Green hydrogen could power the future of passenger and freight transportation

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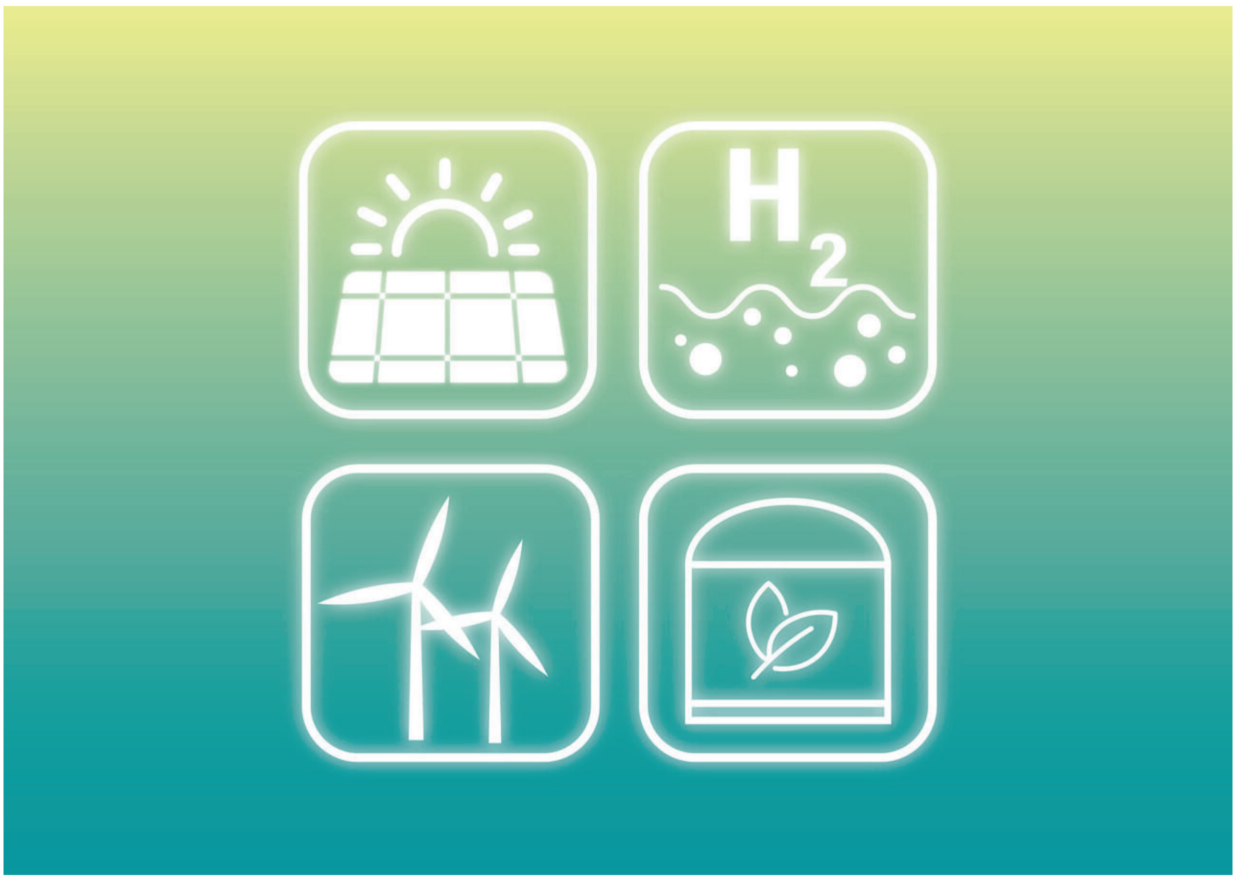

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Green hydrogen is emerging as an important potential solution for decarbonizing transportation, but new energy efficiency findings indicate that it should be used strategically in heavy-duty road, rail, aviation and marine transportation, a University of Michigan study shows.

Green hydrogen is produced by electrolysis with renewable energy to split water into hydrogen and oxygen. It can be used directly or in synthetic fuels, also known as e-fuels, to decarbonize road, rail, marine and air transportation. The transportation sector is responsible for about 22% of global and 37% of U.S. fossil fuel carbon dioxide emissions.

