

HYDROGEN TECH NEWS

Earth Has a Third Form of Life—and It Could Change How We Generate Power



Scientists found hydrogen enzymes in ancient archaea, potentially transforming energy generation and paving the way for a greener, sustainable future. © PM Images - Getty Images

- Earth's immense web of life fill three broad domains—archaea, bacteria, and eukarya.
- Scientists from Monash University recently discovered hydrogen-producing enzymes in archaea, which were thought to *only* exist in the other two orders.
- These archaea enzymes, known as hydrogenases, are smaller and more complex than those found in the other two domains, and could help biotech firms develop better, more efficient hydrogen energy systems.

Earth is home to [an estimated 8.7 million species](#), only a fraction of which have been scientifically identified. However, despite this vast, disparate [tree of life](#), every living thing falls into one of three large categories, or “domains”—archaea, bacteria, and eukarya.

All of the usual stuff we think of as “life”—things like trees, fungi, and [animals](#)—are eukaryotes, meaning that their cells contain a nucleus and other membrane-bound organelles. Archaea and bacteria, on the other hand, are prokaryotic, meaning they don’t contain such structures. While these two other domains might look similar under a microscope, there is [a long list of differences](#) that make archaea as different from bacteria as they are from humans.

Since the discovery of archaea in the late 1970s, scientists have believed that one difference between this third domain and other forms of life is that these [organisms](#) didn’t produce hydrogen-using enzymes known as “hydrogenases.” However, a new study published this week [in the journal Cell](#) says that not only is this *not* true, but in fact, archaea have been consuming and producing hydrogen for two billion years—a process that has allowed them to live in some of the most hostile locales on Earth.

Understanding this process can also help illuminate how all other life came to be—the leading biological theory suggests that the first [eukaryotes](#) formed when an ancient species of archaea merged with a bacteria cell (a.k.a. [endosymbiosis](#)) via hydrogen-gas exchange.

“[Humans](#) have only recently begun to think about using hydrogen as a source of energy, but archaea have been doing it for a billion years,” Bob Leung, a co-author of the study, [said in a press statement](#). “Our finding brings us a step closer to understanding how this crucial process gave rise to all eukaryotes, including humans.”

In the study, the research team looked at the genomes of thousands of archaea, found hydrogen-producing [enzymes](#), and then created those enzymes in a lab for further study. What they noticed is that some of these archaea produced an enzyme [known as \[FeFe\]-hydrogenase](#).

This goes against the idea that only the other two domains made use of these kinds of enzymes, and also highlights the fact that archaeal enzymes were both the smallest and most-complex form hydrogen-using enzymes found amongst the all three domains. This could have big implications as engineers continue exploring ways to use [hydrogen](#) as a green energy source.

“Industry currently uses precious [chemical](#) catalysts to use hydrogen. However, we know from nature that biological catalysts function can be highly efficient and

resilient,” Chris Greening, the lead author of the study, said in a press release. “Can we use these to improve the way that we use hydrogen?”

Amazingly, uncovering a two *billion*-year-old process—related to the one of the least understood domains of life—could help illuminate a path toward a desperately needed, zero-emission future. While archaea can survive beyond boiling [temperatures](#) or freezing points, a lot of us eukaryotes need things to be a bit more mild.

New study reveals how hydrogen kickstarted life at the dawn of time

New study reveals how hydrogen kickstarted life at the dawn of time© www.flickr.com

New research shows how [hydrogen gas](#) plays a crucial role in generating energy within cells, and was essential in kickstarting life on [Earth](#).

Now a [study](#) from William F. Martin at the University of Düsseldorf and Martina Preiner at the Max Planck Institute (MPI) for Terrestrial Microbiology in Marburg is highlighting how the first cells on Earth harnessed hydrogen gas as an energy source.

The very first cells on Earth originated from hydrogen gas produced in hydrothermal vents, the reaction of hydrogen gas with carbon dioxide created living molecules.

In order to harvest energy, cells have to push the electrons from hydrogen gas energetically uphill. “That is like asking a river to flow uphill instead of downhill, so cells need engineered solutions,” explains one of the study authors, Max Brabender. How cells achieved this was only discovered 15 years ago, by Wolfgang Buckel and Rolf Thauer.

They found that cells send the two electrons in hydrogen down different paths. One electron goes so far downhill that it sets a pulley-like system in motion,

pulling the other electron energetically uphill. This process is known as electron bifurcation. In cells, the process requires several enzymes.

So, how an energetically uphill reaction could occur in early evolution, prior to enzymes or cells, has been a difficult puzzle to piece together.

"Several different theories have proposed how the environment might have pushed electrons energetically uphill to ferredoxin before the origin of electron bifurcation," says Martin. "We have identified a process that could not be simpler and that works in the natural conditions of hydrothermal vents".

Since the discovery of electron bifurcation, scientists have identified the process to be ancient, as well as essential in microbes that live from hydrogen gas. But how was hydrogen gas harnessed for carbon dioxide before the existence of proteins?

"Metals provide answers," Preiner says. "At the onset of life, metals under ancient environmental conditions can send the electrons from [hydrogen gas] uphill, and we can see relicts of that primordial chemistry preserved in the biology of modern cells."

But metals alone are not enough.

"[Hydrogen gas] needs to be produced by the environment as well" adds co-first author Delfina Pereira from Preiner's lab.

Hydrothermal vents, both modern and ancient, generate hydrogen gas in such large amounts that the gas can turn iron-containing minerals into shiny metallic iron. However, this is nothing new. The surprise is that nature does this too, especially at hydrothermal vents, and that this naturally deposited iron could have played a crucial role during the origin of life.

Green, grey and blue hydrogen: What's the difference?



Green, grey and blue hydrogen: What's the difference?

August 12, 2024
By [Matt Lister](#), Editor

Hydrogen Atom,

Ever wondered what all the buzz around hydrogen is about? You've probably heard terms like green, blue and grey hydrogen thrown around, but what do they actually mean?

Driving Hydrogen Editor Matt Lister breaks it down and explains all of the different flavours.

What is grey hydrogen?

Grey hydrogen is the old-timer, the legacy colour of the hydrogen family. It's the most common form of hydrogen production today, created through a process called Steam Methane Reforming (SMR).

Sounds fancy, but while it produces a lot of affordable hydrogen, it also pumps out a fair amount of CO₂ – with some estimates at 9-12 tons of it for every ton of hydrogen produced.

Economically, grey hydrogen has been a winner so far – cheap to produce thanks to the abundance of natural gas, with a world filled with well-established infrastructure.

But with society cracking down on carbon emissions, grey hydrogen is quickly becoming a cassette tape in the age of Spotify.

What is blue hydrogen?

Now, blue hydrogen – this is the middle child trying to please everyone.

Like grey hydrogen, it starts with SMR, but blue hydrogen captures most of that pesky CO₂ and stores it underground or repurposes it for industrial uses.

It's a bit like grey hydrogen, but with a DPF filter and a catalytic converter.

Blue hydrogen cuts CO₂ emissions by 50% to 90%, depending on who you ask, and how efficient the capture and storage processes are. However, some CO₂ can escape, and the energy used in capturing and storing CO₂ can reduce overall efficiency.

Blue hydrogen is more expensive than grey hydrogen, mainly because of the added costs of carbon capture and storage.

But as carbon taxes rise and environmental regulations tighten, blue hydrogen could become the more economical option. Really, it's a stepping stone to a cleaner future while we build up the renewable energy infrastructure needed for the ultimate goal: green hydrogen.

What is green hydrogen?

Finally, we get to green hydrogen – the golden child, and environmentalists' wet dream type of hydrogen.

This is produced through electrolysis – a fancy word for electrocuting water and splitting it into hydrogen and oxygen.

Green hydrogen is as clean as it gets.

The magic happens when this electricity comes from renewable sources like wind, solar, or hydro. The result being that green hydrogen has zero carbon emissions – just pure, clean energy, with oxygen as the only byproduct.

There is a slight catch though: green hydrogen is currently the most expensive type to produce.

The high cost comes from the price of renewable electricity and the relatively low efficiency of current electrolysis technology.

But don't count it out just yet – costs are expected to drop as renewable energy becomes cheaper and electrolysis technology improves.

In the long run, green hydrogen will be the backbone of a fully-decarbonised energy system, making it the fuel of the future.

Why does it matter?

Why should we care about these different types of hydrogen?

Well, as we move towards a more sustainable future, hydrogen **will** play a key role in decarbonising industries that are hard to electrify, like most of automotive, steelmaking, heavy transport, and aviation.

Grey hydrogen is holding us back, blue hydrogen offers a solid compromise, and green hydrogen is where we need to be if we're serious about tackling climate change.

The underused energy source under the Earth's surface that could mean a carbon-free future



Scientists have discovered vast underground reserves of a clean energy source capable of replacing fossil fuels and helping feed the world for centuries.© Pixabay

A recent scientific discovery could change the course of the global energy crisis: **under the earth's surface** there are vast reserves of **natural hydrogen, a clean and sustainable resource**.

According to a study published in Science Advances, these reserves could be the key to **replacing fossil fuels** and **feeding the world for the next 200 years**.

Until recently it was believed that hydrogen **could not accumulate underground** due to its volatile nature, but recent **research has shown otherwise**.

Computer models suggest the planet is home to approximately **6.2 trillion tons of hydrogen** trapped in rocks and underground deposits, a figure **26 times greater than known oil reserves**.

READ ALSO: *No longer science fiction, scientists test quantum teleportation*

The promise of natural hydrogen

Hydrogen, known for being a **clean, emissions-free energy source**, can power vehicles, industrial processes and generate electricity.

According to Geoffrey Ellis, a geochemist at the U.S. Geological Survey and lead author of the study, even a small fraction of these reserves- about 2%- would be **enough to meet global energy demand** and move toward a **carbon-free future**.

The first signs of significant accumulations of natural hydrogen have been found in places such as **West Africa and a chrome mine in Albania**.

These discoveries have opened up new possibilities for the use of this resource, provided that **technologies are developed** that allow the reserves to be **located and extracted efficiently**.

Hydrogen as an energy source: Challenges and opportunities

While calculations indicate there is **more than enough hydrogen** to meet the planet's energy needs, scientists acknowledge much of the reserves may be **too deep or found in inaccessible locations**.

Some deposits may be **too small to justify extraction**. But these limitations do not negate hydrogen's transformative potential.

A crucial advantage of natural hydrogen is its **stability in the reservoirs** where it is found, eliminating the need for costly storage and transportation systems. In addition, its ability **to release twice as much energy** as known natural gas reserves makes it an attractive alternative for a variety of energy sectors.

A future powered by hydrogen

With global demand for hydrogen expected to increase fivefold by 2050, experts predict the resource will account for **up to 30% of energy supply** in some sectors.

Most hydrogen is **currently produced artificially** through processes such as electrolysis, but the **discovery of natural reserves** could significantly reduce costs and accelerate the transition to clean energy.

In the coming months, researchers hope to more precisely identify **hydrogen deposits in the United States** and other countries, ushering in a new energy era. If these findings are confirmed, **natural hydrogen could become the key to abandoning fossil fuels** and tackling climate change once and for all.

There Could Be Trillions Of Tons Of Natural Hydrogen Right Under Our Feet

Is the future hydrogen-powered? It might be, if a new study turns out to be correct: using longstanding geological models tweaked to include data about natural hydrogen, researchers have estimated an untapped reservoir of potentially trillions of metric tons of the element within the Earth's subsurface.

For a while now, we've been told that the future of energy lies in hydrogen fuel. It's clean, producing **only water and heat** in its use; it has a **higher energy density** than batteries; it can be produced, stored, and transported using existing resources; and, let's face it, it's not like the universe is going to run out of it **any time soon**.

The problem, however, is getting hold of it. Until now, the best option has been to create so-called "green" hydrogen – to use a renewable energy source like wind or solar power to split water molecules into their constituent oxygen and hydrogen atoms. In the race for net zero, it's a powerhouse player, creating

just [one kilogram or less](#) of CO per kilo of hydrogen produced, even at this early stage in the industry.

So, why aren't we all already living off green hydrogen power? Unfortunately, there are some drawbacks: it's expensive, and production times are limited. That's why most hydrogen power, where it is used at all, is either "gray" or "blue" hydrogen – energy sources that are [often advertised as being clean](#) despite relying on fossil fuels to produce.

There is another option, though. Hydrogen *can* be produced via natural chemical reactions that occur when rocks come into contact with each other – but until recently, it was thought that this was pretty rare. That was, until geologists [discovered](#) huge reservoirs of the element in Bourakebougou, in Mali – triggering what has, over the past year or two, become something of a global gold rush in the hunt for hydrogen.

The search for natural wells of hydrogen has taken prospectors to France and Spain; to Nebraska, Arizona, and Kansas; to Australia; Morocco; Brazil, and elsewhere. According to the team behind the new paper, there's good reason for that – as, according to their calculations, we're sitting on up to 5.6×10 million metric tons of the stuff.

Now, there's a lot of wiggle room in their values: "the estimated amount of in-place hydrogen in the Earth's subsurface is highly uncertain, varying over seven orders of magnitude," they admit in the paper, although "the predicted flux to the atmosphere is less variable (three orders of magnitude), with the most probable value roughly within a factor of 2 of current observations."

On top of that, the pair readily acknowledge that most of what they suspect to exist is inaccessible: "Given what is known about the distribution of petroleum and nonpetroleum fluids [...] it is likely that recovery of most subsurface hydrogen can be expected to be in accumulations that are too deep, too far offshore, or too small to be economically recovered," they write.

But even with these caveats, it's a vast amount of hydrogen that could be available. Just two percent of what they think is out there would be enough to fulfill the global demand for hydrogen needed to reach net-zero carbon emissions for the next 200 years – and even just that small amount would yield

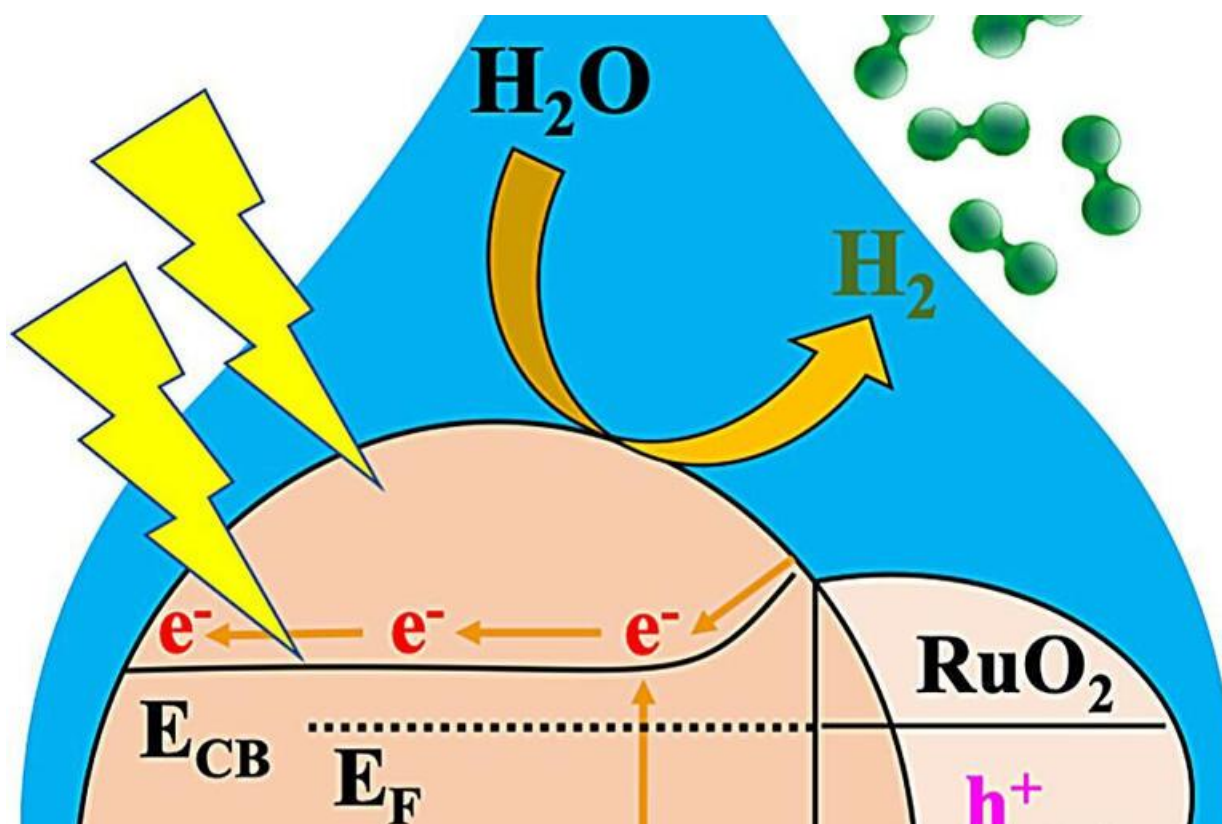
“roughly twice the amount of energy in all the proven natural gas reserves on Earth,” they write.

There are, admittedly, still a lot of unanswered questions. Where, exactly, is all this hydrogen, for example, and what would be the consequences of harnessing such a vast amount of a basically untested and non-renewable fuel type? And then there’s the crucial one: is all this hydrogen really there at all – or has it “leaked” out over time, [as some experts suspect](#)?

But for those whose hopes are pinned on a hydrogen-powered future, it’s a glimmer of hope – and with more data and interest in the topic, estimates will likely sharpen.

“Our model provides an initial framework for assessment of the global resource potential of natural hydrogen,” the paper concludes. “These findings indicate that further research in this field is warranted.”

The paper is published in the journal [Science Advances](#).



Credit: Oregon State University© Provided by Phys.org

Researchers at Oregon State University have developed a material that shows a remarkable ability to convert sunlight and water into clean energy.

A collaboration led by Kyriakos Stylianou of the OSU College of Science created a photocatalyst that enables the high-speed, high-efficiency production of hydrogen, used in fuel cells for cars as well as in the manufacture of many chemicals including ammonia, in the refining of metals and in making plastics. The research was published in [Angewandte Chemie](#).

The findings represent a potential new tool to use against greenhouse gas emissions and climate change, said Stylianou, whose research focuses on crystalline, porous materials known as metal organic frameworks, usually abbreviated as MOFs.

Made up of positively charged metal ions surrounded by organic "linker" molecules, MOFs have nanosized pores and tunable structural properties. They can be designed with a variety of components that determine the MOF's properties.

In this study, researchers used a MOF to derive a metal oxide heterojunction—a combination of two materials with complementary properties—to make a catalyst that, when exposed to sunlight, quickly and efficiently splits water into hydrogen.

The heterojunction, which they refer to as RTTA, features MOF-derived ruthenium oxide and titanium oxide doped with sulfur and nitrogen. They tested multiple RTTAs with different amounts of the oxides and found a clear winner.

"Among various RTTA materials, RTTA-1, with the lowest ruthenium oxide content, exhibited the fastest hydrogen production rate and a high quantum yield," Stylianou said.

In just one hour, he noted, a gram of RTTA-1 was able to produce over 10,700 micromoles of hydrogen. This process utilized photons—light particles—at an impressive rate of 10%, meaning that for every 100 photons that struck RTTA-1, 10 contributed to hydrogen production.

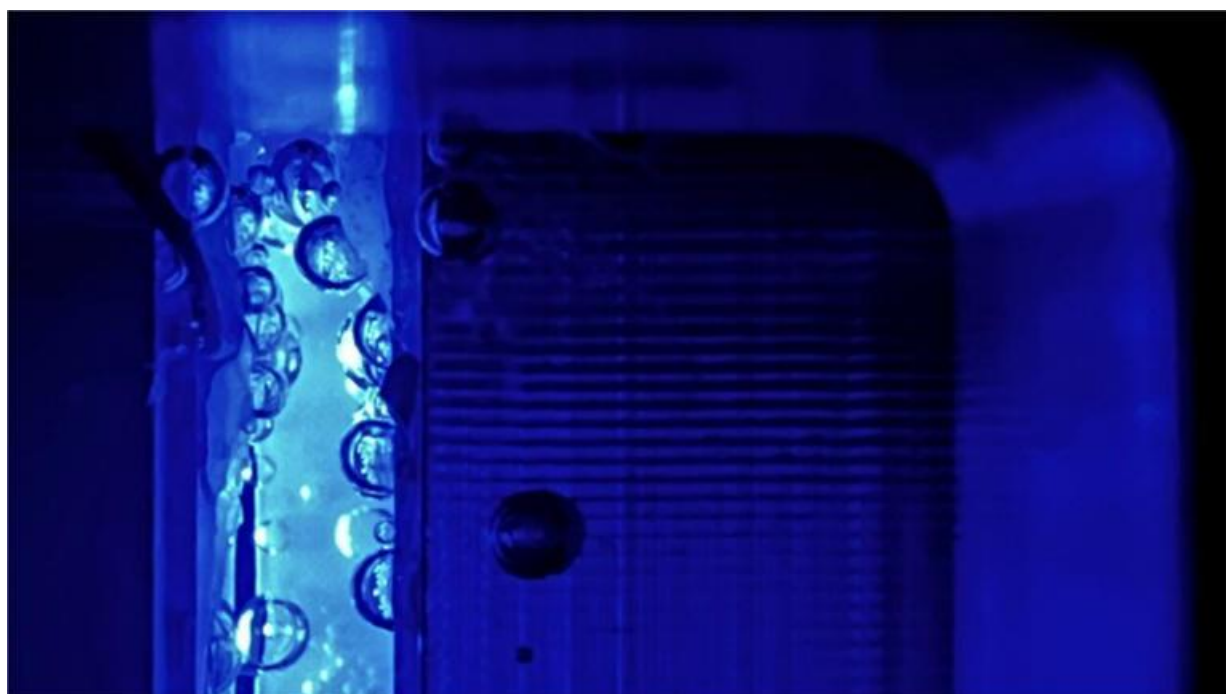
"The remarkable activity of RTTA-1 is because of the synergistic effects of the metal oxides' properties and surface properties from the parent MOF that enhance electron transfer," Stylianou said. "This study highlights the potential of MOF-derived metal oxide heterojunctions as photocatalysts for practical hydrogen production, contributing to the development of sustainable and efficient energy solutions."

Producing hydrogen by splitting water through a catalytic process is cleaner than the conventional method of deriving hydrogen from natural gas via a carbon-dioxide-producing process known as methane-steam reforming.

Current catalytic processes for producing hydrogen from water involve electrocatalysis—running electricity through the catalyst. The sustainability of electrocatalysis depends on using renewable energy, and to be competitive in the market the energy has to be inexpensive.

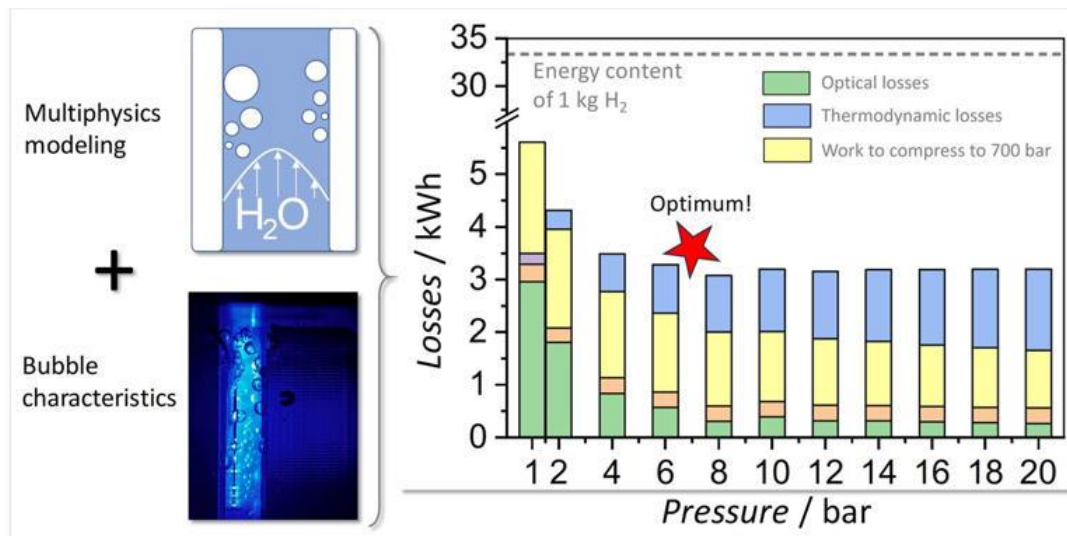
Presently, methane-steam reforming produces hydrogen at a cost of about \$1.50 per kilogram, compared to about \$5 a kilogram for green hydrogen.

"Water is an abundant source of hydrogen, and photocatalysis offers a method to harness the Earth's abundant solar energy for hydrogen production," Stylianou said. "Ruthenium oxide is not cheap but the amount used in our photocatalyst is minimal. For industrial applications, if a catalyst shows good stability and reproducibility, the cost of this small amount of ruthenium oxide becomes less important."



Keywords: Science Highlight 31.07.2024 The efficiency of a PEC cell depends on many factors, including the size of the gas bubbles. Credit: Feng Liang /HZB

Hydrogen can be produced via the electrolytic splitting of water. One option here is the use of photoelectrodes that convert sunlight into voltage for electrolysis in so-called photoelectrochemical cells (PEC cells). A research team at HZB has now shown that the efficiency of PEC cells can be significantly increased under pressure.



The combined energy losses have been evaluated up to 20 bar of the PEC-generated hydrogen. Efficiency losses are lowest at a pressure of 6–8 bar, especially optical and thermodynamic losses. The team achieved this result by combining experimental data with a physical model. Credit: HZB/Nature Communications 2024

Some call it an 'artificial leaf': instead of the natural Photosystem II complex that green leaves in nature use to split water with sunlight, photoelectrochemical cells, or PEC cells for short, use artificial, inorganic photoelectrodes to generate the voltage required for the electrolytic splitting of water from sunlight.

Minimizing losses

The best performing devices already achieve impressive energy conversion efficiencies of up to 19%. At such high efficiencies, losses due to bubble formation start to play an important role. This is because bubbles scatter light, preventing optimal illumination of the electrode.

Moreover, bubbles may block the electrolyte from contacting the electrode surface and thus cause electrochemical deactivation. To minimize these losses, it would help to reduce the bubble sizes by operating the device at higher pressure. However, all PEC devices reported thus far have been operating at atmospheric pressure (1 bar).

Enhancing the pressure

A team from the Institute for Solar Fuels at HZB has now investigated water splitting at elevated pressure under PEC-relevant conditions. They used gas to pressurize PEC flow cells to between 1 and 10 bar and recorded a number of different parameters during electrolysis. They also developed a multiphysics model of the PEC process and compared it with experimental data at normal and elevated pressure.

Related video: Running on empty: surviving a hydrogen-powered road trip (Dailymotion)

This model now allows to play with the parameters and identify the key levers. "For example, we investigated how the operating pressure affects the size of the gas bubbles and their behavior at the electrodes," says Dr. Feng Liang, first author of the paper now [published](#) in *Nature Communications*.

Energy losses halved

The analysis shows that increasing the operating pressure to 8 bar halves the total energy loss, which could lead to a relative increase of 5–10% in the overall efficiency.

"The optical scattering losses can be almost completely avoided at this pressure," explains Liang. "We also saw a significant reduction in product cross-over, especially the transfer of oxygen to the counter electrode".

At higher pressures, however, there is no advantage, so the team suggests 6–8 bar as the optimum operating pressure range for PEC electrolyzers.

"These findings, and in particular the multiphysics model, can be extended to other systems and will help us to increase the efficiencies of both electrochemical and photocatalytic devices," says Prof. Dr. Roel van de Krol, who heads the Institute for Solar Fuels at HZB.

Oregon State University researchers working on a way to make

cleaner [hydrogen](#) have been busy beavers. As a result, they have [developed](#) a material that leverages sunlight to separate hydrogen from water, OSU reported. The science is happening on the molecular level — measured in tiny micromoles. But the team is optimistic the research will lead to something big. The goal is to make a high-speed, efficient, clean, and cost-effective way to make a reliable fuel source for transportation, chemical manufacturing, metal refining, and [plastic](#)-making, all [per](#) a lab summary.

[Hydrogen](#) produces mainly water when used in a fuel cell, eliminating heat-trapping air pollution generated from gas-burning vehicles. It's part of the government's clean-energy [strategy](#), and its use and production is even being [vetted](#) as part of a big U.S. Energy Department-backed project in Texas.

In Oregon, the research is focused on crystalline, porous materials called metal organic frameworks. Simply put, the substance's nano-sized pores and other structural elements help it to produce hydrogen from sunlight and water.

"Water is an abundant source of hydrogen, and photocatalysis offers a method to harness the Earth's abundant solar energy for hydrogen production," project lead Kyriakos Stylianou, from the university's College of Science, said in the report. [Photocatalysis](#) uses chemical catalysts to improve the rate of a reaction that occurs by absorbing light.

The procedure involves some in-depth lab work and chemistry. The recipe is a complementary list of ingredients well-suited for the task, [per](#) the experts. The team tested multiple combinations until they found a "clear winner" that "exhibited the fastest hydrogen production rate and a high quantum yield," Stylianou [said](#) in the OSU summary.

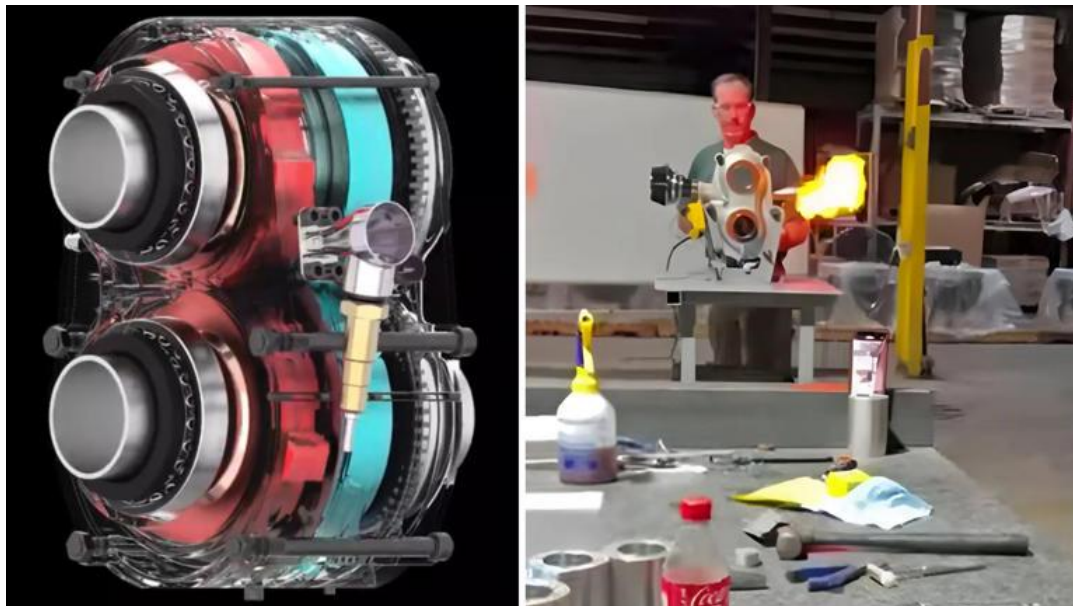
In an hour, a gram of the material, dubbed RTTA-1 by the researchers, made more than 10,700 micromoles of hydrogen. It utilized light particles "at an impressive rate of 10%." So, every time 100 photons hit RTTA-1, there were 10 that helped to make hydrogen, all [per](#) the experts.

Hydrogen is being developed as a scalable fuel option for vehicles and even [planes](#). The cleaner fuel could help [transform](#) our energy sector to avoid [worst-case](#) climate scenarios caused by worldwide overheating.

There are some hurdles to overcome. [Natural gas](#) is primarily used to make hydrogen through a process called steam-[methane](#) reforming. Electrolysis, another method, uses electricity to split hydrogen from water. It's a cleaner process when renewable sources supply the power, all [according](#) to the Energy Information Administration.

The Sierra Club has some other [concerns](#), as well. For one, the club cites [nitrogen oxide](#) pollution that is released when hydrogen is burned to make electricity as a detriment to human health. The government [acknowledges](#) the nitrogen oxide fumes during combustion but claims the impact can mostly be mitigated with "existing and emerging technologies."

Regardless, the lab work is continuing in Oregon and elsewhere. In Chicago, for example, a team is working on a way to [make hydrogen](#) from sunlight and biowaste



Astron's hydrogen engine achieves record 60% efficiency with 0 emissions

If the dawn of the electric vehicle (EV) age has you worried about losing the sounds and vibrations of an internal combustion engine (ICE), then Kansas-based Astron Aerospace has a solution for you.

Meet H2 Starfire, a hydrogen-powered combustion engine that produces water as a byproduct and emits no planet-warming emissions whatsoever.

Countries plan to phase out the sales of ICE vehicles to promote the use of non-polluting vehicles. Tail-pipe emissions are major contributors to the transportation industry's emissions, and while the puzzle of long-haul transport is yet to be solved, governments are hopeful that they can make an impact by switching commuters to electric modes.

This would require many automobile enthusiasts to give up their fuel-guzzling and noise-producing vehicles, and rightly so. An ICE-powered car is only 20 percent efficient, meaning 80 percent of the energy from the fuel is lost as heat. The best car engines on the road today hit the 40 percent mark, but Astron's H2 Starfire engine could replace them all, thanks to its 60 percent efficiency.

How does it work?

Hydrogen is touted as the next best thing to fossil fuels since it can be burned to produce large amounts of energy but only generates water as a byproduct.

Interesting Engineering has previously reported on how hydrogen can be used in [fuel cells](#), but it needs a different set of conditions to be burnt inside a combustion engine.

Related video: Running on empty: surviving a hydrogen-powered road trip (Dailymotion)

Astron's H2Starfire achieves these using two sets of counter-rotating rotors: one aluminum half does the intake and compression jobs, while the titanium half at the rear handles expansion and exhaust.

Inside the engine, temperatures reach 1,400 Fahrenheit (760 degrees Celsius), and here, hydrogen can burn cleanly to produce energy, noise, and mechanical vibrations that motorheads fear they will miss.

High-efficiency claims

The company claims it has achieved another major milestone by eliminating the need for water cooling. This has also helped it reduce the complexity of its design and weight, which gives it an efficiency boost.

H2Starfire's design is quite linear and avoids the use of apex seals. The company claims that the engine is frictionless, and its tolerances are so tight that only timing gears and bearings need oiling. This has been achieved with a simplistic design of the engine, which consists of only 82 parts.

So far, we have seen a partial prototype of the engine, so a fair bit needs to be done before we see a prototype vehicle with this anytime soon.

There is a reason why limited engine designs have made it to market, even though two centuries have passed since the first automobile was rolled out.

Even if Astron perfects its hydrogen engine soon enough, the other piece of the puzzle needs to be solved as well. Currently, hydrogen production is largely achieved through the use of fossil fuels, so burning hydrogen or fossil fuels is quite the same as now.

Once the firm achieves mass-scale [green hydrogen](#) production and rolls it out, Astron's H2Starfire could definitely be in high demand.

A photoluminescent hydrogen-bonded biomass aerogel for sustainable radiative cooling

Editor's summary

Passive radiative cooling materials eject infrared radiation through the atmospheric window and into outer space, providing several degrees of cooling relative to ambient temperature. Many passive cooling strategies rely on polymers that do not degrade and may not be recyclable. Ma *et al.* present a biomass-based aerogel that has attractive radiative cooling properties (see the Perspective by Shen and Liu). The gelatin- and DNA-based aerogel has a large cooling effect, in part due to fluorescence and phosphorescence. It is also degradable and recyclable, which are important factors when considering the environmental impact of this type of material. —Brent Grocholski

Abstract

Passive radiant cooling is a potentially sustainable thermal management strategy amid escalating global climate change. However, petrochemical-derived cooling materials often face efficiency challenges owing to the absorption of sunlight. We present an intrinsic photoluminescent biomass aerogel, which has a visible light reflectance exceeding 100%, that yields a large cooling effect. We discovered that DNA and gelatin aggregation into an ordered layered aerogel achieves a solar-weighted reflectance of 104.0% in visible light regions through fluorescence and phosphorescence. The cooling effect can reduce ambient temperatures by 16.0°C under high solar irradiance. In addition, the aerogel, efficiently produced at scale through water-welding, displays high reparability, recyclability, and biodegradability, completing an environmentally conscious life cycle. This biomass photoluminescence material is another tool for designing next-generation sustainable cooling materials.

Scientists have discovered a way to [store electrical energy](#) in liquid fuels in what could be a major boost for transitioning to renewable energy sources.

Batteries are essential for optimising the [potential of solar and wind](#), allowing energy to be stored during periods of overproduction and fed back into the grid when there is low production.

Current lithium-ion batteries – which are found in everything from laptops to electric vehicles – are costly for such large-scale purposes, leading scientists to search for alternative systems.

A team from Stanford University in the US have now unveiled a new way to use liquid organic hydrogen carriers (LOHCs) as a means of [renewable energy](#) storage. LOHCs – or liquid batteries as they are referred to by the researchers – store hydrogen using catalysts and increased temperatures, before releasing it as electricity when needed.

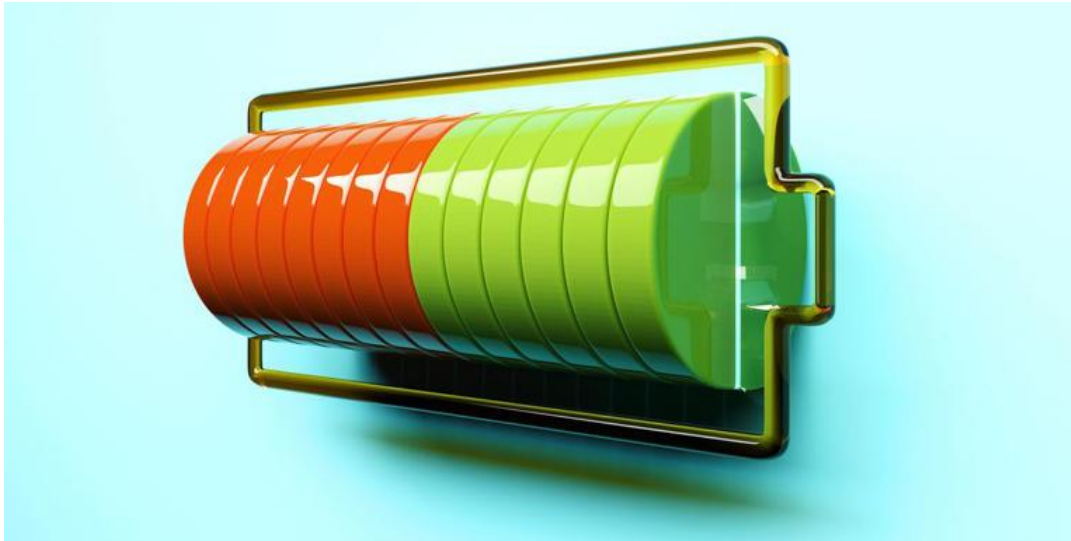
“The electric grid uses energy at the same rate that you generate it, and if you’re not using it at that time, and you can’t store it, you must throw it away,” said Robert Waymouth, a professor in chemistry in the School of Humanities and Sciences at Stanford University.

“We are developing a new strategy for selectively converting and long-term storing of electrical energy in liquid fuels. We also discovered a novel, selective catalytic system for storing electrical energy in a liquid fuel without generating gaseous hydrogen.”

The discovery hinges on a “magic additive” called cobaltocene that works as a catalyst in the reaction to store and release the energy without releasing hydrogen gas.

“This is basic fundamental science, but we think we have a new strategy for more selectively storing electrical energy in liquid fuels,” said Professor Waymouth.

The research was detailed in [a study](#), titled ‘Cobaltocene-Mediated Catalytic Hydride Transfer: Strategies for Electrocatalytic Hydrogenation’, published in the *Journal of the American Chemical Society*.



Discover how Stanford chemists' new liquid battery could revolutionize renewable energy storage and stabilize the power grid for a sustainable future. © taylanibrahim - Getty Images

- A team of Stanford chemists believe that liquid organic hydrogen carriers can serve as batteries for long-term renewable energy storage.
- The storage of energy could help smooth the electrical grid and give renewable energy a prominent place without the risk of uneven production.
- Future solutions could combine a chemical compound of cobalt—or potentially even iron—with isopropanol and acetone.

Stanford chemists hope to stop the variability of renewable energy on the electrical grid by creating a liquid [battery](#) that offers long-term storage. Hopefully, this liquid organic hydrogen carriers (LOHC) battery will offer storage and smooth out ebb and flow of renewable power production without certain negative side effects. The team described its work in a study [published](#) in the *Journal of the American Chemical Society*.

"We are developing a new strategy for selectively converting and long-term storing of electrical energy in liquid fuels," Robert Waymouth, Stanford chemistry professor, said in a university [news release](#). "We also discovered a novel, selective catalytic system for storing electrical energy in a liquid fuel without generating gaseous [hydrogen](#)."

Our current electrical grid uses energy at the rate it gets generated. That works well with methods of energy generation that are relatively consistent, but unfortunately, renewable energy like solar or wind is known for uneven [energy](#) production. As a result, we need to find ways of storing any excess energy produced on high-energy-production days so that it can be used on low-energy-production days.

The team from Stanford believes that LOHCs can one day serve as “liquid batteries”—storing energy and efficiently releasing it as usable fuel or [electricity](#) when needed. And it may do by converting the excess into relatively simple ingredients—such as acetone and isopropanol, more commonly known as rubbing alcohol—that can exist for extended periods of time as high-density liquid forms of hydrogen.

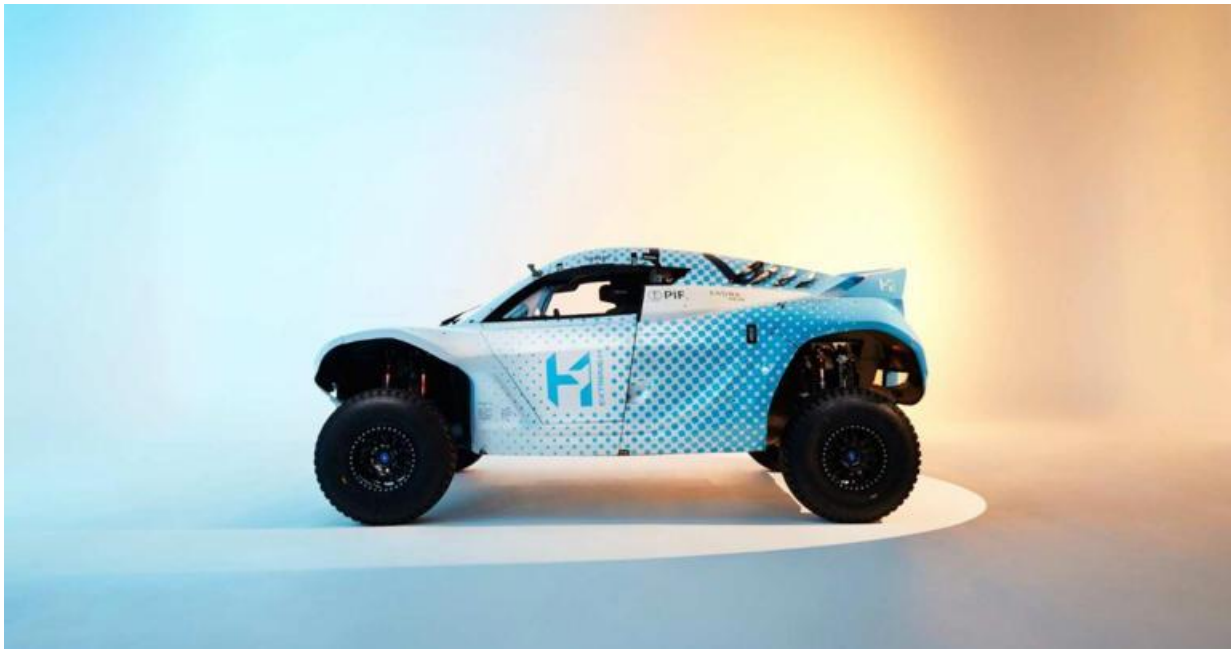
“When you have excess energy, and there’s no demand for it on [the grid](#), you store it as isopropanol,” Waymouth said. “When you need the energy, you can return it as electricity.”

Making it efficient, though... that’s the trick. Currently, methods to produce isopropanol with electricity prove inefficient. “We need a way to make isopropanol directly from protons and [electrons](#) without producing hydrogen gas,” Waymouth said.

This study offers up a solution that uses acetone, iridium, and a surprise additive of cobaltocene, a chemical compound involving the metal cobalt. “The researchers found that cobaltocene is unusually efficient when used as a co-catalyst in this reaction,” the news release read, “directly delivering [protons](#) and electrons to the iridium catalyst rather than liberating hydrogen gas, as was previously expected.”

The effort combines a mixture of accessible ingredients to create a non-toxic way of storing energy long-term. The team hopes to continue to mine the possibilities of differing catalysts (such as iron) to make this [liquid](#) battery system even more affordable and scalable.

Australian mining company Fortescue Metals Group is investing a lot of money into green tech through a subsidiary called Fortescue Future Industries (FFI), which has recently completed the acquisition of UK-based Williams Advanced Engineering. Last November, FFI announced it would have the world's first ammonia-powered ship in operation by the end of this year, along with ammonia-fueled trains and hydrogen fuel cell mining trucks. But that's not all! It's also establishing itself as a significant global player in green hydrogen production and distribution, on top of beginning construction on an Australian factory that will more than double the world's present electrolyzer production capacity.



Extreme H car debut PlanetF1© PA Images

Extreme E announced its intentions to transform from a battery electric vehicle off-road series to a hydrogen-powered series in 2025 — but the incredible amount of resources required to achieve that goal has resulted in the indefinite postponement of 2024's final three races.

