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FEATURE

Stanford University: Hydrogen's key role in creating clean energy grids

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Abstract

New research shows it's now possible to develop cost-effective and 100% reliable clean energy grids – and the best way to do this in most world regions is by combining green hydrogen with battery storage.

Professor Mark Jacobson, Stanford University

Scientists have long understood that for the sake of our planet, we need to act quickly and decisively to electrify all energy – and to move the world towards 100% clean, renewable electricity grids to provide this energy.

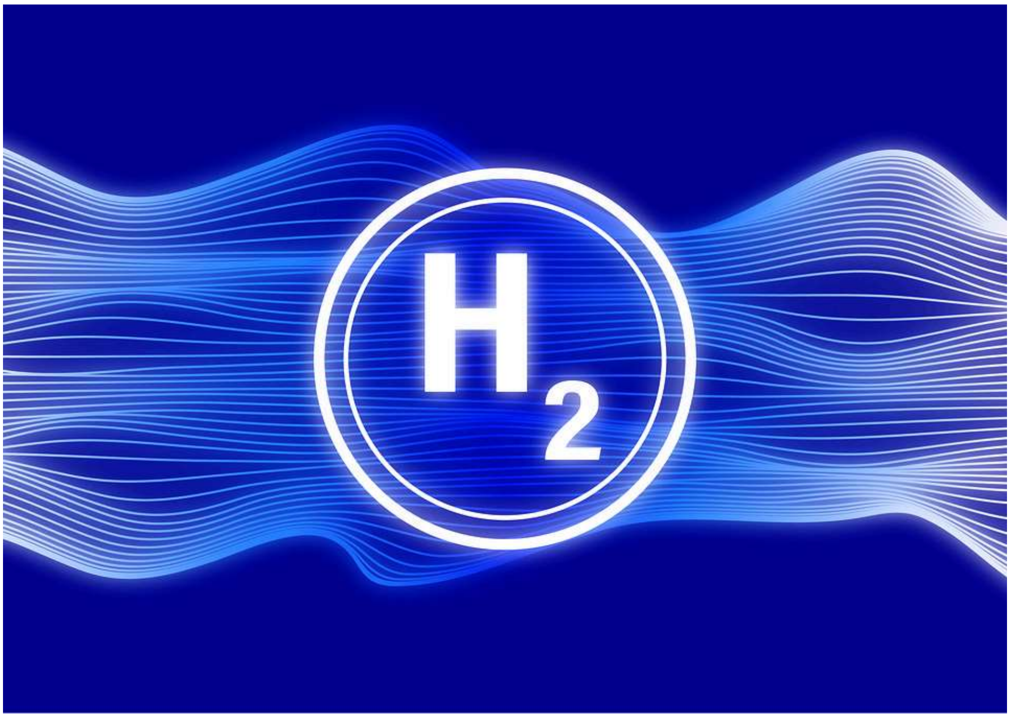
This is spurring a new industrial revolution away from fossil fuels to renewables, to address air pollution, energy security and the climate crisis. But what hasn't always been so clear is how we can achieve this transition in a cost-efficient and reliable manner.

Wind turbines and solar power are rapidly replacing fossil fuels worldwide as a source of electricity. However, the wind does not always blow and the sun does not always shine, leading to fears of power outages.

While those concerns have been temporarily exploited by the fossil fuel industry, given their financial interest in maintaining the *status quo*, the scientific, investment and engineering communities have been busy addressing the concern. And I'm pleased to report that we now have scientific evidence and confidence that 100% clean, renewable grids will not only lower costs but will be just as reliable as the current grid system.

Cutting-edge computer modelling now allows us to analyse the cost of keeping the grid stable for all energy purposes (electricity, transportation, buildings, industry, agriculture, forestry, fishing and the military) using clean, renewable energy – namely electricity and heat – coming from wind, hydroelectric, geothermal and solar sources.

This research also helps us determine how some regions can achieve the best mix of technologies to achieve a clean, renewable energy future. And we now have studies that have examined the best path forward for a particular region, and provide global answers too.



Green hydrogen is one of the main contenders to replace fossil gas for storage.

Keeping the lights on

One Stanford University study that I recently published in *iScience* busts the myth that fossil fuels are needed to keep the lights on 24/7.

