is processed into a number of conventional transportation fuels such as kerosene (jet fuel), gasoline, methanol, and other liquid hydrocarbon fuels.

Though this mini-refinery only produces about 0.1 litres of liquid fuel per day, it demonstrates the feasibility of the technology under real intermittent field conditions, even under the local solar radiation in Zurich. The scope of this project is far broader, however, as the ETH engineers operate within the framework of the SUN-to-LIQUID project, supported by the EU's Horizon 2020 research and innovation programme as well as the Swiss Office of Energy and the Swiss State Secretariat for Education, Research and Innovation. Steinfeld's team has scaled up the solar reactor system and tested it in the solar tower facility of IMDEA Energy near Madrid, thereby advancing the technology readiness level beyond the laboratory.

Drop-in solutions
Though the idea of using renewable energy to make fuels may seem counterintuitive, this approach offers a viable solution for those transportation sectors (e.g., aviation and maritime shipping) that depend strongly on liquid hydrocarbons and for which alternative power sources such as batteries are currently not feasible. Here, the synthetic fuels produced 'from thin air' by the solar-driven refinery, such as carbon-neutral gasoline and kerosene, can continue to use the existing worldwide infrastructures for their storage, distribution, and utilization.

The strong interest from industry in the commercial application of the innovative solar fuels concept can be seen in the success of Climeworks and Synhelion, the two spin-off companies that originated in Steinfeld's research group. Climeworks, founded in 2010, commercializes the technology for CO_2 capture from air, while Synhelion, founded in 2016, commercializes the solar technology for the conversion of CO_2 into fuels. "A future industrial solar fuel plant spanning an area of one square kilometre could be able to yield 20,000 litres of kerosene a day," said Philipp Furler, CTO of Synhelion and a former doctoral student in Steinfeld's group. Partnerships with global players, such as with the energy company ENI and the cement manufacturer Cemex, as well as with the Lufthansa Group and Zurich Airport, have been created to accelerate implementation of the first generation of commercial-scale production plants. "Sustainability is not for free, it comes at a price. Personally, I see it as a long-term investment that is being repaid to our children as an environmentally friendly solar fuel supply system," says Steinfeld.

➚ **Fuels from Sunlight and Air**