At 2023's season-ending Copper X Prix in Chile, we spoke with Extreme E and Extreme H founder Alejandro Agag about the goals of the hydrogen-powered series — and it provided a compelling look into what could be going wrong with the series now.

Alejandro Agag: “The key here is to be the only ones racing on hydrogen”

Extreme H was announced late in 2023 as a hydrogen-powered off-road series designed to replace Extreme E, where cars are powered by electric batteries — and the whole goal was to use the series as a way to develop and refine hydrogen power for both motorsport and road usage.

Hydrogen isn't exactly a brand-new form of transportation power, but it has been admittedly difficult to implement the technology in motorsport. The 24 Hours of Le Mans has been keen to introduce a hydrogen class for several years, though ample delays have pushed the introduction of the class back by several years — perhaps until 2027.

But in speaking to media at the 2023 Copper X Prix, before the official announcement that Extreme H would replace Extreme E and that XH would join a “hydrogen research group” with both Formula 1 and the FIA, series founder Alejandro Agag repeatedly expressed his goal for the series: That it would be the first — and only — hydrogen-powered form of motorsport.

“The key here is to be the only ones that will be racing with hydrogen,” Agag said to assembled media, including **PlanetF1.com**.

“We want to be the first [racing with hydrogen].”

At the time, Agag made the premise sound realistic; he shared that the series had already developed a hydrogen-powered racer, and that it was able to move under its own power. Today, XH also announced that the car had passed FIA crash testing, but that it still needs to undergo resilience tests and further on-track testing.

But there's just one problem: It has taken so many resources to design and build the XH cars that the 2023 Extreme E season — the final with battery-electric vehicles — has been placed on indefinite hold.

That means that upcoming events in both Sardinia and Phoenix, Arizona have been canceled for the time being; the series stated that it is “working closely with

our teams and stakeholders to find alternative solutions to fulfill Extreme E's final season schedule," but there is no indication when that change would come.

The first of two Island X Prix events in Sardinia was expected to begin next weekend, on September 14-15.

Learn more about Extreme E:

In Chile in 2023, Agag stated that he felt it would be a "challenge" to create a race series powered by hydrogen from scratch — which is why it initially made sense to maintain Extreme E's format, albeit with different cars.

Later in the interview, Agag again stressed that he felt there is a "big, big business opportunity in hydrogen" — opportunity that would only exist "because we're going to be the only ones [racing with hydrogen], because we're the first one there."

Unfortunately, it appears that being the first race series to go hydrogen has been more challenging than expected.

That is perhaps because hydrogen has not become the "alternative fuel" that many had hoped it would be.

Alejandro Agag made waves in 2013 when he announced his role in founding Formula E, which seemed an audacious ask — but not an entirely impossible one.

In 2013, Tesla had already released its Model 3, which began to change the name of the game in terms of the power used for personal transportation. However, Ford, Mitsubishi, Nissan, Fiat, Honda, Scion, and smart had all released battery-electric powered vehicles to the consumer market. The technology existed in a variety of forms, but it was up to FE to create a comprehensive racing package.

By contrast, only four hydrogen cars currently exist in the consumer market: The Honda Clarity Fuel Cell, the Hyundai Nexo SUV, the Toyota Mirai, and, most recently, the Honda CR-V e:FCEV.

Hydrogen is more commonly found in industrial and commercial uses, to power rockets, ships, and other large forms of transportation. That means finding

experts who can scale their hydrogen knowledge to encompass racing cars can be a challenge.

Even more challenging is actually sourcing hydrogen. This year, Toyota Mirai owners filed a class action lawsuit in California alleging that a lack of hydrogen fuel stations meant they were unable to drive their cars. It would be somewhat simpler for a 10-car race series to cart around enough hydrogen to refuel for a race — but over 98% of hydrogen is sourced from fossil fuels and therefore creates carbon emissions.

Producing hydrogen is less efficient than charging a battery. Hydrogen is difficult to transport, store, and dispense. Hydrogen can be extremely reactive, and leaks can be difficult to spot.

All of these factors have resulted in automakers largely avoiding any experimentation with hybrid-powered vehicles — but even battery-powered EVs are becoming less popular as consumers grow disillusioned with an institutional lack of charging infrastructure.

In some ways, Agag is correct; being the first people to corner a market gives you a massive commercial boost. Formula E, for example, holds the exclusive rights to be the only all-electric open-wheel racing series until 2039; sponsors and teams that want to engage in racing, then, have little choice but to opt for FE.

But there was, at least, consumer interest in electric vehicles when Formula E debuted — meaning that sponsors and automakers could join the series in order to learn about the kinds of technologies they wanted to implement in more vehicles in the future.

Honda is the sole automaker to introduce a hydrogen-powered vehicle in the last five years. Why? Because most automakers have determined that hydrogen-powered vehicles will be more challenging to develop than they're worth.

In Chile, Agag admitted that he was "optimistic" about being able to race hydrogen-powered cars in Extreme H by February of 2025, but that he "wasn't optimistic three months ago."

He noted that the XH designers had run into concerns with fuel cell supply and production, with testing, with software, and with generally making the hydrogen

fuel cell technology work. But in Chile, Agag told us the car was up and running, and that it had achieved almost all of its Key Performance Indicators.

There is, however, a large gap between building a functional prototype and developing multiple race-ready machines that have been tested for safety, resilience, and reliability. It appears that the task has proven far more difficult than expected — and the final season of Extreme E has suffered for it.

Rail is having a moment in the U.S. But amid talk of [electric commuter trains](#) and new [high speed passenger lines](#), freight rail doesn't often make the headlines. Still, it's an industry ripe for innovation, and one of the largest locomotive manufacturers is moving that way.

Wabtec, which has 25,000 locomotives operating in North America, is developing an engine that can be powered by hydrogen and diesel, which would be an important step in reducing emissions.

Freight rail is currently responsible for 1.8% of the carbon emissions from transportation in the U.S., according to the EPA.

Broadly, the railroad industry has made fuel efficiency gains in recent years. According to the [Association of American Railroads](#), a gallon of fuel powers one ton of freight for almost 500 miles—three to four times more than a truck. Freight trains became 47% more fuel efficient between 1990 and 2020.

"Railroads are already very efficient. They're producing relatively few emissions per ton of freight transported over distance compared to alternative modes," says C. Tyler Dick, a professor at UT Austin who researches railroad energy technologies. "But, like everyone else, there's this incentive to try and further reduce the energy consumption and associated emissions with them."

Wabtec aims to retrofit existing engines to use a blend of diesel and hydrogen fuel, which Chief Technology Officer Eric Gerbhardt says would reduce the carbon emissions by 80%. But the company says it will be several years until its first

retrofitted locomotive is commercially available and at least 2030 before the economics of hydrogen make sense for a broader rollout.

Availability of clean hydrogen

Locomotives last between 30 to 40 years, and rail companies aren't inclined to swap in new versions of the expensive equipment early. By modifying the existing locomotives to use hydrogen, Wabtec hopes to speed up the adoption of alternative fuels.

"It gives optionality, because our hypothesis is that these fuels are not going to be available everywhere all at once," Gebhardt says.

Indeed, availability is a key concern. Approximately 10 billion kilograms of hydrogen is [produced](#) in the U.S. every year—the equivalent of 10 billion gallons of fuel. Powering U.S. freight rail required 3.1 billion gallons of fuel in 2022. However, trucks—a potential competitor for hydrogen fuel—used 172 billion gallons of fuel that [same year](#). In other words, the amount of hydrogen currently being produced in the U.S. is a drop in the bucket of what would ultimately be needed.

The federal government is trying to help solve this issue. As a part of the Infrastructure Investment and Jobs Act, \$8 billion was earmarked for [hydrogen hubs across the country](#).

There's also the fact that hydrogen isn't necessarily a clean fuel. While it produces no carbon dioxide, it requires a lot of electricity to produce—and that energy can come from [clean or dirty sources](#).

"In some cases, depending on where that electricity is coming from, you are actually creating more emissions than if you just had a diesel engine on the locomotive providing that power," Dick said.

[Green hydrogen](#) is rare at the moment (95% is made using natural gas, which comes with significant emissions), but as production scales up, that could change.

Hydrogen also presents safety challenges, as it's a very small, very flammable molecule prone to finding its way through cracks in storage containers. Dick says these containers would require a cryogenic component to keep the hydrogen at a low enough temperature to maintain its density. Wabtec plans to have a car behind the locomotive that would carry the hydrogen at a low temperature.



Wabtec's hydrogen powered engine. [Photo: courtesy Wabtec]

Lowering Rail Emissions

Regulators and shippers seeking to reduce carbon emissions have pushed the industry to clean up its operation. Last year, for example, California [passed regulations](#) requiring all freight rail locomotives built after 2035 to be zero-emission.

Right now, the vast majority of freight and passenger rail operations in the U.S. are powered by diesel. In addition to hydrogen, companies are looking at a range of alternatives, including battery, overhead electric, renewable diesel, and biodiesel.

While Dick says overhead electric would be three to four times more efficient than using electricity to produce hydrogen, it would require a massive investment to update rail infrastructure across the country. Wabtec says the lack of infrastructure is why it's not currently investing in electric freight trains.

A transition from diesel to hydrogen fuel offers some unique advantages, Dick said. The actual process of fueling is similar. With a diesel engine, the train pulls into the station, and fills up its 5,000 gallon tank with a hose in 20 to 30 minutes, Dick said. The process with hydrogen would be similar—albeit with a molecule that's more of a compressed gas. That said, it takes much more time. If a locomotive were running on 100% hydrogen, it would take [6.5 hours](#) to refuel, although Wabtec hopes to significantly reduce that in the next few years.

Wabtec also plans to launch engines that can use 20% biodiesel and 100% renewable diesel later this year, which Gebhardt said would reduce carbon emissions from the engine by 60%. (Although there are still broader questions about their emissions.)

Diversifying Rail

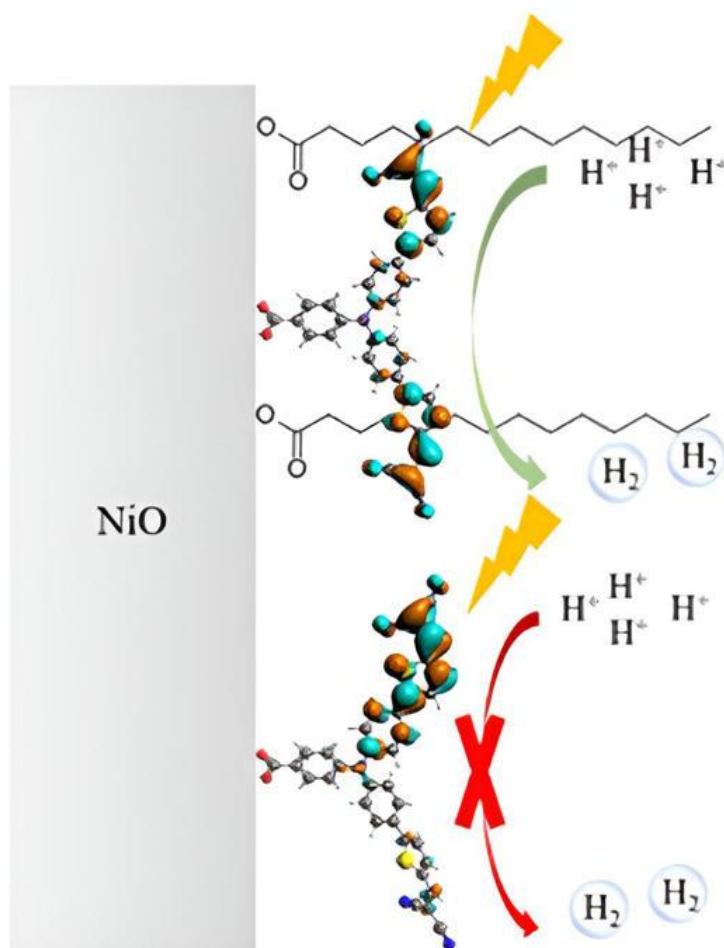
There are already some examples of non-diesel rail operations in the U.S. For example, the short haul Pacific Harbor Line in the Los Angeles area uses battery powered locomotives. The Florida East Coast Railway is using Wabtec locomotives powered by a blend of diesel and liquid natural gas—a similar technology to its blended diesel and hydrogen engine.

Europe has made greater strides toward a cleaner rail operation, which Dick attributes partially to the continent's climate goals. Lighter European freight trains largely use electric overhead wires and are more nimble so they can operate on a rail network that caters to passenger rail.

In the U.S., passenger rail is also exploring alternative energy. A train in San Bernardino, California is [aiming](#) to be the first hydrogen-powered, zero-emission passenger train in North America next year.

Dick doesn't expect a dramatic, overnight change. Things move slowly in the freight rail industry. However, he believes there's too much momentum behind alternative energy for there not to be advancements in the coming years.

"If the regulations continue, if there continues to be this pressure from shippers and the public pushing toward certain climate goals . . . then you'll gradually see these technologies gain momentum and gain a foothold within the railroad industry," he says. "I think it's inevitable that there will be some change."



Credit: Advanced Science (2024). DOI: 10.1002/advs.202403454

Researchers from the Faculty of S&T at the University of Twente have developed a novel approach for the design of efficient solar fuel devices. Research performed by graduated Ph.D. student Kaijian Zhu shows that reducing

the light-induced twisting of molecules can turn hydrogen generation on. The [study](#) is published in *Advanced Science*.

Photoelectrochemical cells are promising for the production of solar fuels, for example, the conversion of water into hydrogen or CO₂ into organic molecules. However, their efficiency has been limited by the performance of the photocathode, one of the functional electrodes in these cells. Present research focuses on manipulating the behavior of molecules on the nickel oxide (NiO) surfaces of these photocathodes.

Twisting molecules

When light is absorbed by the dye molecules on the NiO surface, they twist to promote the separation of positive and negative charges. A key question is how this twisting affects the performance of the photocathode. Zhu's research has demonstrated that by reducing this twisting process, hydrogen generation under illumination can be turned on.

By adding a long chain, hydrophobic hydrocarbon (myristic acid) to the NiO surface next to the light-sensitive dye molecules, the researchers were able to control and reduce the degree of twisting of the dye molecules when light is absorbed. Interestingly, the presence of myristic acid enabled light-induced hydrogen evolution in water even without a hydrogen evolution catalyst.

"The hydrogen generation is likely a synergetic effect of inhibited twisting of the dye radical anion, increasing its electrochemical potential, combined with charge transfer and reduction of protons at the hydroxylated NiO surface," says Annemarie Huijser, the corresponding author of this work.

The research illustrates the importance of understanding the effects of light-induced intramolecular twisting and demonstrates that control of the process enables a straightforward design approach for efficient photocatalysis.

More information: Kaijian Zhu et al, Limiting Molecular Twisting: Upgrading a Donor–Acceptor Dye to Drive H₂ Evolution, *Advanced Science* (2024). DOI: [10.1002/advs.202403454](https://doi.org/10.1002/advs.202403454)



Should truck manufacturers bet on battery, hydrogen or both? © Daimler Truck AG

From food to clothes to electronics, most things consumers purchase are likely delivered on trucks. One could even call them the backbone of commerce.

But they are massive polluters. In Europe, heavy duty vehicles are responsible for 28% of transport emissions though they only make up 2% of vehicles on the road, according to the European Federation of Transport and Emission.

And as more and more freight is moved around, these emissions will keep increasing — unless truck manufacturers and governments [take drastic action](#).



How do we slash trucks' emissions?

Truck producers' best bet is to make their new vehicles zero emissions by using electric motors. These can be powered with two options already familiar from the car industry: [batteries](#) or [hydrogen](#) fuel cells.

Batteries won the race to power passenger vehicles because they are cheaper. But trucks face a completely different set of challenges: They usually drive further and carry much heavier loads. That means truck companies are weighing their options.

Are battery electric trucks even feasible?

Just a few years ago, talk of a battery-powered truck might have gotten you "laughed out of a room," says Felipe Rodriguez, director for the Heavy-Duty Vehicles Program at the International Council on Clean Transportation (ICCT).

"There were many preconceived notions about what batteries could do. They were too expensive, too heavy, too big," he said.

The idea was that big trucks would need massive batteries, which would compromise how much cargo the vehicle could carry. And transporting heavy loads would make them run out mid-journey, making drivers stop for hours of charging. Not a great choice for operators running on tight profit margins.

"But what has happened in the last few years is mind-boggling," says Rodriguez.

The price for lithium-ion batteries has plummeted in the last decade because raw materials and component prices have become cheaper. At the same time production capacity increased across the battery value chain. Part of the reason is governments' high-scale investment in EVs as they try to reduce passenger cars' emissions.

"It's a whole automotive industry really bringing down the cost of batteries, but only a small industry working on engineering fuel cells and hydrogen delivery," said David Cebon, professor of mechanical engineering at Cambridge University in the UK.

Over the years, the energy density of batteries has also improved, meaning a truck can get much more range from the same size unit.

And researchers are working on megawatt charging systems that could reduce battery-powered trucks' charging time from several hours to as little as 15 minutes. That would allow them to charge the vehicle during their mandated driving break. In the US and Europe, this break ranges from 30 to 45 minutes.



Infrastructure for megawatt charging systems would cut down charging time for trucks© MAN Trucks & Bus

What are the advantages of hydrogen fuel cell trucks?

Hydrogen trucks' major selling point is that they can reduce emissions without compromising cargo or requiring long breaks.

That's because they use fuel cells. These devices essentially work like batteries, but instead of running on electricity, they run on hydrogen fuel and oxygen. The only by-products are heat and water.

"Refueling a hydrogen truck is more or less the same as refueling your diesel truck," said Volker Hasenberg who manages the hydrogen strategy at Daimler Truck. "You have a fueling station, you store your energy in the truck and this takes a couple of minutes."

Fuel cell trucks are an especially attractive option to carry extremely heavy loads because battery-powered trucks run out of energy quicker the more cargo they carry.

"Think about machines, construction — in general, what weighs a lot? When the threshold is the weight, not the space to be transported, then we have an advantage for hydrogen trucks," said Hasenberg.

How do the technologies' emissions compare?

Battery-powered trucks have a leg up when it comes to reducing emissions.

According to the ICCT, they save about 65% in emissions compared to their diesel counterparts when they run on an electricity mix of fossil fuels and renewables. If they are powered by clean energy, they emit 92% less.

Meanwhile, fuel cell trucks only save up to 33% compared to diesel trucks. This figure goes up to 89% if they run on green hydrogen, which is produced with [renewable energy](#). But this is barely happening.



The only by-products when powering a fuel cell truck are heat and water © Daimler Truck AG

Which technology is cheaper?

Battery electric trucks have a higher upfront cost than hydrogen trucks. But they are so efficient that they are much cheaper to operate — and ultimately more cost competitive.

When charging a fully electric truck, there are far fewer opportunities to lose energy along the way: The battery is charged at a station and then powers the motor.

Compare that to a fuel cell truck where energy needs to be converted into hydrogen, transported to refueling stations and pumped into a fuel cell where it is then turned back into electricity.

Because of all these extra steps, a hydrogen-fueled vehicle needs about three times more energy than a battery-powered one.

What is the future for these technologies?

As batteries become cheaper and more efficient, most major truck manufacturers are opting for them instead of fuel cells.

Some companies, like Daimler and Volvo, are betting that batteries will never mature enough to carry very heavy loads though. So they are developing hydrogen trucks as well.

"We can't really be sure that one technology will serve all our customers' needs," said Hasenberg. "We stand better on two feet than one."

But projections show that fuel cell trucks likely won't make up more than 10% of the market share before 2050. The vast majority will be powered by batteries.

Edited by: Tamsin Walker



Hydrogen industry chief joins Elon Musk in calling H2 energy 'ridiculous'

A prominent figure in the hydrogen industry has backed Elon Musk's comments that hydrogen energy is "dumb."

Tesla CEO Elon Musk called hydrogen "the most dumb thing I could possibly imagine for energy storage."

During an interview recently, Musk was asked if he thought hydrogen had a role in accelerating the transition from fossil fuels.

"No," he replied. "I really can't emphasize this enough — the number of times I've been asked about hydrogen, it might be ... it's well over 100 times, maybe 200 times," he said. "It's important to understand that if you want a means of energy storage, hydrogen is a bad choice."

Ridiculous H2

A top leader in the [H2](#) industry has supported Elon Musk's statement, citing various problems with hydrogen production and distribution.

Nam Hoon Kang, chairperson of the organizing committee of the H2 Mobility Energy Environment Technology (MEET) conference, which is being held in Seoul from September 25 to 27, said that hydrogen energy is 'ridiculous.'

He supported his comment by saying that the current cost of producing hydrogen fuel and energy is way too high, making it difficult to afford, even for big corporations.

He said hydrogen energy is still in the early stages of development, and the technology will take some time to develop, but as of now, the "energy is ridiculous."

However, he said Elon Musk's comment was inspired by a fear that the hydrogen may kill his electric vehicles business.

"It [H2 energy] may be ridiculous, but we are working hard to develop the technology; the future of the hydrogen energy could be bright," he added.

H2 high cost

The US Department of Energy (DOE) recently outlined its research and development (R&D) priorities to achieve the ambitious cost targets for clean hydrogen set by the Biden administration.

The DOE aims to significantly reduce the cost of zero-emission hydrogen by targeting a \$ 1/ kilogram price.

Kang said the current price of producing a kilogram of hydrogen is about \$10.

It takes work to bring the cost down, he added.

He said that bringing the cost down to \$1 to produce 1 kilogram of hydrogen by 2030 is impossible.

"Hydrogen is still a very new technology, and the entire industry is working on it to bring the cost down," he added.

However, he added that as the world transitions from gray hydrogen to green [hydrogen](#), the cost will increase instead of decrease in the initial period.

Creating green hydrogen is a fascinating process that taps into one of the most abundant resources on Earth—water.

It starts with electrolysis, where water is split into hydrogen and oxygen using electricity.

But the key here is that the electricity must come from renewable sources like solar, wind, or hydropower. That's what makes hydrogen "green," as opposed to the kind that comes from fossil fuels.

The idea is to make hydrogen in a way that doesn't pump more carbon dioxide into the atmosphere. So, instead of relying on natural gas, the process uses clean, sustainable energy.

However, adding solar and wind energy to create hydrogen energy will boost the cost of H2 production at a marginal level.

The leaders are still figuring out how to produce hydrogen energy cheaply, making H₂ feasible for most people.

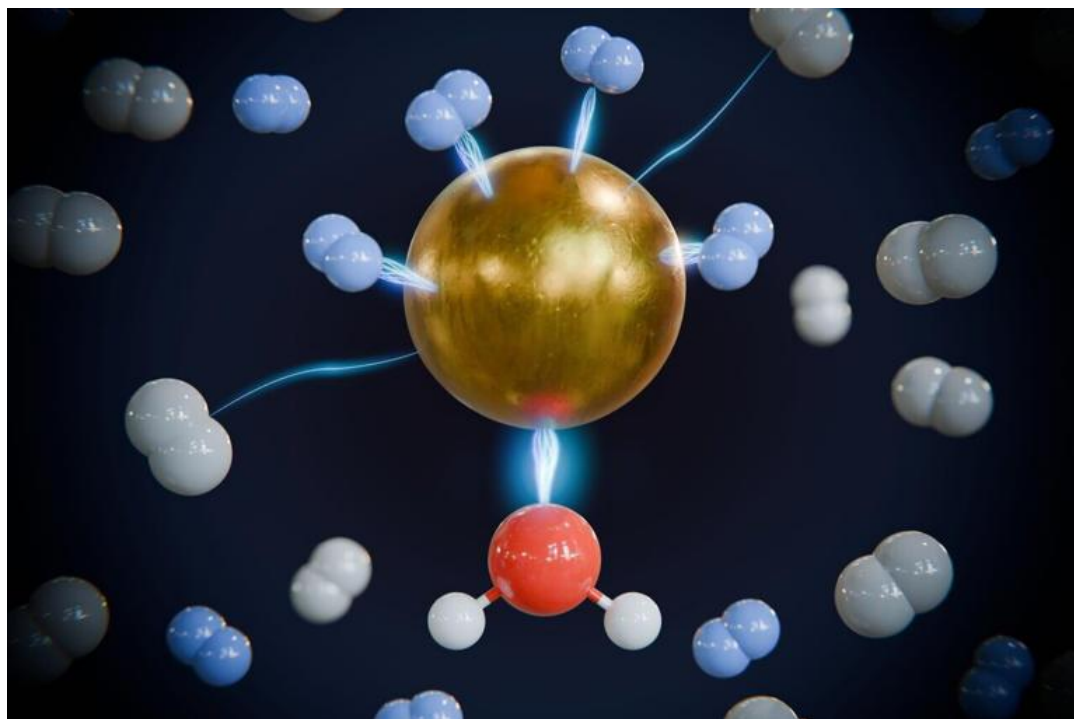


Illustration of the preferential binding of heavy hydrogen (blue) to light hydrogen (white) at the metal centre, activated by the binding of a water molecule (oxygen red, hydrogen white). Credit: Leipzig University

The lightest of all elements, hydrogen, is in great demand due to its promising role as a sustainable resource in the energy transition. A team from Leipzig University and TU Dresden, as part of the Hydrogen Isotopes 1,2,3H Research Training Group, has made an important breakthrough in the efficient and cost-effective provision of isotopes.

These are the three forms in which hydrogen occurs in nature—as protium, deuterium or tritium. The international team of researchers has taken a big step towards realizing its dream of separating hydrogen isotopes at room temperature at low cost. The team's [findings](#) have been published in *Chemical Science*.

Protium, or hydrogen-1, is the most common form of hydrogen. Deuterium, known as heavy hydrogen, is playing an increasingly important role, for example, in the development of more stable and effective pharmaceuticals. A mixture of

deuterium and tritium, "super-heavy" hydrogen, serves as the fuel for nuclear fusion, a sustainable energy source of the future.

One of the unsolved problems in hydrogen research is how to provide these isotopes in a highly pure form in an efficient and cost-effective way, as they have very similar physical properties. Current isotope separation processes are not very efficient and consume vast amounts of energy.

"It has been known for almost 15 years that porous metal-organic frameworks can, in principle, be used to purify and separate hydrogen isotopes. However, this has only been possible at very low temperatures, around minus 200 degrees Celsius—conditions that are very costly to implement on an industrial scale," says Professor Knut Asmis from the Wilhelm Ostwald Institute for Physical and Theoretical Chemistry at Leipzig University and spokesperson for the Research Training Group.

He adds that the separation mechanism is based on the strongly favored adsorption of one of the isotopes present on one of the free metal centers in the porous solid. Adsorption is a process by which atoms, ions or molecules from a gas or liquid adhere to a solid, often porous, surface.

The doctoral researchers of the 1,2,3H Research Training Group, Elvira Dongmo, Shabnam Haque and Florian Kreuter, who are all members of one of the research groups led by Professor Thomas Heine (TU Dresden), Professor Knut Asmis and Professor Ralf Tonner-Zech (both Leipzig University), have now gained a deeper insight into the influence of the framework environment on binding selectivity.

This means the question of why one of the isotopes is more likely to stick than the other. This was deciphered in detail in the present study through a synergistic interplay between state-of-the-art spectroscopy, quantum chemical calculations and chemical binding analysis on a model system.

"For the first time, we have been able to show the influence of the individual atoms of the framework compounds on adsorption. We can now optimize them in a targeted manner in order to obtain materials with high selectivity at room temperature," says Heine.

More information: Elvira Gouatieu Dongmo et al, Direct evidence for ligand-enhanced activity of Cu(i) sites, *Chemical Science* (2024). DOI: [10.1039/D4SC04582C](https://doi.org/10.1039/D4SC04582C)

Provided by Leipzig University

As a fuel, hydrogen has a lot going for it. You can burn it for heat to replace coal, you can run it through an electrolyzer to generate electricity, and you can use it to refuel a vehicle as quickly as gasoline or diesel. But it's challenging to get hydrogen to where it's needed.

As the universe's lightest gas, [hydrogen](#) is tricky to contain. It leaks through tiny cracks, and it can diffuse into certain metals, breaking them down. To transport the stuff usually requires compression or liquefaction, both of which require a lot of energy. But there's an alternative: attaching hydrogen atoms to a carrier molecule that's easier to move.

The idea isn't new: so-called liquid organic hydrogen carriers (LOHC) have been around for decades, and most rely on volatile organic compounds like toluene and methylcyclohexane. Those chemicals play nice with hydrogen, but little else given their toxicity and how much heat and pressure they need to release the gas.

A new startup, [Ayrton Energy](#), says it has an alternative: an LOHC that can be transported and processed at room temperature and pressure. And it's nontoxic.

"It actually looks like water," Natasha Kostenuk, co-founder and CEO of Ayrton Energy, told TechCrunch. "It's a safe, non-toxic liquid. I wouldn't drink it, but it wouldn't kill you."

Kostenuk and her co-founder, Brandy Kinhead, didn't set out to upend how hydrogen is transported. Initially, they had a vision of replacing diesel generators with ones that ran on clean hydrogen.

"We needed a hydrogen storage solution," she said. "First we thought, well, we'll just find one. We were just going to integrate pieces from the industry. But we

could not find a hydrogen storage solution that made any sense to us. So we came up with a solution.”

Kostenuk wouldn’t disclose which oil her company is using, but said it stores hydrogen similar to how canola oil is turned into margarine, which is made from vegetable oils. Unlike the animal fats that make up butter, vegetable oils are liquid at room temperature. To make margarine, producers expose vegetable oils to hydrogen gas in the presence of a catalyst (which helps facilitate the reaction). As the oils are hydrogenated, they solidify.

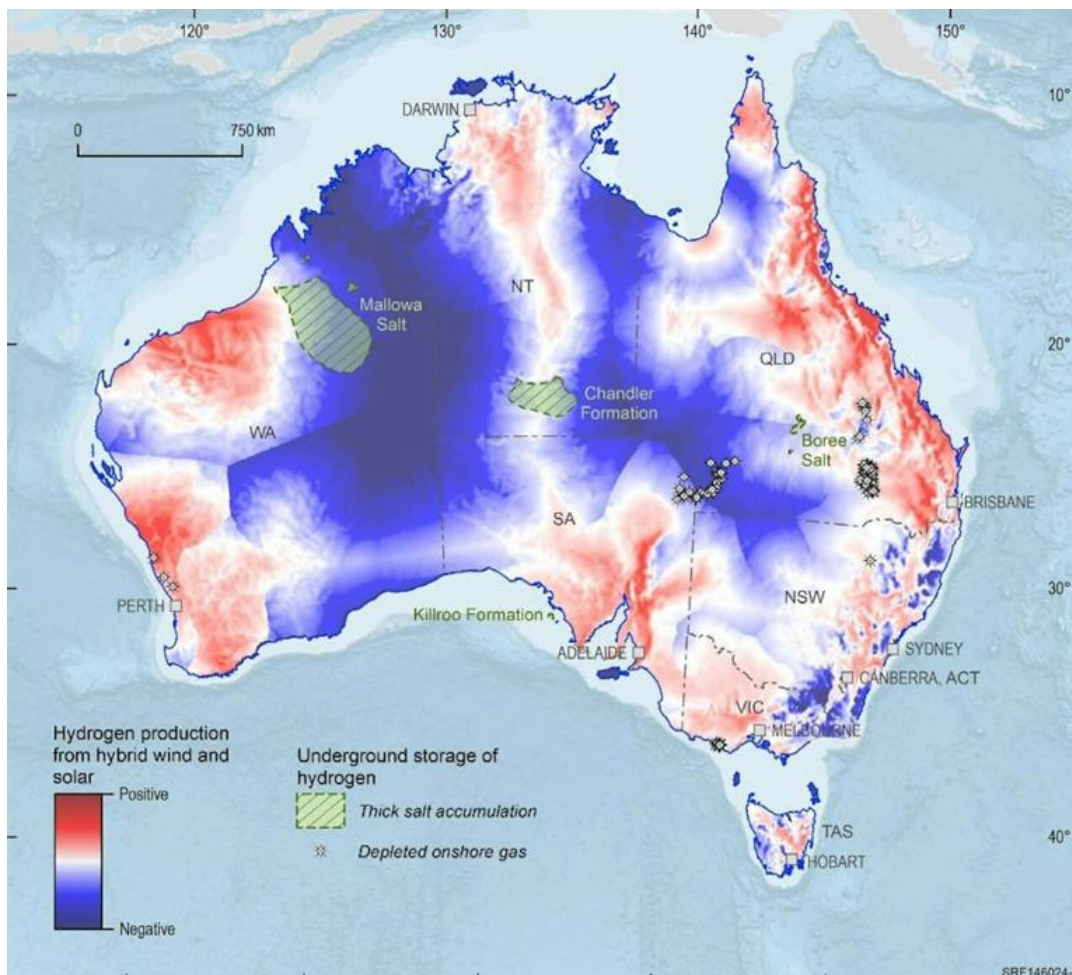
Ayrton takes a similar approach. “It’s hydrogenation,” Kostenuk said. “We’ve just found a novel way of doing the hydrogenation and dehydrogenation compared to traditional LOHC.” The equipment that adds and releases the hydrogen to and from the oil is similar to electrolyzers that are used today to produce hydrogen from electricity. As a result, the company can use commercially available equipment for a large part of its operations, and scaling will just require building more modules, not bigger parts.

Transporting Ayrton’s oil doesn’t require anything special, either. “People who are already using liquid fuels, for example, we can reuse a lot of that infrastructure. Pipelines, rail cars, trucks,” she said. “I’ve spoken to pipeline companies that have excess lines that aren’t being used they’re trying to find ways to reuse older infrastructure.”

Kostenuk envisions using tanker trucks to deliver hydrogenated LOHC to an industrial facility. Once empty, it’ll take dehydrogenated LOHC back to the processing plant so it can be reused.

Ayrton’s process requires less energy round trip than liquefied hydrogen, ammonia, or methanol, Kostenuk said, and a little bit more than compressed hydrogen. The advantage, though, is that the LOHC can carry twice as much hydrogen per liter than compressed hydrogen and has lower up-front costs because it can reuse existing trucks, pipes, and pumps.

The company recently raised a \$6.8 million seed round led by Clean Energy Ventures and BDC Capital, with participation from Antares Ventures, EPS Ventures, SOSV, the51, and UCeed Investment Funds. With the funding, Ayrton plans to scale its technology to the point where it’s making two to three tons of hydrogen per day by 2027.



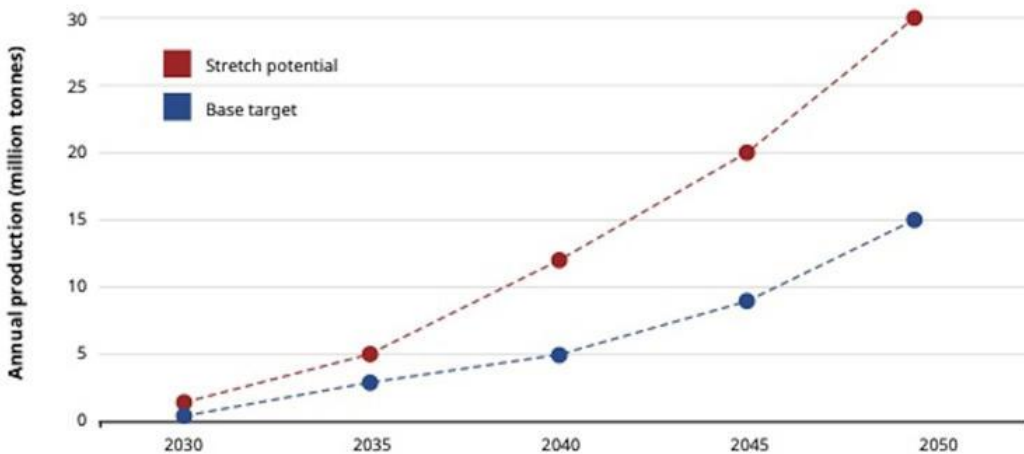
A map included in the new strategy, showing places in Australia best suited to green hydrogen production. Credit: Geosciences Australia

Producing hydrogen remains vital to Australia's prosperity through the net-zero transition, according to a major strategy that lays a national pathway to becoming a global leader in low-emissions technology.

The new [National Hydrogen Strategy](#), released today by Federal Climate Change and Energy Minister Chris Bowen, aims to ensure Australia produces green hydrogen at a competitive cost. It's also designed to guide investment and signal Australia's bold ambitions for the world.

The document updates the first national hydrogen strategy, released in 2019 by then Chief Scientist Alan Finkel. I helped devise that strategy in my previous job

as a federal public servant. I was also part of a panel convened to advise the government on the strategy released today (although it was up to the government whether the advice was accepted).



A graph showing the strategy's targets for green hydrogen production out to 2050. Credit: National Hydrogen Strategy 2024

In my view, this new version of the hydrogen strategy improves on the old one, and responds to changing circumstances. But much remains unclear, including how the strategy interacts with existing policies, and whether taxpayer money will be used to fund hydrogen projects doomed to fail.

What is hydrogen?

Hydrogen is the smallest, lightest and most abundant element in the universe. It's usually found as a gas, or bonded to other elements.

The element is used to make products such as fertilizers, explosives and plastics. In the future, it may also be a zero-emissions replacement for fossil fuels in industries such as steel and chemical manufacturing.

Hydrogen can also store electricity—so it may one day be used to shore up domestic electricity supplies, or be transported in liquid form to countries less able to produce renewable energy.

Australia currently makes very low volumes of hydrogen using natural gas, which produces greenhouse gas emissions.

We are well-placed to produce "green" or zero-emissions hydrogen, through a process powered by renewable energy which releases hydrogen from water.

But creating a large green hydrogen industry won't be easy. Today's strategy—led by the federal government in collaboration with the states and territories—seeks to find a path through.

Aiming for a new target

The cost of producing green hydrogen is currently higher than what most buyers are willing to pay. The new strategy seeks to overcome this by scaling up production.

It sets production targets: 500,000 metric tons of green hydrogen a year by 2030, and 15 million metric tons a year by 2050.

The strategy also sets more ambitious "stretch targets" of 1.5 million metric tons by 2030 and 30 million metric tons by 2050. Achieving this will require finding new customers for the hydrogen we produce.

The new strategy dispenses with [a previous target](#) set by the Coalition government in 2020, to produce hydrogen for less than \$2 a kilogram.

As I've written before, that target did not account for the high costs of moving and storing hydrogen, and switching to new technology that can use it.

Production and price targets can both be effective, if they are realistic. But whether those targets are achieved comes down to governments' policy choices.

Time to prioritize

The strategy identifies three industries—iron, alumina and ammonia—where hydrogen could best be used to build new export industries. It also identifies three areas where hydrogen shows promise in cutting emissions: aviation and shipping, electricity storage and freight trucks.

These priorities show governments are coming to grips with hydrogen's limitations, in a technical and economic sense. For example, in passenger vehicles, hydrogen has [lost out to electric cars](#). And using hydrogen to replace natural gas in homes is far more expensive than simply going electric.

What's not clear is how the new priorities will guide government decisions. For example, will priority sectors get first dibs on funding or infrastructure assistance? And will governments stop funding hydrogen projects once it becomes clear they are not competitive?

Without guidance on these and other questions, investors may find it hard to decide where to put their money.

A nuanced view of exports

The 2019 strategy was squarely focused on exporting liquid hydrogen to prospective buyers in Japan and South Korea.

Now, the [likely big buyers are in Europe](#). In fact, Bowen today announced Australia and Germany are working towards a A\$660 million deal, funded equally by the two nations, to guarantee European buyers for Australia's green hydrogen.

Importantly, however, hydrogen is very difficult and expensive to transport. As my colleagues and I have written, Australia should instead focus on using hydrogen to produce green iron from iron ore.

The new strategy treads a fine line on the question of exports. It identifies priority sectors and aims to develop those new industries in Australia. But it doesn't rule out liquid hydrogen exports.

Getting communities on board

The 2019 strategy emphasized the need for community acceptance of hydrogen technologies—particularly in relation to safety. Overseas experience showed communities feared the risk of explosions and fires from this volatile gas.

Safety remains a meaningful concern in the strategy. But the new version also emphasizes community benefits, such as jobs and more diverse regional economies.

In particular, the document seeks to ensure proper consultation with First Nations people and to manage impacts on water.

Cart before the horse?

This strategy interacts with two measures the Albanese government announced in recent months: the \$2 billion [Hydrogen Headstart](#) grants program, and a [tax credit](#) for hydrogen producers.

The credits are only available for ten years, and there's nothing in their design to ensure they help the priority sectors. It would be a shame if they were taken up by producers pursuing hydrogen technology that will never work.

More broadly, it's not clear whether these measures were calibrated to achieve the strategy's production and export targets. It's also unclear whether governments would pull the plug on support for technologies that turn out to be less promising than first thought.

Where to next

The hydrogen strategy will be reviewed again in 2029. Its success can be measured by watching for the following developments:

- large hydrogen projects attracting finance and starting construction

- hydrogen suppliers signing multi-year contracts with users, possibly including exports
- the building of hydrogen storage facilities, and wind and solar farms to supply electricity for hydrogen production
- commitments and timelines from domestic heavy industry to replace fossil fuels with hydrogen.

If these signs don't emerge in the next decade, Australia may need to adjust its hydrogen strategy, and global ambitions, accordingly.

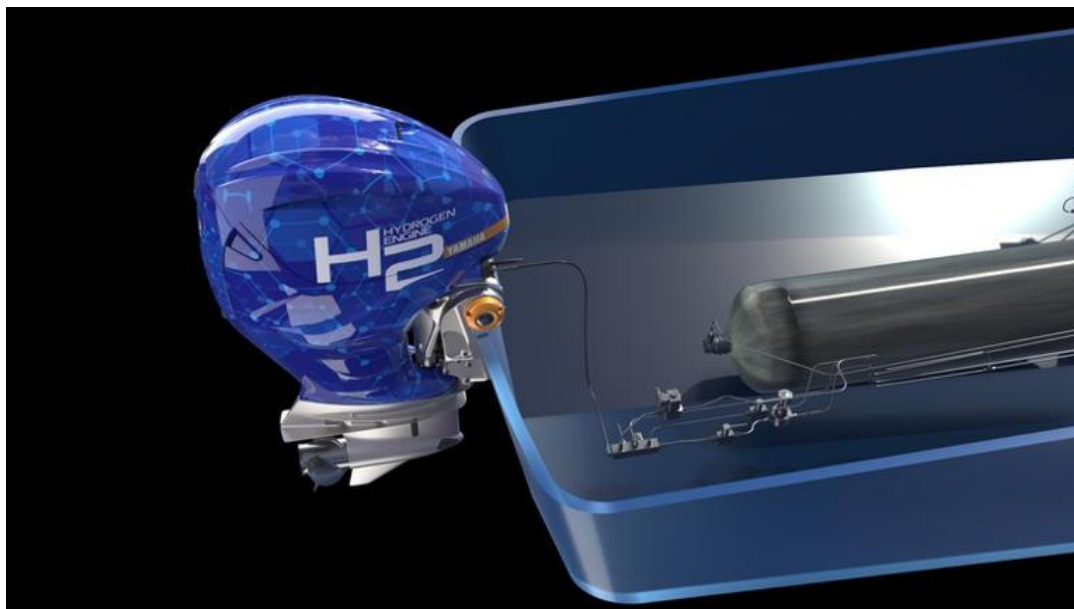


Illustration of Yamaha's H2 Hydrogen outboard© YAMAHA

Ben Speciale, President of Yamaha's U.S. Marine Business Unit, confirmed Yamaha's commitment to attaining carbon neutrality of its operations by 2035 and its products by 2050. Speciale went on to say, "We believe hydrogen is a viable method of achieving these goals," at the unveiling of the Yamaha Motor Corporation, U.S.A. [hydrogen-powered outboard engine](#) in Miami, Florida, on February 14, 2024. With that announcement, Yamaha joins other [companies working on hydrogen-powered vehicles](#).

Yamaha's hydrogen-powered outboard engine, dubbed the H2, is part of a prototype project announced in December of 2023 that includes fuel system engineering by Roush CleanTech, part of the same organization as Roush Racing, and a modified 26-foot boat built by Regulator Marine. Joan Maxwell, President of Regulator Marine, said the project is important for testing hydrogen as an outboard engine fuel source, explaining, "If we don't look for a new source, we won't find a new source."

The H2's hydrogen fuel system requires large hydrogen storage tanks, one of the [cons associated with hydrogen-powered vehicles](#), which the boat's hull must accommodate. Maxwell admits the Hydrogen tanks are larger than she envisioned at first, occupying valuable space in the prototype hull that typically houses fish boxes and marine head facilities.

Roush's Matt Van Benschoten, Vice President of Advance Engineering, said, "Yamaha is trying to determine if hydrogen can successfully be used in this market." In support of the prototype, scheduled to begin testing during the summer of 2024, Roush is providing the design and integration of the hydrogen fuel system, as well as safety analysis.

Yamaha's H2 Outboard Engine



Detail view of the Yamaha H2 outboard© YAMAHA

Yamaha's H2 hydrogen-powered outboard engine uses hydrogen instead of gasoline in its combustion chambers. While this technology is a departure from the systems found in hydrogen fuel-cell vehicles (HFCV) driving the streets of California, it's more like the internal combustion engine we're accustomed to rather than battery electric vehicle (BEV) power.

The H2 hydrogen outboard is a derivative of Yamaha's XTO Offshore outboard engines. The XTO Offshore outboard's 5.6-liter V8 gasoline-engine produces up to 450 horsepower, making it one of [the most powerful Yamaha boat motors ever made](#). Hydrogen's low volumetric energy density means the H2 will produce slightly less horsepower than the XTO Offshore using the same 5.6-liter displacement.