It first compares the cost of matching supply with demand, storage and demand response worldwide when converting all energy sectors to 100% clean, renewable energy. The results were striking, showing that a 100% clean power grid is expected to reduce countries' overall annual energy costs by around 61%.

The study then took a deeper look, for the first time, at two of the main contenders for replacing fossil gas for storage: batteries and green hydrogen used in fuel cells.

Utilising computer modelling, we were able to demonstrate that existing hydropower plus batteries avoids blackouts throughout the world; while adding green hydrogen to the mix reduces energy overall cost in some regions.

Meanwhile, using hydropower and green hydrogen but no batteries is always more expensive than using hydropower with both batteries and green hydrogen.

To reliably meet energy demand with a 100% clean energy grid, the model also determined the level of hydrogen budget needed (at the lowest price point in 2050) to satisfy demand across the 24 global regions that collectively emit over 99.7% of the world's fossil-fuel CO2.

Four of these regions have already achieved a 100% renewable grid and are not in need of additional storage – namely, Canada, Iceland, Russia and South America.

The study then showed that the vast majority of the remaining regions benefit from an approach that combines conventional hydropower with both battery storage and green hydrogen storage. Those regions include Africa, Australia, Central America, Cuba, Europe, Haiti, India, Israel, Jamaica, Japan, Middle East, New Zealand, South Korea, Taiwan and the US.

The remaining five regions in the study (Central Asia, China, Mauritius, Philippines, Southeast Asia) perform best when combining conventional hydropower with battery storage alone.

These results don't just underscore that different geographic areas should consider different paths to a 100% clean energy grid. They also help explain why certain regions fare better with some technologies over others, giving policymakers and industry leaders new tools to understand how to best move forward in their local area.

Every region in the world needs short-term bursts of power with 100% renewables on the grid – thus every region needs either hydropower or batteries. But not every region needs new long-term storage.

This is because such regions have either a good combination of wind and solar resources that provide energy continuously over long periods, have a lot of existing hydropower for long-term storage, and/or can use the same number of new batteries that they use for short power bursts for long-term storage as well.

Although batteries can be linked together to provide both short-term power and long-term energy storage, they are more cost-effective for short-term (seconds to hours) power bursts than for long-term (hours to days or weeks) storage.

Green hydrogen storage, on the other hand, is more cost-effective for long-term energy storage than for short-term power bursts. The reasons are that batteries cost more per unit energy (kilowatt-hour) than hydrogen storage, but less per unit power (kilowatt) than hydrogen fuel cells. Hydropower can be used for both short power bursts and long-term energy storage.

When determining the cost-effectiveness of using different storage systems on the grid, our computer model provided some important insights.

In addition to the cost and efficiency of current storage products, the ratio of battery storage capacity to the actual peak discharge rate of batteries can help inform when green hydrogen storage should be added to the grid.

For the Stanford study, we used four-hour concatenated batteries. As such, during the simulation, batteries were used optimally in a region when the ratio of their summed energy capacity (kilowatt-hours) to their summed-peak discharge rate (kilowatts) was close to four hours. This ratio is called R-ideal.

Because battery storage is more expensive per kilowatt-hour than green hydrogen storage, replacing some battery storage with green hydrogen storage lowers total cost in situations where R-ideal is high.

In fact, in all five instances where R-ideal was greater than 25.1 hours, the region's cost decreased when adding green hydrogen storage to its energy mix. In the 15 regions where R-ideal was less than 25 hours, the results were more mixed.

In other words, R-ideal is a good indicator for the use of green hydrogen storage, but only when it is high. On the other hand, when R-ideal is low (close to four hours), battery storage is being used for both peaking and storage – so the addition of green hydrogen storage usually drives costs up because of the low round-trip efficiency of green hydrogen storage coupled with its high cost of discharging electricity.

Main findings

To summarise a few key takeaways:

1. An approach that uses both batteries and green hydrogen storage led to the most optimum result in a majority of the world's regions.
2. R-ideal can provide a useful framework for determining the energy storage mix that a local area should pursue for a 100% clean energy grid, particularly when that R-ideal indicator is high.
3. Green hydrogen storage when used without batteries always resulted in a less cost-effective system.

