Hydrogen instead of electrification? Potentials and risks for climate targets

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Hydrogen-based fuels should primarily be used in sectors such as aviation or industrial processes that cannot be electrified, finds a team of researchers. Producing these fuels is too inefficient, costly and their

availability too uncertain, to broadly replace fossil fuels for instance in cars or heating houses. For most sectors, directly using electricity for instance in battery electric cars or heat pumps makes more economic sense. Universally relying on hydrogen-based fuels instead and keeping combustion technologies threatens to lock in a further fossil fuel dependency and greenhouse gas emissions.

"Hydrogen-based fuels can be a great clean energy carrier—yet great are also their costs and associated risks," says lead author Falko Ueckerdt from the Potsdam Institute for Climate Impact Research (PIK). "Fuels based on hydrogen as a universal climate solution might be a bit of false promise. While they're wonderfully versatile, it should not be expected that they broadly replace fossil fuels. Hydrogen-based fuels will likely be scarce and not competitive for at least another decade. Betting on their wide-ranging use would likely increase fossil fuel dependency: if we cling to combustion technologies and hope to feed them with hydrogen-based fuels, and these turn out to be too costly and scarce, then we will end up further burning oil and gas and emit greenhouse gases. This could endanger short- and long-term climate targets."

Prioritizing to applications like aviation and steel productions

"We should hence prioritize those precious hydrogen-based fuels to applications for which they are indispensable: long-distance aviation, feedstocks in chemical production, steel production and potentially some high-temperature industrial processes," says Ueckerdt. "These are sectors and applications that we can hardly electrify directly." The researchers identify a "merit-order of hydrogen and e-fuel demand": a priorization of where to use these new fuels.

So-called green hydrogen is produced through a process called

electrolysis. To crack the stable H2O water molecules into Hydrogen and Oxygen, a lot of electricity is needed. The hydrogen can then be used to synthesize hydrocarbon fuels by adding carbon from CO_2. The resulting electro-fuels or e-fuels are easier to store and transport than electricity or pure hydrogen. "Most importantly, e-fuels can be burned in conventional combustion processes and engines and thus directly substitute fossil fuels," says Gunnar Luderer, co-author of the paper. "However, given their limited availability, it would be wrong to think that fossils can be fully replaced this way."

Driving a car with hydrogen-based fuels needs five times more energy than a battery-electric car

"We are currently far from 100% renewable electricity—so making efficient use of it is key. However, if we use hydrogen-based fuels instead of direct electrification alternatives, two to fourteen times the amount of electricity generation is needed, depending on the application and the respective technologies," says co-author Romain Sacchi from the Paul Scherrer Institute. "Efficiency losses happen both on the supply side, in the production process of the hydrogen-based fuels, and on the demand side—a combustion engine wastes a lot more energy than an electrical one."

"Low energy efficiencies cause a fragile climate effectiveness," says Sacchi. "If produced with the current electricity mixes, hydrogen-based fuels would increase—not decrease—greenhouse gas emissions. For the German electricity mix in 2018, using hydrogen-based fuels in cars, trucks or planes would produce about three to four times more greenhouse gas emissions than using fossil fuel." In contrast, electric cars or trucks cause greenhouse-gas emissions that are comparable to or lower than those of diesel or gasoline cars already based on today's electricity mixes in most countries, the researchers show based on a full

cradle-to-grave life-cycle analysis that includes also those emission associated with the battery production.

"Only for truly renewable-based power systems do hydrogen-based fuels become an effective means to help stabilize our climate," says co-author Jordan Everall. "Hydrogen-based fuels thus clearly require building up loads of additional renewable energy production facilities."

Greenhouse gas abatement costs of hydrogen-based fuels are currently around 1000 Euro per ton CO_2

Even if assuming 100% renewable electricity, the costs of avoiding one ton of CO_2 emissions by using hydrogen-based fuels would currently be 800 Euro for liquid and 1200 Euro for gaseous fuels, the researchers calculated. This is much higher than current CO_2 prices for instance in the European Emissions Trading Scheme, which currently are below 50 Euro per ton. However, if there is continued technological progress driven by CO_2 prices as well as subsidies and investments into hydrogen and related industries, by 2050 these CO_2 abatement costs could drop to roughly 20 Euro for liquid and 270 Euro for gaseous e-fuels.

Hence, with increasing CO_2 prices hydrogen-based fuels could become cost competitive probably by 2040. This is too late for those sectors where direct electrification alternatives exist, given the urgency of greenhouse gas emissions reductions to stabilize our climate.

Carbon pricing is needed to make hydrogen-based fuels competitive

"Despite the uncertainties about future costs, hydrogen-based fuels have the potential to become a backstop technology for replacing all remaining fossil fuels around 2040-50. However, the realization hinges

on substantial large-scale policy support and in fact subsidies for about two decades before business cases might be secured solely by increasing carbon pricing," says Falko Ueckerdt. "An overall policy strategy could rest on two pillars: First, broad technology support to foster innovation and initial scale-up including direct electrification. Second, substantial carbon pricing and an energy tax reform that together create a level-playing field for all technologies and thus a sensible balance between direct and indirect electrification."

"The long term vision of hydrogen-based fuels is promising," says Gunnar Luderer. "Tapping into the huge wind and solar energy potential of the global sun belts, e-fuels can be globally traded and thus resolve renewable energy bottlenecks in densely populated countries such as Japan or in Europe. However, as international and national climate targets require immediate emission reductions, from a climate perspective direct electrification should come first to assure a safe future for all."

The study is published in *Nature Climate Change*.

More information: Potential and risks of hydrogen-based e-fuels in climate change mitigation, *Nature Climate Change*, DOI: 10.1038/s41558-021-01032-7

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