Examples from Cummins, a reputable diesel engine innovator, demonstrate the loss of power by comparing horsepower ratings of two 6.7-liter internal combustion engines, one gasoline powered and the other using hydrogen. The gasoline-powered Cummins 6.7-liter is rated at up to 325 horsepower compared to the hydrogen version with its 290-horsepower rating.

If the 10-percent power loss of the Cummins example is seen in the H2 outboard, it could still produce in excess of 400 horsepower. That output would put it in the ranks as one of [the most powerful outboard boat engines](#) available and with zero carbon emissions.

China has debuted its hydrogen-powered high-speed train with zero-emission technology that reaches a top speed of 200 kilometers (124 miles) per hour.

China unveiled CINOVA H2, the country's first train of the kind at InnoTrans 2024, a transportation tech trade fair in Berlin, Germany. Developed by CRRC Qingdao Sifang Co Ltd, a subsidiary of China Railway Rolling Stock Corp (CRRC), it can reach its top speed using hydrogen fuel cells to generate electricity.

Producing only water as a byproduct, this technology results in zero carbon emissions throughout its operation. Liang Caiguo, a senior designer at CRRC

Qingdao Sifang, said that the train's high-power fuel cells can produce up to 960 kilowatts of electricity.

"Its design emphasizes a green and sustainable approach," said Caiguo. "The water emitted from the hydrogen fuel cell reaction is purified and recycled to meet passenger water needs. Additionally, the waste heat from cooling the hydrogen fuel cell is repurposed for heating the air conditioning system during winter."

The four-car train has a cruising speed of 160 kilometers (99 miles) per hour and, with a full refueling time of 15 minutes, the CINOVA H2 can cover a full range of 1,200 kilometers. The train's design allows it to carry over 1,000 passengers. Its lightweight structure and integrated saloon make for high passenger capacity, making it suitable for intercity travel.

Wang Xueliang, deputy director of the CRRC Qingdao Sifang technology center, told *China Daily* that the train "can be used in nonelectrified railway areas, replacing traditional diesel-powered alternatives."

"It effectively reduces carbon dioxide and other air pollutant emissions, showcasing significant environmental benefits, and will strongly promote a new green upgrade for passenger transport equipment on nonelectrified railways," added Xueliang.

CINOVA H2 uses CRRC's SmartCare system to monitor and maintain the vehicle. It combines data from both the vehicle and its environment to provide smart maintenance services throughout the vehicle's life.

CRRC says it helps make operations safer and cuts down on maintenance expenses, and that the hydrogen system has been thoroughly tested for safety in all situations with AI features including smart detection and automatic isolation.



CRRC Launches the CINOVA H2 New Energy Intelligent Intercity Train at InnoTrans 2024 in Berlin, Germany on September 24, 2024. © Messe Berlin GmbH© Messe Berlin GmbH

The speeds of China's new CINOVA H2 hydrogen-powered train are notably higher compared to other hydrogen-powered trains around the world. For example, Alstom's Coradia iLint, which was the first hydrogen train to enter commercial service in Europe, has a top speed of 140 kmph (87 mph) but typically operates at 80-120 kmph (50-75 mph) in day-to-day services across Germany and other countries including Austria and the Netherlands.

When it comes to traditional high speed trains, however, those powered by hydrogen fuel cells lag significantly behind. The Shanghai Maglev (magnetic levitation) is officially the world's fastest train, reaching a top speed of 460 kph (286 mph) during commercial operations. It connects Shanghai Pudong International Airport to the city, covering 30 kilometers in 7.5 minutes.

Following China's CR400 'Fuxing', which hits speeds of 350 kph (217 mph), Germany's InterCity Express (ICE) has a normal operating speed of 300 kph (186 mph), but the ICE3 - the fastest model - is authorized to hit 330 kph (205 mph) when running late.

Meanwhile, [U.S. high-speed trains](#) achieved two milestones in 2024: construction began in April on Brightline West, a high-speed rail project connecting the Los Angeles metropolitan area to Las Vegas, allowing trains to reach speeds up to

200 mph. Additionally, in January, Amtrak began testing new high-speed *Acela* trains that are set to reach over 155 mph when they launch.



Hydrogen fuel cell engine© Scharfsinn/Shutterstock

A little more than a decade ago, hydrogen fuel cell vehicles appeared poised to challenge hybrid and battery-powered electric vehicles as a green alternative to gasoline-powered cars and trucks, but [the hydrogen revolution never happened](#). Although [EVs come with their own complex issues](#), the lack of a hydrogen refueling infrastructure and the flammability of hydrogen gas doomed that technology as a viable consumer alternative. Only about 15,000 hydrogen-powered vehicles are on the road in the United States, and all of them are in California. That number is dwarfed by the more than 2 million electric vehicles in the U.S.

Ironically, hydrogen fuel cell vehicles are essentially EVs in that they are powered by electric motors that get their juice from an electrochemical reaction between hydrogen and a catalyst such as platinum. The hydrogen gas is stored in a tank and then channeled to a stack of fuel cells, where it is converted to electricity, which is stored in a battery. The only emission from hydrogen vehicles is water vapor.

The Toyota Mirai Comes With A Small Li-Ion Battery



Toyota Mirai engine© Stefano Montesi - Corbis/Getty Images

Most current hydrogen fuel cells use a polymer electrolyte membrane (PEM) construction. PEM fuel cells are also called Proton Exchange Membrane Fuel Cells. These cells are made of thin (less than 20 microns) layers of a material resembling plastic wrap.

The catalyst is spread on both sides of the fuel cell, the anode and cathode. On the cell's anode side, the hydrogen molecules are split into protons and electrons. The protons mix with an ion-conducting polymer (ionomer) and pass through the membrane to the cathode, where a reaction known as oxygen reduction takes place, producing the electrical energy necessary to power the vehicle's motor.

Fuel cells also have additional layers of carbon paper known as Gas Diffusion Layers (GDLs), which work to channel the components of water vapor away from the reactive layers of the fuel cell and into the vehicle's exhaust system.

Because hydrogen fuel cell systems don't produce electricity until they reach a temperature of 50°F, hydrogen-powered vehicles like the Toyota Mirai come equipped with a lithium-ion battery to help get the electrochemical reaction started.

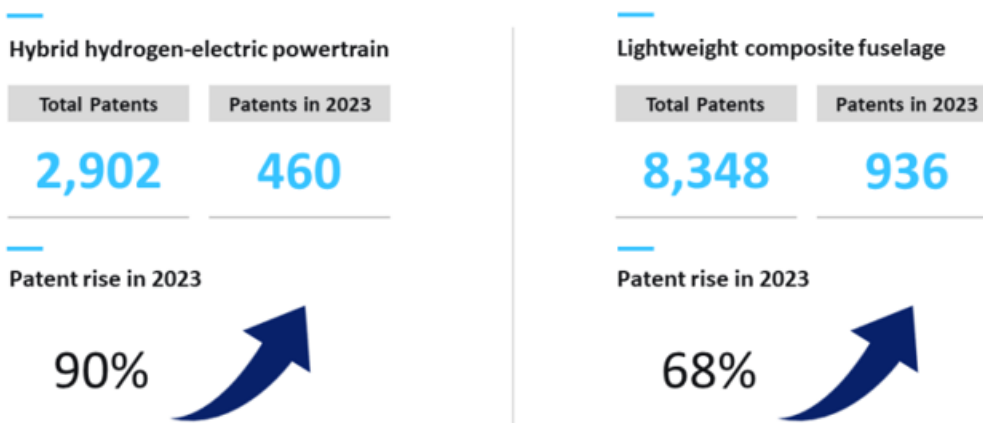
Hydrogen-electrification among key aviation disruptors – GlobalData

The aerospace sector is undergoing significant changes, fueled by advancements in electrification, alternative fuelling and powertrain technology, and composite materials to create a "green airplane".

As manufacturers struggle to meet global emissions targets, the rise in patent filings for hybrid hydrogen-electric powertrains and lightweight composite fuselages highlights the growing desire for hydrogen engines and eco-mobility.

GlobalData's latest FutureTech report *Tech Frontiers: The Aerospace Edition* revealed a 90% rise in patent filings for hybrid hydrogen-electric powertrains and a 68% increase for lightweight composite fuselage in 2023. These technologies, along with innovations in thermal management systems, have the potential to enhance fuel efficiency, reduce emissions, and reshape both commercial and defense aviation, according to company analysts.

Aerospace select innovations patenting landscape



Vaibhav Gundre, [Disruptive Tech](#) manager at GlobalData said: "Electrification and composite materials are no longer future concepts—they are now central to the transformation of the aerospace sector. The patent filings highlight that market leaders are rapidly adopting these technologies, driven by regulatory pressures and the need to reduce fuel costs.

"The challenge lies in scaling these innovations while navigating complex regulations."

GlobalData's report analyses the key innovations, including hybrid hydrogen-electric powertrains, lightweight composite fuselages, and advanced thermal management systems, identified through its proprietary "Technology Foresights" tool.

Rahul Kumar Singh, [Disruptive Tech](#) analyst at GlobalData, added: "Hybrid hydrogen-electric powertrains offer a strategic solution for [reducing carbon emissions in short-to-medium haul flights](#).

"At the same time, lightweight composite materials significantly improve operational efficiency in long-haul flights by reducing aircraft weight. However, challenges remain around the production costs, material durability, and retooling existing manufacturing lines."

Market movers

Avio Aero, a GE Aerospace company, launched a hybrid-electric technology demonstration program in Europe in June 2024, focused on integrating advanced propulsion systems to reduce emissions and significantly improve operational efficiency in aerospace.

[Airbus subsidiary UpNext](#) introduced superconducting technologies for electric propulsion systems in future hydrogen-powered aircraft, advancing efforts to accelerate the transition towards more sustainable aviation, in May 2024.

[French hydrogen fuel cell developer H3 Dynamics](#) has been selected as the fuel cell supplier for an EU-funded research project HyPoTraDe's modular hydrogen powertrain system. The company will supply its newest class of aviation-grade fuel cell systems for the project, which is powered by a consortium led by Textron

subsidiary Pipistrel in partnership with Honeywell International, Netherlands Aerospace Centre, and Fraunhofer Society.

HyPoTraDe is partially funded by the EU's Clean Aviation joint undertaking and is designing and testing 500kW modular fuel cell-battery hybrid-electric distributed electric propulsion (DEP) powertrain architecture for use on small aircraft.

Meanwhile, engineers at the German Aerospace Center (DLR), in collaboration with Airbus, Aerotec, and Aernnova, developed a fuselage demonstrator made from carbon-fiber-reinforced thermoplastic in October 2023 to reduce aluminum use, lower aircraft weight, and enhance fuel efficiency.

Germany remains a leader in aviation innovation, as Airport Technology discovered at ILA Berlin earlier in 2024. You can read our [summary of the event, and its focus on future fuels, here](#).

Singh concluded: "While these technologies offer significant promise, scaling production remains a challenge due to high costs and specialized manufacturing needs. Regulatory frameworks must evolve to keep pace with innovation. Infrastructure, like charging solutions for hybrid-electric systems and production facilities for advanced composites, must also grow to support widespread adoption."

"Hydrogen-electrification among key aviation disruptors – GlobalData" was originally created and published by [Airport Technology](#), a GlobalData owned brand.

Green Giants: Riding the Hydrogen Wave to New Heights



Hydrogen renewable energy production - hydrogen gas pipeline for clean electricity solar and windturbine facility
Concept image - Photo

The U.S. clean hydrogen sector is poised for a transformative expansion driven by favorable government policies, escalating demand for decarbonization solutions, and a growing recognition of the technology's potential to revolutionize **energy production** and consumption. While regulatory hurdles and certification standards still present challenges for companies operating in this space, a select group of innovators is well-positioned to capitalize on this emerging market.

Plug Power: A Fuel Cell Pioneer

Plug Power (NASDAQ: PLUG) is a frontrunner in fuel cell technology, and it is actively constructing green hydrogen production facilities and expanding its hydrogen refueling network. This strategic approach has propelled them to a leadership position in the clean hydrogen market. Their recent collaborations with major corporations, such as Walmart and Amazon, underscore the growing commercial interest in clean hydrogen solutions. These partnerships further validate the potential of this market and showcase the tangible impact of Plug Power's technology on real-world operations.

Plug Power's commitment to building a green hydrogen highway across North America and Europe underscores their ambitious vision for the future of energy. This initiative involves developing a network of fueling stations and hydrogen production facilities designed to meet the growing demand for clean energy solutions across various industries.

Their strategy is further supported by their Gigafactory, a state-of-the-art facility for producing electrolyzers and fuel cells, which ensures a consistent supply of critical components for their hydrogen solutions.

Plug Power's earnings report for the second quarter of 2024 reflects its ongoing growth strategy. Revenue reached \$143.4 million, driven by increasing electrolyzer deployments and improved pricing for fuel and other product lines. While the company reported a net loss of \$262.3 million, this was attributed to strategic investments, market dynamics, and non-cash charges, including depreciation and amortization, stock-based compensation, and impairment charges.

Despite these headwinds, Plug Power is poised for continued growth. It plans to deploy an additional 100 MW of electrolyzers by the end of the year. This expansion and its commitment to building a robust green hydrogen infrastructure position Plug Power to remain a key player in this rapidly evolving market.

Bloom Energy: A Solid Oxide Fuel Cell Powerhouse

Bloom Energy (NYSE: BE) is known for its solid oxide fuel cell technology, and it is leveraging its expertise to produce clean hydrogen through electrolysis. Bloom's innovative approach to hydrogen production focuses on reducing costs and improving efficiency, making it a strong contender in the clean hydrogen market. Bloom Energy's solid oxide fuel cells offer a unique advantage by utilizing multiple fuel sources, including natural gas, biogas, and renewable fuels. This flexibility positions them well to address the diverse needs of customers across various industries.

Bloom Energy's financial performance reflects the company's commitment to cost reduction and efficiency. Revenue for the second quarter of 2024 reached \$335.8 million, marking an 11.5% year-over-year increase. Their non-GAAP gross margin also improved, reaching 21.8%, an increase of 1.4 percentage points year-over-year.

This positive performance underscores their success in leveraging technology to drive efficiency and **profitability**. Bloom Energy's non-GAAP operating loss for the quarter was \$3.2 million, a significant improvement compared to the previous year. This indicates their ongoing efforts to optimize operations and reduce costs.

Bloom Energy's commitment to innovation and collaboration is further highlighted by its partnership with CoreWeave, a leader in **artificial intelligence** (AI), to power a high-performance data center in Volo, Illinois. This agreement demonstrates their ability to provide clean energy solutions for demanding applications. Additionally, their agreement with Silicon Valley Power to provide power using Bloom fuel cells to power 20 megawatts of AWS data centers in Santa Clara, CA, showcases their commitment to expanding their reach in the data center market.

NextEra Energy: A Renewable Energy Giant Embraces Hydrogen

NextEra Energy (NYSE: NEE) is a renewable energy giant making significant investments in green hydrogen production and aiming to become a major player in this emerging sector. Their vast experience developing and operating renewable energy projects gives them a competitive advantage in scaling up clean hydrogen production. NextEra Energy is actively pursuing opportunities to leverage its expertise and infrastructure to create a more sustainable energy future. They also benefit from the regulatory tailwinds that favor adopting clean hydrogen solutions.

NextEra Energy's financial performance reflects its commitment to growth and innovation. Their second-quarter 2024 net income attributable to NextEra Energy on a GAAP basis reached \$1.622 billion, or \$0.79 per share, while adjusted earnings for the quarter were \$1.968 billion, or \$0.96 per share.

This strong performance highlights their ability to generate substantial revenue from their **renewable energy** assets and to manage costs effectively. The regulatory capital employed also saw significant growth, increasing by approximately 10.7% year-over-year, reflecting their ongoing investments in their infrastructure and operations.

NextEra Energy's subsidiary, NextEra Energy Resources, is actively pursuing opportunities in the clean hydrogen sector. Their second-quarter 2024 GAAP net income attributable to NextEra Energy reached \$552 million, or \$0.27 per share, compared to \$1.462 billion, or \$0.72 per share, in the prior-year comparable quarter. Adjusted earnings for the quarter were \$865 million, or \$0.42 per share, compared to \$781 million, or \$0.39 per share, in the prior-year comparable quarter. NextEra Energy Resources added over 3,000 megawatts (MW) to its backlog, totaling roughly 22.6 gigawatts. This expansion reinforces their commitment to becoming a leader in the clean hydrogen sector.

Investing in Clean Hydrogen

The clean hydrogen sector presents a compelling investment opportunity but has challenges. Investors must carefully **evaluate the risks** and opportunities associated with this sector before making any investment decisions.

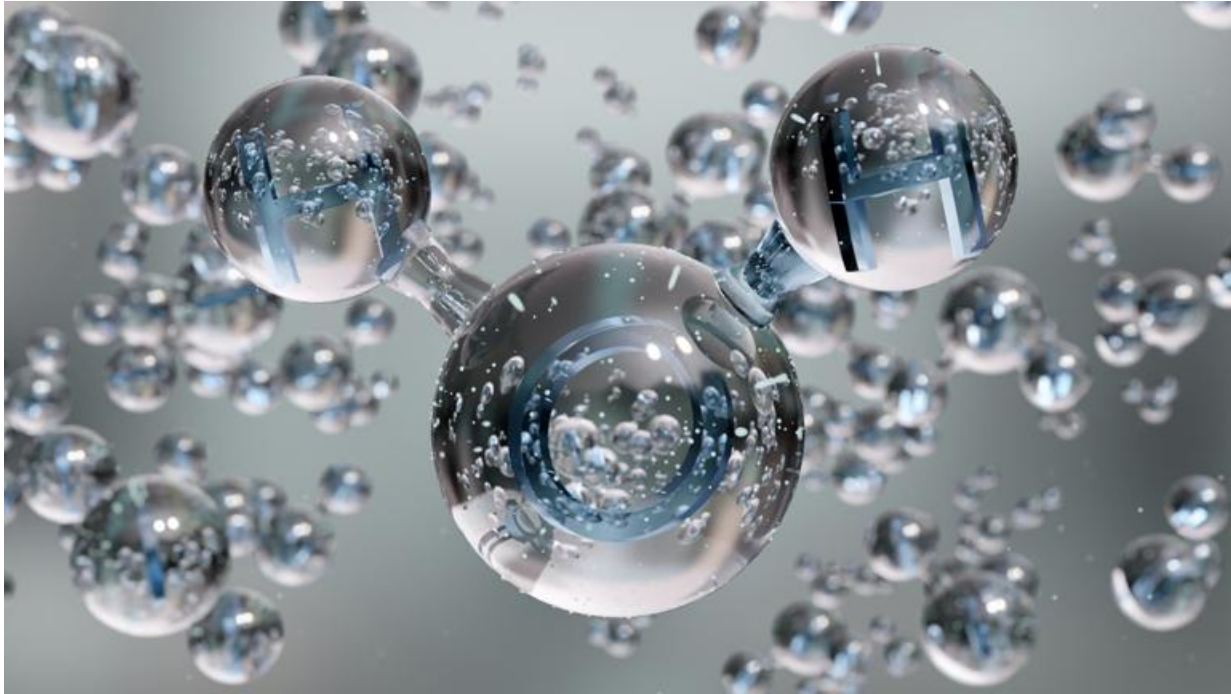
One of the critical factors to consider is the regulatory landscape. The development of clear and consistent regulations is crucial for the growth of the clean hydrogen sector. However, the current regulatory environment is still evolving, and the pace of change can be unpredictable. This uncertainty can create challenges for investors seeking to assess the long-term viability of companies operating in this sector.

Another key factor is the development of certification standards. Consistent and reliable certification standards are essential for ensuring the safety and performance of hydrogen production and storage technologies. The lack of established standards can create uncertainty for investors trying to assess the quality and reliability of hydrogen products.

The overall growth potential of the clean hydrogen sector is another factor to consider. The increasing demand for decarbonization solutions and the growing recognition of hydrogen's potential to revolutionize energy production and consumption are positive indicators for the future of this market. However, it is essential to recognize that the clean hydrogen sector is still in its early stages of development, and the pace of adoption may not be as rapid as some investors anticipate.

The clean hydrogen sector presents a compelling investment opportunity. Despite the regulatory challenges and uncertainties, the growing demand for clean energy solutions, coupled with technological advancements, suggests a bright future for this sector. As the regulatory landscape becomes clearer and certification standards improve, the U.S. clean hydrogen sector is set for substantial growth, presenting investors with opportunities in a rapidly evolving market. Investors willing to take a long-term view and carefully research the companies operating in this sector may be well-positioned to reap the rewards of this fledgling industry.

Quantum secret of hydrogen bonds in liquid water revealed for the first time



Quantum secret of hydrogen bonds in liquid water revealed for the first time

The hydrogen bonds that form water molecules are responsible for the many properties that make water a unique liquid. However, even today scientists don't fully understand the science behind these bonds.

This is because these H-bonds have a very short lifetime as they constantly form and break due to the motion of water molecules.

For instance, the typical lifetime of a hydrogen bond in liquid water is one millionth of a millionth of a second. This dynamic behavior makes it difficult to capture and study their interactions accurately.

However, [researchers](#) at the Swiss Federal Institute of Technology Lausanne (EPFL) claim to have developed a new method that can allow scientists to study

the electronic and nuclear quantum [effects of liquid water](#)'s hydrogen bonds in depth.

This new method called correlated vibrational spectroscopy (CVS), can finally reveal what factors make the hydrogen-bond networks in water such a strong and mysterious force.

Understanding H-bond through CVS

Not all water molecules are involved in hydrogen-bond network interactions. CVS first identifies and separates the interacting and no-interacting molecules. This is done by shooting [ultra-fast laser pulses](#) on water molecules.

These quick bursts of light create tiny movements in the water's atoms, which then emit visible light. The pattern of this light reveals how the molecules are arranged, and the color of the light shows how the atoms inside and between the molecules are moving.

"Current spectroscopy methods measure the scattering of laser light caused by the vibrations of all molecules in a system, so you have to guess or assume that what you are seeing is due to the molecular interaction you're interested in," Sylvie Roke, one of the study authors and a professor at EPFL, [said](#).

However, in the case of CVS, different types of [water molecules](#) exhibit different vibrational patterns. These distinct patterns reveal how a particular molecule moves along H-bonds — allowing researchers to directly measure things like how much charge is shared between the hydrogen and oxygen atoms that form the H-bonds and how strong the bonds are.

"This charge-sharing is a key feature of the three-dimensional 'H-bond' network that gives liquid water its unique properties, but quantum phenomena at the heart of such networks have thus far been understood only through theoretical simulations," the study authors note.

For the first time, scientists have an experimental method to investigate this phenomenon and various other aspects of the H-bond in liquid water.

The use of CVS goes beyond water

Correlated vibrational spectroscopy (CVS) enables scientists to study changes water molecules experience on a quantum scale. For instance, it is already known that when OH^- (hydroxide) ions are added to water, it becomes basic, and the addition of [protons](#) makes water acidic.

“With CVS, we can now quantify exactly how much extra charge hydroxide ions donate to H-bond networks (8%), and how much charge protons accept from it (4%) – precise measurements that could never have been done experimentally before,” Mischa Flór, first author of the study, and a doctoral student at EPFL, said.

However, CVS isn’t just limited to revealing the details of H-bond networks in water molecules. The study authors suggest that it can also be used to study other chemicals at the molecular scale.

Hopefully, in the future, CVS will help scientists unravel many mysteries associated with other liquids as well as [other chemical](#) and physical systems.

The [study](#) is published in the journal *Science*.

Scientists develop revolutionary material that could unlock next-level efficiency for existing engines: 'It opens the door for new possibilities'

Hydrogen fuel, which produces no heat-trapping air pollution at the point of use, could be the future of clean energy. But first, some of the [technology](#) around still has to be improved, and researchers at the University of Alberta believe they have made an important step in that direction, [AL Circle reported](#).

The breakthrough out of the University of Alberta is a new alloy material — dubbed [AlCrTiVNi5](#) — that consists of metals such as aluminum and nickel. The alloy has great potential for coating surfaces that have to endure extremely high temperatures, such as gas turbines, power stations, airplane engines, and hydrogen combustion engines.

Hydrogen combustion engines are [different from](#) fuel cells, which also run on hydrogen. They are being used to develop cars that run on clean energy. While fuel cells rely on a chemical process to convert hydrogen into electricity, hydrogen [combustion engines](#) burn hydrogen fuel, creating energy via combustion, just like a traditional gas-powered car (but without all the pollution).

Both hydrogen combustion engines and fuel cells are viable, clean energy alternatives to traditional gas-powered cars, and both still have drawbacks that scientists and researchers must find ways to overcome.

"As we move toward a 100% hydrogen combustion engine, we want to know which alloys can withstand the conditions. None of the existing ones did, but we learn valuable insights from these failures. This alloy outperforms anything else on the market right now. It opens the door for new possibilities and will hopefully advance the Canadian hydrogen economy," project supervisor Jing Liu [said](#).

Other hurdles for hydrogen-powered cars to clear include creating hydrogen fuel that does not produce large amounts of planet-overheating air pollution while being manufactured. Nearly all the hydrogen fuel being made at present [involves a process](#) that relies on [methane](#), a potent heat-trapping gas. While there are also

processes that produce hydrogen fuel cleanly, they are mostly considered prohibitively expensive.

Korea's hydrogen-powered tank of the future



Korea's hydrogen-powered tank of the future© Hyundai Rotem

The Rotem branch of the Hyundai group has presented the prototype of a future tank that is currently in preparation. The K3 runs on hydrogen to be fast and stealthy. It's also capable of operating in automated mode.

Silent, fast and maneuverable, the future K3 tank from Hyundai Rotem would be difficult to detect. Its stealth is partly linked to the use of an electric motor powered by a fuel cell. It therefore runs on hydrogen. A noiseless and smokeless engine that makes it more difficult to detect. A hybrid variant of the South Korean tank is also planned, with a thermal engine in reserve, to remain operational longer in the field. Among the other qualities touted by Hyundai Rotem, there is its great crossing capacity, its acceleration and an unmanned driving mode. It can also be guided by an accompanying drone.

(MH with Olivier Duquesne – Source: H2Mobile & Hyundai Rotem – Picture: © Hyundai Rotem)

Is Hydrogen the New Frontier? Alpine's HY6 Sports Car Shakes Up EV Market

The EV market faces a chasm

Thanks to the rapid rise of hydrogen vehicles

Now Renault Alpine has joined the fray

Alpine Glow HY6 / topelectricsuv

As global car registrations rise and concerns over exhaust pollution grow, the call to eliminate internal combustion engine vehicles intensifies. Automakers worldwide invest heavily in developing eco-friendly alternatives like hybrid, electric, and hydrogen-powered vehicles. Yet, the transition to environmentally friendly cars is not without challenges, as consumer preferences and technological advancements don't always align.

Read more: [Convertible Meets Pickup: Daihatsu's Basket Concept Still Stuns with Innovative Design](#)

Despite the push for greener alternatives, many consumers still favor internal combustion engines, and the infrastructure for electric vehicles (EVs) remains underdeveloped. Recent reports of battery fires in EVs have further deterred buyers, contributing to a growing divide in the market. Attention is shifting toward hydrogen vehicles, which offer another path to sustainable transportation.



Alpine Unveils Hydrogen Supercar Concept at Paris Motor Show

While hydrogen vehicles have existed for years, their development was often overshadowed by the rapid advancement of electric vehicles and technological hurdles. However, manufacturers are refocusing their efforts on hydrogen-powered cars. At the 2024 Paris Motor Show, Renault's performance brand, Alpine, unveiled the *Alpenglow HY6*, a concept hydrogen-powered supercar that demonstrates the potential of this technology.

The *Alpenglow HY6* features a cutting-edge hydrogen propulsion system powered by a 3.5L twin-turbo V6 engine that produces 730 horsepower and 578 lb-ft (78.51 kg.m) of torque. The fuel is stored in three high-pressure hydrogen tanks in gaseous form, while the engine is equipped with four overhead camshafts and four valves per cylinder. This combination results in a high-performance vehicle powered by clean hydrogen fuel.





A Modern Design Meets Racing Performance

The Alpenglöw HY6, the successor model to the HY4, was unveiled at the 2022 Paris Motor Show. It boasts a modern design and powerful performance that more than doubles the output of the existing HY4. It has a size of 5,199 mm(204.7 inches) in length, 2,100 mm(82.7 inches) in width, and 1,140 mm(44.9 inches) in height, and looks a little upgraded from the design of the H4 unveiled in 2022. The all-carbon body remains the same, but the details have been improved to increase aerodynamic efficiency.

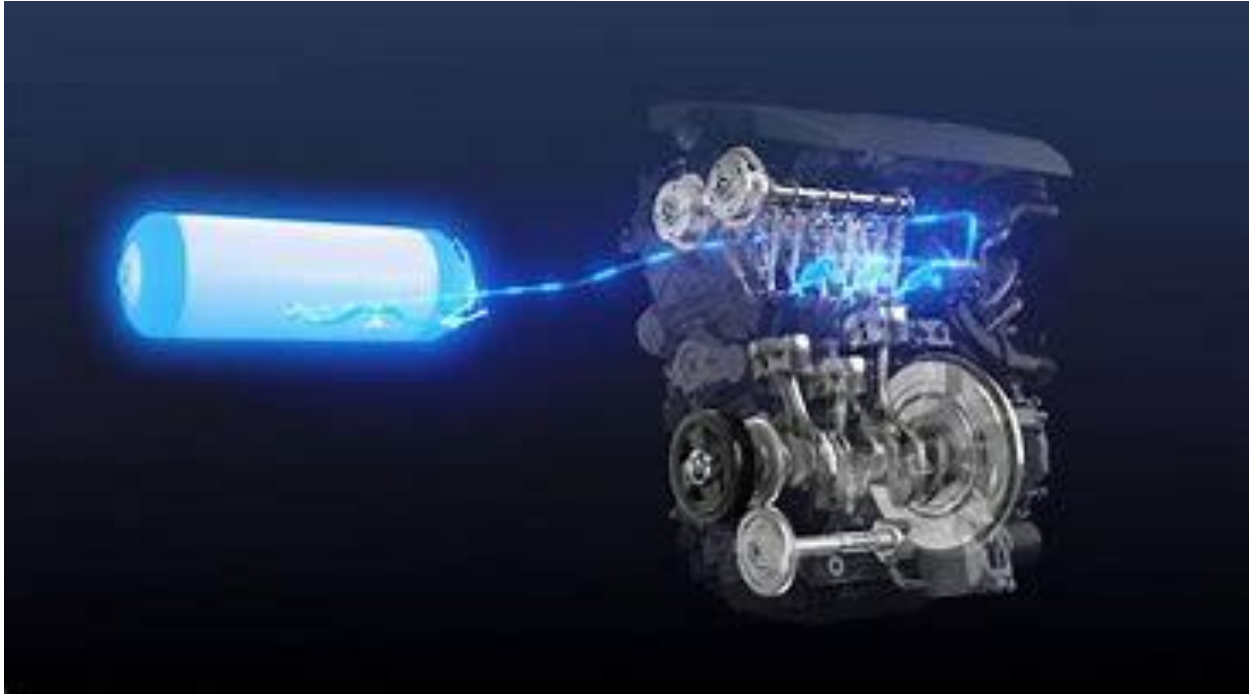
Additional intakes were created for the hood, and the engine cover was designed to be transparent to be seen from the outside. The rear deck was also redesigned with a traditional rear wing style. True to Alpine's dedication to motor racing, the Alpenglöw HY6 was created to reduce [emissions](#) without compromising performance or lap times.



Hydrogen Vehicles Gain Traction Globally

In the case of the Alpenglow HY6, which is currently still in development as a prototype, Alpine is urging the FIA to create a hydrogen-fueled racing car category for the 24 Hours of Le Mans in 2028. Furthermore, Alpine has hinted that this vehicle is not simply a concept car or racing car but aims to produce a model that can be driven on the road and produced in a continuous series.

The rise of hydrogen vehicles is not limited to Alpine. [Hyundai](#) is set to launch the second-generation Nexo in 2025, and both BMW and Toyota have entered into partnerships to accelerate hydrogen vehicle development. Hydrogen cars, which emit only water and offer significantly faster refueling times compared to electric vehicles, are gaining recognition as a promising solution in the race to decarbonize the automotive industry.



Ferrari's got a secret up its sleeve, and it's not what you'd expect from the iconic brand. While the auto world scrambles to go green, the Prancing Horse is quietly (well, not that quietly) working on an engine that would surprise even Enzo himself. It's an internal combustion engine, but with a twist – it runs on hydrogen!

[This patent, filed by Fabrizio Favaretto, a 24-year Ferrari veteran and current Innovation Manager of Vehicle Architectures and Powertrains](#), according to his LinkedIn, has been spotted in Europe, the US, China, and Japan.

Inverted six-cylinder Hydrogen Engine

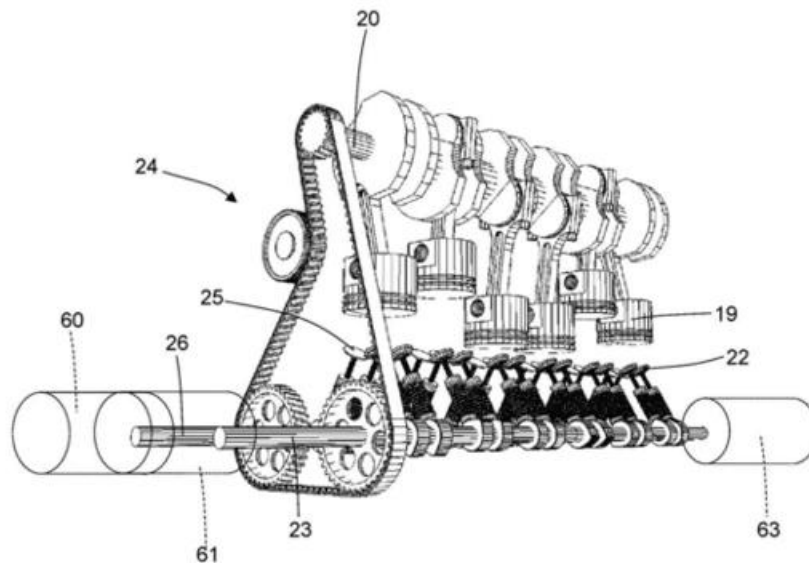


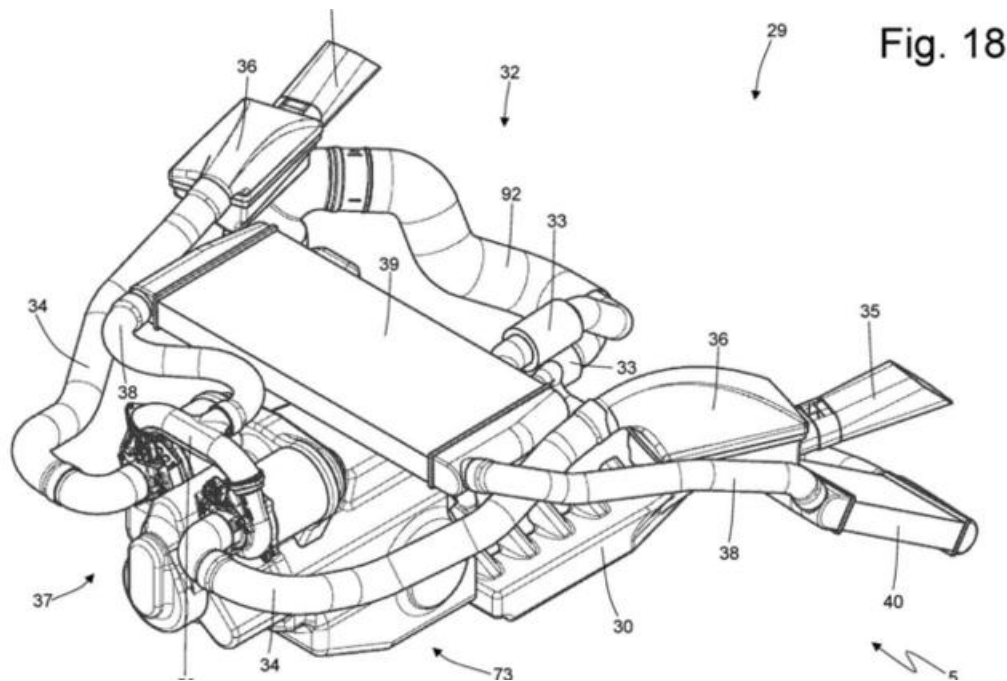
Fig. 27

Part of Ferrari's inverted supercharged V6 engine.© Provided by TORK US

The patent shows a straight-six engine layout, which Ferrari last used back in the 1950s. This design allows for better performance and easier placement of the hydrogen fuel tanks compared to a traditional gasoline engine (or even electric motors found in some cars today).

But here's the twist: Ferrari's planning to flip this hydrogen engine on its head! The crankshaft would be on top, with the cylinder heads down below. This lets them position the gearbox higher up, creating space for a more effective rear diffuser, according to Motor 1.

A drive with forced induction



Part of Ferrari's inverted supercharged V6 engine.© Provided by TORK US

Ferrari's got a trick up its sleeve to boost power: a supercharger. This system crams more air into the engine by squeezing it under pressure. That extra air lets the engine burn more fuel, making it more powerful.

There's more than one way to skin a cat, though, and Ferrari has a few ideas for how to make this supercharger work. One option involves two spinning air compressors mounted on either side of an electric motor, like a sandwich. Another option uses two compressors in a different layout, still powered by an electric motor.**

Finally, they consider two other approaches: an MGU-H system, similar to what they use in Formula 1 cars, that captures energy from exhaust fumes to run the compressors. The last option is a more traditional mechanical supercharger, directly powered by the engine's crankshaft.

Conclusion

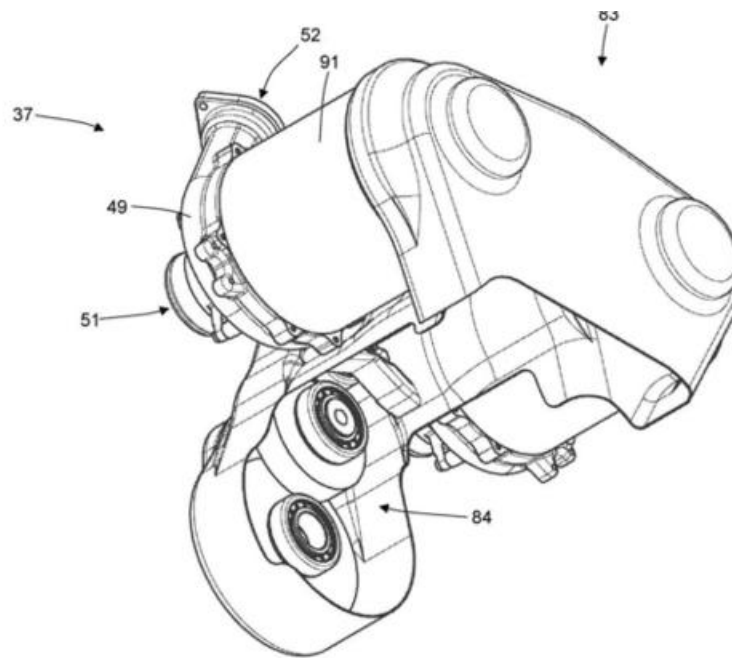
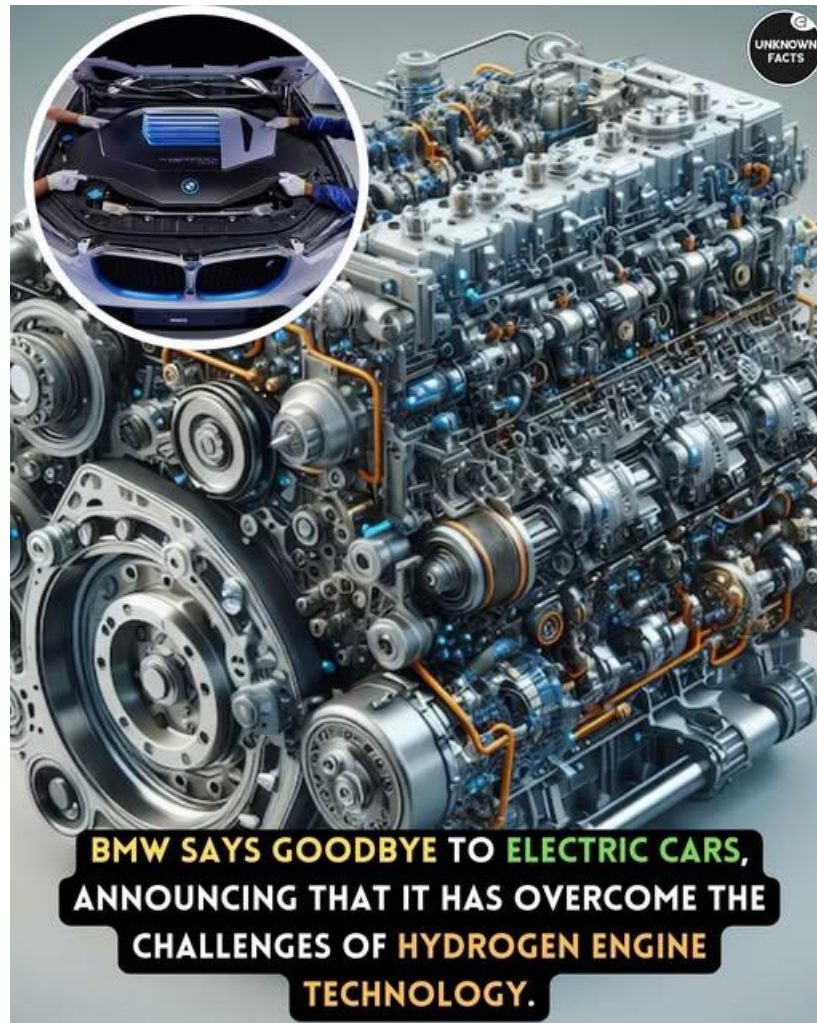


Fig. 24

Part of Ferrari's inverted supercharged V6 engine.© Provided by TORK US

This patent is still under wraps, so we'll have to wait and see how it develops. In the meantime, Ferrari already offers a hybrid V6 in their 296 GTB. It uses gasoline and electric power to crank out a whopping 830 horsepower! This proposed hydrogen-powered supercharged engine sounds like cutting-edge tech with the potential to seriously boost performance and efficiency. But like any new idea, there are hurdles to overcome before we see it on the road.



BMW has announced a move away from electric vehicles, stating that it has successfully addressed the challenges of hydrogen engine technology. The company revealed significant progress in hydrogen fuel cell development, which it sees as a more sustainable alternative to conventional electric cars. Unlike electric vehicles that depend on large batteries, hydrogen engines use lightweight fuel cells, offering faster refuelling and greater range. BMW also emphasized the environmental benefits, highlighting that hydrogen-powered vehicles emit only water vapor, making them a promising solution for the future of eco-friendly transportation.

Hydrogen bonding discovery could transform the use of glowing properties in organic materials

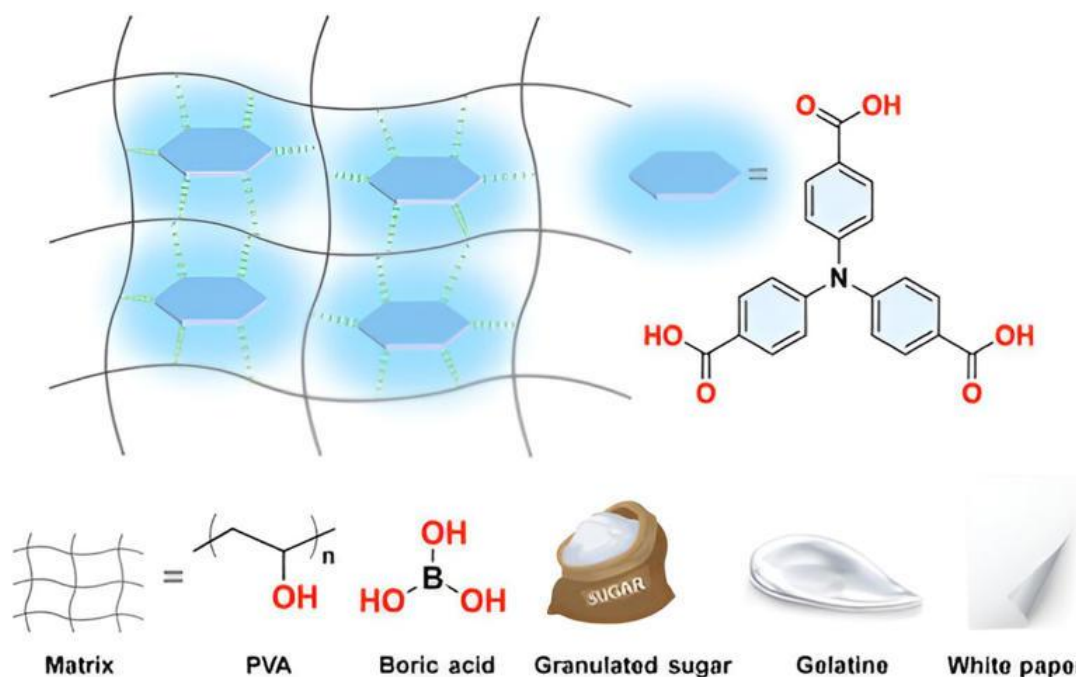


Illustration of supramolecular networks that show hydrogen-bonding-restricted molecular motions in various matrices. Credit: CCS Chemistry (2024). DOI: 10.31635/ccschem.024.202404623

New research from the University of St Andrews has uncovered how hydrogen bonds can enhance the phosphorescence efficiency and versatility of organic luminescent materials, potentially transforming fields such as imaging, anti-counterfeiting, and electronics.