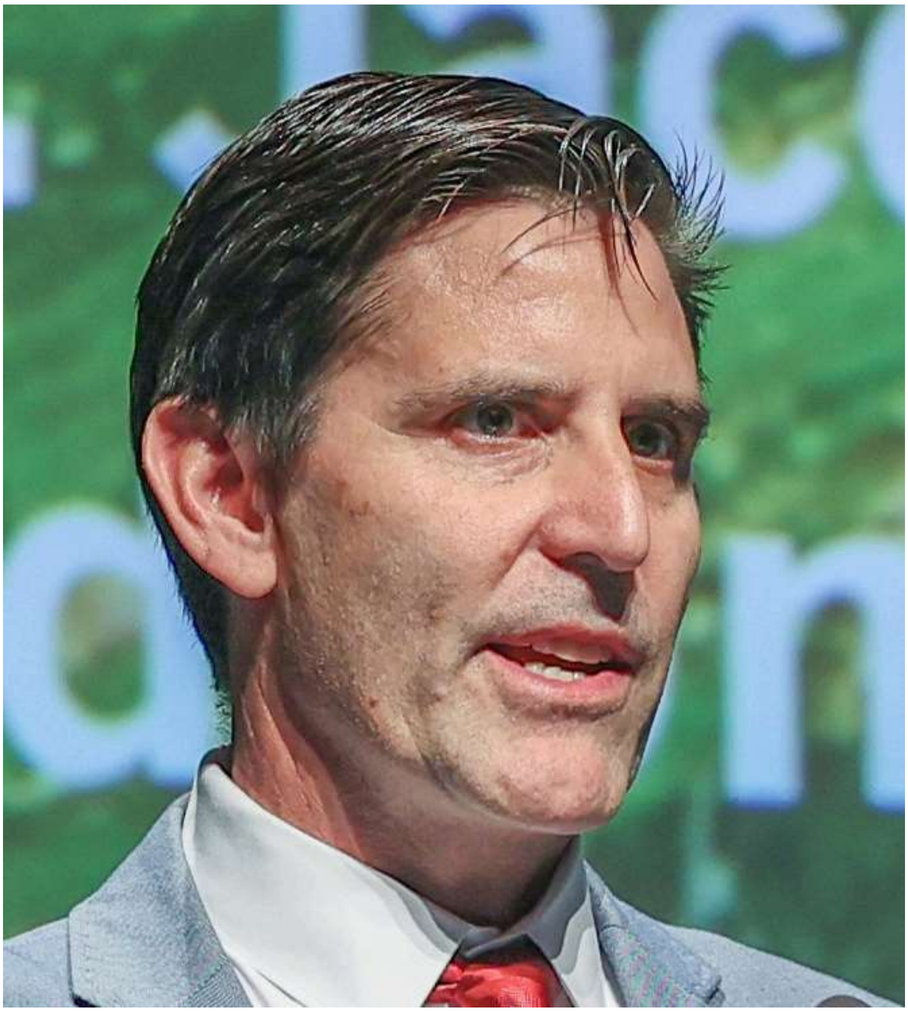
The research also found that combining hydrogen production and storage for grid and non-grid purposes (steel production, ammonia production and long-distance heavy transport) generally reduces overall energy cost relative to separating such production and storage, due to economies of scale.

Research methods

The study was carried out through three types of computer modelling: a spreadsheet model, a three-dimensional global weather-climate-air pollution model, and a model that matched electricity, heat, cold and hydrogen demand with supply, storage and demand response assuming perfect grid interconnection.

To analyse the data, we performed time-dependent trial-and-error simulation runs over three years (from 2050-2052). Four case studies were analysed:

1. A baseline case that used batteries but no hydrogen for grid electricity.
2. A case that used batteries and hydrogen for both grid and non-grid purposes, while hydrogen rectifiers, electrolysers, compressors and storage tanks were shared for both purposes.
3. A case that used batteries and hydrogen for both grid and non-grid purposes, except that unique rectifiers, electrolysers, compressors and storage tanks were used for grid versus non-grid hydrogen.
4. A case that replaced all batteries with hydrogen for both grid and non-grid purposes, while hydrogen rectifiers, electrolysers, compressors and storage tanks were shared for both purposes.



About the author

Professor Mark Z Jacobson is director of Stanford University's Atmosphere/Energy programme. He is a senior fellow at the Precourt Institute for Energy, a senior fellow at the Stanford Woods Institute for the Environment, and author of 'No Miracles Needed: How Today's Technology can Save our Climate and Clean our Air'.