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Fuel produced from sunlight, CO_2 and water: an alternative for jet fuel?

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Water and carbon dioxide (CO_2) can be converted into 'solar thermochemical fuel' using energy from the sun and very high temperatures. A new study has analysed the production of this fuel and found that, under favourable future conditions, costs could be as little as €1.28 per litre, with close to zero life-cycle greenhouse gas (GHG) emissions. Although suitable as a substitute for any hydrocarbon fuel, it could be particularly useful as a much-needed alternative for energy-dense jet fuel.

Modern modes of transport depend on fuels derived from crude oil, a dwindling natural resource with negative environmental impacts. While electricity and hydrogen could be viable alternative energy carriers for vehicles, aircraft have requirements for energy and power density that cannot be met by either electricity or hydrogen. Therefore, conventional jet fuel and synthetic fuels remain aircraft's only current options. Biofuels for aviation are still expensive, and biofuel crop farming competes for land with food crop farming.

This study, which derives from the EU-funded SOLAR-JET project[1], evaluated solar thermochemical fuel. To produce this fuel, energy from the sun is concentrated to drive the high-temperature conversion of water and CO_2 to synthesis gas (or 'syngas'), which is a mixture of hydrogen and carbon monoxide. The syngas is stored and converted into jet fuel via the Fischer-Tropsch process (a series of chemical reactions that convert hydrogen and carbon monoxide into liquid hydrocarbons). The end result — synthetic paraffinic kerosene — is certified for use in commercial aviation as up to 50% blends with conventional fuel.

Although studies suggest that fuel from the solar thermochemical pathway has less environmental impact than fuel derived from crude oil, few studies have conducted both an environmental and economic analysis. These researchers therefore performed an economic analysis and life-cycle analysis of the GHG emissions of jet fuel.

They based their estimates on a theoretical plant that produces 1 000 barrels per day (bpd) of solar thermochemical jet fuel (1 000 bpd = 1 750 gallons per hour, or 30 gallons per minute). They assumed that the plant is located in a region that receives 2 500 kilowatt hours per square metre (kWh/m^2) of energy from the sun annually and does not need external sources of heat or electricity. In the plant, CO_2 is captured from the air and water is extracted from the sea.

Life-cycle GHG emissions for the fuel (i.e. the emissions associated with its production and use) were estimated at 0.49 kilograms of CO_2 equivalents per litre (kg CO_2 eq/l). Compared to conventional jet fuel derived from crude oil (which has overall emissions of 3.03 kg CO_2 eq/l), over 80% of GHG emissions could be saved by using this solar jet fuel. This is a significant reduction, and well above the threshold of 35% emissions reductions set by the Renewable Energy Directive and the Fuel Quality Directive[2] in the EU.

Solar thermochemical jet-fuel production costs were estimated to be €2.23 per litre. The main costs arise from operations and maintenance, which were around twice that of the initial investment costs over the plant lifetime.

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1. SOLAR-JET (Solar chemical reactor demonstration and optimisation for long-term availability of renewable jet fuel) was funded by the European Union under the Seventh Framework Programme for Research. See: http://www.solar-jet.aero

2. According to the Renewable Energy Directive and the Fuel Quality Directive, greenhouse gas emissions of biofuels must be at least 35% lower than from the fossil fuel they replace to count towards the 2020 target for 10% renewable energy in transport, and towards the target for 6% reduction of greenhouse intensity of road transport.

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(continued)

Production costs could be reduced by 15% if CO_2 is captured from a natural gas combined cycle (NGCC) power plant (where a gas turbine generator produces electricity and the waste heat is used to make steam to generate extra electricity), instead of the air. However, this would increase GHG emissions considerably, due to the fossil origin of the CO_2. The researchers estimate that the emissions of the production process and fuel combustion could not be counterbalanced by the removal of CO_2, leading them to conclude that solar thermochemical fuels can only provide a viable alternative to conventional fuels if the CO_2 is taken from renewable sources (such as the atmosphere) and not from the flue gases of a fossil power plant. It is important to note, however, that direct air capture technology is still under development, and currently less efficient and more expensive than capturing CO_2 from flue gases.

Under more favourable conditions, which are unlikely today but could possibly materialise in the future, GHG emissions could be reduced to almost zero (0.1 kg CO_2 eq/l) and production costs to just €1.28 per litre. These conditions are: a publicly funded plant in a sunny area that receives 3 000 kWh/m^2 energy from the sun annually, a thermochemical conversion efficiency of 30% (the efficiency at which CO_2 and water are converted into syngas, set to 20% in the baseline case but which could be increased by using new materials or recuperating heat, for example) and CO_2 capture costs of €50 per tonne (set to €100 in the baseline, but which could be reduced by capturing carbon from alternative sources such as ethanol plants or an advancement of the air capture technology).

According to the study's authors, production costs could be even lower if oxygen (a by-product of the process) was commercialised (for example, sold for use in technological processes and industry). This study shows the potential for solar thermochemical jet fuel which, although in its early stages of development, could aid the move away from fossil fuels.