The research, led by Dr. Sen Wu, Dr. Tao Wang and Professor Eli Zysman-Colman from the School of Chemistry at St Andrews, and [published](#) in *CCS Chemistry*, reveals a major advancement in understanding how hydrogen bonding can improve the performance and adaptability of organic room-temperature phosphorescence (RTP) materials.

By harnessing hydrogen bonds, these light-emitting materials, which glow after being exposed to light, could open new possibilities in areas such as imaging, data storage, and anti-counterfeiting technologies.

RTP occurs when materials emit light after being excited, creating a long-lasting luminescent effect. Although many RTP materials have been developed, achieving high-efficiency RTP has proven challenging due to complex underlying processes.

Hydrogen bonding, a key interaction between molecules, has been considered essential for optimizing these materials. However, previous studies have struggled to confirm its universal role.

The new study by the Zysman-Colman Group at St Andrews provides a comprehensive analysis of the role hydrogen bonding plays in activating RTP, by comparing its effects in different host materials. By doing so, the researchers have shown how these bonds can influence the brightness and stability of RTP, making it possible to fine-tune these properties for specific applications.

Commenting on the research, Professor Zysman-Colman said, "Through systematic structural and photophysical investigations, this work has elucidated the universal role hydrogen bonding has in triggering RTP by investigating the properties in a diverse range of hosts that either can hydrogen bond or not with the guest molecule.

"The findings open new possibilities for the practical use of RTP materials, including luminescent origami, anti-counterfeiting measures, and even light-based data writing techniques. This study not only deepens our understanding of how RTP works but also highlights new ways to control and optimize these fascinating materials for a range of cutting-edge applications."

More information: Sen Wu et al, Hydrogen-Bonded Supramolecular Network Triggers High-Efficiency Blue Room-Temperature Phosphorescence, *CCS Chemistry* (2024). DOI: [10.31635/ccschem.024.202404623](https://doi.org/10.31635/ccschem.024.202404623)

Provided by University of St Andrews

Why aren't we driving hydrogen powered cars yet? There's a reason EVs won.



graphic depicting the inner workings of a 2024 Toyota Mirai, showing the vehicle's hydrogen storage system, fuel cell, and electric motor.© Credit: Toyota

Hydrogen fuel-cell vehicles aren't just fodder for [science fiction](#) or far-out R&D experiments. Cars fueled by hydrogen, like the Toyota Mirai and Hyundai Nexo, are already here, and fuel-cell technology is actively [evolving](#) and benefiting from billions of dollars in [federal research and infrastructure funding](#). So then, why are hydrogen cars virtually non-existent on U.S. roads today? What happened?

"The answer is very simple: economics," Sergey Paltsev, a senior research scientist at the MIT Energy Initiative told *Popular Science*. [Politicians](#) and [automakers](#) once held up the fuel cell, which [turns the chemical energy of hydrogen into electricity](#) to drive an electric motor, as the future of passenger automobiles, but the falling cost of batteries and the upsides of a preexisting fueling infrastructure (see: the electrical grid) have propelled battery-electric cars well into the lead.

[Related: [How some automakers are still pushing ahead for a hydrogen-powered future](#)]

"It's not just the cost of the car," explained Paltsev, who is also deputy director of the MIT Center for Sustainability Science and Strategy. This is an important point, because in California, low-milage hydrogen cars [sell at a steep discount](#).

What makes hydrogen passenger cars altogether costlier than their battery-electric counterparts is the lack of fueling infrastructure, [energy-conversion inefficiencies](#), and the [price of the fuel at the pump](#).

A big switch to hydrogen cars would require enormous infrastructure development; the Department of Energy's Alternative Fuels Data Center shows [55](#) public hydrogen fueling station locations in the U.S. today, almost exclusively in California, next to more than [68,000](#) active public electric vehicle charging stations across the country. (Even in California, refueling passenger hydrogen cars can apparently be such a trial that it sparked a July [class action suit](#) against Toyota.)

In a separate call with *Popular Science*, Gregory Keoleian, the co-director of Sustainable Systems and MI Hydrogen at the University of Michigan, paused to double check if automakers are still releasing new hydrogen passenger cars in California. While Honda discontinued its two hydrogen passenger cars available in California in 2021, Toyota and Hyundai continue to produce new hydrogen passenger cars for sale in the state. Along with a desire for precision on professor Keoleian's part, his pause highlights how attention on hydrogen fuel-cell vehicles has shifted from passenger cars in favor of more advantageous applications, including [medium- and heavy-duty trucks and aviation](#).

"Battery-electric vehicles can be problematic when you have problems with range or fueling time," or heavy loads, Keoleian said. "That's where hydrogen can play a role with, for example, long-haul trucks."

When it comes to things like rail and commercial trucks, "your fueling stations are more dispersed. You don't need the concentration of fueling facilities. You don't need them on every corner. There's really an opportunity to decarbonize with hydrogen for those applications," he explained.

‘Brighter pathways’ for hydrogen passenger cars

“Nothing is going to change next year, or probably not in the next five years, but there are brighter pathways for hydrogen cars,” said Paltsev. For one, if hydrogen turns out to be a “much bigger source of our energy needs in other parts of the economy, like in heavy-duty transportation and industry,” then the fueling and infrastructure challenges are “going to be easier to resolve,” providing “positive spillovers and synergies for hydrogen cars.”

Paltsev noted that the economics of hydrogen cars are already more attractive in some parts of the world than in others—citing, for example, [Japan](#), where electricity costs are high. Several automakers are also still invested in hydrogen fuel-cell passenger cars, as evidenced by a [recently announced collaboration between BMW and Toyota](#); the two say a BMW hydrogen production car will arrive in 2028.

The current [impracticalities](#) of hydrogen passenger vehicles in places like the U.S. are additionally not a reason to “just give up” on this particular application of fuel-cell tech, cautioned Paltsev. “We may need it for many other reasons in the future,” he added, citing geopolitical issues as a factor that could disrupt access to raw materials for batteries and make hydrogen cars suddenly more economically viable.

Hyundai's Initium concept offers a glimpse of the future of hydrogen

Hyundai's Initium concept offers a glimpse of the future of hydrogen© Provided by TAG24 NEWS

Hyundai has revealed its latest concept car, the Initium, which could become the next Nexo hydrogen SUV.

The concept previews a new hydrogen fuel-cell electric vehicle that Hyundai plans to unveil in the first half of next year. The Initium uses the firm's new "Art of Steel" design language which Hyundai says gives a more sturdy and sophisticated appearance.

Its exterior design incorporates 21-inch alloy wheels, camera door mirrors, flush door handles, a triangular rear quarter light and a very large roof rack. Meanwhile, the back features a full-length light bar and square LED brake lights.

In terms of range, Hyundai claims that the Initium can do up to 650 kilometres between fill-ups, and that the electric motor produces 150kW/204hp. Furthermore, the battery on-board features vehicle-to-load – or "V2L" – to allow various household appliances and personal devices to be charged via the car's battery.

Jaehoon Chang, President and CEO of Hyundai Motor Company, said: "Hyundai Motor's clear, unwavering commitment to hydrogen over the past 27 years is rooted in our belief in its potential as a clean, accessible and therefore a fair energy source for everyone. We are dedicated to pioneering a future where hydrogen is used by everyone, in everything, and everywhere. We invite you to join us on this journey."

The Initium will make its debut at the LA Auto Show and Auto Guangzhou in November.

Electric vs. Hydrogen: Which Technology Will Drive the Future of Sustainable Transportation?

As electric cars continue to gain momentum, hydrogen-powered vehicles are emerging as a promising alternative. But how do these technologies compare, and which one could dominate the future?



Future of Automotive Technology: Electric, Hydrogen, and Beyond© Provided by Ever-Growing

Electric vehicles (EVs) are taking the automotive world by storm. With their quiet operation and zero local emissions, it's no wonder they're becoming more popular. The secret behind their performance lies in a simple electric motor that drives the wheels, powered by a rechargeable battery. Range anxiety, once a common concern, is fading as modern EVs easily cover 200 miles or more on a single charge. While the upfront cost remains higher than traditional vehicles, the long-term savings on fuel and maintenance make EVs an attractive option for many.

Hybrid Cars: The Best of Both Worlds?

Hybrid vehicles combine the efficiency of electric motors with the power of internal combustion engines. These versatile cars switch between electric and gasoline power, providing the best of both worlds. In city driving, the electric motor handles the load, while the gas engine takes over on the highway. This reduces fuel consumption and emissions. There are various types of hybrids, from mild hybrids, which offer minimal electric assistance, to plug-in hybrids, which have larger batteries and can run solely on electricity for short distances.

Hydrogen-Powered Cars: The Future in Waiting

Hydrogen fuel cell vehicles (FCVs) are another innovative alternative. They generate electricity by converting hydrogen into power, with water as the only emission. While hydrogen cars offer the potential for clean energy, the technology still faces significant hurdles. Producing and storing hydrogen is challenging, and hydrogen refueling stations are scarce. However, if infrastructure improves, hydrogen vehicles could provide a viable solution, particularly for long-distance and heavy-duty applications.

Compressed Natural Gas (CNG) Cars: An Overlooked Option

Compressed natural gas (CNG) vehicles have been around for years but remain less common. They run on natural gas or biogas, which is cheaper and cleaner than gasoline or diesel. The downside? CNG offers less energy per volume, requiring larger fuel tanks that take up more space. Additionally, the limited number of refueling stations makes CNG cars less convenient for many drivers. Despite these challenges, CNG cars remain a cost-effective and environmentally friendly choice for specific users.

In conclusion, each alternative fuel technology offers unique benefits and challenges. Electric vehicles are leading the charge, but hydrogen and hybrid technologies could play key roles in the future of transportation.

Hydrogen fuel cell cars: four things you should know

How does a hydrogen car work? What is a fuel cell system? What advantages does this technology offer, and what challenges does it face? The BMW Group team answers the key questions.

How does a hydrogen drive work?

Hydrogen cars are powered by an electric motor and are therefore classified as e-cars. The common abbreviation is FCEV, short for “Fuel Cell Electric Vehicle” – in contrast to battery-powered electric cars, or Battery Electric Vehicles, BEV for short.

There is one crucial difference to other electric vehicles: hydrogen vehicles produce the electricity themselves. This means that their power does not come from a built-in battery, as is the case with purely electric vehicles or plug-in hybrid vehicles, which can be charged from an external power source. Instead, hydrogen cars effectively have their own efficient power plant on board, which converts the hydrogen in the fuel tank into electricity. And this power plant is the fuel cell.

A process known as reverse electrolysis takes place in a fuel cell. Hydrogen reacts with oxygen in the process. The hydrogen comes from one or more tanks in the car while the oxygen comes from the ambient air. The only things this reaction produces are electrical energy, heat and water, which exits through the exhaust as water vapour – with no emissions at all.

The electricity generated in the fuel cell takes two routes, depending on what the specific driving situation demands. It flows to the electric motor and directly drives the vehicle, and/or it charges a battery that acts as temporary storage until the energy is needed for the drive. This “buffer” battery is significantly smaller

than the battery of an all-electric car – meaning it's also lighter. It's also being constantly recharged by the fuel cell.

Like other EVs, hydrogen vehicles can also recover or "recuperate" braking energy. In this process, the electric motor converts the car's kinetic energy back into electrical energy and feeds it into the buffer battery.

2. The pros and potential of hydrogen cars

Hydrogen cars are powered purely by electricity and drive with zero local emissions. The driving experience is therefore similar to that of electric cars. Namely: dynamic, virtually silent acceleration, since electric motors provide their full torque even at low speeds.

The main pro – and the biggest competitive advantage – is the short refuelling time. Unlike the charging time of e-cars, which are dependent on both the model and infrastructure, it just takes three to four minutes to refill the hydrogen tank of a [BMW iX5 Hydrogen](#) (pilot fleet). This brings vehicle availability and flexibility into line with those of a regular car.

Hydrogen vehicles have a similar range to e-cars with very large battery storage. A single hydrogen refuelling in the BMW iX5 Hydrogen will take you 504 kilometres. The range of hydrogen vehicles does not depend on the outside temperature, so it does not deteriorate in cold weather.

Hydrogen drives can help put the infrastructure on a broader footing to meet the increasing demand for electric charging stations for all BEVs. Hydrogen is also one of the most efficient ways to store and transport renewable energy so it plays an important role in the future energy supply.

FCEVs use the same electric drive as BEVs, but they differ in the way they store energy. This means that marketing hydrogen cars benefits both fuel cell and battery technologies in equal measure – which will reduce costs for all in the long term.

3. How much do hydrogen cars cost — and why?

The few fuel-cell-powered models that are already available on the market still cost more than comparable e-cars with batteries or internal combustion engines.

There are a range of reasons why hydrogen cars are currently more expensive. Industrialization in production is not yet fully developed and the demand for platinum also plays a role. The precious metal acts as a catalyst in electricity generation. However, the amount of platinum needed for automotive fuel cells has already been greatly reduced; moreover, platinum recovered through recycling catalytic converters is also increasingly returning to the material cycle. Low production volumes are also a factor, albeit a temporary one. Hydrogen technology is very similar in the way it is used for many applications – for example, commercial vehicles, trains, aircraft or even fixed location solutions – so it can be assumed that increased production volumes will produce benefits. It is also significant that there is less raw material dependence than with BEVs.

As well as acquisition costs, operating costs play an important role in the cost-effectiveness and acceptance of a drive technology. In the case of a hydrogen car, these depend not least on the price of the fuel. A kilogram of hydrogen currently costs around 14 EUR. A fuel cell car can travel about 100 kilometres on one kilogram of hydrogen. This makes the cost per kilometre of a hydrogen car currently about the same as for combustion vehicles. If hydrogen production increases worldwide, as is currently foreseen, the price per kilogram in Germany could feasibly fall to around 4 to 6 EUR by 2030.

4. How environmentally friendly and sustainable are hydrogen drives?

A car that uses only regenerative energies and generates no harmful emissions would be ideal from an ecological point of view. How close does the fuel cell car come to achieving this ideal compared to other types of drive?

- By law, alternative drives must be designed to reduce the emission of pollutants, in particular climate-harming CO₂, but also other gases that are harmful to health, such as nitrogen oxides. The exhaust air of a hydrogen car consists of pure water vapour. The fuel cell drive is therefore locally emission-free. This means it keeps the air in cities clean. But does it protect the climate at the same time?
- That depends on how the hydrogen is produced. Hydrogen production requires electrical energy. In the process of electrolysis, the electrical energy breaks down water into its separate hydrogen and oxygen components. If the electricity used comes from renewable energies, hydrogen production has a neutral carbon footprint. If, on the other hand, fossil fuels are used, this ultimately has an adverse impact on the climate footprint of a hydrogen car. How strong this impact is depends on the energy mix used. In this respect, the hydrogen car is no different from other electric vehicles.
- The disadvantage of hydrogen production is how much is lost during electrolysis. The efficiency of the entire energy chain – from production of the electricity to operation of the vehicle – is currently still only half that of a BEV. However, if you look at the entire life cycle of FCEVs and BEVs, they are not far apart.
- However, hydrogen can be produced at times when there is an oversupply of electricity from renewable energy sources because the wind or solar energy currently being produced is not being used elsewhere. The potential for this is huge. Hydrogen is also a by-product in numerous industrial processes – and is too often treated as waste, i.e. not put to any further use. Fuel cell drives offer a way to upcycle hydrogen here. In the case of hydrogen production from fossil fuels, there is also the opportunity to store the resulting CO₂ ("carbon capture

and storage”) or even utilise it (“carbon capture and utilisation”) – this hydrogen is referred to as “blue” hydrogen.

- The energy balance of fuel cell cars also includes transporting and storing the hydrogen. Different costs for compression, cooling, transport and storage arise depending on the transport technology used (liquid vs. gaseous). Nevertheless, it is still a good deal more complex and energy-intensive to transport and store hydrogen than it is for gasoline or diesel. In contrast to fossil fuels, though, hydrogen can be produced anywhere there is access to electricity and water, even directly at filling stations themselves, as examples in Antwerp (Belgium) and Fürholzen (Germany) show. Transportation distances could be significantly shortened in future as the infrastructure expands further.

In conclusion, hydrogen drives have the potential to make ecologically sustainable mobility possible. However, this depends in particular on using renewable energies in hydrogen production and expanding the technical infrastructure to achieve shorter transport routes.

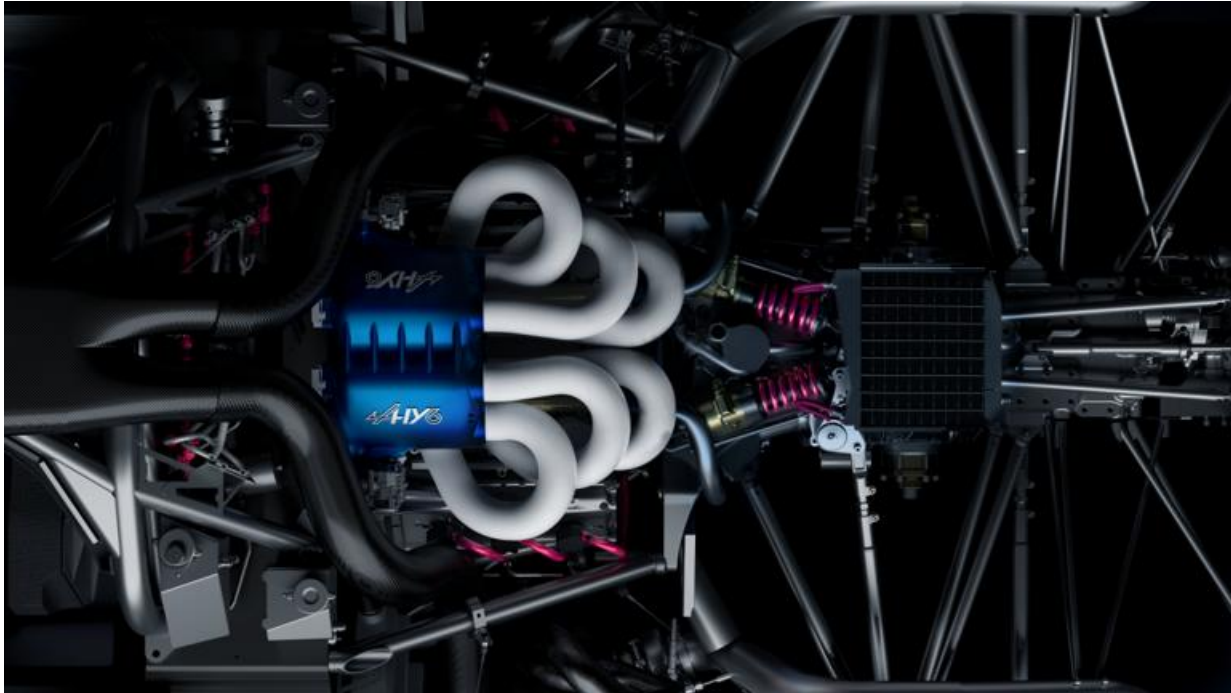
"Hydrogen fuel cell cars: four things you should know" was originally created and published by [Motor Finance Online](#), a GlobalData owned brand.

Alpine's new hydrogen engine could change motorsports

Alpine is pushing the boundaries of sustainable high-performance motorsports with the introduction of the Alpenglow Hy6, the first vehicle to feature their all-new hydrogen-powered V6 engine. Initially presented as a concept car in 2022, the Alpenglow has evolved into its most advanced form, returning to the Paris Motor Show in 2024 as a rolling prototype. Showcased earlier this year at the 24 Hours of Le Mans, this latest iteration delivers a staggering 730 horsepower, more than double the output of its previous four-banger configuration.

A hydrogen revolution under the hood

So, what makes this car so special? The Hy6 uses a 3.5-liter twin-turbo V6 engine designed entirely in collaboration with French racing team and race car constructor ORECA. Running on hydrogen, it takes the raw power we expect from gas-powered engines and marries it with cleaner technology.



Alpenglou Hy6 Alpine

When you think of hydrogen-powered cars you likely think of fuel cells. As opposed to internal combustion, hydrogen fuel cells produce electricity through a chemical process. This means that fuel cells also need a battery and electric motor, similar to a hybrid vehicle. But the Hy6 is interesting because it offers similarly reduced emissions through its hydrogen fueling while maintaining the ICE format that we all know and love.

Paving the way for hydrogen-powered motorsports

The Alpenglou Hy6 isn't just a concept; it's a glimpse into how hydrogen engines could shape the future of racing. The new engine not only produces 730 horsepower at 7,600 rpm and 570 lb-ft of torque at 5,000 rpm, it even makes more horsepower per liter than Alpine's new ultra-exclusive, gas-powered A110 R Ultime.

With a top speed of over 330 km/h, Alpine is betting that hydrogen powertrains could soon be competitive in motorsport, especially as global regulations continue to shift toward greener technologies. Alpine is eyeing hydrogen's

potential for the racetrack and beyond, laying the groundwork for more sustainable high-performance cars.

"With the development of this brand new Hy6 V6 engine, we are demonstrating our commitment to hydrogen research, which could herald motorsport applications with high-performance levels," said Bruno Famin, vice president of Alpine Motorsports. "A solution for continuing to cultivate the passion for motor racing using a very noble V6 with remarkable specific power and a sound to thrill drivers and spectators with its maximum revs at 9,000 rpm."

A (nearly) zero-emissions drivetrain

Now, while hydrogen engines are often touted as "clean," they're not entirely emissions-free. Hydrogen combustion does produce near-zero CO₂. However, there's a catch: nitrogen oxides (NO_x), a byproduct of the combustion process, are still released into the atmosphere. So, while this tech is a big step forward, it's not completely pollution-free.

Final thoughts

As concept cars go, it's anyone's guess when or how we will ultimately see this tech in real-world applications. But, there's clearly a desire to see more hydrogen-powered race cars on track in the near future, with both the ACO and the FIA authorizing the use of hydrogen cars in future races.

The fuel might be different, but high-revving engines and screaming exhausts may not be disappearing so quickly after all.

Making jet engines fit for the hydrogen age

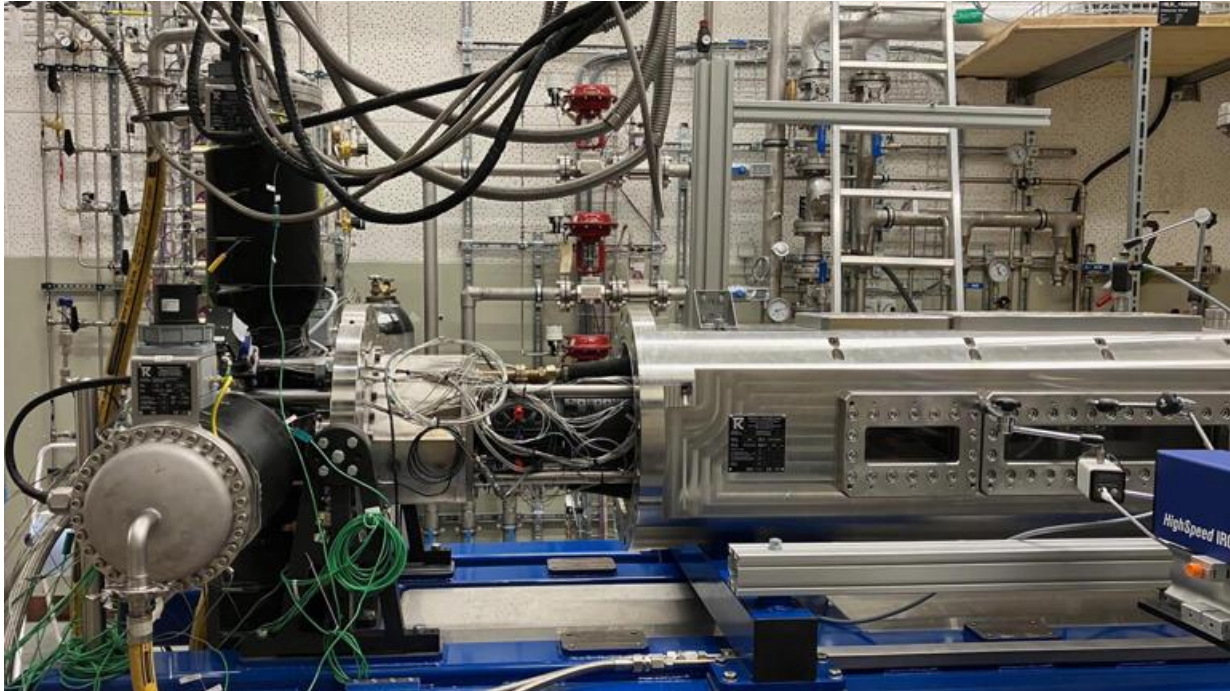
Flame from a hydrogen injection nozzle. Credit: Nicolas Noiray / ETH Zurich

Europe is preparing for climate-neutral flight powered by sustainably

produced hydrogen. Last year, the EU launched a project to support industry and universities in the development of a hydrogen-powered medium-haul aircraft. Among other things, jet engines will have to be adapted to run on the new fuel. Today's engines are optimized for burning kerosene.

"Hydrogen burns much faster than kerosene, resulting in more compact flames," explains Nicolas Noiray, Professor in the Department of Mechanical and Process Engineering at ETH Zurich. This has to be taken into account when designing hydrogen engines. Experiments by Noiray's team now provide an important basis for this. The team has just [published](#) its results in the journal *Combustion and Flame*.

One problem is vibrations, which engineers try to minimize. In typical jet engines, about 20 fuel injection nozzles are arranged around the annular combustion chamber of the engine. The turbulent combustion of the fuel there generates sound waves. These waves are reflected back from the walls of the chamber and have a feedback action on the flames. This coupling between the sound wave and the flames could give rise to vibrations that would induce a heavy load on the engine combustion chamber.



Injection nozzles for hydrogen engines are tested in this chamber at ETH Zurich. The researchers can replicate real conditions at cruising altitude. Credit: Nicolas Noiray / ETH Zurich

"These vibrations can fatigue the material, which in the worst case could lead to cracks and damage," says Abel Faure-Beaulieu, a former postdoctoral researcher in Noiray's group. "This is why, when new engines are being developed, care is taken to ensure that these vibrations do not occur under operating conditions."

Simulating conditions at cruising altitude

When engineers developed today's kerosene engines, they had to get these vibrations under control. They achieved this by optimizing the shape of the flames as well as the combustion chamber's geometry and acoustics. However, the type of fuel has a major impact on the interactions between sound and flame. This means engineers and researchers must now make sure that they will not arise in a new hydrogen engine.

An elaborate test and measurement facility at ETH Zurich allows Noiray to measure the acoustics of hydrogen flames and predict potential vibrations. As part of the EU project HYDEA, in which he is involved together with GE Aerospace, he tests hydrogen injection nozzles produced by the company.

"Our facility allows us to replicate the temperature and pressure conditions of an engine at cruising altitude," Noiray explains. The ETH researchers can also recreate the acoustics of various combustion chambers, enabling a wide range of measurements. "Our study is the first of its kind to measure the acoustic behavior of hydrogen flames under real flight conditions."

In their experiments, the researchers used a single nozzle and then modeled the acoustic behavior of the collection of nozzles as it would be arranged in a future hydrogen engine. The study is helping engineers at GE Aerospace to optimize the injection nozzles and to pave the way for a high performance hydrogen engine. In a few years, the engine should be ready for initial tests on the ground, and in the future, it could propel the first hydrogen-fueled aircraft.

ETH Professor Noiray does not consider the development of the engines or the development of hydrogen tanks for aircraft to be the greatest challenge in transitioning aviation to the hydrogen age. "Humanity has flown to the moon; engineers will undoubtedly be able to develop hydrogen planes," he says.

But planes alone aren't enough. Another major challenge, Noiray says, is to put in place the entire infrastructure for hydrogen aviation, including producing climate-neutral hydrogen in sufficient quantities and transporting it to airports. Achieving this within a reasonable timeframe requires a concerted effort now.

Why hydrogen for aviation?

Most ground vehicles can be electrified with batteries; however, batteries are too heavy for high-performance aircraft. Storing the energy needed to fly 200 passengers over thousands of kilometers with hydrogen in cryogenic tanks weighs at least thirty times less than storing it in batteries.

"In the coming decades, only small aircraft with very low payload capacity will be battery-powered," ETH Professor Noiray says. "For passenger and cargo aircraft, synthetic fuels are the only alternative to today's kerosene, and hydrogen is the most economical to produce sustainably."

Depending on the aircraft's size and range, there are two potential hydrogen solutions. For smaller regional aircraft with low cruising speeds and short ranges,

hydrogen can be converted into electricity in a fuel cell on board. This drives propellers via an electric motor.

However, for long-haul commercial aircraft, fuel cells are unsuitable due to their size and weight. In the future, these aircraft will be propelled by jet engines fueled with hydrogen. Several industrial consortia are currently working to develop such engines.

More information: Abel Faure-Beaulieu et al, Measuring acoustic transfer matrices of high-pressure hydrogen/air flames for aircraft propulsion, *Combustion and Flame* (2024). DOI: [10.1016/j.combustflame.2024.113776](https://doi.org/10.1016/j.combustflame.2024.113776)

Provided by ETH Zurich

Futuristic truck breaks world record after traveling 1,800 miles without refueling: 'A triumph'



The voyage represents a great proof of concept for fuel-cell vehicles as an alternative to diesel-powered vehicles.

A hydrogen-powered heavy-duty truck recently set a world record by traveling a remarkable 1,806 miles on a single fill.

Clean energy brand [Accelera](#) announced the mind-blowing achievement of their [H2Rescue](#) prototype, a [hydrogen fuel-cell](#) electric truck designed for emergency response. Best of all, the truck remarkably [contributed no air pollution](#) during its marathon journey.

Lest you think they weren't serious about the world-record aspect, a Guinness Book of World Records adjudicator was present throughout.

The 33,000-pound H2Rescue was powered by a 250-kilowatt traction motor that consumed 168 kilograms of the 175 kilograms of hydrogen brought on board. It took off in Central California and navigated rush-hour traffic on public roads while cruising at a speed of 50-55 mph.

The voyage represents a great proof of concept for [fuel-cell vehicles](#) as an alternative to diesel-powered vehicles. Accelera teamed with the Department of Homeland Security, Science and Technology Directorate, the Department of Energy, and the Department of Defense for the project.

"This world record is a triumph for interagency collaboration and proof that hydrogen is a viable alternative fuel for vehicles," [said Nicholas Josefik](#), Industrial Engineer at the U.S. Army Engineer Research and Development Center.

"By using hydrogen, we can improve our Nation's energy security and reliability," Josefik added.

An impressive statistic from the feat was that a comparable diesel vehicle would have contributed 664 pounds of pollution over the same journey, per Accelera. Annually, the company says using a single [fuel-cell truck](#) instead of a diesel one could save over 1,800 gallons of fuel and cut carbon pollution by an estimated 2.5 million tons.

[Hydrogen-powered vehicles](#) with fuel-cell [technology](#), like the H2Rescue, offer tantalizing possibilities. [The vehicles](#) release water and steam instead of the [planet-heating pollution](#) of diesel and gas-powered vehicles.

When compared to battery-powered EVs, [hydrogen vehicles](#) could charge quicker and possess astonishing range.

That being said, there are roadblocks. One is a current lack of charging infrastructure [compared to EVs](#). Another potential pitfall that researchers are looking to solve is the [degradation of fuel-cell tech](#).

Another concern is the currently fossil-fuel-dependent hydrogen production process that [includes dirty energy like methane](#). Fortunately, experts around the world are working on producing "[green hydrogen](#)" that could create a [hydrogen economy](#).

As it stands, Accelera touted the results as proof that fuel-cell engines of its kind can provide a quieter, pollution-free foundation for a range of applications such as [heavy-duty trucks](#), buses, and [rail systems](#).

Specific to the H2Rescue, they say it can offer major benefits to disaster-relief sites by powering Federal Emergency Management Agency (FEMA) trailers or

even homes. It's not yet clear where Accelera and the team that collaborated on the project will go next, but it's clear the results provide a strong platform.

"We look forward to transitioning lessons learned throughout this project to future fuel-cell systems and joint efforts," said [Eric Wasiloff](#), Project Manager with the U.S. Army's Ground Vehicle Systems Center.



Race for the Planet

Extreme E is a radical off-road racing series in the most remote corners of the planet impacted by climate change. 8 teams, consisting of one male and one female driver, racing to highlight global issues and inspire the next generation.

Launching in 2025, Extreme H represents a bold, pioneering step forward in the clean energy revolution, demonstrating cutting-edge hydrogen technology in a competitive racing environment.

Extreme H How Motorsport Can Accelerate Hydrogen Technologies

London, 19 November - As world leaders meet to discuss solutions to climate change, including how technologies such as hydrogen can be part of decarbonisation of large industries, such as transport, we're digging deeper into how Extreme H is working with leaders in hydrogen innovation to showcase its exciting potential.

We caught up with Mark Grain, Extreme H's Technical Director, to find out more about the Pioneer's cutting-edge hydrogen fuel cell technology, showcasing hydrogen's viability in demanding environments, and why motorsport is a crucial platform for accelerating sustainable energy adoption in motorsport and beyond.

Q: Mark, firstly, what was behind Extreme E's decision to switch to Extreme H?

A: Mark Grain: We chose to transition to Extreme H and focus on hydrogen because it's essential for a zero-emission future in mobility, energy storage, and beyond. We know a lot more about electric now, thanks to the performance settings of championships like Formula E and Extreme E.

This sporting platform does not currently exist for hydrogen so there was a huge gap to be filled. Extreme H is designed to be a proving ground for hydrogen technology, demonstrating that hydrogen can deliver top-tier performance while also being sustainable.

The exposure to a widespread global audience, and the extreme racing test bed Extreme H enables, which will include high temperatures, sandy, tough terrains, and of

course the potential for crashes and impact, will help supercharge R&D learnings in hydrogen, and also crucially demonstrate its safety.

Q: Why is motorsports such a crucial platform for advancing hydrogen fuel cell technology?

A: Mark Grain: Motorsports, especially a pioneering platform like Extreme H, are perfect environments for pushing the limits of hydrogen fuel cell technology. The demands of racing, high power, endurance, and extreme conditions, really challenge fuel cells, enabling us to rapidly improve performance, efficiency, and durability. Innovations here can translate directly to other sectors, allowing us to make huge leaps forward in hydrogen technology that could take years in traditional R&D settings.

Q: Why is testing the safety aspect so important?

A: Mark Grain: People often think hydrogen is unsafe because it's associated with past incidents. Motorsport can help change this perception by rigorously testing hydrogen in extreme conditions, demonstrating safe handling, storage, and refueling practices, and driving innovation in hydrogen technology.

Rigorous safety protocols in racing ensure that every hydrogen component is meticulously tested. The competitive nature of motorsport also drives rapid innovation in safe hydrogen storage, handling, and refueling. Success on the track can boost public confidence and set new safety standards for hydrogen use globally.

Q. Can you explain the hydrogen technology that has gone into the Extreme H car?

A: Mark Grain: Against the clock, our team has worked extensively over the past year with our technical suppliers at; Spark Racing Technology , which leads on the vehicle design; Symbio, which provides the fuel cells; Fortescue Zero which provides our battery packs; and Fox which supplies the suspension, over the past year.

Symbio has engineered a tailor-made 75kW hydrogen fuel cell system, the Symbio StackPack™ 75, which replaces the battery as the primary power source of all of the Extreme H Pioneer 25 vehicles, and is specifically developed to meet the rigorous demands of motor racing.

The system charges and powers the battery pack, ensuring consistent and reliable performance. The hydrogen used to power the fuel cell comes from renewable sources,

thus demonstrating the crucial role of hydrogen as both a source of energy and a means of storage, offering new ways of managing the consumption of renewable energies that until now could not be stored.

The Symbio StackPack™ 75 has been pushed to the limits during an intensive testing programme, to prepare the Pioneer 25 for its debut. Over the past twelve months of development, the car has completed as many test miles as three seasons of Extreme E which have proved that technology meets the expected technical and performance targets, in order for it to match the demands of off-road motor racing.



Q: What is the single most important advantage of bringing hydrogen to motorsport?

A: Mark Grain: Motorsport's performance-driven culture speeds up innovation tenfold compared to usual R&D; every race is a test of technology. With hydrogen, that's particularly powerful. The advances we make to improve power density, efficiency, and durability on the racetrack can have immediate impacts on commercial fuel cell technology. By proving hydrogen's capability in one of the toughest arenas, we set a strong precedent for its potential in other industries.

Q: What does the future hold for hydrogen in motorsport and beyond?

A: Mark Grain: Hydrogen has the potential to revolutionise motorsport, but motorsport powered by hydrogen will, on its turn, be a key mover in accelerating the widespread adoption of this technology for mobility and, more generally, in the world of energy. Hydrogen is an integral part of the clean energy puzzle as it offers a clean mobility solution without compromising on performance. Extreme H is setting the stage, and

hydrogen technology companies like Symbio provide a key technology. I think it will be a turning point for hydrogen's role in clean mobility and energy

This is just the beginning. We're proving that hydrogen isn't just a dream for the future, it's here, it works, it's powerful, and it's going to reshape how we think about energy in every industry. Working with pioneers in the hydrogen space is the key to our success.

Over the next five years, our aim is not only to improve fuel cell tech but also to normalise hydrogen as a practical and essential part of our energy solution. Extreme H can inspire broader hydrogen integration across industries, sparking investment, and making it accessible at scale.

“I think every race car should be built like this.” Munnings, Hansen Brothers and Grönholm Get First Taste of Hydrogen Racing with Extreme H

France, 22 October, 2024 — Veteran Extreme E drivers Catie Munnings, Kevin Hansen, and Timmy Hansen, along with newcomer Niclas Grönholm, became the latest drivers to take the wheel of the Pioneer 25. Taking place in Fontjoncouse in France, this test marks the latest positive milestone in the development of Extreme H, the world's first hydrogen motor racing championship, set to debut in 2025.



The Pioneer 25, named to signify the dawn of a new era in motorsport, is the result of extensive research and development process. Since the championship's announcement in 2022, the Extreme H car has been designed to embody the future of sustainable, high-performance racing. It features cutting-edge hydrogen fuel cell technology, supplied by Symbio, the series' Official Fuel Cell Provider, and delivers a peak output of 400 kW (550 hp), capable of propelling the 2200 kg car from 0-100 kph in just 4.5 seconds.

After months of anticipation, this new slew of drivers got to put the car through its paces, providing invaluable feedback as it gears up for its competitive debut. The car has already undergone an intensive testing program equivalent to three full seasons of racing, ensuring it is race-ready for its inaugural campaign.

The Hansen brothers, alongside Munnings, are veteran drivers in the Extreme E series, with Andretti Altawkilat Extreme E and E.ON Next Veloce Racing respectively, and have all been strong advocates for environmental consciousness in motorsport. Their involvement in the development and testing of the Extreme H Pioneer 25 highlights their commitment to advancing the sport while promoting sustainable innovation.



Reflecting on the first test session, Catie Munnings said, "I've been waiting to get behind the wheel of this car ever since I first heard about it, and it did not disappoint! The handling and performance of the car are outstanding, with great improvement on the Odyssey 21. It's also a thrill to know that we are pioneering something that could change the face of motorsport."

"It's really cool to have a championship that's a world first in using a hydrogen fuel cell. The car is so stable, it flies really well and it was super fun to test it."

Timmy Hansen echoed Catie's sentiments, saying: "They've taken all the learnings from the Odyssey 21 to build the Pioneer 25. Overall you can tell the car is much better designed and there's so many more tools for the teams to use to optimise the setup for each track, which could be very interesting."

"This car is very stable. So now we sit in the middle of the car, like you just have full control of where your wheels are. I think every race car should be built like this."

Kevin Hansen added, "It's been my first time in the Pioneer 25 and it has been fascinating to try a new part of the future of motorsport."

"It's crazy to think that five years ago we were testing the Odyssey 21 me and my brother and here we are five years later with the brand-new future of the series."

"They've learned a lot from the Extreme E car. It's a better chassis, handles better and has a lower centre of gravity."

The hydrogen fuel cell at the heart of the Pioneer 25 represents a revolution in sustainable energy. Symbio's 75 kW fuel cell charges and powers the battery pack produced and supported trackside by Fortescue ZERO. This groundbreaking approach to energy storage, already in use behind the scenes in Extreme E, will be a defining feature of the Extreme H series, showcasing how motorsport can be a driving force for green technology.



Mark Grain, Technical Director for Extreme H, highlighted the importance of the test: "This test session is another crucial milestone for the development of the Pioneer 25 and the entire Extreme H championship. The feedback from top-tier drivers like Catie, Kevin, Timmy, and Niclas is invaluable as we fine-tune the car's performance and reliability. Their insights help us ensure that the car is not only fast and competitive but also ready to showcase the full potential of hydrogen technology in motorsport."

The successful test in France is the latest of many positive steps leading to the official launch of the Extreme H series in 2025. Over the

past 12 months of development, the car has completed as many test miles as three seasons of Extreme E, and last month became the first hydrogen racing car to pass FIA crash testing.



2006 Honda FCX Concept

The groundbreaking Honda FCX Concept, a hydrogen fuel cell vehicle, influenced eco-friendly car designs. Its sleek, aerodynamic shape and advanced technology were pioneering. Modern electric and hydrogen-powered vehicles owe much to the FCX's influence. Environmental responsibility and cutting-edge design were combined in this concept car.



Photo: Shutterstock© Photo: Shutterstock

Hydrogen-powered vehicles have long been hailed as the clean fuel of the future, offering zero emissions and impressive ranges. However, despite early optimism, hydrogen cars remain a niche market, struggling to gain widespread adoption even years after their initial promise.

Impressive Acceleration

Initially, hydrogen fuel cell electric vehicles (FCEVs) like the Toyota Mirai and Hyundai Nexo captivated enthusiasts with their ability to travel several hundred kilometers on a single tank and refuel in just four to five minutes — significantly faster than many electric vehicles (EVs), according to [Hotnews](#).

Additionally, these cars boast impressive acceleration, reaching 100 km/h in under nine seconds. Optimists predicted that by 2030, hydrogen cars would become as affordable as their electric counterparts, but reality has fallen short.

One of the primary barriers is the lack of infrastructure. As of mid-2024, Europe hosts fewer than 200 hydrogen fueling stations. Countries like Spain and South Korea are leading the charge, establishing multiple public and private stations to support their limited fleets.

In contrast, regions like California in the United States see a modest presence of hydrogen stations, but users often face closures and rising fuel costs, undermining the practicality of owning an FCEV.

The “Chicken and Egg” Dilemma

Moreover, the environmental benefits of hydrogen cars are under scrutiny.

Currently, about 96% of hydrogen production relies on fossil fuels, undermining the green credentials of FCEVs.

While countries like Denmark and Iceland explore greener hydrogen production methods using wind and geothermal energy, these technologies remain expensive and not yet scalable.

European nations have developed strategies to integrate hydrogen into their energy mix, recognizing its potential alongside renewable sources.

However, significant investments and sustained political commitment are essential to overcome the “chicken and egg” dilemma — without widespread hydrogen cars, fueling stations remain unviable, and vice versa.

Creating biohydrogen from wood waste



From left: Untreated old wood, wood in pulping solution, cellulose fibers (after boiling and washing), sugar solution from cellulose fibers, anaerobic hydrogen producers (bacteria), micro-algae Credit: Fraunhofer-Gesellschaft

Up to now, wood waste has had to be disposed of at great expense and, at best, has been used to generate energy in incineration plants. Fraunhofer researchers are now using this valuable resource to produce biohydrogen in the Black Forest region of Germany.

In the joint project H2Wood—BlackForest, fermentation processes using hydrogen-producing bacteria and microalgae have been specially developed for the biotechnological production of this green energy carrier. A pilot plant for the production of biohydrogen is to be commissioned as early as 2025.

A study published as part of the project also examines the potentials, barriers and measures for regenerative hydrogen production from waste wood and old wood in the Black Forest region.

The Black Forest region is home to a large number of wood processing companies, including many furniture manufacturers. Large quantities of wood

waste are produced during furniture processing, pallet disposal and building demolition.

Until now, this waste has been disposed of in incineration plants. Since old wood often contains wood preservatives that have long been banned due to their harmful effects on human health, the waste gas from the incineration process also has to be cleaned at great expense. This motivated the Fraunhofer researchers to look for alternative uses for the regional wood waste.

The idea was that waste wood and old wood could be used to produce regenerative hydrogen, and that biohydrogen could be produced from the waste using biotechnological processes—perfectly in line with a wood-based circular economy.

The trick is that the researchers use sugar from the wood to produce hydrogen using bacteria. The resulting CO₂ is then used to grow microalgae that can also produce hydrogen.

In addition to the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, the University of Stuttgart, with its Institute of Industrial Manufacturing and Management IFF, and Campus Schwarzwald are also involved in the implementation of the H2Wood—BlackForest project, which was initiated in 2021.

The production process of biohydrogen starts with the pre-processing of old and waste wood. First, the wood waste, such as pallets or old garden fences, is pulped and broken down into its basic components.

To do this, the researchers boil the wood under pressure at up to 200 °C in a mixture of ethanol and water. Lignin as well as adhesives, solvents and paints from the wood waste dissolve in the ethanol, separating the chemical contaminants from the wood fibers.

In the next step, the wood fiber fraction that remains after boiling, the cellulose, and part of the hemicellulose are broken down into individual sugar molecules (glucose and xylose), which serve as food or substrate for the hydrogen-producing microorganisms.

"Separating wood into its fractions is a process that requires experience. This is where we draw on the many years of expertise that we have gained in the construction of our lignocellulose biorefinery in Leuna," says Dr. Ursula Schliessmann, deputy institute director at Fraunhofer IGB in Stuttgart, which is responsible for the project coordination and technology development.