To mitigate climate change, it's crucial to decarbonize transportation—both passenger and freight transportation, according to the researchers, who computed the total system energy efficiency of using green hydrogen directly, or indirectly in e-fuels, to power planes, trains, automobiles and ships. The system energy efficiency measures the energy used to drive the wheels for ground modes and thrust for planes and ships relative to the total renewable electrical energy invested.

The U-M researchers considered both the direct use of hydrogen in engines or fuel cells as well as indirect use of hydrogen in the form of e-fuels such as e-gasoline, e-diesel, e-jet fuel, e-methanol and e-ammonia. Comparing these uses with battery electric options, they found that the system inefficiencies during hydrogen or e-fuel production, storage, transportation, dispensing and use leads to about 80%-90% energy loss of the initial electrical input.

By contrast, electric-powered transport is about three to eight times more efficient than using hydrogen directly or in e-fuels. Their results will appear online Aug. 7 and in print Aug. 21 in the journal *Joule*.

"We have an urgency to decarbonize transportation, given the adverse impacts we are seeing from climate change, which are only going to intensify," said Greg Keoleian, a senior author of the paper and codirector of U-M's MI Hydrogen initiative. "We examine where hydrogen can play a role by looking at the energetics to help guide deployment along with other factors such as cost, fueling time, range and safety."

The study was conducted as part of U-M's MI Hydrogen initiative, which aims to foster collaboration among U-M researchers, community groups, government and industry partners to create hydrogen solutions that accelerate clean energy transitions. The research team included scientists from the Center for Sustainable Systems, Michigan Engineering's Department of Aerospace Engineering and Department of Naval Architecture and Marine Engineering.

"We found that renewable electricity sources in the U.S. are insufficient to support hydrogen production for light-duty vehicles. Green hydrogen should be used strategically in heavy-duty road, rail, aviation and marine transportation where electric alternatives are constrained by load and range," said Tim Wallington, first author on the report and a research specialist in the Center for Sustainable Systems at the U-M School for Environment and Sustainability.

However, Wallington says, batteries would not work for heavy transport vehicles that need to cover long distances. Batteries are too heavy and too large to power flight more than 200 miles, to send a shipping freighter across an ocean or to power a train across a continent.

Hydrogen or e-fuels make more sense as energy sources for these heavy transport applications, according to the researchers. Using hydrogen as a direct fuel source would require massive changes in fueling and infrastructure. Using hydrogen-based e-fuels would avoid these changes, but in most cases they are approximately 20%-50% less energy efficient than direct uses of green hydrogen.

To characterize the system efficiency and visualize the energy inputs and losses for each hydrogen pathway, the research team developed a set of 25 Sankey diagrams. These diagrams start with renewable electricity inputs and track the energy flows across hydrogen production and delivery to its end use in a fuel cell, internal combustion engine or turbofan in the case of aircraft. These hydrogen pathways were compared with another set of 6 diagrams for all electric options.

The researchers also measured the energy intensity of each hydrogen pathway, which is how much renewable energy it takes to move freight in ton-miles or people in passenger-miles for all major modes of transportation.

"What we found is that the trends here follow the energy intensity trends of petroleum-based transportation: with hydrogen, the rail and shipping are most efficient, and an aircraft is least efficient because you have to hold that weight up in the sky," said Keoleian, also a professor of sustainable systems. "From a sustainable transportation perspective, you'll want to use the most efficient modes and least energy intensive mode of transportation. Renewable electricity is a scarce resource, so we must use it wisely "

Study co-authors include doctoral student Maxwell Woody and research specialist Geoffrey Lewis of the Center for Sustainable Systems, doctoral student Eytan Adler and professor Joaquim Martins of the U-M Department of Aerospace Engineering, and Matthew Collette, professor of naval architecture and marine engineering.

More information: Timothy J. Wallington et al, Green hydrogen pathways, energy efficiencies, and intensities for ground, air, and marine transportation, *Joule* (2024). DOI: 10.1016/j.joule.2024.07.012

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