To convert the produced sugar into hydrogen, the researchers at Fraunhofer IGB have established two interlinked fermentation processes using hydrogen-producing bacteria and microalgae.

Carbon-based by-products produced in addition to hydrogen

Pre-processing produces by-products such as lignin, and the biotechnological conversion of the wood releases hydrogen and CO₂. The latter is then converted into by-products such as starch and carotenoids during microalgae production.

Dr. Schliessmann explains, "When the wood is fractionated, the wood fibers are freed from lignin, which, in addition to cellulose and hemicellulose, makes up 20 to 30% of the wood cell wall substance. As one of the by-products, this lignin has many uses—for example, in composite materials. One example of its use is in car panels."

The long sugar chain molecules of the cellulose are used to produce glucose, which is added to the fermentor with bacteria and serves as a carbon source for bacterial growth. The bacteria then produce hydrogen and CO₂.

The researchers separate the CO₂ from the gas mixture and transfer it to the algae reactor, a photobioreactor. The microalgae are able to use CO₂ as a carbon source and multiply. Unlike bacteria, they do not require sugar.

"The metabolic products of the bacteria, i.e., the apparent waste stream of CO₂, are food for the microalgae and therefore do not enter the exhaust as a harmful greenhouse gas. The microalgae use this to synthesize carotenoids or pigments under the influence of light as further by-products that can be used by various industrial sectors."

In a second step, the microalgae are transferred to a specially designed reactor where they release hydrogen via direct photolysis.

Biotechnological process with a high hydrogen yield

The project partners expect a high yield. Initially, around 0.2 kilograms of glucose can be produced from one kilogram of old wood. "We can then produce 50 liters of H₂ with this using anaerobic microorganisms," says Dr. Schliessmann.

During fermentation with anaerobic bacteria, CO₂ is produced in equal portions, i.e., 50%. Once the hydrogen has been separated from the gas mixture, approx. two kilograms of CO₂ in the photobioreactor can produce one kilogram of microalgae biomass.

This biomass has a starch content of up to 50%. It also contains the pigment lutein. The by-product algae biomass could, for example, be used for plastic components with the help of bacteria.

The modularly expandable pilot plant with three bioreactors is currently under construction. The biorefinery is scheduled to go into operation in Campus Schwarzwald at the beginning of 2025. In the future, it will be possible to combine different process steps in a modular way—an ideal prerequisite for testing new technologies.

Hydrogen road map for the Black Forest region

In this project, Fraunhofer IPA, together with the Institute of Industrial Manufacturing and Management IFF, is conducting a study to determine how the local demand for green hydrogen in the industrial, transport, household and building sectors can be met, and what quantities of waste wood and old wood are available for its production.

As a result of this hydrogen road map, recommendations have been made for the development of the hydrogen economy in the Black Forest region.

The proposed measures include the promotion of research and development, the expansion of the regional hydrogen infrastructure and the strengthening of energy systems integration in order to establish hydrogen as an integral part of the energy transition.

"The study shows that the Black Forest region has a significant potential to produce hydrogen from local resources, but this potential can only be fully exploited by further developing the technologies and expanding the infrastructure," says Vladimir Jelschow, a research scientist at Fraunhofer IPA and one of the authors of the hydrogen road map.

Provided by Fraunhofer-Gesellschaft

Rice develops new catalyst that uses light, not heat, to produce green hydrogen



Rice develops new catalyst that uses light, not heat, to produce green hydrogen

Hydrogen, a clean-burning, powerful, and versatile energy commodity, could be crucial in transitioning to a sustainable energy ecosystem.

However, the chemical process for over half of global hydrogen production significantly contributes to greenhouse gas emissions.

To curb this, researchers at Rice University have developed a catalyst that could make steam methane reforming (SMR) completely emissions-free by utilizing light instead of heat to drive the reaction.

SMR is a chemical reaction that generates hydrogen and carbon monoxide from natural gas and other methane sources.

Using light instead of heat

The research could be essential for prolonging catalyst lifetimes, enhancing efficiencies, and lowering costs in various industrial processes affected by coking, a type of carbon buildup that can deactivate catalysts.

The new copper-rhodium photocatalyst features an antenna-reactor design that decomposes methane and water vapor without needing external heating when exposed to a specific wavelength of light.

This process produces hydrogen and carbon monoxide, which are valuable feedstocks for the chemical industry and do not contribute to greenhouse gas emissions.

“This is one of our most impactful findings so far, because it offers an improved alternative to what is arguably the most important chemical reaction for modern society,” said Peter Nordlander, Rice’s Wiess Chair and Professor of Physics and Astronomy and professor of electrical and computer engineering and materials science and nanoengineering.

“We developed a completely new, much more sustainable way of doing SMR.”

Nordlander and Naomi Halas, a Rice University professor and the Stanley C. Moore Professor of Electrical and Computer Engineering, are the corresponding authors of a study recently published in *Nature Catalysis*.

The new SMR reaction pathway utilizes the 2011 [discovery](#) made by the Halas and Nordlander labs at Rice University. They found that plasmons—collective oscillations of electrons in metal nanoparticles when they are exposed to light—can emit “hot carriers,” which are high-energy electrons and holes that can drive chemical reactions.

Producing green hydrogen

“We do plasmonic photochemistry — the plasmon is really our key here — because plasmons are really efficient light absorbers, and they can generate very energetic carriers that can do the chemistry we need them to much more

efficiently than conventional thermocatalysis,” said Yigao Yuan, a Rice doctoral student who is a first author on the study.

The new catalyst system utilizes copper nanoparticles as its energy-harvesting antennas.

Since the plasmonic surface of the copper nanoparticles does not bond well with methane, rhodium atoms and clusters were added as reaction sites.

The rhodium particles attach water and methane molecules to the plasmonic surface, utilizing the energy from hot carriers to drive the SMR reaction.

“We tested many catalyst systems, but this one turned out to work best,” Yuan said.

The research indicates that antenna-reactor technology can effectively address catalyst deactivation caused by oxidation and coking.

This technology [successfully](#) regenerates the catalyst using light by utilizing hot carriers to remove oxygen species and carbon deposits.

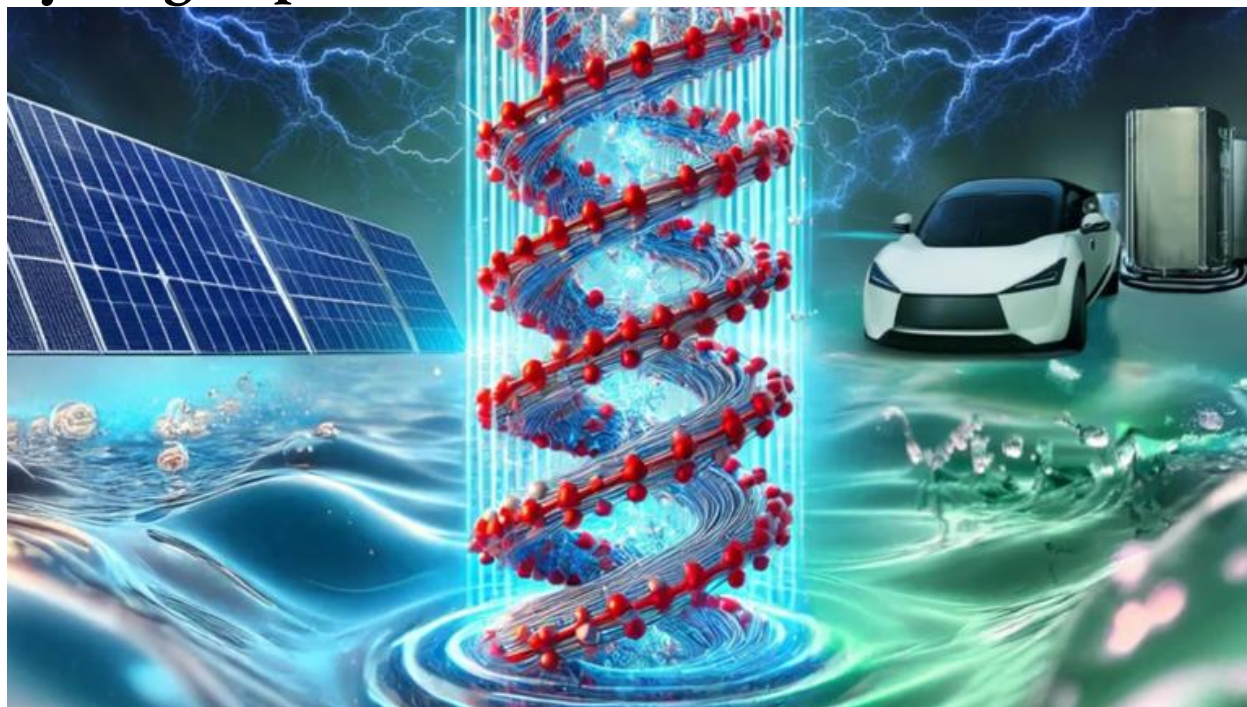
Nordlander said the key to this “remarkable effect was the clever placement of the rhodium,” which is spread sparingly and unevenly across the surface of the nanoparticles.

Hydrogen is currently mostly produced in large, centralized facilities, which require gas to be transported to the point of use.

In contrast, light-driven SMR allows for on-demand hydrogen generation, a key benefit for use in mobility-related applications such as hydrogen fueling stations or vehicles.

“This research showcases the potential for innovative photochemistry to reshape critical industrial processes, moving us closer to an environmentally sustainable energy future,” Halas [said](#).

Spin-powered crystals could boost clean hydrogen production 200 times



Spin-powered crystals could boost clean hydrogen production 200 times

Hydrogen is increasingly seen as an important element in the transition to a low-carbon future.

Now, researchers have discovered a new approach to improve the efficiency of water splitting, a process that produces clean hydrogen fuel.

Max Planck Institute researchers used a special type of crystal called topological chiral crystals.

These crystals, with their unique chiral structure, possess extraordinary quantum properties. They can manipulate the spin of electrons, allowing for a highly efficient water-splitting process.

"By leveraging the unique spin properties of electrons, we've created a catalyst that outperforms traditional materials by a factor of 200," said Binghai Yan.

Overcoming slow reaction challenge

Hydrogen is a versatile fuel that can be used in various applications, including transportation, power generation, and industrial processes. It offers a clean and sustainable alternative to greenhouse gas-emitting fossil fuels.

Moreover, it can be stored and transported efficiently, making it a valuable solution for storing excess renewable energy. Therefore, the demand is expected to exponentially increase in the coming years.

Water splitting is a promising technique for producing clean hydrogen energy by breaking water molecules into hydrogen and oxygen.

However, this process is hindered by the slow oxygen evolution reaction (OER).

The OER involves a complex series of electron transfer steps, which are inherently slow. This sluggishness majorly reduces the overall efficiency of water splitting, making it less cost-effective.

To overcome this challenge, researchers are actively exploring new ways to accelerate the process.

In this new development, the researchers turned to these crystals with unique "chiral" structures.

"These crystals are essentially quantum machines," said Dr. Xia Wang, lead researcher from the Max Planck Institute for Chemical Physics of Solids.

These crystals possess a distinct left- or right-handed atomic arrangement, which allows them to interact with light and other chiral molecules in specific ways.

This manipulation helps to speed up the oxygen evolution reaction for successful water splitting.

Enhances the process

The researchers designed topological chiral crystals, which were composed of various elements like rhodium, silicon, tin, and bismuth. This provides the crystals with a remarkable ability to manipulate the spin of electrons.

The unique quantum properties of these crystals allow electrons to move more efficiently toward the oxygen generation sites during the water-splitting process.

This accelerated electron transfer significantly boosts the overall reaction rate, making it 200 times more efficient than traditional catalysts.

“We are aware that our catalysts still contain rare elements, however we are confident that based on our design scheme we will come up soon with highly efficient and also sustainable catalysts,” Yan added in the [press release](#).

This discovery has the potential to advance the energy sector. With more efficient hydrogen production, it can power our homes, vehicles, and industries with clean, renewable energy.

Currently, [clean hydrogen](#) production faces challenges like high costs and efficiency issues, but continued research and development promise to make it a crucial part of a clean energy future.

The findings were published in the journal [Nature Energy](#).

Expediting the Innovation and Application of Solid Hydrogen Storage Technology

1. Introduction

[Hydrogen energy](#) can be stored and transported, which is not only one of its advantages, but also the main bottleneck in its application. Solid [hydrogen storage](#) provides an important means of storing hydrogen energy with high density and safety. First, this

method can greatly improve the hydrogen storage density. Among the three existing hydrogen storage methods, namely, high-pressure compression, liquefaction, and solidification, solid-state hydrogen storage has the highest volumetric hydrogen storage density. For example, the volumetric hydrogen storage density of MgH_2 can reach 106 kg H_2 per cubic meter, which is 1191 times higher than that of standard hydrogen density, 2.7 times higher than that of 70 MPa compression hydrogen, and 1.5 times higher than that of liquid hydrogen. Second, solid-state hydrogen storage can enhance the safety of hydrogen storage and transportation, because it makes it possible to store hydrogen under atmospheric temperature and pressure, with an easy-to-seal storage tank. Even in the emergency case of hydrogen leakage, a solid-state hydrogen storage tank can automatically reduce the flow rate and amount of hydrogen leakage, so as to gain valuable time for taking safety measures.

However, high-pressure compression technology still remains dominant in the storage and transportation of hydrogen energy, and solid-state hydrogen storage technology is limited to small-scale applications in certain specific scenarios. The main reasons are as follows: First, the overall performance of solid hydrogen storage cannot fully meet the requirements of onboard hydrogen storage systems. The gravimetric density of well-developed hydrogen storage materials, such as rare earth series, titanium (Ti) series, and titanium vanadium (TiV) solid solution materials, is relatively low. TiV solid solution materials, which have the greatest reversible hydrogen storage capacity among these materials, have a capacity of only 2.6 wt%. Lightweight and high-capacity hydrogen storage materials, such as complex hydrides, amides, and metallic aminoborane, are still under development. Although these materials have a high gravimetric density (e.g., the capacity of ammonia borane is as high as 19.6 wt%), they also have disadvantages, such as the high temperature, slow speed, and poor cycle life of hydrogen absorption and desorption. Second, the cost of solid hydrogen storage is relatively high, because the technology is mostly in the demonstration application stage. Hydrogen storage materials and systems are still in the laboratory or pilot-scale phase; thus, small manufacturing batches, a low yield of hydrogen storage materials and systems, high processing costs for materials and containers, and high prices for accessories such as valves and pipelines all result in the high cost of a solid hydrogen storage system.

In order to promote the application of solid hydrogen storage in the hydrogen energy market, fully make use of its advantages of high density and safety of hydrogen storage, increase the market shares, and continuously improve this technology in practical application, suggestions and ideas include:

- (1) Expanding the market for hydrogen energy applications beyond transportation. More mature technologies should be adopted as soon as possible for specific market segments, and effective measures should be taken to control costs in order to meet specific market requirements, such as those of distributed energy supply systems.
- (2) Combining solid hydrogen storage with compression and liquid hydrogen storage in order to develop composite hydrogen storage, such as static compression high-density hydrogen storage integration systems and composite hydrogen slurry using magnesium-based hydrogen storage materials.

(3) Speeding up the development of onboard hydrogen storage systems and related high-capacity materials. A [green hydrogen](#) supply chain should be established, the hydrogen supply process should be simplified, and the cost of hydrogen supply should be reduced through the application of low-pressure and high-density onboard hydrogen storage systems in [fuel cell vehicles](#).

2. Expediting the application of mature technologies in stationary hydrogen storage

Mature metal [hydrogen storage materials](#) have a low gravimetric density for [hydrogen storage](#), but are very suitable for stationary applications due to their high volumetric density for hydrogen storage, small occupied area, low storage pressure, and high safety. The key to developing the stationary hydrogen storage market lies in identifying market segments, effectively controlling costs, and boosting the technical and economic competitiveness of solid hydrogen storage.

In 2012, we developed a solid hydrogen storage system with a hydrogen storage capacity of 40 m³, which was successfully coupled with a 5 kW [fuel cell system](#) to provide a continuous power supply for a communication [base station](#) for nearly 17 h. However, the system has not been well promoted after its demonstration, due to a lack of market demand. When the third generation (3G) of mobile telecommunications technology was replaced by 4G in that year, the [power consumption](#) of communication base stations decreased significantly, such that lithium-ion batteries could meet the application demand. Moreover, as the cost of lithium-ion batteries dropped rapidly, the price of fuel cells, which were priced as high as 10 000 CNY·kW⁻¹ in that year, was obviously uncompetitive. In the past two years, with the promotion of 5G, the power consumption of communication base stations has increased, highlighting the advantages of the powerful and long-term power supply of fuel cells. At the same time, [fuel cell technology](#) in China has developed rapidly in the last two years, causing the price per kilowatt of fuel cells to drop to 1699 CNY, and rapidly improving the technical and economic competitiveness of fuel cells in the base station power-supply market. A supporting solid hydrogen storage device should be developed synchronously in order to fully meet the technical and economic requirements of a base station communication power supply. If the cost of solid-state hydrogen storage is controlled at about 8000 CNY per kilogram of H₂, the energy [storage cost](#) can compete well with that of lithium-ion batteries. Reducing the cost of solid hydrogen storage quickly has become an urgent task in order to accelerate the commercial application of fuel cell backup power-supply systems.

Onsite hydrogen storage that matches the scale of [hydrogen production](#) from [renewable energy sources](#) is another important arena for the current application of mature solid-state hydrogen storage technologies. The McStore magnesium-based solid-state hydrogen storage system developed by the McPhy Energy S.A. in France has been used in renewable-energy-scale energy storage. We have also developed a 1000 m³ TiFe solid-state hydrogen storage system, which is expected to be used in the Hebei Guyuan wind power [hydrogen production](#) project as a safe and compact onsite hydrogen buffer, providing a 6N (99.9999%) high-purity [hydrogen source](#) for high-value utilization. The

key point that this solid-state hydrogen storage system can be recognized by the market, is whether the comprehensive cost of the system is competitive in comparison with high-pressure hydrogen storage. Important ways to reduce the cost of a solid-state hydrogen storage system include reducing the cost of hydrogen storage materials and expanding their application scale appropriately.

3. New attempts at composite hydrogen storage

To broaden the application of metal hydrogen storage materials, solid hydrogen storage is combined with high-pressure and [liquid hydrogen](#) storage to develop composite hydrogen storage technologies, such as static compression high-density hydrogen storage [integrated systems](#) and composite hydrogen slurry using magnesium-based hydrogen storage materials. As these new technologies develop, it is expected that new application fields for solid hydrogen storage can be exploited.

In the process of [hydrogen absorption](#) and desorption, hydrogen storage materials exhibit a plateau. When the temperature rises, the plateau pressure increases exponentially. Given this characteristic, a heat-exchange medium can be used to realize the static [pressurization](#) of hydrogen—that is, hydrogen storage at a low pressure and low temperature, and hydrogen refueling at a [high pressure and high temperature](#). Moreover, this type of hydrogen storage has a low hydrogen storage pressure, a high hydrogen storage density, and good safety when stored at atmospheric temperature, which can reduce the area occupied by storage tanks and decrease the necessary safety distance between stations. In order to improve the rapid response characteristics of hydrogen desorption in storage tanks, solid-state hydrogen storage and compression hydrogen storage can be appropriately combined, and the rapid response characteristics of a mixed hydrogen storage system can be improved by utilizing the rapid hydrogen desorption characteristics of compression hydrogen storage. Based on this principle, we have successively developed 45 and 90 MPa static compression and high-density hydrogen storage integrated systems.

Magnesium has a high hydrogen storage density but a high [hydrogen desorption temperature](#). As long as the links of high-temperature hydrogenation and [dehydrogenation](#) are fixed at the application terminal and hydrogen transport is maintained at atmospheric temperature and pressure, magnesium-based hydrogen storage will be a very good method for high-density and high-safety [hydrogen transportation](#). In order to increase the hydrogen transport capacity of a single vehicle, magnesium-based hydrogen storage materials should be packed in a large tank in order to significantly reduce the weight of the hydrogen transport tanks, and multi-tube bundle reactors should be fixed at the terminals of hydrogenation and application. This method requires magnesium-based hydrogen storage materials to flow. To realize such flow, we have combined magnesium-based hydrogen storage materials with organic hydrogen storage materials to form a hydrogen slurry. In this hydrogen slurry, magnesium-based hydrogen storage material powder and organic liquid are both high-density hydrogen storage media.

In addition, magnesium-based hydrogen storage materials can be used as catalysts for organic liquid hydrogen storage, while organic liquid hydrogen storage materials can be

used to improve the heat and mass-transfer characteristics of magnesium-based hydrogen storage materials; thus, these two types of material complement each other. Preliminary experiments have demonstrated that hydrides have a good catalytic effect on hydrogen storage and release in organic liquids, and can replace the original noble metal catalysts. Magnesium-based hydrogen storage materials still have good hydrogen absorption and desorption performance at the gas–solid–liquid three-phase interface. These results prove the feasibility of this idea.

4. High-density onboard hydrogen storage systems for a green hydrogen supply chain

The original intention of [hydrogen energy](#) application is to develop “green” hydrogen. We should make full use of the characteristics of [green hydrogen](#), build a green hydrogen supply chain, simplify the hydrogen supply process, and reduce the hydrogen supply cost. The 4 MPa green hydrogen obtained by the [electrolysis of water](#) using electricity from [renewable energy sources](#) can be directly introduced into a 4 MPa pure hydrogen transmission pipeline and sent to a low-pressure [hydrogen refueling station](#) without [pressurization](#). It can then be directly charged into the low-pressure and high-density onboard solid-state hydrogen storage systems of [fuel cell vehicles](#). Low-pressure hydrogenation makes it unnecessary to use a high-pressure compressor or high-pressure storage tank in a high-pressure [refueling station](#), thus significantly reducing the equipment costs of refueling stations, improving the safety and reliability of hydrogenation, and reducing the hydrogenation cost, all of which stem from the application of low-pressure onboard hydrogen storage systems.

We have undertaken a preliminary exploration using TiMn hydrogen storage materials. A low-pressure solid hydrogen storage system loaded on a 9 m fuel cell bus can be refilled fully with 17 kg of hydrogen in 15 min under 5 MPa low-pressure hydrogenation. The hydrogen consumption per 100 km under a full-load bus mode is 4.77 kg, so a hydrogen storage capacity of 17 kg can meet the requirements for driving continuously for more than 300 km with one charge. However, the hydrogen consumption of a fuel cell bus using solid hydrogen storage per 100 km is still 0.2–0.3 kg higher than an equivalent bus using compression hydrogen storage. Reducing the weight of the hydrogen storage system is an urgent task; furthermore, it is particularly urgent to develop hydrogen storage materials with higher capacity. The LiMgBNH material we have developed can absorb 5.3% of hydrogen in 10 min at 150 °C and 8 MPa, and can release 4.1% of hydrogen at 0.1 MPa. The gravimetric density of a hydrogen storage tank using this material is similar to that of a 35 MPa compression hydrogen storage system. An onboard hydrogen storage system using this material, developed by our partner Maximilian Team in Karlsruher Institut für Technologie (KIT) of [Germany](#), was coupled with a high-temperature proton-exchange membrane fuel cell and met the application requirements for fuel cells [1]. Recently, an [MXene](#) incompletely etched with [hydrofluoric acid](#), which was developed by Jianglan Shui et al. at Beijing University of Aeronautics and Astronautics, China, showed an unprecedented hydrogen uptake of 8.8 wt% at room temperature and 60 bar H₂ (1 bar = 10⁵ Pa). The hydrogen release was controllable by pressure and temperature below 95 °C. The [MXene](#) also exhibited a good reversible cycle performance of hydrogenation and [dehydrogenation](#) [2]. These

researches are exploring a new path for the application of high-capacity hydrogen storage materials.

There is still a long way to go to achieve high-density onboard hydrogen storage systems based on a green hydrogen supply chain. The reliability and economics of high-temperature proton-exchange membrane fuel cells still need to be verified, the performance of high-capacity hydrogen storage materials must be continuously enhanced, and the relevant standards of solid-state hydrogen storage systems require improvement. Once these problems are solved, the situation of the application of hydrogen energy will be changed.

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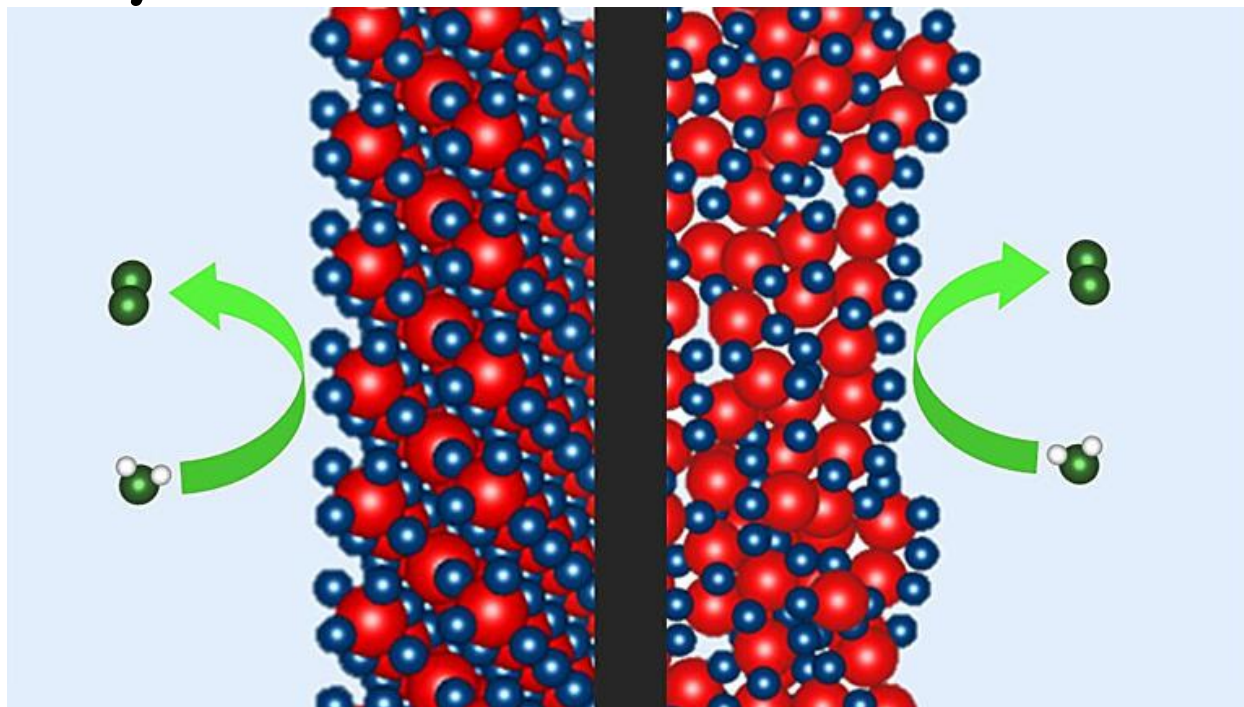
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Less is more: Why an economical iridium catalyst works so well



Two different Iridium-based nanocatalysts for water electrolysis were examined by a HZB-led team: A commercial benchmark catalyst (left) and the newly developed P2X catalyst (right), which is more amorphous and needs four times less Iridium. The spectroelectrochemical data show how the specific chemical environments differ in both materials and how these influence the oxygen evolution reaction. Credit: M. van der Merwe / HZB

Iridium-based catalysts are needed to produce hydrogen using water electrolysis. Now, a team at HZB has shown that the newly developed P2X catalyst, which requires only a quarter of the iridium, is as efficient and stable over time as the best commercial catalyst. Measurements at BESSY II have now revealed how the special chemical environment in the P2X catalyst during electrolysis promotes the oxygen evolution reaction during water splitting.

In the future, hydrogen will be needed in a climate-neutral energy system to store energy, as a fuel, and a raw material for the chemical industry. Ideally, it should be produced in a climate-neutral way, using electricity generated from harnessing the sun's or wind energy, via the electrolysis of water.

In that respect, Proton Exchange Membrane Water Electrolysis (PEM-WE) is currently considered a key technology. Both electrodes are coated with special electrocatalysts to accelerate the desired reaction. Iridium-based catalysts are best suited for the anode, where the sluggish oxygen evolution reaction occurs. However, iridium is one of the rarest elements on earth, and one of the major challenges is to significantly reduce the demand for this precious metal.

A [rough analysis](#) showed that to meet the world's hydrogen demand for transport using PEM-WE technology, iridium-based anode materials should contain no more than 0.05 mg_{Ir}/cm². The current, best commercially available catalyst made from iridium oxide contains about 40 times as much as this target value.

P2X-catalyst needs less iridium

But new options are already in the pipeline: Within the Kopernikus P2X project, a new efficient iridium-based nanocatalyst was developed by the Heraeus Group, consisting of a thin layer of iridium oxide deposited on a nanostructured titanium dioxide support. The so-called "P2X catalyst" requires only an extremely small amount of iridium, reducing precious metal loading substantially (four times lower than in the current best commercial material).

A team at HZB led by Dr. Raul Garcia-Diez and Prof. Dr.-Ing. Marcus Bär, together with colleagues from the ALBA synchrotron in Barcelona, have studied the P2X catalyst, which shows remarkable stability even in long-term operation, and compared its catalytic and spectroscopic signature with the benchmark commercial crystalline catalyst.

The paper is [published](#) in the journal *ACS Catalysis*.

Operando measurements at BESSY II

The HZB team has thoroughly investigated the commercial benchmark catalyst as well as the P2X catalyst at BESSY II during water electrolysis (operando measurements).

"We wanted to observe how the two different catalyst materials change structurally and electronically during the electrochemical oxygen evolution reaction using operando Ir L₃-edge X-ray absorption spectroscopy (XAS)," says Marianne van der Merwe, a researcher in Bär's team.

They also developed a new experimental protocol to ensure that the results are measured in both samples under exactly the same oxygen production rate. This made it possible to compare the two catalysts under equivalent conditions.

Different chemical environments explored

"From the measurement data, we were able to conclude that the mechanisms for OER in the two classes of iridium oxide catalysts are different, and this is driven by the different chemical environments of the two materials," says van der Merwe.

The measurement data also show why the P2X catalyst performs even better compared to its more crystalline benchmark: in the P2X sample, the bond lengths between iridium and oxygen decrease significantly more than in the reference catalyst at OER relevant potentials. This reduction in Ir-O bond lengths can be associated to the participation of defective environments that are proposed to be key players in highly active pathways of the oxygen evolution reaction.

"In addition, the electronic state observations also correlate with local geometric information," van der Merwe points out.

"Our work provides valuable key information about the different mechanisms of iridium oxide-based electrocatalysts during the oxygen evolution reaction and deepens our understanding of catalyst performance and stability, while our newly

proposed in situ spectroscopic electrochemical protocol approach is generally applicable to all anode materials studied under relevant OER conditions."

More information: Marianne van der Merwe et al, Electronic and Structural Property Comparison of Iridium-Based OER Nanocatalysts Enabled by Operando Ir L3-Edge X-ray Absorption Spectroscopy, *ACS Catalysis* (2024). DOI: [10.1021/acscatal.4c03562](https://doi.org/10.1021/acscatal.4c03562)

Provided by Helmholtz Association of German Research Centres

Trillions of tons of underground hydrogen could power Earth for over 1,000 years: Study

Trillions of tons of underground hydrogen could power Earth for over 1,000 years: Study

A recent study has suggested that trillions of tons of hydrogen gas could be buried beneath the Earth's surface. Led by a petroleum geochemist at the U.S. Geological Survey, the study suggests that Earth could hold around 6.2 trillion tons (5.6 trillion metric tons) of hydrogen in rocks and underground reservoirs.

Researchers claimed that just a fraction of this massive amount of hydrogen gas could reduce humans' dependency on fossil fuels for almost 20 decades.

Formed during natural geochemical processes on Earth, geologic hydrogen could fulfill multiple needs. So far, it has been discovered in just a few places, including Albania and Mali.

Reserves could stretch all around globe

However, a recent study claims that these reserves could [stretch](#) all around the globe. Although, most of the hydrogen is expected to be too deep or too far offshore to be accessed.

Some of the reserves are probably too small to extract in a way that makes economic sense, the researchers suspect. However, the results indicate there's more than enough hydrogen to go around, even with those [limitations](#), Geoffrey Ellis, a petroleum geochemist at the U.S. Geological Survey (USGS) and lead author of the new study, told [Live Science](#).

Researchers claimed that geologic hydrogen could be a low-carbon primary energy resource; however, the magnitude of Earth's subsurface endowment has not yet been assessed. Knowledge of the occurrence and behavior of natural hydrogen on Earth has been combined with information from geologic analogs to construct a mass balance model to predict the resource potential.

5.6×10^6 metric tonnes of hydrogen

The study published in [Science Advances](#) predicts a wide range of values for the potential in-place hydrogen resource (103 to 1010 million metric tons (Mt)) with the most probable value of $\sim 5.6 \times 10^6$ Mt. Although most of this hydrogen is likely to be impractical to recover, a small fraction or two percent (e.g., 1×10^5 Mt) would supply the projected hydrogen needed to reach net-zero carbon emissions for ~ 200 years.

This amount of [hydrogen](#) contains more energy ($\sim 1.4 \times 10^{16}$ MJ) than all proven natural gas reserves on Earth ($\sim 8.4 \times 10^{15}$ MJ). Study results demonstrate that further research into understanding the potential for geologic hydrogen resources is merited, according to the study.

Researchers developed a model to estimate the size of these reservoirs globally, combining a prior understanding of how hydrogen occurs and behaves with geologic data. This model suggests there may be as much as 5.6×10^6 metric tonnes (that's the equivalent weight of 3.7 million cars or 1.56 billion flamingos) of hydrogen hiding beneath the [surface](#).

Prof Bill McGuire, an Earth scientist at University College London (UCL), told [BBC Science Focus](#) that to suck up hydrogen at a scale required to make a contribution to bringing down emissions and tackling the climate emergency would require an enormous global initiative for which we simply don't have time.

Hidden hydrogen reserves could power world for 200 years

Scientists did not believe that hydrogen accumulates underground, but recent discoveries suggest otherwise.
(illustrative photo) @andreiuc88/ Adobe Stock© Licensar

Vast amounts of hydrogen lie beneath the Earth's surface, and scientists have discovered that only a fraction of it could power the world for the next 200 years. This groundbreaking discovery has the potential to revolutionize energy production and serve as an alternative to coal, oil, or natural gas.

Until recently, scientists did not believe that hydrogen accumulates underground, but new discoveries suggest otherwise. "Trillions of tons of hydrogen gas are likely buried in rocks and reservoirs beneath the surface," researchers claim, although the exact locations are still unknown. Their latest findings have been published in the scientific journal "Science Advances."

Hydrogen as an energy source could replace coal, oil, and gas

Hydrogen is a source of clean energy that can power vehicles, drive industrial processes, and generate electricity. Until now, it was believed that hydrogen in the natural environment could not accumulate significantly because it evaporates easily due to its small molecular size. Recent discoveries, including **in West Africa and a chrome mine in Albania**, prove that hydrogen can indeed accumulate in substantial quantities.

New research indicates that **the planet holds approximately 6.2 trillion tons of hydrogen** (6.2 billion US tons) in rocks and underground reservoirs. That's about 26 times more than the amount of oil left in the ground (1.6 trillion barrels, each weighing about 0.15 tons). However, the locations of these hydrogen reserves remain undiscovered for now.

Petroleum geochemist: energy from hydrogen is twice as much

Geoffrey Ellis, a petroleum geochemist at the US Geological Survey (USGS), and the lead author of the new study, emphasizes that even just a fraction of this amount could meet our energy needs for the next 200 years and importantly **replace fossil fuels** (coal, oil, or natural gas). It is an emission-free and clean energy source. Only **2 percent of the hydrogen resources** found in the study, which **equates to 123 billion US tons of gas**, "would provide all the hydrogen we need to achieve a net-zero [carbon] value for several hundred years," conveyed Geoffrey Ellis. He explains that the energy released by this amount of hydrogen is about **twice as much** as the energy stored in all known natural gas reserves on Earth.

According to scientists, most hydrogen is likely located too deep or too far offshore to be reached, and some reserves are probably too small to extract economically. However, the results suggest there is more than enough hydrogen to meet global needs, even with these limitations. Importantly, natural hydrogen reserves are stable in their locations, meaning they do not require additional storage costs or further generation processes.

Demand for new energy to increase several-fold by 2050

It is projected that hydrogen will account for up to 30 percent of future energy supplies in certain sectors, and **global demand is expected to increase fivefold by 2050**. How can it be used? Hydrogen gas is artificially produced through water electrolysis, a process in which water molecules are split by electric current. When renewable energy is used, the product is called "green hydrogen," and when fossil fuels are used, it is known as "blue hydrogen." According to scientists, a precise determination of hydrogen deposits in the US may become available in the coming months.

Scientists Built a Sunlight Reactor to Fuel the Future

- Green hydrogen is an excellent resource for weening humanity off of fossil fuels, but making it currently uses too much renewable energy.
- A new method being explored by Japanese researchers would primarily use sunlight and a photocatalyst to separate hydrogen and oxygen in water.
- This could help lower the cost of green hydrogen, making it a key player in the green energy transition.

Hydrogen fuels come in many colors—each one an indicator of how the fuel was initially created. Blue hydrogen refers to fuel created from steam (and capturing the resulting carbon underground), pink hydrogen means that nuclear energy powers the electrolysis process, and black and brown hydrogen (as their name denotes) splits H_2O using fossil fuels, which isn't exactly helpful with the whole cutting emissions thing. The industry's holy grail is what's known as "green hydrogen," which is a climate-neutral process that uses renewable energy sources to create hydrogen.

However, according to the [World Economic Forum](#), only 0.1 percent of all hydrogen production can be described as "green." That's because it requires so much renewable energy to create, making the process cost prohibitive. For green hydrogen to really take off, the industry needs a [material](#) breakthrough to lower the cost of this energy-dense alternative. Luckily, scientists at Shinshu University, located in Matsumoto, Japan, think they may be nearing a solution.

Detailed in a new paper published in the journal [Frontiers in Science](#), the researchers describe a proof-of-concept panel reactor built with a photocatalytic sheets that can split water using the power of [sunlight](#).

"Sunlight-driven water splitting using photocatalysts is an ideal [technology](#) for solar-to-chemical energy conversion and storage," Kazunari Domen, a senior author of the study from Shinshu University, [said in a press statement](#), "and

recent developments in photocatalytic materials and systems raise hopes for its realization.”

Photocatalysts are materials that promote chemical reactions—in this case, splitting hydrogen and [oxygen](#). A one-step excitation system breaks apart the two elements, but the researchers say that this process is inefficient and delivers a low solar-to-hydrogen energy conversion rate. A two-step excitation process on the other hand, where one photocatalyst is dedicated to the evolution of each element, is much more efficient.

“Obviously, solar energy conversion technology cannot operate at night or in bad weather, but by storing the energy of sunlight as the [chemical](#) energy of fuel materials, it is possible to use the energy anytime and anywhere,” Takashi Hisatomi from University of Shinshu said in the press release.

Sounds great, right? Well, Domen readily admits that some challenges still remain. While the two-step excitation process is more efficient, the team still needs to find materials robust enough to withstand daily start-up and shut-down operations when the [Sun](#) is and isn’t shining while also increasing conversion efficiency so that these reactors can be as small as is physically possible. Designs also need to incorporate the safe handling of oxyhydrogen, which can be highly explosive.

But there is also some good news. Domen and his team operated their proof-of-concept reactor for three years, and the machine actually performed *better* under natural sunlight than it did in [laboratory](#) conditions.

“The most important aspect to develop is the efficiency of solar-to-chemical energy conversion by photocatalysts,” Domen said in a press statement. “If it is improved to a practical level, many researchers will work seriously on the development of mass production technology and [gas](#) separation processes, as well as large-scale plant construction.”

Japan is the world’s leader in hydrogen fuel, but some experts—including the [Renewable Energy Institute](#)—have worried that the country’s extreme focus on the technology has caused it to lag behind on implementing other green energy technologies. If scientists could somehow make the production of green hydrogen economically feasible, Japan’s dream of a “hydrogen society” could one day become a reality.

Researchers invent futuristic fuel cell with potential to transform industries: 'Perfect for smaller industrial companies'



"Ideal starting material for climate-friendly generation of electricity and heat energy."

A research team in Germany says it has developed an innovative way to [store](#) and transport hydrogen, which can unleash its [pollution-free energy](#).

The secret ingredient that the Fraunhofer Institute for Ceramic Technologies and Systems scientists tapped into is ammonia, a hydrogen derivative.

"Ammonia has been used in the chemical industry for decades, for example to produce fertilizers, so there are established and familiar processes of handling this substance," Fraunhofer researcher Laura Nusch said in a [press release](#).

Nusch said ammonia's "high energy density" and relative ease in storage and transport made it an "ideal starting material for climate-friendly generation of electricity and heat energy."

The Fraunhofer team's process was to feed ammonia into a cracker that they'd heat to temperatures exceeding 570 degrees Fahrenheit. That created both hydrogen and nitrogen. They then paired water vapors with the nitrogen, forming harmless exhaust gases.

Meanwhile, the scientists transmitted the hydrogen into a [high-temperature ceramic fuel cell](#). The resulting electrochemical reaction created electricity with 60% efficiency, which is comparable to processes using [natural gas](#).

Of course, hydrogen-generated energy avoids the [planet-warming](#) carbon pollution associated with burning [dirty energy](#) like [natural gas](#).

Watch now: Tide director reveals how the company convinced millions to change laundry habits

Additionally, the researchers said the process created thermal heat that could be used to heat the cracker or for other purposes. It's also important to point out that the scientists completed the process in one fuel-cell demonstrator device.

As the world looks for [clean energy](#) solutions, maximizing the power of hydrogen is a major challenge. The appeal is obvious — unlike competing [dirty energy](#) sources, [hydrogen doesn't pollute](#) and instead turns into harmless water vapors and steam when burned in a fuel cell.

Storage is a major sticking point, though, and the Fraunhofer scientists' ammonia solution joins other ideas in development, such as [storing in reservoirs and lakes](#).

Another challenge holding up the bright promise of the [hydrogen economy](#) is the current dominant forms of extraction that [rely heavily](#) on [dirty energy](#).

Unlocking "[green hydrogen](#)" is an objective of multiple companies and [researchers](#).

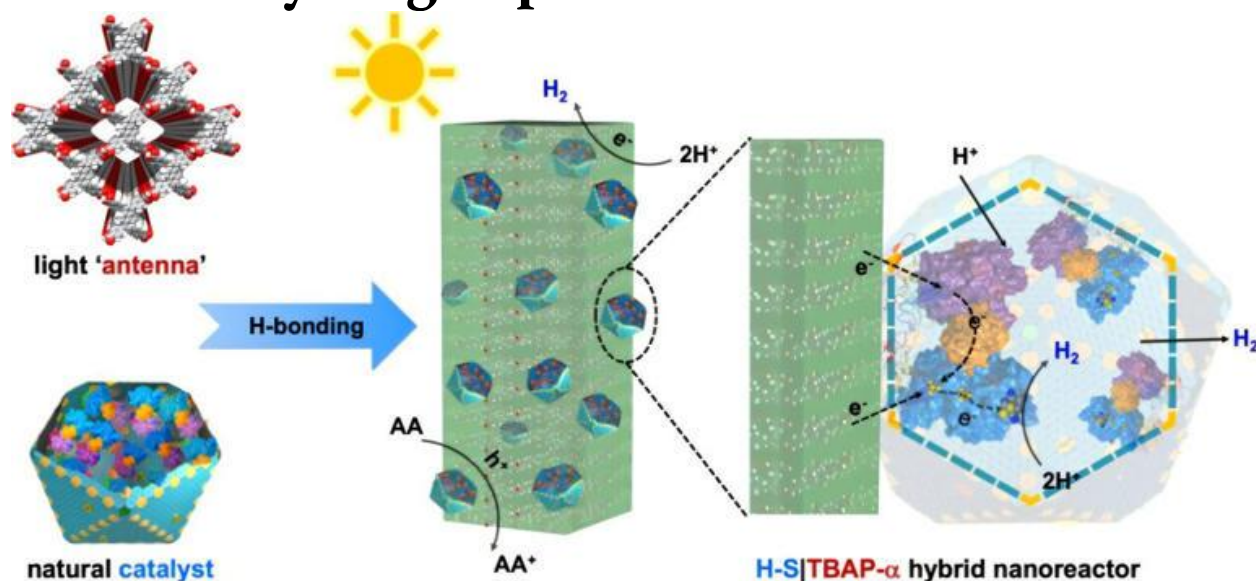
Even as hydrogen faces major roadblocks to viability, there are inspiring examples of [fuel-cell cars](#), record-setting [hydrogen trucks](#), [planes](#), and [ships](#), which point to all of the potential technological uses.

The Fraunhofer team has specific use cases in mind as they can leverage "targeted design and smart thermal management" with fuel-cell stacks of different sizes and power levels to deliver "customized solutions," Nousch said in the [press release](#).

"The system is perfect for smaller industrial companies that want to generate electricity without carbon emissions...or for municipalities and local utility companies looking to supply green heat to their customers," Nousch added.

One more exciting potential customer is [large ships](#), which Nousch said, "can be equipped with eco-friendly drives based on ammonia/hydrogen in this way."

Light-driven hybrid nanoreactor offers cost-effective hydrogen production



Credit: ACS Catalysis (2024). DOI: 10.1021/acscatal.4c03672

The University of Liverpool has reported a significant advancement in engineering biology and clean energy. A team of researchers has developed an innovative light-driven hybrid nanoreactor that merges natural efficiency with cutting-edge synthetic precision to produce hydrogen—a clean and sustainable energy source.

The study, [published](#) in *ACS Catalysis*, demonstrates a pioneering approach to artificial photocatalysis, addressing a critical challenge in using solar energy for fuel production. While nature's photosynthetic systems have evolved for optimal

sunlight utilization, artificial systems have struggled to achieve comparable performance.

The hybrid nanoreactor is the product of a novel integration of biological and synthetic materials. It combines recombinant α -carboxysome shells—natural microcompartments from bacteria—with a microporous organic semiconductor. These carboxysome shells protect sensitive hydrogenase enzymes, which are highly effective at producing hydrogen but prone to deactivation by oxygen. Encapsulating these enzymes ensures sustained activity and efficiency.

Professor Luning Liu, chair of microbial bioenergetics and bioengineering at the University of Liverpool has worked in collaboration with Professor Andy Cooper, from the Department of Chemistry and Director of the University's Materials Innovation Factory. Together, their teams synthesized a microporous organic semiconductor that acts as a light-harvesting antenna. This semiconductor absorbs visible light and transfers the resulting excitons to the biocatalyst, driving hydrogen production.

Professor Luning Liu said, "By mimicking the intricate structures and functions of natural photosynthesis, we've created a hybrid nanoreactor that combines the broad light absorption and exciton generation efficiency of synthetic materials with the catalytic power of biological enzymes. This synergy enables the production of hydrogen using light as the sole energy source."

This latest work has significant implications and has the potential to eliminate the reliance on expensive precious metals like platinum—offering a cost-effective alternative to traditional synthetic photocatalysts while achieving comparable efficiency. This breakthrough not only paves the way for sustainable hydrogen production but also holds potential for broader biotechnological applications.

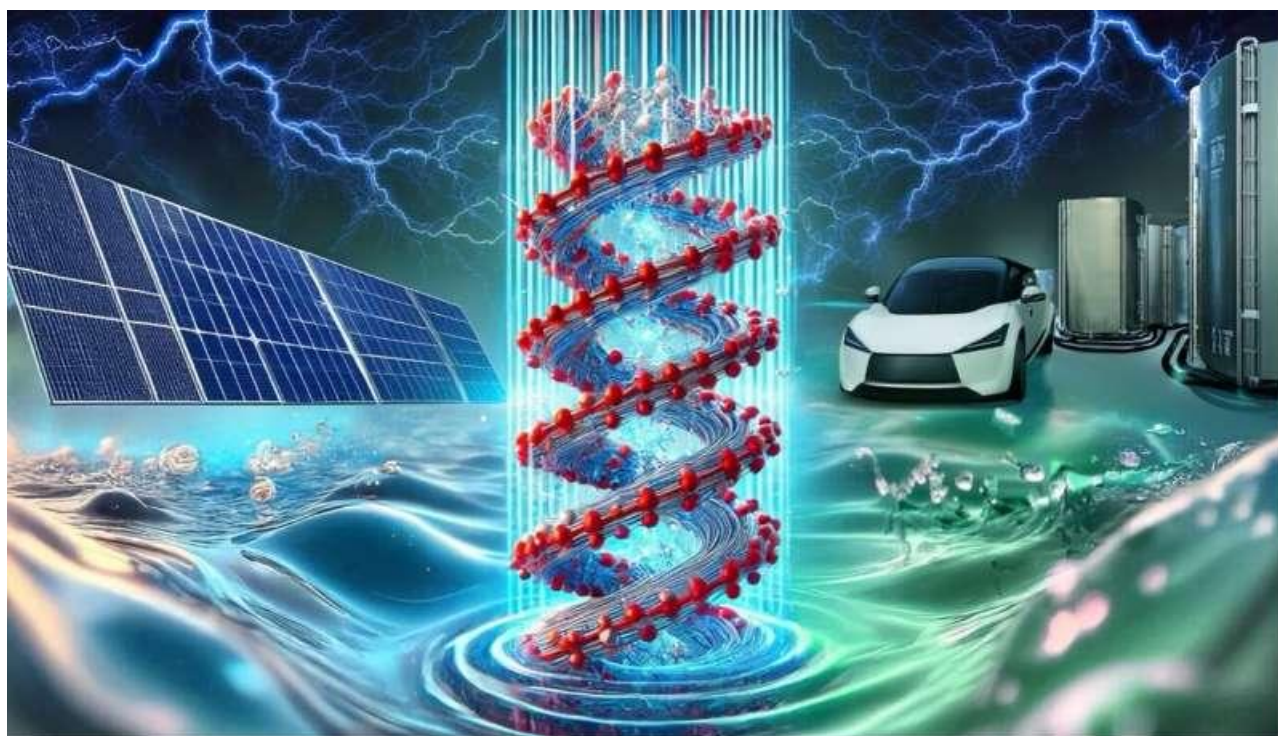
Professor Andy Cooper, director of the Materials Innovation Factory concluded, "It's been fantastic to collaborate across university faculties to deliver these results. The study's exciting findings open doors to fabricating biomimetic nanoreactors with wide-ranging applications in clean energy and enzymatic engineering, contributing to a carbon-neutral future."

More information: Jing Yang et al, Light-Driven Hybrid Nanoreactor Harnessing the Synergy of Carboxysomes and Organic Frameworks for Efficient Hydrogen Production, *ACS Catalysis* (2024). DOI: [10.1021/acscatal.4c03672](https://doi.org/10.1021/acscatal.4c03672)

DECEMBER 16, 2024 **FEATURE**

Harnessing spin: New electrocatalysts could transform hydrogen production efficiency

by Ingrid Fadelli , Tech Xplore



Credit: OpenAI Dall-E.

Electrocatalytic water splitting, a process that entails breaking down water into hydrogen and oxygen, is a promising approach to produce clean hydrogen for fuel cells, which could in turn be used to power large electric vehicles. So far, the real-world use of this process has been limited by the sluggish kinetics of the oxygen evolution reaction (OER), a key chemical reaction occurring at the anode.

Researchers at Max-Planck-Institute for Chemical Physics of Solids, Weizmann Institute of Science and other institutes recently introduced an innovative approach to accelerate this reaction, using topological chiral semimetals as electrocatalysts.

Their findings, [published](#) in *Nature Energy*, demonstrate that spin-orbit coupling (SOC) inherent in these materials can be leveraged to boost OER activity, facilitating more efficient electrocatalytic water splitting.

"Our research was driven by the pressing need for clean and sustainable energy solutions," Xia Wang, first author of the paper, told Tech Xplore.

"Specifically, we aimed to address the challenge of improving electrocatalytic water splitting for [hydrogen production](#), with a focus on the OER, a critical step often hindered by sluggish kinetics. The inspiration came from the distinctive electron transport properties of topological chiral semimetals, which offered a promising pathway to address the limitations of traditional catalysts."

The key goal of the recent study by Wang and her colleagues was to harness the quantum properties of topological chiral semimetals to enhance OER efficiency. To achieve this, the team first synthesized a series of Rh-based topological chiral semimetals with varying SOC strengths, including RhSi, RhSn and RhBiS.

"These materials feature both highly ordered geometrical chirality and electronic chirality, which enable the generation of spin-polarized carriers critical for enhancing [catalytic activity](#)," explained Wang.

"By benchmarking their performance against achiral reference materials, we demonstrated that the chiral crystals significantly outperform state-of-the-art catalysts, such as RuO₂, achieving up to two orders of magnitude higher specific activity in alkaline electrolytes."

The results gathered by Wang and her colleagues reveal a direct link between the strength of SOC in topological chiral semimetals, the polarization of spins, and the materials' catalytic activity. This important finding could guide the future design of electrocatalysts for water splitting, leading to the identification of topological materials that result in optimal OER activity.

"The most notable achievement of our study is the experimental validation of a direct link between SOC and OER performance, establishing a robust design principle for spin-dependent catalysts," said Wang. "Among the materials we studied, RhBiS emerged as a standout performer, demonstrating remarkable OER activity, with specific activity far exceeding that of conventional catalysts."

The recent work by this team of researchers could ultimately help to accelerate the development of advanced water-splitting technologies. This could in turn facilitate the adoption of green hydrogen-based energy solutions, including fuel cells to power electric planes, trucks and other large vehicles.

"This work lays a foundation for employing [spin-orbit coupling](#) as a tool to design more effective topological catalysts," said Prof. Maggie Lingerfelder at EPFL, who is an expert in the field.

"In my view, spin orbit coupling has been an underexplored aspect in the design of selective catalysts, but it could potentially explain even why Pt exhibits such versatile catalytic behavior across various reactions. This work opens up exciting avenues for future exploration, as it brings the solid state physics community closer to applications of chiral topological materials in spin-controlled chemistry."

In their next studies, Wang and her colleagues plan to build on their findings, expanding their investigations to other topological materials with different electronic and magnetic properties. This could allow them to further optimize spin-polarized carrier generation.

"We also plan to focus on real-world applications by developing scalable, cost-effective catalysts and evaluating their performance in industrially relevant settings," added Wang.

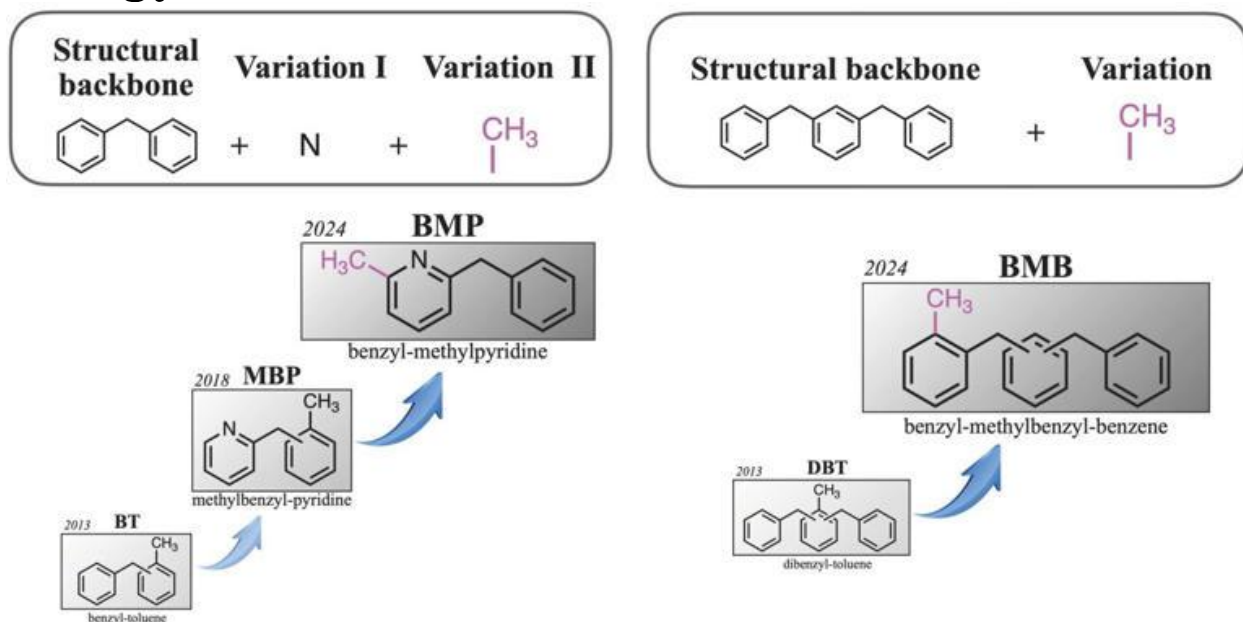
"By bridging the gap between fundamental research and practical implementation, we hope to contribute meaningfully to the advancement of sustainable energy technologies."

More information: Xia Wang et al, Topological semimetals with intrinsic chirality as spin-controlling electrocatalysts for the oxygen evolution reaction, *Nature Energy* (2024). DOI: [10.1038/s41560-024-01674-9](https://doi.org/10.1038/s41560-024-01674-9).

Journal information: [Nature Energy](#)

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Exploring new liquid organic hydrogen carrier materials for a safer, more transportable energy source



Optimization of LOHC molecules through molecular engineering approach. Modification of the position of methyl group in nitrogen-containing bicyclic LOHC (left) and hydrocarbon-based tricyclic LOHC (right). Credit: Korea Research Institute of Chemical Technology (KRICT)

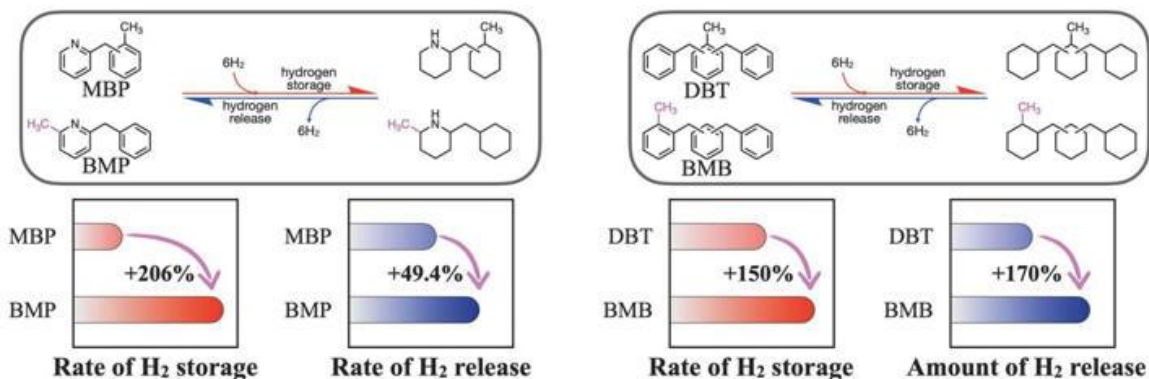
To reduce CO₂ emissions, the energy transition from a carbon-based energy system to a more sustainable system based on hydrogen energy is urgently needed. However, the nature of hydrogen (such as low volumetric density, flammability, and embrittlement) makes its use as a widespread energy source extremely challenging. Therefore, the key to establishing a hydrogen-based society is the safe and efficient use of hydrogen.

One way to do this is by using liquid organic hydrogen carrier (LOHC) technology, which can safely store and transport hydrogen in large quantities through chemical bonding.

LOHC technology offers a solution by allowing hydrogen to be stored in liquid organic compounds that remain stable at ambient temperature and pressure, much like gasoline or diesel fuel. This technology also streamlines hydrogen transportation by utilizing existing fossil fuel infrastructure, thereby reducing the costs associated with hydrogen distribution compared other hydrogen storage methods.

Significant efforts have been directed towards developing catalysts and new reactor designs to enhance the dehydrogenation and hydrogenation efficiency of LOHC-based systems. However, the most effective approach lies in addressing the inherent limitations of the LOHC material itself.

The key to LOHC technology relies on developing the proper organic compounds for hydrogen storage. The characteristics of LOHC materials are crucial in determining key factors such as hydrogen storage capacity, reaction kinetics, energy consumption during the dehydrogenation/hydrogenation process, and reversibility.



Comparison of hydrogen storage/release reaction performance between the structure-optimized LOHCs and the existing LOHCs. Credit: Korea Research Institute of Chemical Technology (KRICT)

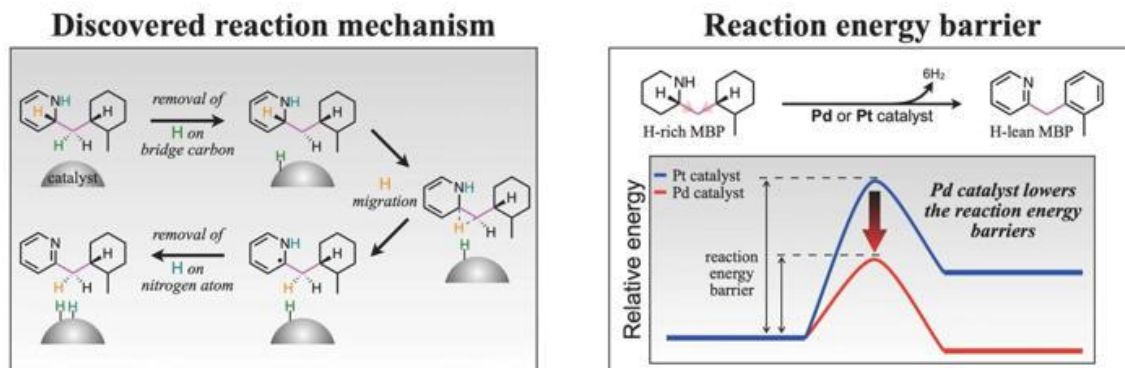
In previous studies, the focus on meeting hydrogen storage capacity (>6 wt%) and physicochemical properties (a wide liquid range from subzero to 300°C) for aromatic LOHC carriers resulted in a lack of material diversity, limiting the potential for performance improvement.

A research team, led by Dr. Jihoon Park at the Korea Research Institute of Chemical Technology (KRICT), has developed advanced LOHC materials and has been actively exploring new LOHC compounds to increase the diversity of LOHC materials for improved performance.

The findings are [published](#) in the *Chemical Engineering Journal*.

The team focused on optimizing LOHC materials through a molecular engineering approach, redesigning their molecular structure to overcome its limitations. In 2018, the research team developed a new LOHC material (MBP, 2-(n-methylbenzyl)pyridine) that enhanced dehydrogenation performance by adding a N atom into the benzene ring of benzyltoluene.

However, through a combination of experimental and theoretical studies, the research team made a groundbreaking discovery: methyl groups (-CH₃), previously thought to have little impact, played a crucial role in improving the performance of LOHC material. Unlike previous LOHC materials (MBP) that existed as isomer mixtures, the research team suggested a new synthetic method for a pure LOHC material (2-benzyl-6-methylpyridine, BMP) with precise control over the position of the methyl group.



Schematic dehydrogenation mechanism in which the bridge carbon and nitrogen atom facilitate hydrogen removal and migration (left). Reaction energy barriers of MBP dehydrogenation reaction catalyzed by Pd and Pt catalysts (right). Credit: Korea Research Institute of Chemical Technology (KRICT)

The new LOHC materials (BMP) increased hydrogen storage and release rates by 206% and 49.4%, respectively, compared to those of MBP.

Additionally, the research team developed a new LOHC candidate, benzyl-methylbenzyl-benzene (BMB), by rearranging the methyl group of dibenzyltoluene, one of the most promising commercial LOHC materials, to overcome the limitations of slow reaction kinetics due to its chemical structure.

BMB exhibits a hydrogenation rate 150% faster than DBT at 150°C and releases 170% more hydrogen compared to DBT at 270°C. Furthermore, the research team uncovered the dehydrogenation mechanism by which N-heterocyclic LOHC materials interact with various active metals in catalysts to facilitate hydrogen extraction.

Dr. Jihoon Park said, "Our research focuses on optimizing LOHC structures, enabling precise control over the placement of methyl groups as functional groups within LOHC material, unlocking new potential for LOHC systems. Also, these findings are expected to influence the design of next-generation hydrogen storage materials, paving the way for a safer and more efficient hydrogen energy-based society."

More information: Kwanyong Jeong et al, Benzyl-methylbenzyl-benzene: Improving hydrogen storage and release performance of dibenzyltoluene based liquid organic hydrogen carrier, *Chemical Engineering Journal* (2024). DOI: [10.1016/j.cej.2024.150927](https://doi.org/10.1016/j.cej.2024.150927)

Provided by National Research Council of Science and Technology

Pros & Cons Of Hydrogen Powered Vehicles



Front 3/4 view of Toyota Mirai© Toyota

There has been a huge amount of news about all aspects of the coming transition to electric vehicles (EVs). In addition to this general awareness, around three million EVs have been sold so far in the U.S. But there is another, lesser-known clean vehicle technology that has support from some of the world's major automakers. This system uses [hydrogen to power vehicles](#).

The first practical use of hydrogen as a vehicular power source was in 1860, when the three-wheel Hippomobile was created by Belgian inventor Etienne Lenoir. Lenoir sold around 400 of these hydrogen-powered vehicles before the first gasoline-powered vehicle, the 1886 Benz Motorwagen, came along. Lenoir's Hippomobile actually electrolyzed water to create the hydrogen that was then burned to power the car's engine. Other attempts to power vehicles with hydrogen have included using the hydrogen in place of gasoline in conventional internal combustion engines (ICE). The U.S. space program accelerated the development of fuel cells in the early 1960s. These [fuel cells](#) are still used today to provide space crews with drinking water.

Today's hydrogen fuel cell electric vehicles (FCEVs) use highly pressurized hydrogen as their fuel. The hydrogen is fed into a fuel cell, which combines the hydrogen with oxygen from the air to produce electricity. From this point on, the rest of the vehicle is similar to an EV, with an electric motor providing power to propel it down the road. The main difference between an FCEV and a standard EV is that the FCEV does not need a heavy battery that takes a while to charge. Another difference is that the FCEV's "exhaust" is made up solely of water vapor, which is not harmful to the environment and also explains its use in space travel.

The Pros Of Hydrogen Powered Vehicles

There are many benefits to hydrogen-powered vehicles. Compared to the much longer charging times required for battery EVs, FCEVs can be fueled just as quickly as ICE vehicles. The process is similar to fueling up with gasoline, except that the hydrogen is a highly compressed gas. Another advantage is that hydrogen-powered vehicles have a long range. The typical FCEV has a hydrogen tank adequate for a 300-400 mile range, which puts the FCEV ahead of all but the most expensive EVs that have a very large (and very heavy) battery.

In terms of environmental benefits, hydrogen is an inherently clean fuel. Pure hydrogen gas, unlike gasoline, has no carbon in it, and therefore produces no CO₂ or other emissions. As mentioned above, its only byproduct is water vapor, a totally harmless substance.

Hydrogen power also shines as an ideal fuel for large transport vehicles. For vehicles that move goods, like over-the-road trucks, hydrogen is a choice that makes great sense. Instead of a super-heavy battery that cuts into a truck's payload capacity, a lightweight fuel cell that runs on hydrogen eliminates this limitation. An FCEV truck can carry just as much freight as an ICE truck, but with zero tailpipe emissions. The quick refueling advantage of hydrogen over an EV also applies here.

The Cons Of Hydrogen Powered Vehicles

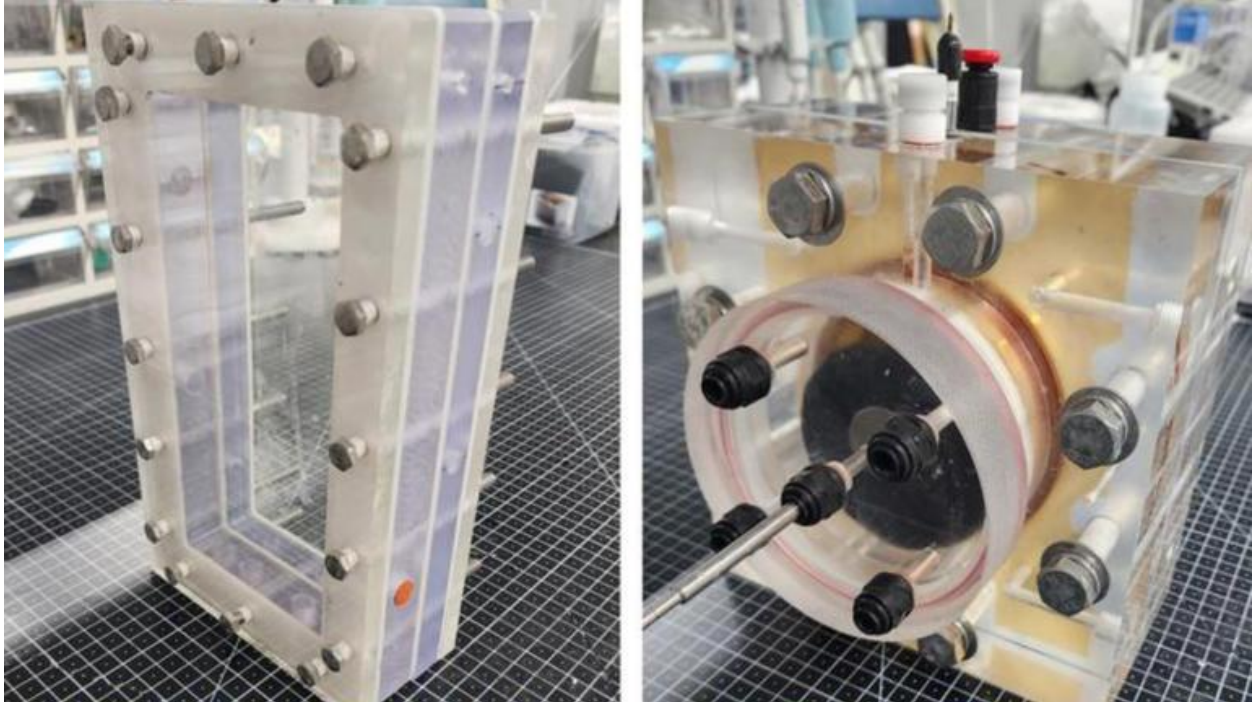
There are quite a few downsides to hydrogen-fueled vehicles. At this point in time, there are only three FCEVs available in the U.S. and they can only be purchased in California. They are the Honda CR-V e:FCEV, the Hyundai Nexo, and

the Toyota Mirai. [BMW](#) has made some X5 FCEVs, but they will be used as technology demonstrators, not production vehicles. Another is the minimal hydrogen fueling infrastructure, which is the real problem with owning and operating an FCEV -- Even in California, the only state where FCEVs are sold, hydrogen fueling stations are few and far between. There are now only 55 locations in the entire state to refuel your hydrogen-powered car. This does not inspire confidence in prospective FCEV buyers.

To make hydrogen a truly clean fuel, there will need a cheap and plentiful supply of "green" hydrogen that is produced using renewable energy before it can be considered a clean, carbon-free fuel. The vast majority of the hydrogen produced today is "gray," "brown," or "black" hydrogen, which is made by using fossil fuels. As you might expect, "green" hydrogen costs much more to make than the fossil fuel-based versions, raising fuel costs for consumers significantly above the cost of recharging an EV in your garage overnight.

All of these limitations make it tough for FCEVs to succeed. With single-state availability, very few FCEVs available, not many places to refuel, and a lack of "green" hydrogen, FCEVs are unlikely to be most people's next vehicle. Hydrogen has potential for trucks, but lots of hydrogen infrastructure will need to be built out around the country to make it feasible. For most of us, a battery-powered EV is much more likely to be a future vehicle choice.

Green hydrogen from waste: 'Zero-Gap' tech breakthrough boosts clean fuel production



Green hydrogen from waste: 'Zero-Gap' tech breakthrough boosts clean fuel production

Scientists at the Korea Institute of Energy Research (KIER) have achieved a major breakthrough in the production of clean hydrogen energy. The team research team has successfully developed and certified a groundbreaking "Zero-Gap" technology for bio-electrochemical cells (BECs).

It has the potential to pave the way for large-scale, cost-effective hydrogen production from organic waste. This breakthrough addresses two critical challenges: the growing need for clean energy sources and the effective management of organic waste.

"This technological development not only addresses the environmental and economic challenges of processing organic waste in Korea but also represents a significant breakthrough in the high-efficiency production of clean hydrogen energy," said Dr Jwa Eunjin, the lead researcher.

BEC technology harnesses the power of microorganisms to convert organic waste into valuable hydrogen fuel. The microorganisms consume the organic matter in the waste, and this process releases electrons and hydrogen ions, which then combine to produce hydrogen gas.

BEC suffers from limitations

This approach offers a more sustainable and cost-effective alternative to traditional [hydrogen production](#) methods, which often rely on fossil fuels and generate significant carbon emissions.

“By operating at low temperatures and emitting significantly less carbon dioxide, BEC technology aligns with global decarbonization goals,” said the scientists in a press release.

However, as BEC systems increase in size, the longer pathways for electrochemical reactions lead to higher internal resistance and reduced [efficiency](#).

“This limitation poses a significant barrier to large-scale commercialization, highlighting the need for further technological advancements to improve system efficiency and scalability,” added the [press release](#).

The research team has introduced a groundbreaking “Zero-Gap” technology to overcome this limitation. This innovative design minimizes the distance between the cell’s electrodes and separator, optimizing reaction efficiency and electron transfer.

“This advancement resolves longstanding power loss challenges in conventional processes, offering a transformative pathway toward large-scale, cost-effective hydrogen production,” read the press release.

Confirmed effectiveness and pilot-scale success

What sets KIER’s Zero-Gap technology apart is its unique design, which ensures consistent performance even in large-scale systems.

Conventional zero-gap structures often struggle with pressure imbalances as systems grow larger. This can create gaps between components and lead to drops in efficiency. KIER's design avoids this problem, maintaining optimal performance regardless of system size.

Rigorous testing conducted by the Korea Testing Laboratory (KTL) has confirmed the effectiveness of this new technology.

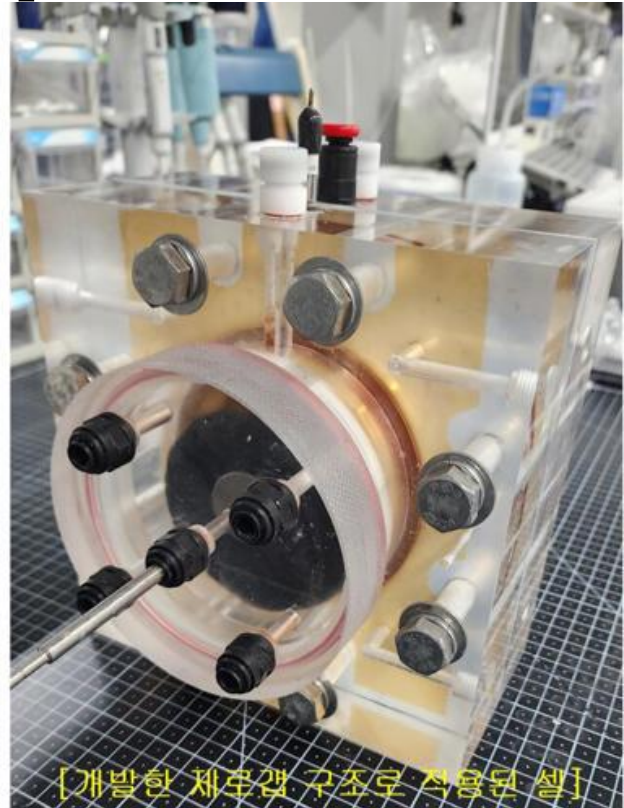
"The process utilizing the newly developed cell achieved 1.2 times higher hydrogen productivity and more than 1.8 times higher electron production compared to existing bio-electrochemical hydrogen production processes," explained the team.

"The same performance was maintained in pilot-scale experiments, a critical step toward large-scale implementation."

The model can benefit countries seeking sustainable waste management and clean energy solutions.

"The commercialization of the high-performance bio-electrochemical cell we developed is expected to make a substantial contribution to achieving carbon neutrality and transitioning to a hydrogen-based society," Dr Eunjin concluded.

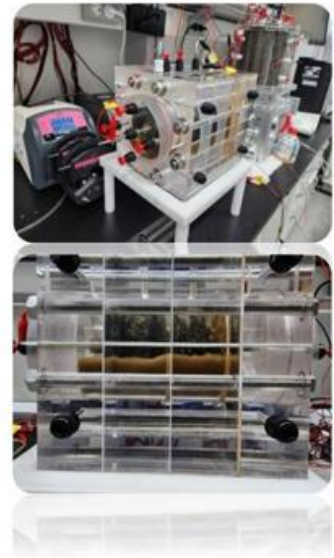
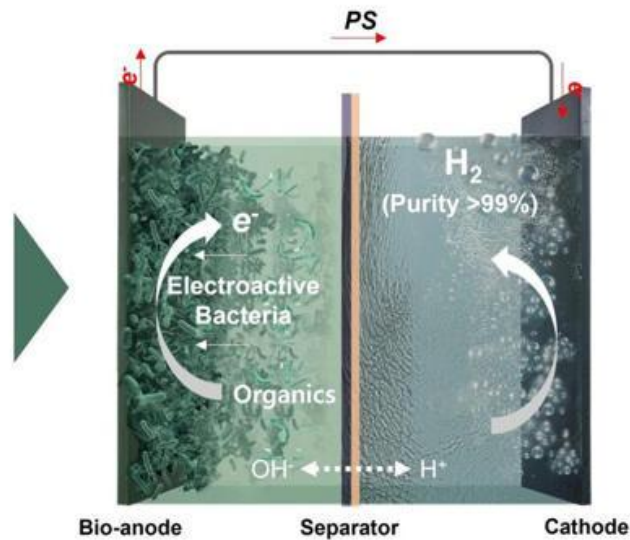
Hydrogen from waste: Bio-electrochemical cell design cuts power loss for large-scale implementation



Comparison of the existing cell structure vs. the newly developed cell structure. Credit: Korea Institute Of Energy Research

A research team has achieved a significant breakthrough in clean energy technology. The team has successfully enhanced a crucial component of a bio-electrochemical cell, enabling more efficient hydrogen production from microorganisms found in waste. This advancement resolves longstanding power loss challenges in conventional processes, offering a transformative pathway toward large-scale, cost-effective hydrogen production.

Organic Wastewater



Principles of the developed process. Credit: Korea Institute Of Energy Research

The work is [published](#) in the journal *Science of The Total Environment*.

Biogas, a renewable gas generated during the microbial decomposition of organic waste, has emerged as a promising source for clean hydrogen production. Through processes like steam reforming or pyrolysis at elevated temperatures, biogas can be converted into hydrogen—a key player in the global transition to carbon neutrality.

However, existing production methods face critical hurdles. These processes not only emit carbon dioxide as a byproduct but also demand substantial energy to sustain high-temperature conditions, posing significant challenges to large-scale commercialization.

To address these challenges, leading countries such as the United States and Europe are actively researching hydrogen production processes using bio-electrochemical cells. In this process, waste and electricity are supplied to the bio-electrochemical cell, where microorganisms consume organic matter, releasing electrons and hydrogen ions that combine to produce hydrogen gas.

Unlike traditional hydrogen production methods, the bio-electrochemical cell (BEC) process offers a more sustainable and cost-efficient solution. By operating at low temperatures and emitting significantly less carbon dioxide, BEC

technology aligns with global decarbonization goals. However, scaling up the process presents a critical challenge.

As system size increases, the pathways for electrochemical reaction materials become longer, resulting in higher internal resistance and increased power loss. This limitation poses a significant barrier to large-scale commercialization, highlighting the need for further technological advancements to improve system efficiency and scalability.

To overcome the power loss issues of conventional bio-electrochemical cells, the research team developed a proprietary improvement to the basic unit of the cell and applied it to the hydrogen production process. The process utilizing the newly developed cell achieved 1.2 times higher hydrogen productivity and more than 1.8 times higher electron production compared to existing bio-electrochemical hydrogen production processes.

The research team has introduced a groundbreaking innovation to the bio-electrochemical cell: a proprietary Zero-Gap technology. This advanced design minimizes the distance between the cell's electrodes and separator, significantly reducing electrical resistance and optimizing reaction efficiency.

By creating a more direct pathway for electrochemical reactions, Zero-Gap technology enables faster electron transfer and more efficient hydrogen production. Widely adopted in cutting-edge electrochemical systems, this approach is a critical step forward in improving the scalability and commercial viability of bio-electrochemical cells.

However, conventional zero-gap structures are typically designed by stacking electrodes and membranes in a sandwich-like configuration. During large-scale implementation, this structure can lead to pressure imbalances, creating small gaps between the electrodes and membranes. These gaps cause localized efficiency drops and an increase in electrical resistance, hindering overall process performance.

In contrast, the zero-gap structure developed by the research team features a cylindrical lid that applies uniform pressure to the back of the electrode as it closes, ensuring complete adhesion between the electrode and the separator. This design can be applied consistently even in large-scale processes, making it a key innovation for the commercialization of bio-electrochemical cells.

The research team successfully applied the developed bio-electrochemical cell to the hydrogen production process, resulting in 1.8 times more electron production and a 1.2-fold increase in hydrogen output compared to conventional processes. The same performance was maintained in pilot-scale experiments, a critical step toward large-scale implementation. This achievement was officially certified by the Korea Testing Laboratory (KTL), further validating its effectiveness.

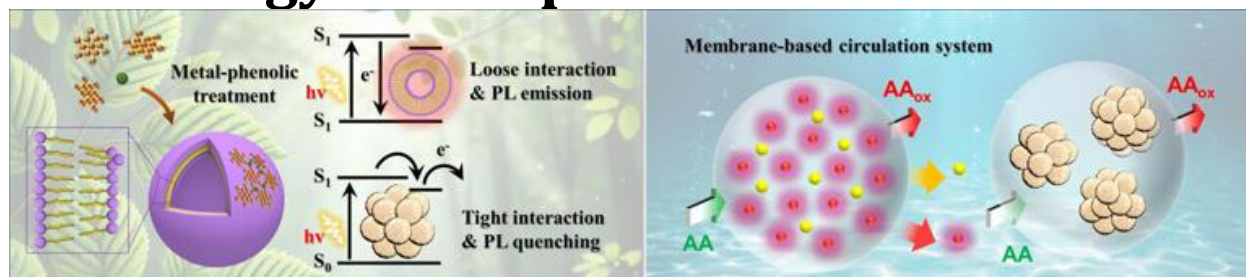
Dr. Jwa Eunjin, the lead researcher, stated, "This technological development not only addresses the environmental and economic challenges of processing organic waste in Korea but also represents a significant breakthrough in the high-efficiency production of clean hydrogen energy.

"The commercialization of the high-performance bio-electrochemical cell we developed is expected to make a substantial contribution to achieving carbon neutrality and transitioning to a hydrogen-based society."

More information: Hee-Jun Kim et al, Evaluation of a mixture of livestock wastewater and food waste as a substrate in a continuous-flow microbial electrolysis cell, *Science of The Total Environment* (2024). DOI: [10.1016/j.scitotenv.2024.176884](https://doi.org/10.1016/j.scitotenv.2024.176884)

Provided by National Research Council of Science and Technology

Artificial photosynthesis learned from nature: New solar hydrogen production technology developed



Graphical Abstract: A robust metal-phenolic coating on the surface of self-assembled nanospheres has been shown to induce supramolecular reconstruction, enhancing the stability and photogenerated electron transfer during photocatalytic reactions. This synergistic hybrid system significantly boosts both hydrogen production and the sustainability of continuous reactions. Credit: *Angewandte Chemie International Edition* (2024). DOI: 10.1002/anie.202416114

Researchers have successfully developed a supramolecular fluorophore nanocomposite fabrication technology using nanomaterials and constructed a sustainable solar organic biohydrogen production system.

The research team used the good nanosurface adsorption properties of tannic acid-based metal-polyphenol polymers to control the self-assembly and optical properties of fluorescent dyes while also identifying the photoexcitation and electron transfer mechanisms. Based on these findings, he implemented a solar-based biohydrogen production system using bacteria with hydrogenase enzymes.

The findings are [published](#) in the journal *Angewandte Chemie International Edition*. The joint research was led by Professor Hyojung Cha at the Department of Hydrogen and Renewable Energy, Kyungpook National University and Professor Chiyoung Park at the Department of Energy Science and Engineering, Daegu Gyeongbuk Institute of Science & Technology.

During natural photosynthesis, chlorophyll absorbs light energy and transfers electrons to convert it into chemical energy. Artificial photosynthesis, which emulates this natural process of photosynthesis, uses sunlight to produce valuable resources, such as hydrogen, and it has garnered attention as a sustainable energy solution.

Professor Park's team developed a supramolecular photocatalyst that can transfer electrons similar to chlorophyll in nature by modifying rhodamine, an existing fluorescent dye, into an amphiphilic structure. The team applied metal-polyphenol nano-coating technology based on tannic acid to improve performance and durability.

Consequently, they demonstrated the production performance of approximately 18.4 mmol of hydrogen per hour per gram of catalyst under the visible spectrum. This performance is 5.6 times as high as that observed in previous studies using the same phosphor.

The research team combined their newly developed supramolecular dye with *Shewanella oneidensis* MR-1, a bacterium capable of transferring electrons, to create a bio-composite system that converts ascorbic acid (vitamin C) into hydrogen using sunlight. The system operated stably for a long period and demonstrated its ability to produce hydrogen continuously.

Professor Park said, "This study marks an important achievement that reveals the specific mechanisms of organic dyes and artificial photosynthesis. In the future, I would like to conduct follow-up research on new supramolecular chemistry-based systems by combining functional microorganisms and new materials."

More information: Seok Hyeong Bu et al, Supramolecular Reconstruction of Self-Assembling Photosensitizers for Enhanced Photocatalytic Hydrogen Evolution, *Angewandte Chemie International Edition* (2024). DOI: [10.1002/anie.202416114](https://doi.org/10.1002/anie.202416114)

Provided by Daegu Gyeongbuk Institute of Science and Technology

5 amazing ways that hydrogen-powered tech could transform our future

There are already some incredibly surprising ways that hydrogen fuel is providing the energy that could power our future.

Hydrogen power is becoming an increasingly attractive energy source — mainly because when used in a fuel cell, it releases water vapor instead of the harmful pollution that comes from dirty energy sources like oil and gas.

There is still a ways to go before hydrogen fuel production can reach a level where it is solidly beneficial over fossil fuel production, as only "green hydrogen" (produced using electricity from renewable energy rather than dirty fuels) is truly promising toward fighting to stop the overheating of the planet. That said, there are some incredibly surprising ways that hydrogen fuel is already providing the energy that could power our future.

01.

HYDROGEN-POWERED SHIPS



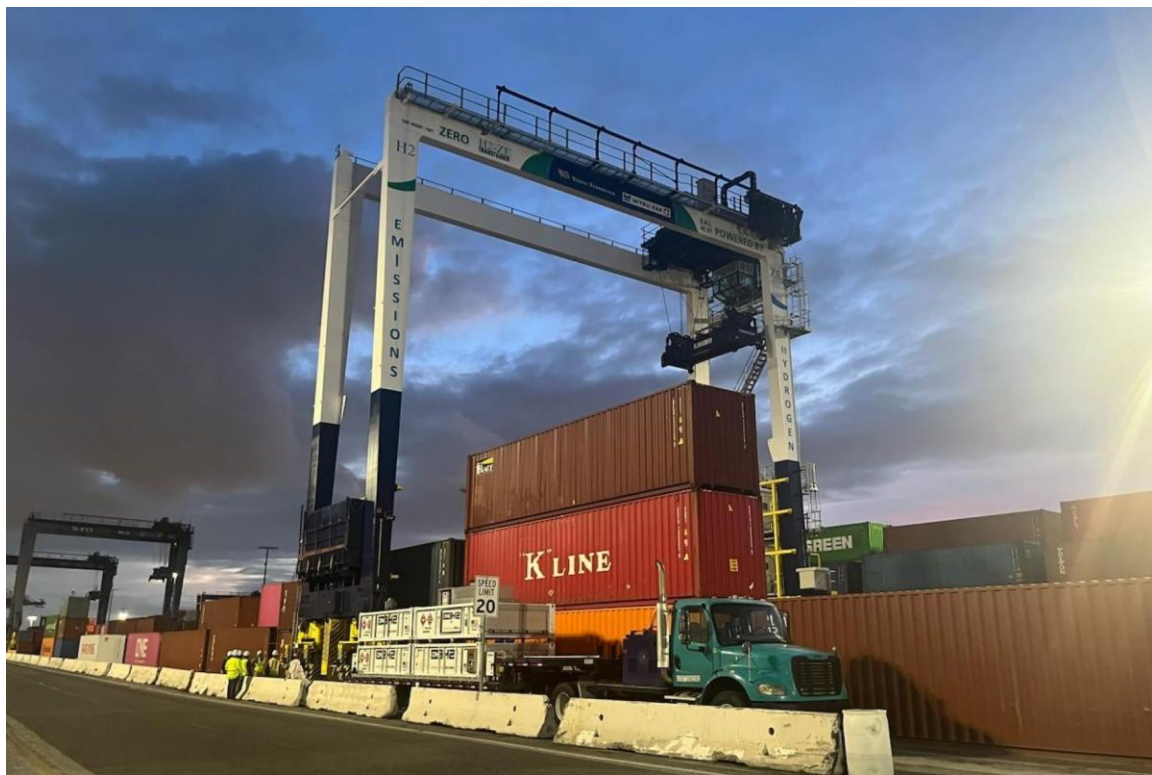
The preliminary designs for a [hydrogen-hybrid](#) research vessel for the University of California San Diego's Scripps Institution of Oceanography have been approved by the American Bureau of Shipping. The proposed ship will run on hydrogen for [75% of its energy](#), with the other 25% coming from clean-running diesel generators.

In 2018, the naval architecture and engineering firm Glosten successfully completed a feasibility study on the vessel, [kickstarting](#) the design project. With this approval, Glosten and

Scripps can move forward with finding a contractor to begin the ship's construction.

02.

ENORMOUS CRANES

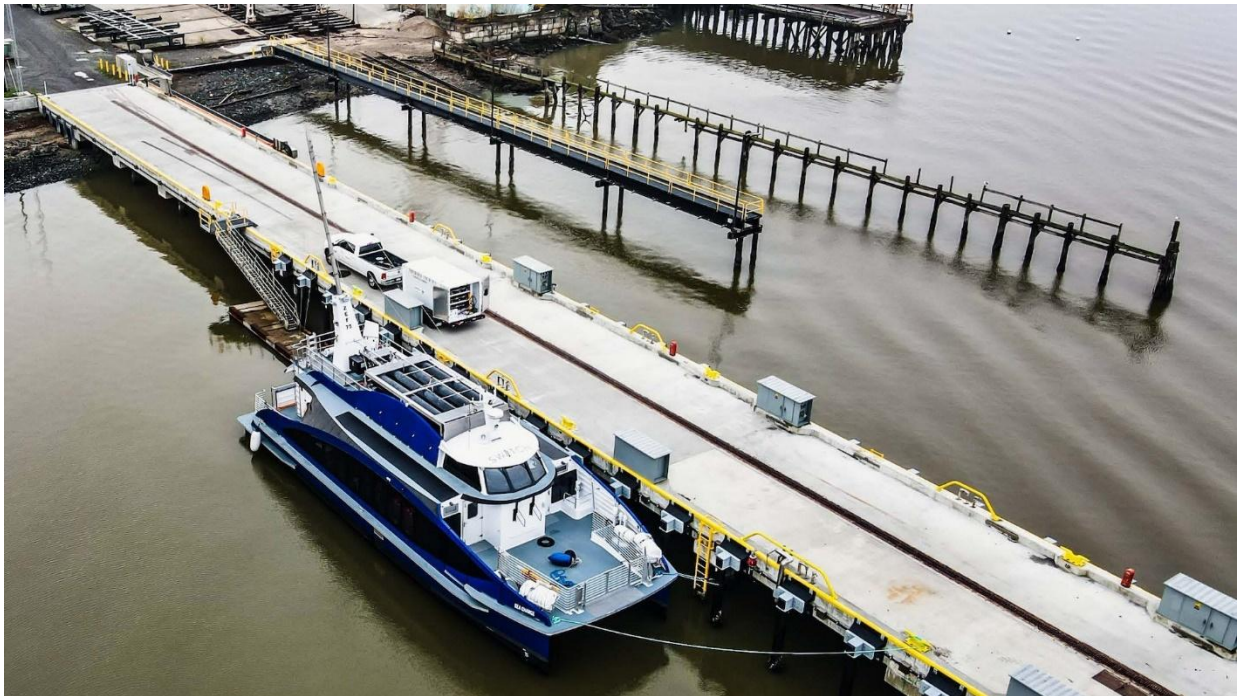


The world's first [hydrogen-powered crane](#) became operational in the Port of Los Angeles just this year. A regular diesel-powered crane releases emissions equivalent to burning [400 barrels of oil](#) per year.

Though the single crane in Los Angeles is part of a pilot program, engineers hope that it can provide findings that [suggest](#) equal performance to diesel-powered cranes.

03.

ULTRA-EFFICIENT PASSENGER FERRIES



San Francisco recently launched the first-ever [hydrogen-powered passenger ferry](#). The MV Sea Change is running for a six-month trial period, making trips from the downtown San Francisco ferry terminal to Pier 41. During trials, the ferry is free of charge.

The vessel holds 75 people, can run for 16 hours, and travel 345 miles before needing to refuel, and its only byproduct is water. Shipping accounts for [3%](#) of the world's carbon pollution, so ships powered by hydrogen could have major benefits.

04.

HIGH-POWERED GARBAGE TRUCKS



Waste management is also getting in on the hydrogen-powered action with a new Class 8 [fuel cell-powered garbage truck](#). The new clean-energy truck is the brainchild of Hyzon, a global hydrogen fuel cell developer, and New Way Trucks, a garbage collection equipment manufacturer.

Waste and [recycling](#) company Bigbelly [reported](#) that refuse trucks are the worst contributors to vehicle pollution on a per-mile basis in cities. Switching to hydrogen-powered refuse trucks could greatly reduce the emissions from waste management services.

05.

A NEW KIND OF AIRCRAFT



Joby Aviation's electric vertical takeoff and landing aircraft flew [over 500 miles](#) powered by hydrogen fuel cells and electricity. Joby's goal is to have a fleet of clean-energy air taxis to reduce pollution and traffic jams in major cities.

The aircraft's all-electric prototype could [previously](#) only travel 100 miles on a single charge but has hugely increased range with the addition of hydrogen fuel cells, which provide more energy without harmful emissions.

SAE J2719 Quality Hydrogen: Guidelines to Select the Most Suitable Purification Technology

APPLICATION NOTE

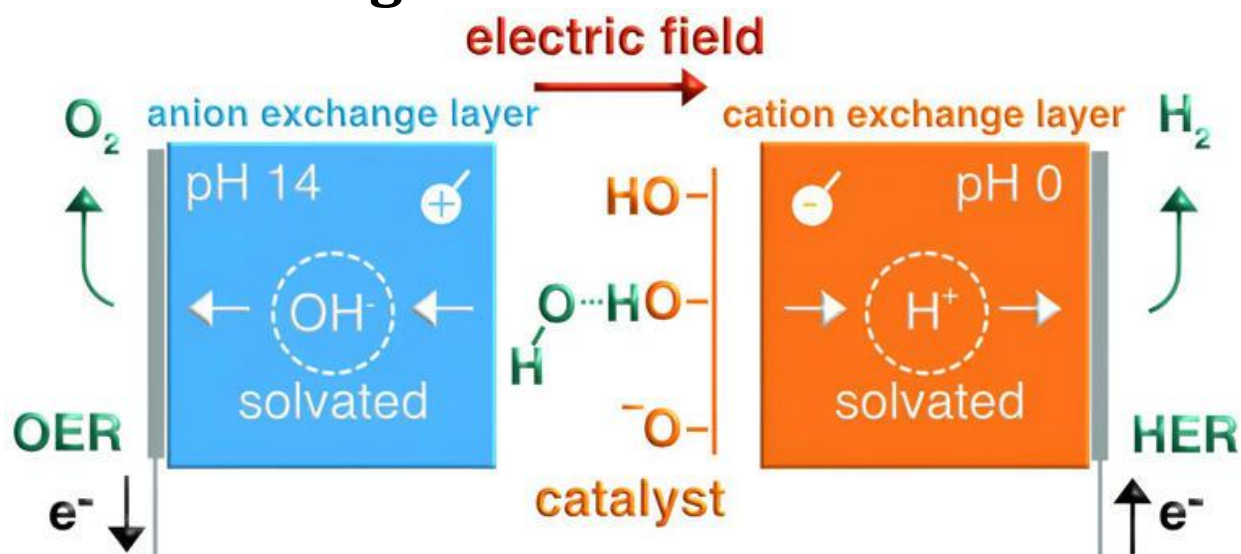
This application note reviews the most common technologies used to improve hydrogen (H_2) quality down to at least 8 nines (8N) quality, explaining where each technology has advantages as transportation uses expand.

All the major car manufacturers have developed cars powered by proton exchange membrane (PEM) fuel cells, with thousands of cars being introduced to the market starting in 2015. This technology is a great step forward in the introduction of clean cars because the exhaust consists of only water vapor.

A necessary requirement for the mass adoption of this new vehicle technology is the development of a suitable infrastructure capable of filling car tanks at high pressure, 700 bars, with high-purity H_2 .

Per the hydrogen fuel quality specifications for polymer electrolyte fuel cells in road vehicles, published by the U.S. Department of Energy, impurities such as carbon monoxide (CO) and sulphur compounds, are very tight, down to 200 ppb or even less. This is because of their ability to deplete the fuel cell.

New insight about the working principles of bipolar membranes could guide future fuel cell design



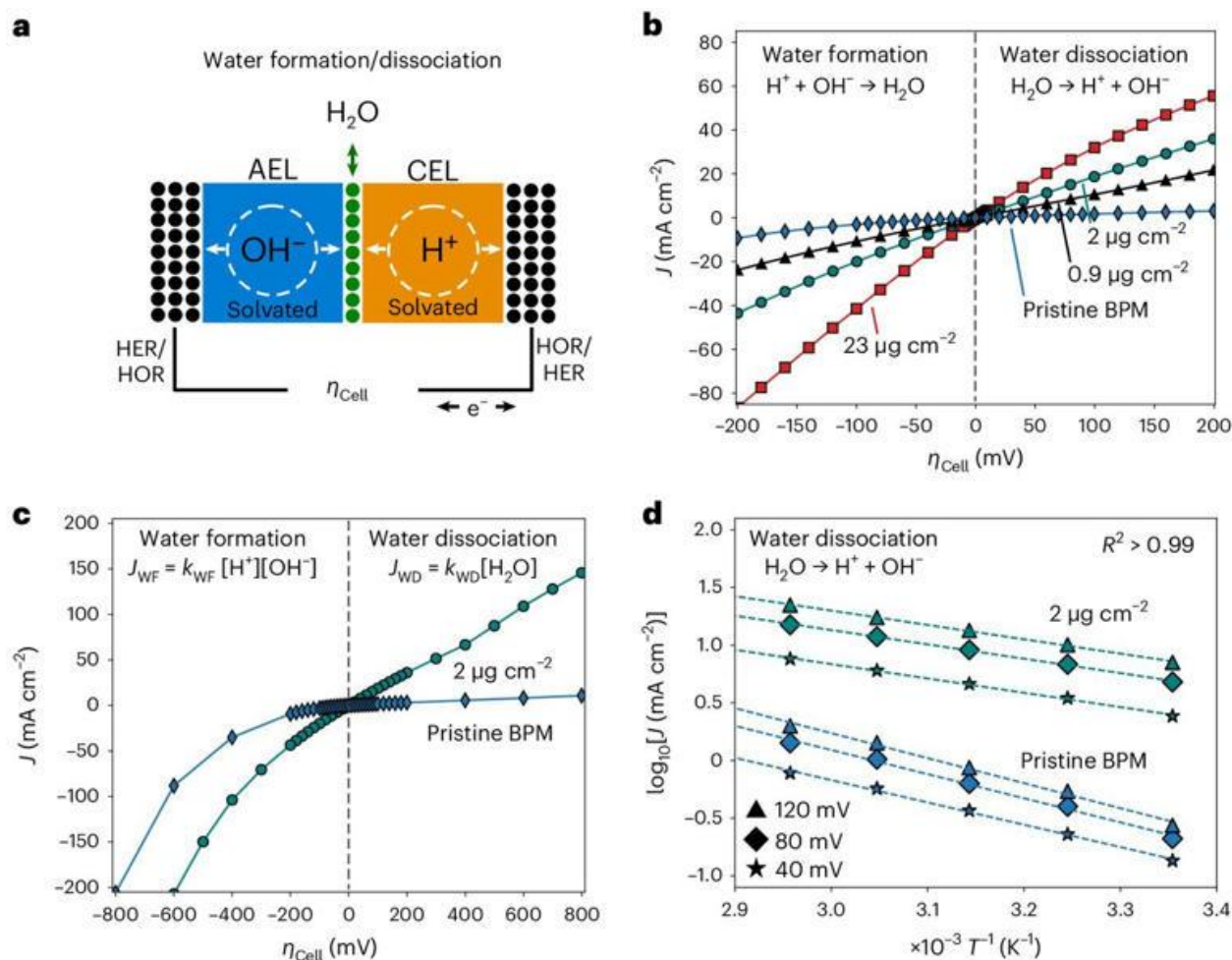
Bipolar membranes consist of a polymeric anion exchange layer (blue) and cation exchange layer (orange) sandwiched together. Build-up of space charge capacitance inside polymer layers can lead to non-equilibrium electric fields across a metal oxide nanoparticle catalyst bed that is placed in the junction between the membranes. These fields, together with the specific acid-base chemistry, determine the water dissociation and ion solvation kinetics of the system. When used inside an electrolyzer, e.g., the oxygen evolution reaction (OER) can be operated at locally alkaline pH and the hydrogen evolution reaction (HER) at a locally acidic pH. Tuning the local pH on the electrocatalyst surface can be used to employ earth-abundant materials, improve catalyst kinetics and stability, and even selectivity in CO₂RR electrolyzers and other systems. Credit: Rodellar et al.© Provided by Tech Xplore

Bipolar membranes are a class of ion-conductive polymers comprised of two oppositely charged layers, known as the cation-exchange and anion-exchange layer. These membranes are central to the functioning of various technologies, including electrolyzers and hydrogen fuel cells.

While many companies and start-ups are using bipolar membranes to develop new energy technologies, their underlying working principles and ion solvation kinetics have not yet been fully elucidated. Better understanding these principles could inform the future fabrication of these materials and facilitate their successful integration in various devices.

Researchers at Fritz-Haber Institute of the Max Planck Society recently carried out a study to examine the water dissociation and ion solvation kinetics at the interface between the two layers in bipolar membranes. Their

paper, published in *Nature Energy*, gathered valuable new insight that could guide the future design of these membranes and of promising electrocatalysts for fuel cells.



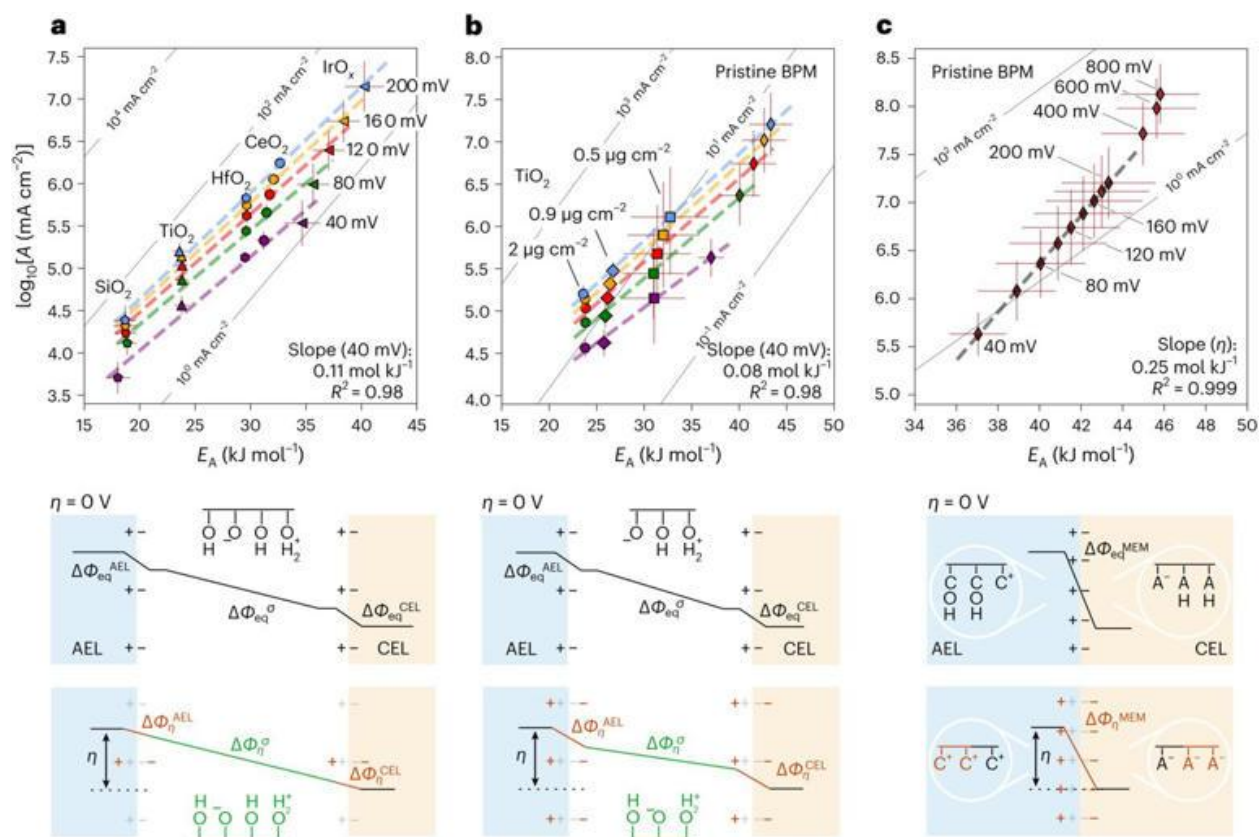
Ion (de)solvation during BPM water dissociation and water formation. Credit: *Nature Energy* (2024). DOI: 10.1038/s41560-024-01484-z © Provided by Tech Xplore

"We wanted to understand the fundamental working principles of bipolar membranes and how they connect to electrochemistry more broadly," Sebastian Oener, corresponding author of the study, told Tech Xplore. "Bipolar membranes exist for over 65 years, but previous explanations about their working principles were rather unsatisfactory. We wanted to change that, connecting two fields that were previously thought to be separate."

To conduct their study, Carlos Gomez Rodellar, first author and Ph.D. student in the Interface Science Department, had to tackle various research challenges in an experimental setting. Firstly, he had to setup and benchmark a system that would

allow him to study the kinetics of bipolar membranes without undesirable interferences from the cross-over of electrolyte ions.

"This system had to apply continuously physical pressure on the membrane electrode assembly with the metal oxide catalysts inside the bipolar junction," Oener explained. "Finally, Carlos had to design the whole system in such a way that we could controllably change the temperature of the cell and the humidified gases to do Arrhenius analysis and extract the bias dependent activation entropy and enthalpy. All of this can be provided with a modified fuel cell test station."



The measurements collected by the researchers paint a comprehensive picture of the fundamental principles underpinning the functioning of bipolar membranes. Specifically, they unveiled bias-dependent relationships between the activation entropy and enthalpy inside the bipolar junction, which appears to be related to a bias dependent dispersion of interfacial capacitance.

The team also observed that solvation kinetics in bipolar membranes exhibit characteristics that are unrelated to the chemical composition of the catalysts employed, but are likely originating from entropic changes in the interfacial electrolyte. Collectively, these insights could help to develop better performing bipolar membranes for electrodialysis, CO_2 electrolyzers and H_2 fuel cells.

"There are many different applications of bipolar membranes that are being explored around the world, including at promising start-ups," Oener said. "There is really a lot of potential. Beyond bipolar membranes, we were also able to show that the same physics are at play when water is dissociated and hydroxide ions solvated at electrocatalyst interfaces."

The results gathered by the research group at the Interface Science Department of the Fritz Haber Institute demonstrate the importance of entropic changes on the solvent side at liquid-solid interfaces. Their work could thus also guide the design of new promising electrocatalysts to initiate specific chemical reactions, such as those required to generate green hydrogen from alkaline electrolytes.

"Regarding bipolar membranes, there are still open fundamental questions that we want to address," Oener added.

"For example, the water formation reaction is important when bipolar membranes are run in forward direction. We also explore several applications in collaboration with others. These include different types of fuel cells and electrodialysis type systems. When it comes to ion solvation in electrocatalysis, we have multiple projects that are either already in review or are getting close to be submitted. Stay tuned for more."

More information: Carlos G. Rodellar et al, Ion solvation kinetics in bipolar membranes and at electrolyte–metal interfaces, *Nature Energy* (2024). DOI: [10.1038/s41560-024-01484-z](https://doi.org/10.1038/s41560-024-01484-z).

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Scientists make game-changing breakthrough that will speed up production of futuristic fuel source: 'A groundbreaking outcome'

One apartment complex in Ulsan, South Korea, is powering 437 units completely from these fuel cells.

[Korean scientists](#) have created a new composite catalyst of nickel and cobalt used in the production of turquoise hydrogen, leading to greater hydrogen production yields at lower energy expenses. This could help make turquoise hydrogen a viable clean energy source for the future.

Ironically, hydrogen is a colorless gas, but there is a whole color spectrum behind hydrogen production methods. Green hydrogen is the cleanest, produced through electrolysis, which splits water molecules using renewable energy sources such as solar, wind, or hydropower, as [National Grid](#) explains.

Blue hydrogen is produced using [natural gas](#) through a process called steam [methane](#) reforming, which produces carbon dioxide as a byproduct. Blue hydrogen isn't entirely clean, as it produces carbon dioxide — a gas that, in excess, traps heat and raises the temperature of the planet to dangerous levels.

Turquoise hydrogen falls somewhere between green and blue. Like blue hydrogen, turquoise hydrogen is also produced with natural gas, but the production process involves splitting methane gas at high — but more manageable — temperatures (around 900 degrees Celsius or 1,652 degrees Fahrenheit), per [Tech Xplore](#). The process splits methane into hydrogen and carbon, but the temperature is "low" enough to keep carbon in its solid state, as opposed to its gas form.

Traditional methods require generating high temperatures — which uses significant energy — to produce turquoise hydrogen. For this reason, turquoise hydrogen has not been sustainable to produce or commercialize.

The new nickel-cobalt composite catalyst, developed by Dr. Woohyun Kim's hydrogen research team at the Korea Institute of Energy Research, lowers the

temperature (and energy) required to produce turquoise hydrogen — by 300 degrees Celsius (540 degrees Fahrenheit), according to [Interesting Engineering](#).

Compared to existing catalyst types — nickel- or iron-only catalysts — the new composite catalyst "demonstrated over 50% higher hydrogen productivity," per Tech Xplore. The nickel-cobalt catalyst maintained "its initial activity for approximately 150 minutes," compared to 90 minutes for existing catalyst types, extending activity duration by 60%.

"This research demonstrates a groundbreaking outcome," Dr. Kim said, per Tech Xplore.

This catalyst development makes turquoise hydrogen production more feasible, which could allow companies, cities, and governments of all levels to [save money](#) when investing in hydrogen production and clean energy sources.

Hydrogen has a strong potential to power our future while protecting the planet's health.

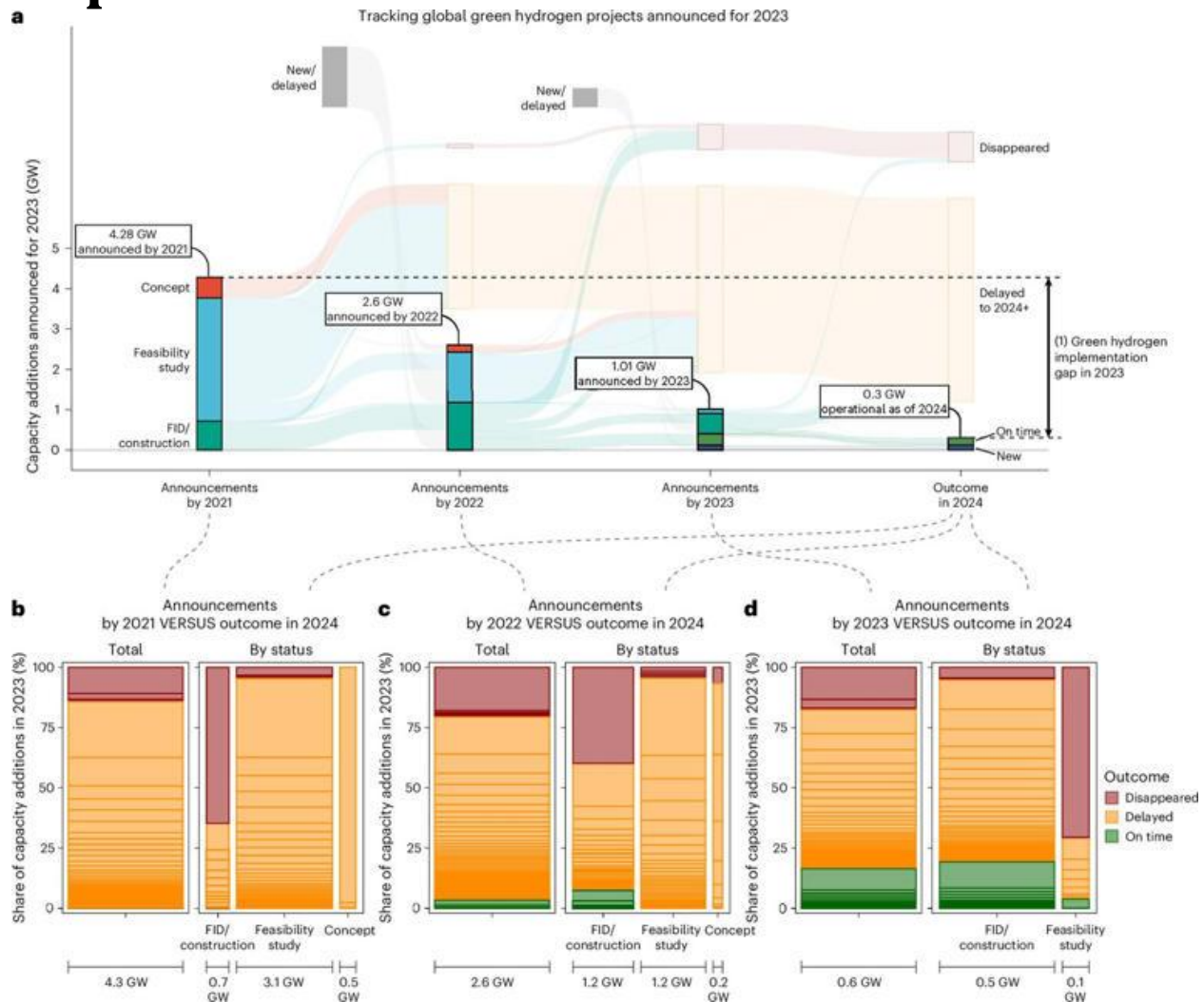
One apartment complex in [Ulsan, South Korea](#), is powering 437 units completely from hydrogen fuel cells, which has helped lower electric bills for renters by 30%-40%. The [trucking industry](#) is looking to transition to hydrogen for a cleaner and cheaper way to fuel transport.

[Researchers](#) at the University of Illinois, Chicago, developed a method to make hydrogen fuel from sun and biowaste. [Hysata](#), an Australian startup, devised a cell that splits water into hydrogen and oxygen, mimicking how trees absorb water from the ground.

Meanwhile, Dr. Kim's team is making strides to bring about turquoise hydrogen in a more affordable yet efficient and productive way.

"We plan to further research mass-production [technology](#) utilizing the developed catalyst, conduct performance evaluations, and secure core material technology and reaction system design capabilities," Dr. Kim said, per Tech Xplore.

Green hydrogen: Study shows big gaps between ambition and global implementation



The 2023 green hydrogen implementation gap. Credit: Nature Energy (2025). DOI: 10.1038/s41560-024-01684-7

In recent years, more than 60 countries have developed strategies to stimulate the market ramp-up of hydrogen, particularly in the industrial sector. However, in 2023, less than 10% of the originally announced green hydrogen production was realized, shows a new study [published](#) in the journal *Nature Energy*.

The main reason: hydrogen remains an expensive good for which there is little willingness to pay. Adrian Odenweller and Falko Ueckerdt from the Potsdam Institute for Climate Impact Research (PIK) determined this competitiveness gap

for all 1,232 globally announced hydrogen projects. They advocate for a robust political strategy that is based on realistic expectations for hydrogen and closes the implementation gap.

"Over the past three years, global project announcements for green hydrogen have almost tripled," says PIK researcher and lead author Odenweller. "However, only 7% of the production capacity originally announced for 2023 has been completed on time during this period."

According to the study, the recent problems with the market ramp-up of green hydrogen can be attributed to increased costs, a lack of willingness to pay on the demand side and uncertainties about future subsidies and regulation.

"Enormous additional subsidies of around one trillion US dollars would be required to realize all announced hydrogen projects by 2030," explains Ueckerdt from PIK, "Green hydrogen will continue to have difficulties meeting the high expectations in the future due to a lack of competitiveness."

However, permanent subsidies are not a solution. The two researchers therefore recommend using demand-side instruments such as binding quotas to channel green hydrogen specifically into sectors that are difficult to electrify, such as aviation, steel or chemicals. For example, according to an EU regulation, 1.2% of all aviation fuels must be blended with synthetic fuels based on hydrogen from 2030. This quota is set to rise to 35% by 2050.

Subsidy requirements far exceed announced global subsidies

In their study, the researchers quantified three key gaps between theory and practice: the past implementation gap, the future ambition gap and the future implementation gap. The first results are from the difference between originally announced hydrogen projects and the projects actually realized in 2023. The ambition gap refers to the discrepancy between the amount of hydrogen that would be required by 2030 according to 1.5-degree scenarios and the projects currently announced by 2030.

Although announced hydrogen projects are sufficient for the majority of the scenarios analyzed, a wide implementation gap remains: The subsidies required to realize all projects by 2030 far exceed the global public financial support announced to date.

The study is based on a global and manually verified project database with 1,232 green hydrogen projects announced until 2030. For each of the 14 designated end uses of the projects, the authors calculate the competitiveness gap between the green product and its fossil competitor. Together with the volume and the timing of the project announcements, this yields the subsidies required to realize all projects by 2030.

The researchers warn against fossil lock-ins, which could tie companies to fossil fuels and thus endanger climate targets. In the long term, a transition to technology-neutral market mechanisms such as carbon pricing is crucial in order to limit public costs and ensure a level playing field with other climate mitigation options. They therefore recommend a robust strategy that supports hydrogen projects in the short term through direct subsidies and demand-side regulation, but is based on realistic expectations for hydrogen.

More information: Odenweller, A. et al. Green Hydrogen ambition and implementation gap, *Nature Energy* (2025). DOI: [10.1038/s41560-024-01684-7](https://doi.org/10.1038/s41560-024-01684-7), www.nature.com/articles/s41560-024-01684-7

Provided by Potsdam Institute for Climate Impact Research

JANUARY 9, 2025

Self-improving catalyst boosts hydrogen generation from ammonia

by [University of Nottingham](#)



A model of a nanocluster catalyst featuring ruthenium atoms as green and white (with the white atoms highlighting the active center) arranged as a flattened pyramid on a carbon support (represented by black atoms). In the background, the magnetron sputtering system is seen used to produce the nanoclusters. Credit: University of Nottingham

Scientists have created a catalyst for hydrogen generation from ammonia that becomes more active with time, and by counting atoms, revealed changes that boost the catalyst's performance.

A research team from the University of Nottingham's School of Chemistry, in collaboration with the University of Birmingham and Cardiff University, has developed a novel material consisting of nanosized ruthenium (Ru) clusters anchored on graphitized carbon. These Ru nanoclusters react with ammonia molecules, catalyzing splitting ammonia into hydrogen and nitrogen—an essential step toward green hydrogen production.

This research is published in *Chemical Science*.

With its high volumetric energy density, ammonia holds promise as a zero-carbon energy carrier that could drive a sustainable new economy in the near future. Finding fast and energy-efficient methods to crack ammonia into hydrogen (H₂) and nitrogen (N₂) on demand is essential.

While catalyst deactivation is common, it is rare for a catalyst to become more active with use. Therefore, understanding the atomic-level mechanisms behind changes in the catalyst activity is critical for designing the next generation of heterogeneous catalysts.

Dr. Jesum Alves Fernandes, an Associate Professor in the School of Chemistry, University of Nottingham, and co-leader of the research team, explained, "Traditional catalysts consist of nanoparticles, with most atoms inaccessible for reactions. Our approach starts with individual atoms that self-assemble into clusters of a desired size.

"Therefore, we can halt the growth of the clusters when their footprints reach 2–3 nm², ensuring that the majority of atoms remain on the surface and available for chemical reactions. In this work, we harnessed this approach to grow ruthenium nanoclusters from atoms directly in a carbon support."

The researchers employed magnetron sputtering to generate a flux of metal atoms for constructing the catalyst. This solvent- and reagent-free technique enables the fabrication of a clean, highly active catalyst. By maximizing the catalyst's surface area, this method ensures the most efficient use of rare elements like ruthenium (Ru).

Dr. Yifan Chen, a Research Fellow at the University of Nottingham's School of Chemistry, said, "We were surprised to discover that the activity of Ru nanoclusters on carbon actually increases over time, which defies deactivation processes typically taking place for catalysts during their usage.

"This exciting finding cannot be explained through traditional analysis methods, and so we developed a microscopy approach to count the atoms in each nanocluster of the catalyst through different stages of the reaction using scanning transmission electron microscopy. We revealed a series of subtle yet significant atomic-level transformations."

Researchers discovered that ruthenium atoms initially disordered on the carbon surface rearrange into truncated nano-pyramids with stepped edges. The nano-pyramids demonstrate remarkable stability over several hours during the reaction at [high temperatures](#). They continuously evolve to maximize the density of active sites, thereby enhancing hydrogen production from ammonia. This behavior explains the unique self-improving characteristics of the catalyst.

Professor Andrei Khlobystov, School of Chemistry, University of Nottingham, said, "This discovery sets a new direction in catalyst design by showcasing a stable, self-improving system for [hydrogen generation](#) from ammonia as a green energy source. We anticipate this breakthrough will contribute significantly to sustainable energy technologies, supporting the transition to a zero-carbon future."

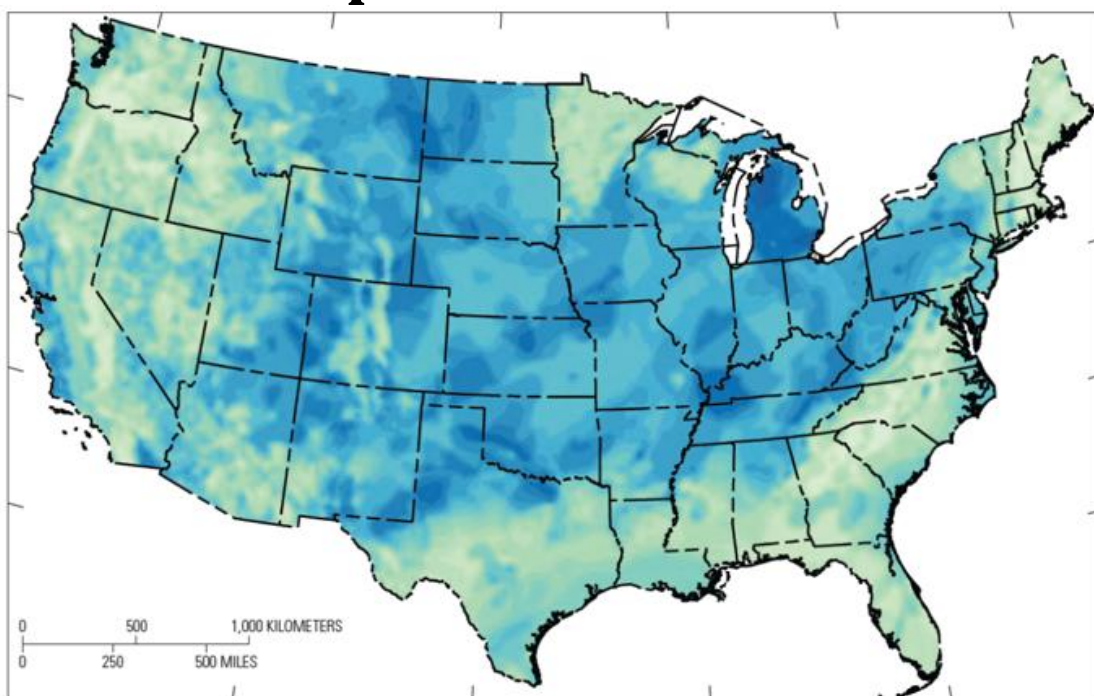
This invention marks a major advancement in understanding the atomistic mechanisms of heterogeneous catalysis for hydrogen production. It paves the way for developing highly active, stable catalysts that use rare metals sustainably by precisely controlling [catalyst](#) structures at the nanoscale.

More information: Evolution of amorphous ruthenium nanoclusters into stepped truncated nano-pyramids on graphitic surfaces boosts hydrogen production from ammonia, *Chemical Science* (2025). doi.org/10.1039/D4SC06382A

Journal information: [Chemical Science](#)

Provided by [University of Nottingham](#)

Giant reserves of 'gold' hydrogen may be lurking beneath at least 30 US states, 1st-of-its-kind map reveals



A map showing areas in the U.S. that are unlikely to host hydrogen reserves (white to light blue) and likely to host hydrogen reserves (blue to dark blue). © U.S. Geological Survey

A first-of-its-kind map of the United States has revealed the likely locations of huge, naturally occurring hydrogen reserves.

The map, which you can [explore here](#), is the first to show prospective locations for hydrogen on such a huge scale, marking areas where hydrogen gas may be lurking beneath the surface in quantities large enough to extract.

The researchers who created the map already suspected there could be more hydrogen buried in Earth's crust than scientists previously thought. But now that the results are out, even the team that created the map can't quite believe their eyes, according to a [statement](#).

"For decades, the conventional wisdom was that naturally occurring hydrogen did not accumulate in sufficient quantities to be used for energy purposes," [Sarah Ryker](#), associate director for energy and mineral resources at the U.S. Geological Survey (USGS), who did not participate in the research, said in the statement.

"This map is tantalizing because it shows that several parts of the U.S. could have a subsurface hydrogen resource after all."

The map is graded from white to dark blue, with dark blue indicating areas that are highly prospective, meaning they are very likely to hold vast hydrogen reserves, and white indicating areas that are not prospective. Highly prospective areas include most of Michigan, eastern Kentucky and southern North Dakota, as well as parts of Kansas, Colorado, Wyoming, Iowa and Oklahoma.

Whether a region is a prospective location for hydrogen depends on three main factors coming together: a source (or sources) of hydrogen, reservoir rocks and natural seals to trap the gas underground. Geologic hydrogen — hydrogen that occurs naturally, also known as "white" or "gold" hydrogen — is produced through chemical reactions in rocks, the simplest being a reaction that splits water into hydrogen and oxygen.

The map shows that at least 30 U.S. states have the conditions needed for hydrogen to accumulate belowground. There is high potential for the gas to be found in large swathes of the Midwest, as well as in areas along the California coast and Eastern Seaboard, according to the statement.

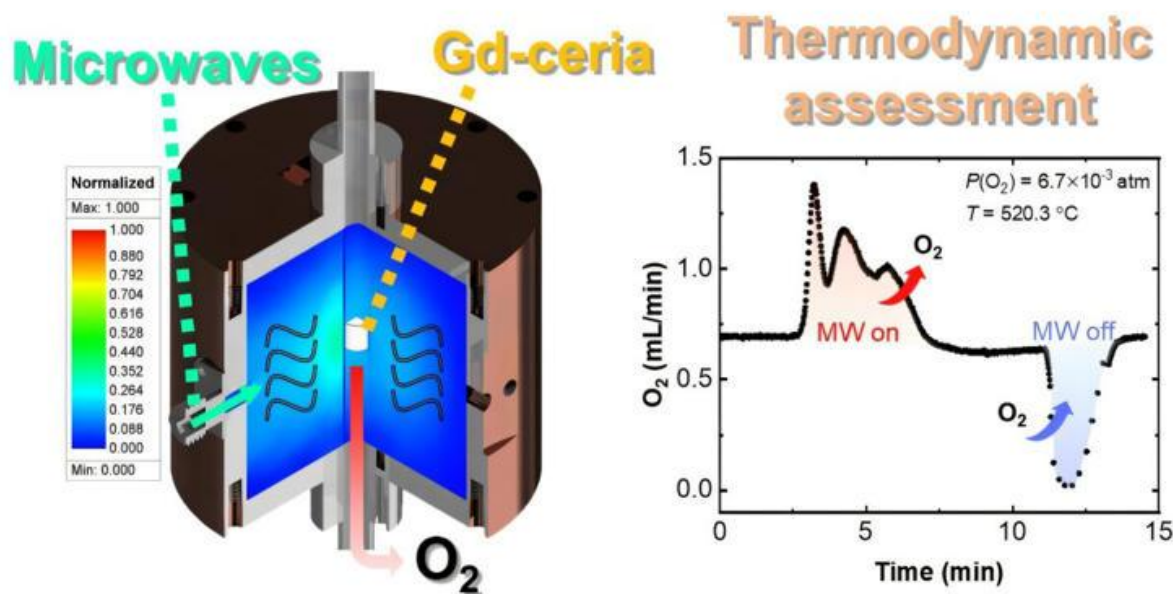
Hydrogen is a [source of clean energy](#). Researchers project that it will account for up to 30% of the future energy supply in some sectors, with demand likely to [rise fivefold by 2050](#).

In a [study](#) published last month, the same researchers calculated that [Earth's total buried hydrogen reserves](#) could amount to 6.2 trillion tons (5.6 trillion metric tons) of gas. Just 2% of that would supply all the energy required to power the world for 200 years, they said.

But that estimate came with no indication of where those reserves are located, which dictates whether they are accessible and, therefore, extractable. In the previous study, "we showed there is a significant potential for geologic hydrogen as an emerging energy resource," [Sarah Gelman](#), a geologist with the USGS Central Energy Resources Science Center who participated in the new research, said in the statement. "The logical next step was to find where it might be in the United States."

The map and an accompanying report detailing the results were published Thursday (Jan. 16) on the [USGS website](#).

Clean hydrogen in minutes: Microwaves deliver clean energy faster



Schematic illustration of oxygen release upon interaction with microwaves (left) and a corresponding graph of oxygen release and uptake (right). Credit: POSTECH

An interdisciplinary team at POSTECH has developed a technology that addresses key limitations in clean hydrogen production using microwaves. They have also successfully elucidated the underlying mechanism of this innovative process.

Their findings, [published](#) as the inside front cover of *Journal of Materials Chemistry A*, mark a transformative step in the pursuit of sustainable energy.

As the world shifts away from fossil fuels, clean hydrogen has emerged as a leading candidate for next-generation energy due to its zero carbon emissions. However, existing hydrogen production technologies face significant barriers. Conventional thermochemical methods, which rely on the oxidation-reduction of metal oxides, require extremely high temperatures of up to 1,500°C. These methods are not only energy-intensive and costly but also challenging to scale, limiting their practical application.

To address these challenges, the POSTECH team turned to a familiar yet underutilized energy source: "microwaves" energy, the same source used in household microwave ovens. While microwaves are commonly associated with heating food, they can also drive chemical reactions efficiently.

The researchers demonstrated that microwave energy could lower the reduction temperature of Gd-doped ceria (CeO_2)—a benchmark material for hydrogen production—to below 600°C, cutting the temperature requirement by over 60%. Remarkably, microwave energy was found to replace 75% of the thermal energy needed for the reaction, a breakthrough for sustainable hydrogen production.

Another critical advancement lies in the creation of "oxygen vacancies," which are defects in the material structure essential for splitting water into hydrogen. Conventional methods often take hours at extremely high temperatures to form these vacancies. The POSTECH team achieved the same results in just minutes at temperatures below 600°C by leveraging microwave technology. This rapid process was further validated with a thermodynamic model, which provided valuable insight into the mechanism underlying the microwave-driven reaction.

Professor Hyungyu Jin stated, "This research has the potential to revolutionize the commercial viability of thermochemical hydrogen production technologies. It will also pave the way for the development of new materials optimized for microwave-driven chemical processes."

Professor Gunsu Yun added, "Introducing a new mechanism powered by microwaves and overcoming the limitations of existing processes are major achievements, made possible through the close interdisciplinary collaboration of our research team."

The research team was led by Professor Gunsu S. Yun, doctoral candidate Jaemin Yoo (Department of Physics, Division of Advanced Nuclear Engineering), Professor Hyungyu Jin, and doctoral candidate Dongkyu Lee (Department of Mechanical Engineering).

More information: Dongkyu Lee et al, Thermodynamic assessment of Gd-doped CeO₂ for microwave-assisted thermochemical reduction, *Journal of Materials Chemistry A* (2024). DOI: [10.1039/D4TA05804F](https://doi.org/10.1039/D4TA05804F)

Provided by Pohang University of Science and Technology

New way to store hydrogen using lignin jet fuel discovered



a) Proposed LJP production pathways; b) Tier α hydrocarbon type analysis on neat LJP. Credit: International Journal of Hydrogen Energy (2024). DOI: [10.1016/j.ijhydene.2024.12.082](https://doi.org/10.1016/j.ijhydene.2024.12.082)

An international team of scientists has discovered a way to store and release volatile hydrogen using lignin-based jet fuel that could open new pathways for sustainable energy production.

In a new [study](#) in the *International Journal of Hydrogen Energy*, Washington State University Professor Bin Yang and colleagues demonstrated that a type of lignin-based jet fuel they developed can chemically bind hydrogen in a stable liquid form. The research has many potential applications in fuels and transportation and could ultimately make it easier to harness hydrogen's potential as a high energy and zero emissions fuel source.

Bin Yang, professor in WSU's Department of Biological Systems Engineering, stands with Andrew Lipton, scientist at Pacific Northwest National Laboratory, next to a nuclear magnetic resonance instrument used in experiments on new sustainable fuels. Credit: by Andrea Starr and Eddie Pablo | Pacific Northwest National Laboratory

"This new, lignin jet fuel-based technology could enable efficient, high-density hydrogen storage in an easy-to-handle sustainable aviation fuel, eliminating the need for pressurized tanks for storage and transport," Yang said.

For the study, researchers at WSU, Pacific Northwest National Laboratory, the University of New Haven, and Natural Resources Canada set out to address one of the major challenges with using hydrogen as a fuel source. The lightest element's low density and explosive nature make storage and transport technically challenging, inefficient, and expensive.

The January article details how the research team discovered the new hydrogen-storing process using chemical reactions that produced aromatic carbons and hydrogen from lignin jet fuel—an experimental fuel developed by Yang's lab based on lignin, an organic polymer found in plants.

"Hydrogen is a versatile energy carrier that could help the U.S. meet its targets for zero-emission mobility, integration of renewables, and decarbonization of industry," Yang said.

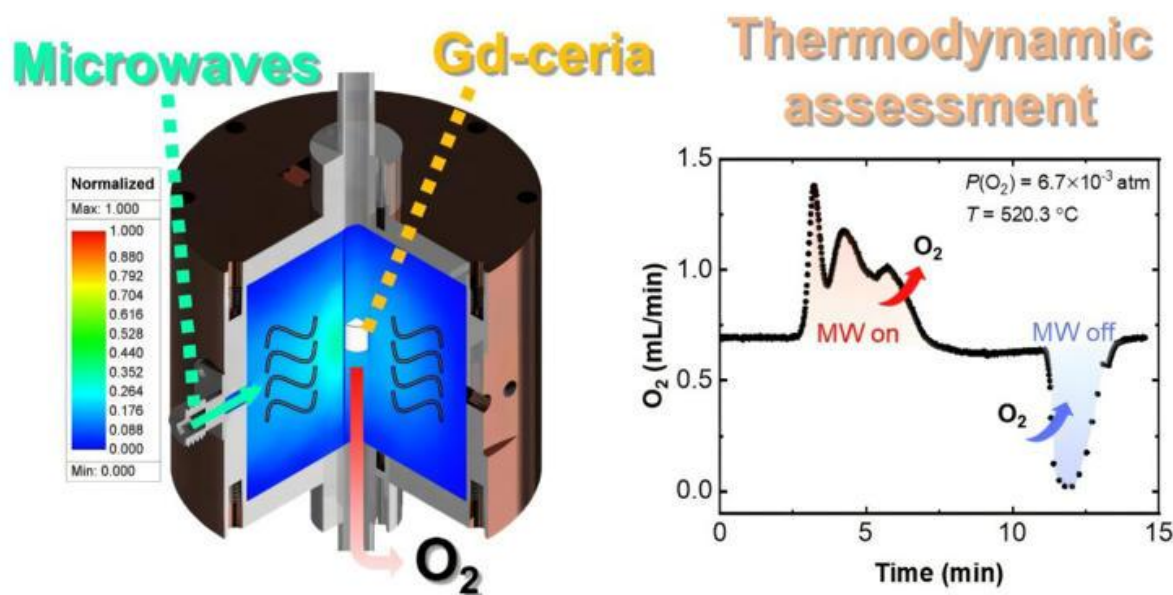
The discovery points to new uses for the lignin jet fuel developed at WSU by Yang, who [previously tested a new continuous process](#) that creates the fuel from agricultural waste. [Experiments have shown](#) that the sustainably produced fuel could increase engine performance and efficiency while dispensing with aromatics, the pollution-causing compounds found in conventional fuels.

"This innovation offers promising opportunities for compatibility with existing infrastructure and economic viability for scalable production," Yang said. "It could help create a synergistic system that enhances the efficiency, safety, and ecological benefits of both sustainable aviation fuel and hydrogen technologies."

Next, WSU researchers will collaborate with scientists at the University of New Haven to design an AI-driven catalyst that enhances and completes the reactions, making them more efficient and cost-effective.

More information: Andrew S. Lipton et al, In-situ dehydrogenation of lignin-based jet fuel: A novel and sustainable liquid organic hydrogen

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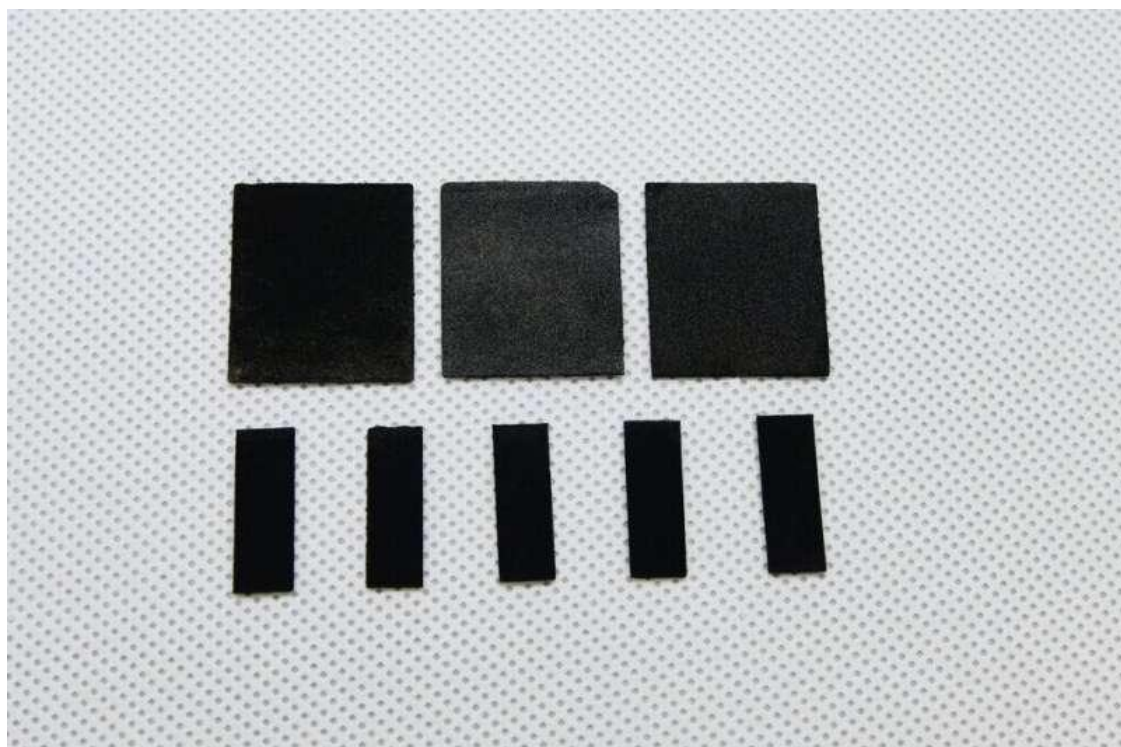
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Provided by Pohang University of Science and Technology

FEBRUARY 7, 2025

One step closer to the green hydrogen era: New material boosts production efficiency and reduces costs

by [National Research Council of Science and Technology](#)



Catalysts

for AEM water electrolysis developed by KRISS. Credit: Korea Research Institute of Standards and Science (KRISS)

Researchers in Korea have successfully developed a new material that significantly enhances the efficiency of green hydrogen production while reducing costs.

The Korea Research Institute of Standards and Science (KRISS) has developed a high-performance base metal catalyst for use in anion exchange membrane (AEM) water

electrolysis. The newly developed catalyst is not only more affordable than precious metal-based alternatives but also exhibits superior performance, bringing the commercialization of green hydrogen a step closer.

The findings are [published](#) in the journal *Applied Catalysis B: Environmental and Energy*.

Currently, AEM water electrolysis systems predominantly rely on precious metal catalysts such as platinum (Pt) and iridium (Ir). However, the high cost of these materials and their susceptibility to degradation significantly increase the cost of hydrogen production. To overcome this challenge, the development of durable and affordable base metal catalysts is essential.

The KRISS Emerging Material Metrology Group has succeeded in developing base metal catalysts by introducing a small amount of ruthenium (Ru) into a molybdenum dioxide with nickel molybdenum ($\text{MoO}_2\text{-Ni}_x\text{Mo}$) structure. While molybdenum dioxide offers [high electrical conductivity](#), its use as a [water electrolysis catalyst](#) has been limited due to degradation in alkaline environments.



researcher operating the water electrolysis system using the newly developed catalysts. Credit: Korea Research Institute of Standards and Science (KRISS)

Through comprehensive structural analysis, the researchers identified hydroxide ion (OH^-) adsorption on molybdenum dioxide as the primary cause of degradation. Building on these findings, they devised a method to incorporate ruthenium at an optimal ratio to prevent molybdenum dioxide degradation.

The resulting ruthenium nanoparticles, measuring less than 3 nanometers, form a [thin layer](#) on the catalysts' surface, preventing degradation and enhancing durability.

Performance evaluations revealed that the newly developed catalysts offers four times the durability and more than six times the activity compared to existing commercial materials. Moreover, when integrated with a perovskite-silicon tandem solar cell, the catalysts achieved a remarkable solar-to-hydrogen efficiency of 22.8%, highlighting its strong compatibility with renewable energy sources.

The catalysts also demonstrated high activity and stability in [saline water](#), producing high-quality hydrogen. This capability is expected to significantly reduce the costs associated with desalination.

Dr. Sun Hwa Park, a principal researcher at the KRISS Emerging Material Metrology Group, commented, "Currently, producing green hydrogen requires purified water, but using actual seawater could substantially lower costs associated with desalination. We plan to continue our research in this area."

This research was conducted in collaboration with Professor Ho Won Jang's team at Seoul National University and Dr. Sung Mook Choi's team at the Korea Institute of Materials Science.

More information: Sang Eon Jun et al, Exsolved Ru-mediated stabilization of $\text{MoO}_2\text{-Ni}_4\text{Mo}$ electrocatalysts for anion exchange membrane water electrolysis and unbiased solar-driven saline water splitting, *Applied Catalysis B: Environment and Energy* (2024). DOI:

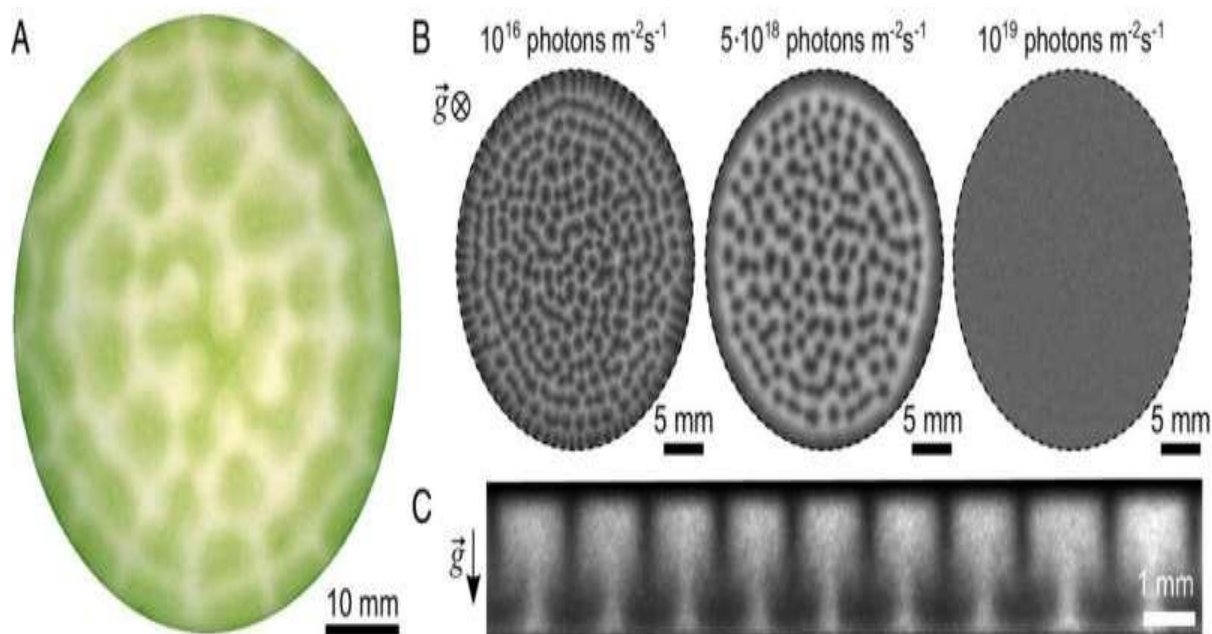
[10.1016/j.apcatb.2024.124364](https://doi.org/10.1016/j.apcatb.2024.124364)

Provided by [National Research Council of Science and Technology](#)

FEBRUARY 7, 2025

Light-regulated movement patterns of hydrogen-producing green algae could improve photobioreactor design

by Theresa Hübner, [Bayreuth University](#)



Light-controlled emergence of coherent flows in living *C. reinhardtii* suspensions.

Credit: *Proceedings of the National Academy of Sciences* (2025). DOI:

10.1073/pnas.2413340122

Researchers from the University of Bayreuth and the Max Planck Institute for Dynamics and Self-Organization in Göttingen have investigated the movement patterns of unicellular, hydrogen-producing green algae under different light intensities. Their findings will contribute to optimizing the use of these microorganisms in biotechnological applications, such as the production of renewable energy sources.

The team has [published](#) its results in *PNAS*.

Photosynthetic microorganisms use light as an energy source and function as living miniature factories that produce oxygen and store carbon while converting sunlight into chemical energy. In addition to their ecological role as carbon sinks, these microorganisms are also crucial for sustainable technological applications in climate-neutral industries.

They are used, for instance, in so-called photobioreactors to selectively produce chemical compounds for renewable biofuels and hydrogen for fuel cells. However, [environmental conditions](#) influence the motility of individual microorganisms, which in turn affects the

movement of the entire community. A better understanding of these [movement patterns](#) will help improve the design of efficient photobioreactors.

Photosynthetic microorganisms such as the unicellular green alga *Chlamydomonas* are true masters of adaptation. In the absence of light and oxygen, the metabolism of this alga switches to a kind of energy-saving mode, in which molecular hydrogen is produced as a by-product.

The intensity of light directly regulates the motility of individual cells: the stronger the [light intensity](#), the faster the cells move in water; the weaker the light, the slower they swim. This reveals a direct correlation between light intensity and swimming speed.

Until now, however, the impact of individual movement on the collective swimming behavior of an entire population of unicellular organisms had not been known.

Researchers led by Prof. Dr. Oliver Bäumchen, chair of Experimental Physics V at the University of Bayreuth, have examined the movement of individual *Chlamydomonas* cells and their effect on a so-called *Chlamydomonas* suspension—a microbial community that swims in an aqueous environment.

Their study has shown that *Chlamydomonas* cells are more likely to be found near the [water surface](#) under high light intensity rather than at lower depths.

"This behavior is due to the microorganisms' tendency to move against gravity. In a natural body of water, this provides an [evolutionary advantage](#), as unicellular organisms at the surface have better access to light than those at greater depths," explains Bäumchen.

Furthermore, the research team discovered that as photosynthetic activity and, consequently, the motility of individual cells decrease, directed currents emerge within the entire cell community. This collective motility manifests as a regular three-dimensional flow pattern, in which flow rates and cell distributions are directly controlled by light intensity.

"These currents arise under the extremely unfavorable conditions of simultaneous light and oxygen deficiency and could potentially help the microbial collective to expand its exploration of its natural habitat in search of better conditions," says Bäumchen.

More information: Alexandros A. Fragkopoulos et al, Metabolic activity controls the emergence of coherent flows in microbial suspensions, *Proceedings of the National Academy of Sciences* (2025). DOI: [10.1073/pnas.2413340122](https://doi.org/10.1073/pnas.2413340122)

Journal information: [Proceedings of the National Academy of Sciences](#)

Provided by [Bayreuth University](#)



Electrical Power from Hydrogen to Dark Matter

Brilliant Light Power has developed a new commercially competitive, non-polluting, plasma-based primary source of massive power from the conversion of hydrogen atoms of water molecules to dark matter, the previously unidentified matter that makes up most of the mass of the universe. The SunCell® that was invented to harness the new power source catalytically converts hydrogen directly into dark matter form called Hydrino® releasing brilliant high-energy light which is down-converted in energy to facilitate the production of electricity using commercially-available concentrator photovoltaic cells.

A Current Commercial Design SunCell®

The Power of the SunCell®

The electricity producing SunCell® uses a catalyst to cause hydrogen atoms of water molecules to transition to the lower-energy Hydrino® states by allowing their electrons to fall to smaller radii around the nucleus. This results in a release of energy that is intermediate between chemical and nuclear energies and a nonpolluting product. The energy release of the hydrogen separated from H₂O, that can be acquired even from the humidity in the air, is over one hundred times that of an equivalent amount of high-octane gasoline. The highest known power density with direct electricity conversion facilitates essentially all power applications untethered to fuels or grid infrastructure. The electrical generation cost is anticipated to be less than 10% that of any known power source.

The World's First Continuous Plasma – Closed SunCell®

Electron paramagnetic resonance proof for the existence of molecular hydrino

Wilfred R. Hagen ^a, Randell L. Mills ^b

<https://doi.org/10.1016/j.ijhydene.2022.05.156>Get rights and content

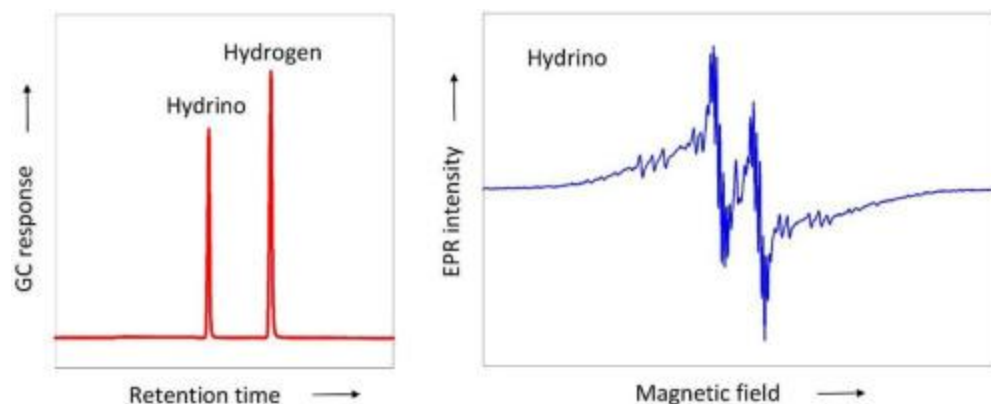
Highlights

- •
New allotrope of molecular hydrogen recoded by EPR.
- •
New molecular orbital structure confirmed having a paired and an unpaired electron.
- •
SQUID behavior noted for a molecular orbital.
- •
New fastest gas migration velocity recorded by gas chromatography.
- •
New state of molecular hydrogen is the basis of a new power source.

Abstract

Quantum mechanics postulates that the hydrogen atom has a stable ground state from which it can be promoted to excited states by capture of electromagnetic radiation, with the energy of all possible states given by $E_n = -13.598/n^2$ eV, in which $n \geq 1$ is a positive integer. It has been previously proposed that the $n = 1$ state is not the true ground state, and that so-called hydrino states of lower energy can exist, which are characterized by fractional quantum numbers $n = 1/p$, in which $1 < p \leq 137$ is a limited integer. Electron transition to a hydrino state, $H(1/p)$ is non-radiative and requires a quantized amount of energy, $2mE_i$ (m is an integer), to be transferred to a catalyst. Numerous putative hydrino-forming reactions have been previously explored and the products have been characterized by a range of analytical methods. Molecular hydrino has been predicted to be paramagnetic. Here, we give an account of an electron paramagnetic resonance (EPR) study of molecular hydrino $H_2(1/4)$ that was produced as gaseous inclusion in polymeric $Ga(O)OH$ by a plasma reaction of atomic hydrogen with non-hydrogen bonded water as the catalyst. A sharp, complex, multi-line EPR spectrum is found, whose detailed properties prove to be consistent with predictions from hydrino theory. Molecular hydrino was also identified in gas chromatography as a compound faster than molecular hydrogen.

Graphical abstract



Introduction

The quantized energy levels of the [hydrogen atom](#) are $E_n = -13.598/n^2$ eV, in which the principal [quantum number](#) n is a positive integer. The electronic [ground state](#) has $n = 1$. Higher states can be populated by absorption of light according to the Rydberg equation $\nu = R_H[(1/n_2)^2 - (1/n_1)^2]$ with $R_H = 109.677$ cm⁻¹. R. Mills has hypothesized and experimentally tested that the $n = 1$ state is not the absolute ground state and that lower-energy hydrino states characterized by fractional quantum numbers $1/p$, with $2 = p \leq 137$, can exist. The underlying theory has been presented in a series of papers [[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]]. A comprehensive compilation of the theory, known as The Grand Unified Theory of Classical Physics (GUTCP) is available as a 3-vol e-book with regular updates [12]. Ample experimental evidence has been presented by the Mills lab that $H(1/p)$ can be produced from $H(n = 1)$ in a non-radiative process whereby a catalyst reversibly takes up an amount of energy equal to $(p - 1) \times 27.196$ eV such that a total amount equal to $(p^2 - 1) \times 13.598$ eV is ultimately released as heat, continuum EUV emission, [energetic](#) signatures, and hydrino [chemical products](#) [[13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70]].

Mills' GUTCP theory has been evaluated – both positively and negatively – by others, however, thus far only on the basis of theoretical arguments [[71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84]].

Experimental support for the existence of hydrino, as H , H^- , or H_2 , has been presented by the Mills lab and other independent laboratories and researchers [[13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70]].

[6], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70]] using vibrating sample [magnetometry](#), magic angle spinning ^1H nuclear magnetic resonance spectroscopy (MAS ^1H NMR), [Raman spectroscopy](#) including [deuterium](#) substitution, [photoluminescence emission spectroscopy](#), [Fourier transform infrared spectroscopy](#) (FTIR), gas chromatography, X-ray photoelectron spectroscopy (XPS), time of flight secondary ion [mass spectroscopy](#) (ToF-SIMS), [electrospray ionization time of flight mass spectroscopy](#) (ESI-ToFMS), and high performance liquid chromatography (HPLC). The energetics of the hydrino reaction was confirmed by the observation of extraordinarily Doppler and Stark H [line broadening](#), [hydrogen plasma afterglow](#), ultraviolet and [visible spectroscopy](#) of [population inversion](#), shockwave formation, 20 MW-level continuum EUV [optical power](#) wherein the reaction rate was greatly increased by applying an arc current to recombine ions and electrons formed by the energy transfer to HOH that is consequently ionized, [differential scanning calorimetry](#) of hydrino solid-fuel reactant mixtures, electrical energy balance of hydrino reaction [electrochemical cells](#), and water bath calorimetry on so-called SunCells® comprising a molten [gallium injector](#) that electrically shorts two plasma electrodes with the molten gallium to maintain an arc [current plasma](#) state that boosted output power to 340,000 W in a 0.5 -liter reactor volume. The present study significantly extends this body of research as it is carried out in an independent laboratory with a technique, [EPR](#), not previously applied in hydrino studies.

Experimental

Full experimental details are given in the [ESI](#). These include descriptions of plasma reactor setup, production of reactants, reaction control, and product processing. Analytical methods for product analysis are detailed covering gas chromatography, scanning electron microscopy, energy dispersive X-ray spectroscopy, Rutherford backscattering [spectrometry](#), time-of-flight [secondary ion mass spectrometry](#), [transmission electron microscopy](#), and X-ray diffraction. The [EPR spectroscopy](#) is described including all in-house developed software for data analysis.

Results and discussion

Molecular hydrino sample production

A common feature of a hydrino state and an excited H state is that both comprise an electron, a proton, and a photon. In an excited H state, the photon superimposes the proton field to decrease the central field at the electron to $+e/n$ (e is the fundamental charge) and creates a radial dipole instability that results in radiation. Conversely, the photon of a hydrino state increases the central field at the electron to $+(1+m)e$ and creates a radial monopole that is radiatively stable. According to GUTCP, ground-state ($n = 1$) atomic hydrogen can be converted to atomic hydrino ($n = 1/(1+m)$) by means of a nonradiative resonant energy transfer to a catalyst with potential energy $= m \times 27.2 \text{ eV}$ (that is $2m \times E_1$) according to the reaction $m \times 27.2 \text{ eV} + \text{H}(1) + \text{Cat} \rightarrow \text{H}^*(1/(1+m)) + \text{Cat}^* + m \times 27.2 \text{ eV}$

in which the energy term on the left is energy absorbed by the catalyst (typically by resonant ionization) and the term on the right is the energy released by the increase in the potential energy of the [hydrogen atom](#) to form $H^*(1/(1+m))$, an intermediate of the hydrino atom of radius a_H . Subsequently the ionized catalyst, Cat^* , regenerates by recombination, with the release of its previously gained [ionization energy](#), and the hydrino intermediate converts to stable $H(1/(m+1))$ having a radius of $a_H/(1+m)$ by release of additional energy such that the overall release of energy is $[(m+1)^2 - 1] \times 13.6 \text{ eV}$. By considering the quantum state $p = m + 1$ the reaction may be written $H(1) \rightarrow H(1/p) + (p^2 - 1) \times 13.6 \text{ eV}$

The hydrino transition reaction requires atomic H and a single catalyst species which is typically formed chemically or by a plasma reaction [[13], [14], [15], [16], [17], [18], [19], [20]]. Further reactivity produces molecular hydrino $H_2(1/p)$ from atomic hydrino $H(1/p)$ when the bond energy is removed by collision with a third body, which can be a reactor-wall constituent [85]. A variety of species can resonantly and nonradiatively accept $m \times 27.2 \text{ eV}$ from atomic hydrogen to serve as catalyst for hydrino formation; in the present case we use the nascent (that is, in situ prepared, not hydrogen-bonded) water molecule with potential energy $3 \times 27.2 \text{ eV}$ [13,14]. Details of the sample preparation are given in ESI. Briefly, the reactor is a closed vessel in which a low-voltage discharge is created between a liquid [gallium](#) electrode and a solid tungsten electrode with water and hydrogen introduced from a supported-Pt H_2/O_2 recombiner supplied with H_2 gas and trace O_2 to form trace nascent, or non-H-bonded water catalyst. Either additional oxygen or water vapor are introduced to produce gallium oxide that is collected. Regular $H_2(1)$ is known to absorb onto Ga_2O_3 [[86], [87], [88]]. It is unknown if molecular hydrino putatively associated with the Ga_2O_3 is sufficiently stable to survive slow transfer to an EPR lab because the Ga_2O_3 collected from the SunCell® reactor is contaminated with metallic gallium along with $Ga(O)OH$. The presence of gallium metal precludes EPR spectroscopy on the mixture. However, high-purity crystalline $Ga(O)OH$ for EPR analysis is isolated as follows. After dissolution of the mixture of gallium metal, gallium oxide, and $Ga(O)OH$ in 4 M KOH, a unique non-soluble product comprising $Ga(O)OH$ in the form of an aggregate of micro-spheres containing molecular hydrino $H_2(1/4)$ slowly polymerizes as shown by scanning electron microscopy (SEM) and [transmission electron microscopy](#) (TEM) in Fig. 1. We denote this stabilized system by $H_2(1/4)@Ga(O)OH$ compliant with a common notation for atomic hydrogen occluded in solid hosts [89,90].

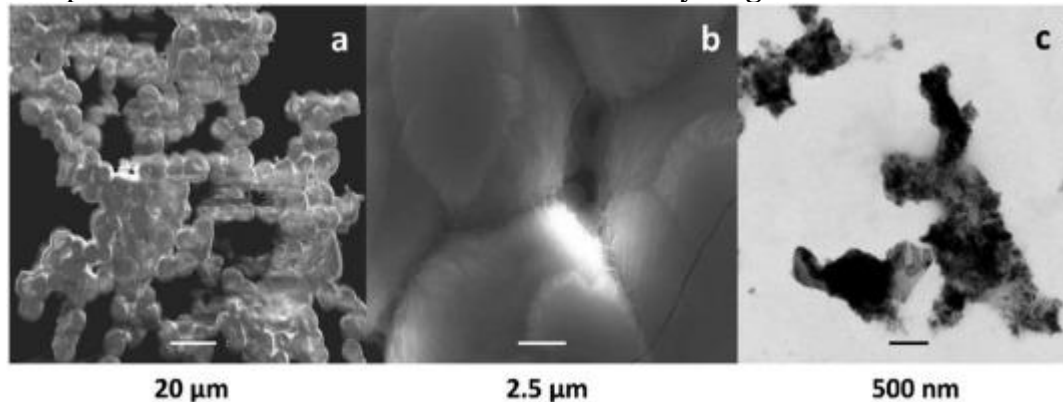


Fig. 1. Scanning electron microscopy and transmission electron microscopy of $\text{H}_2(1/4)@\text{Ga}(\text{O})\text{OH}$. Trace a: SEM at $800\times$ magnification showing chains of microspherical particles; trace b: SEM showing $5\text{ }\mu\text{m}$ width of the particles, each comprising very fine fibers; trace c: TEM imaging of morphologically polymeric crystals of hexagonal structure (Fig. S3), which were very sensitive to the TEM [electron beam](#). Observed spherical particles have approximately 100 nm average diameter.

Energy dispersive X-ray spectroscopy (EDS) showed an elemental [composition](#) of $\text{GaO}_{2.1}$ (Fig. S1). Conventional [elemental analysis](#) of H relies on combustion to H_2O . However, $\text{H}_2(1/4)$ theoretically and experimentally does not undergo combustion with oxygen. The [molecular orbital electron energy level](#) is too low to react with oxygen. Therefore, Rutherford backscattering [spectrometry](#) (RBS) was performed on the $\text{H}_2(1/4)@\text{Ga}(\text{O})\text{OH}$ which identified the composition as $\text{GaO}_{1.68}\text{H}_{1.32}$ with a density of $8.56 \times 10^{22}\text{ atoms/cm}^2$ corresponding to an excess H content, some of which is hydrino hydrogen, based on the results of gas chromatographic identification and EPR spectroscopy reported below. Time-of-flight [secondary ion mass spectrometry](#) (ToF-SIMS), presented in Fig. S2, showed Ga in the [positive ion](#) spectrum and O and H as dominant ions in the [negative ion](#) spectrum wherein the hydride ion was elevated compared to control $\text{Ga}(\text{O})\text{OH}$. No hydrocarbons above adventitious levels were present and no nitrogen was found indicating the unlikelihood for EPR signals to originate from organic radicals. Equally, in the positive spectrum no potentially paramagnetic transition ions were present. Selected area [electron diffraction](#) (SAED) with the transmission [electron microscope](#) (Fig. S3) revealed the samples to comprise two different morphological and crystalline forms of $\text{Ga}(\text{O})\text{OH}$: rods with orthorhombic [diffraction pattern](#) matched control $\text{Ga}(\text{O})\text{OH}$, which lacks molecular hydrino, in morphology and crystalline structure [91] and were not sensitive to the TEM [electron beam](#); on the other hand, morphologically polymeric crystals comprising hexagonal crystalline structure were very electron-beam sensitive, and were assigned to novel $\text{H}_2(1/4)@\text{Ga}(\text{O})\text{OH}$. X-ray diffraction (XRD) showed a phase shift from the $\text{Ga}(\text{O})\text{OH}$ control lines with different deviations between NaOH and KOH formed $\text{H}_2(1/4)@\text{Ga}(\text{O})\text{OH}$ as illustrated in Fig. S4.

Gas chromatography of molecular hydrino

The $\text{H}_2(1/4)$ molecule has a cross section that is circa $1/64$ of that of the [helium atom](#). By consequence it is difficult to store molecular hydrino in a container for extended periods of time. Also, the here employed production scheme always results in contamination with regular $\text{H}_2(1)$. $\text{H}_2(1/4)$ was identified by gas chromatography in two complementary experiments. $\text{H}_2(1/4)$ gas was collected from the SunCell® reactor using a valved microchamber connected to the vacuum line and cooled to 15 K by a cryopump system. The [liquefied gas](#) was warmed to [room temperature](#) to achieve 10 Torr chamber pressure and was injected into a gas [chromatograph](#). $\text{H}_2(1/4)$ was observed as an early peak at 8.31 min and hydrogen that co-condensed with H_2 gas was observed at 12.87 min (Fig. 2a).

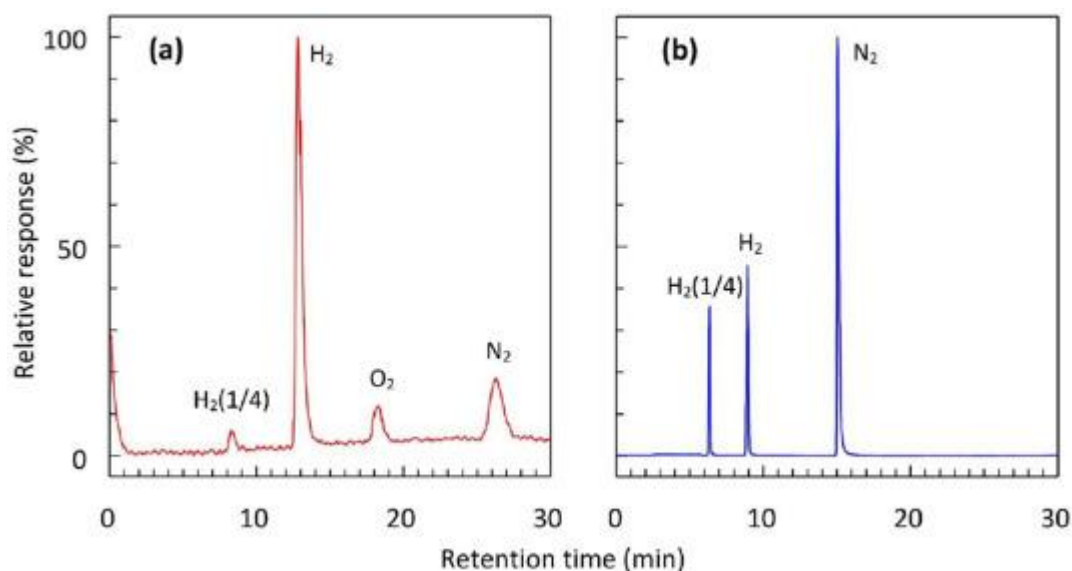


Fig. 2. Gas chromatographic identification of molecular hydrino $H_2(1/4)$. Trace a: GC of gas collected from the SunCell® reactor with a cryopump showing $H_2(1/4)$ at 8.31 min. Trace b: the GC of hydrino gas evolved by heating the KOH-treated $Ga_2O_3/Ga(O)OH$ material collected from the SunCell® to 800 °C. The known hydrogen and nitrogen peaks were observed at ca 8 and 15 min and a novel peak at ca 6 min was assigned to $H_2(1/4)$.

The peak at 18.24 min is oxygen that was condensed before the SunCell® run to serve as a solvent for $H_2(1/4)$. The collected gas contained no helium by mass spectroscopy. The early peak was negative with a helium carrier gas indicating that the early peak had a higher thermal conductivity, and the migration rate was faster than that of helium with an argon carrier gas. No known gas has a faster migration rate and higher thermal conductivity than H_2 or He, which is characteristic of and identifies hydrino since it has a much greater mean free path due to exemplary $H_2(1/4)$ having 64 times smaller volume and 16 times smaller ballistic cross section. Hydrogen condensed under pressure and temperature conditions that violate the Clausius Clapeyron equation due to the raising of the H_2 liquefaction temperature by co-condensation with $H_2(1/4)$.

In a different experiment gas chromatography was performed on the gases released by thermal desorption of gas bound to the KOH-treated $Ga_2O_3/Ga(O)OH$ sample originally collected from a SunCell® plasma run. Known gases such as hydrogen were also run to identify their migration times to compare to the results of the SunCell®-derived sample. The gas chromatograph of hydrino gas evolved by heating the $Ga(O)OH$ material to 800 °C is shown in Fig. 2b. Note that the amplitudes of the peaks assigned to molecular hydrino in the experiments of Fig. 2 are not quantifiable: since $H_2(1/4)$ is not obtained in pure form, its effect on the thermal conductor sensor cannot be quantified.

Paramagnetism of molecular hydrino

Alternative to the probabilistic matter waves of quantum mechanics, the electron in a hydrogen atom is modelled in GUTCP as a two-dimensional spherical membrane of

infinitesimal thickness in which current flows along two infinite, nested rotation sets of great circle filaments. This current pattern naturally gives rise to both orbital and spin [angular momentum](#) wherein the latter defines a free-electron factor $g_e = 2.0023193$ [3,4,[7], [8], [9],12,13]. In the hydrogen molecule the spherical current pattern becomes a prolate spheroid in which the pairing of two electrons leads to a [diamagnetic ground state](#). Atomic hydrino differs from $H(n > 1)$ states in that rather than the absorption of a photon to form an excited state, $H(n = 1/p)$ is formed by a non-radiative energy transfer to a resonant energy acceptor followed by continuum [extreme ultraviolet radiation](#) to the final stable hydrino atomic state. Two hydrino atoms react to form molecular hydrino having two photons that are phase-locked to the electron current and circulate in opposite directions. Consequently, the molecule has a diamagnetic and a paramagnetic electron, the latter with $g \neq g_e$ equal to $2 + 2 \times 0.0023193 = 2.0046386$ [92]. This fundamental prediction from [first principles](#) provides a unique, simple, and accurate testing criterion for the existence of molecular hydrino. Moreover, the theory predicts a specific and detailed splitting, or fine structure, of the $g = 2.00464$ resonance into a multi-line pattern due to internal magnetic and spin-orbit couplings affording a distinguishing EPR signature of molecular hydrino $H_2(1/4)$.

EPR spectroscopy of molecular hydrino

A wide [magnetic field](#) scan [EPR spectrum](#) of the Ga(O)OH solid powder taken at ambient temperature, exhibits a single derivative feature only against an essentially flat background, and with g value close to the free-electron value (Fig. 3a).

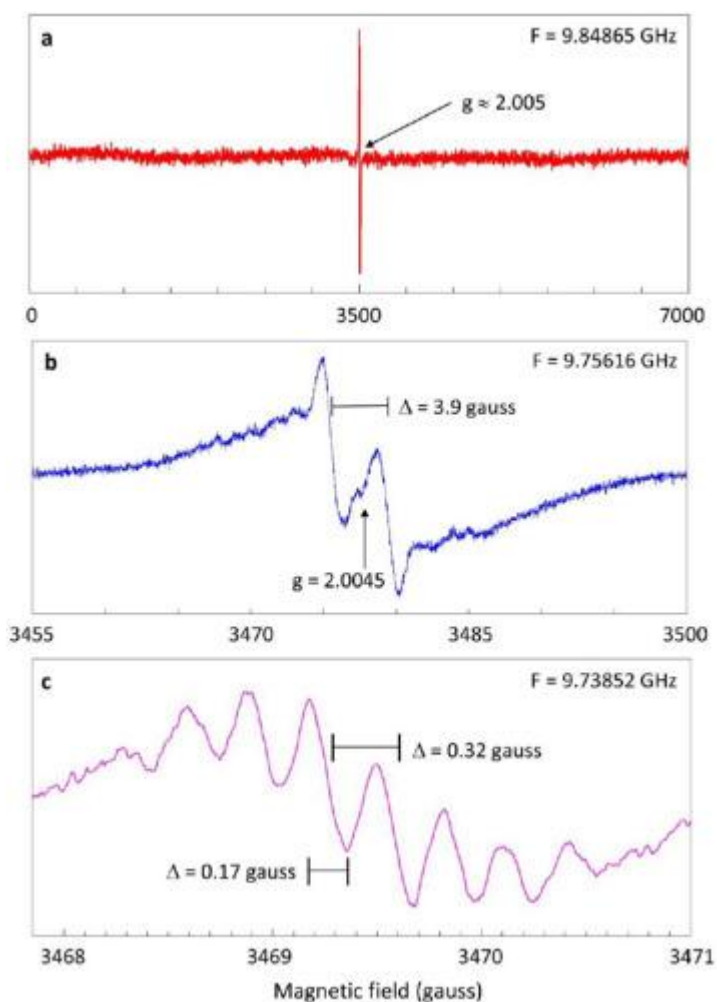


Fig. 3. EPR of postulated molecular hydrino $H_2(1/4)$ caged in solid $Ga(O)OH$ polymer. Trace a: wide-scan overview spectrum showing a single feature only close to the [free electron](#) g value. Trace b: zoom-in of the single feature in trace a shows two main lines of equal intensity, separated by circa 4 gauss, and whose center is distinctly shifted from the [free electron](#) value to $g = 2.0045$. Trace c: further zoom-in on one of the lines now recorded with a very small [modulation amplitude](#) reveals a fine structure of multiple lines with apparent peak-to-peak derivative [line width](#) of 0.17 gauss and separated by circa 0.32 gauss. Data collection times for traces a-c were 10, 16, and 375 min, respectively. Modulation amplitudes were 1, 1, and 0.25 gauss, respectively. All spectra were taken at ambient temperature. Other experimental conditions are given in ESI.

Zooming-in on this feature (Fig. 3b) shows it to consist of two separate lines plus multiple weak signals in the low- and high-field wings. The center of the two main lines corresponds to an apparent g value of 2.0045(6) which is close to the value of 2.00464 predicted for the $H_2(1/4)$ $S = 1/2$ spin-only doublet system. The two lines are separated by circa 4 gauss and are of equal intensity. Microwave power saturation plots (Fig. S5) are very similar for the two peaks and are consistent with inhomogeneous broadening [93] (see below).

Concentrating on resolving fine structure in the main peaks we reduce the magnetic-field modulation amplitude to 25 mG (that is, below the bandwidth of the 100 kHz modulation frequency). The spectral amplitude in a single scan drops to below a signal-to-noise ratio of unity and extensive averaging over 6 h and filtering is required to afford the high-resolution pattern in Fig. 3c. Each line has resolved in an isotropic equidistant beat pattern with sub-line separation of circa 0.32 gauss.

For individual sub-lines we observe an apparent peak-to-peak width of circa 170 mG which is highly unusual for solid-state samples. Such narrow lines have only been found for (i) organic radicals in organic solvents at ambient temperature [94]; (ii) small paramagnetic molecules in matrices of noble gasses solidified at cryogenic temperatures [95]; (iii) single hydrogen atoms encapsulated in molecular cages [96]; and (iv) paramagnetic molecules in the gas phase at low pressure [97]. Excluding the first two options on obvious grounds (no organic solvents and no cryogenic temperatures) and the third one on spectroscopic grounds (atomic hydrogen EPR is a single line at the free electron g_e value split by over 500 gauss through proton hyperfine interaction), the narrow line width that we observe would only be consistent with the detection of a low-pressure paramagnetic gas occluded in a solid.

We recorded the spectrum in Fig. 4a under optimized conditions for the detection and resolution of satellite lines whose existence was indicated by the small periodic peaks in the wings of the spectrum in Fig. 3b. Thus, the fine structure of the two central lines was slightly deformed by over-modulation, and the data collection was extended to 40 h with constant frequency monitoring for subsequent correction of individual 4-min traces for minor frequency drift. The spectrum has been reproduced completely in duplicate on two different spectrometers in a lab of the spectrometer's manufacturer (Bruker, Billerica, MA, USA) [13]. The spectrum of Fig. 4a is stable for at least two years; it is reproducible over 11 samples produced in 11 reactor runs (Fig. S6), and the spectrum of an empty tube is a straight baseline (Fig. S6).

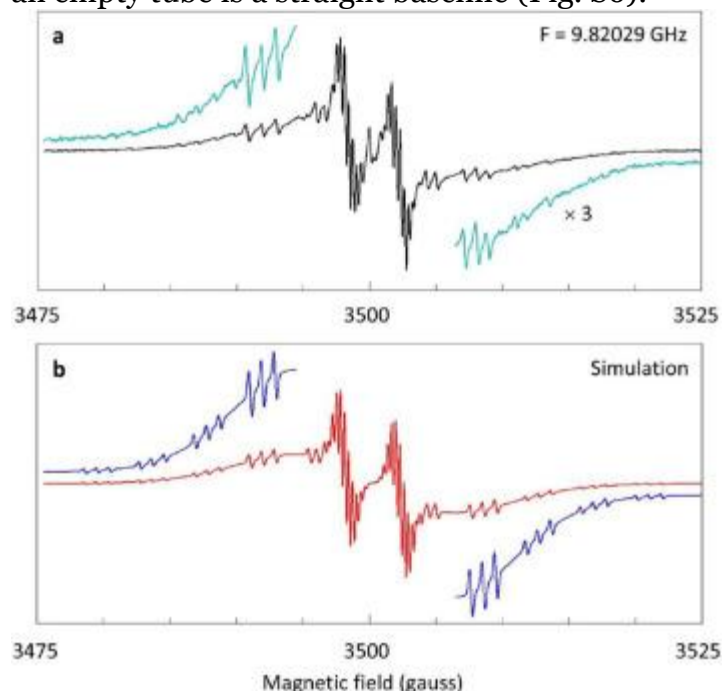


Fig. 4. Full EPR spectrum at high resolution of molecular hydrino $H_2(1/4)$. Trace a: extensively averaged spectrum (2400 min) taken under conditions optimized for maximal signal-to-noise ratio at the expense of minor over-modulation (0.2 gauss), exhibits a complex pattern of triplet satellite lines. Trace b is a simulation using field positions predicted by hydrino theory.

In spin quantification (ESI) we find that a complete spectrum of high resolution, such as in Fig. 4a, represents an $S = 1/2$ concentration of circa $2.6 \mu\text{M}$ if the paramagnet would be homogeneously distributed over the sample volume. Transmission electron microscopy (Fig. 1) and XRD show the $\text{Ga}(\text{O})\text{OH}$ polymer to comprise micro-spherical particles of the order of 100 nm diameter with an estimated spatial occupancy of roughly 10%. This would make the actual concentration of the $H_2(1/4)$ gas in occlusion very approximately $26 \mu\text{M}$, which is equivalent to a [partial pressure](#) of circa 6×10^{-4} bar, qualitatively consistent with the observed narrow [EPR line](#) width [94,98]. Even if regular H_2 would co-occlude at, say, atmospheric pressure the small cross section for collision of molecular hydrino $H_2(1/4)$ would ensure a low collision frequency in agreement with the observed [line width](#).

Simulation of the fine structure in spectrum Fig. 3c indicated the line shape to be [Gaussian](#) within the limitation set by the overlap of individual lines. The sets of satellite lines are better separated, and analysis of the first down-field triplet clearly shows the line shape to be essentially [Gaussian](#) (Fig S7). This implies inhomogeneous broadening, consistent with the power-saturation analysis (Fig. S5), and could be caused by interaction of hydrino molecules with the inner ‘wall’ of the inorganic polymer cage. In turn, this would imply the real lifetime line width from gas collision to be significantly less than the observed 170 mG inhomogeneous line width.

Interpretation of molecular hydrino EPR

Molecular hydrino comprises two protons at the foci of a two-electron prolate spheroid molecular orbital membrane, and an absorbed photon. The latter splits into two photons that are phase locked with the oppositely directed current patterns of the two electrons each consisting of an angularly distributed infinite ensemble of closed grand ellipse filaments of moving charge of an equipotential, minimum energy membrane surface [92]. Under this model exact solutions of a fine structure in the EPR ensues with parameters whose predicted magnitudes can be tested against experimental values.

The unique electronic structure results in one paramagnetic and one diamagnetic electron. The former induces a current in the latter by means of spin-orbit coupling resulting in a split of the original resonance into two lines separated by a frequency-independent interaction, which is for $H_2(1/4)$ predicted to be of magnitude 3.9943 gauss with the field center of the two lines corresponding to the original g value of 2.00464 [92]. Experimentally we observe two lines of equal intensity separated by 3.9 gauss whose center is found at $g = 2.0045(6)$.

Linkage of [magnetic flux](#) by the electron is quantized in units of the [magnetic flux](#) quantum $\phi_0 = h/2e$, which results in a sub-line pattern of each of the two main lines with a predicted separation of 0.311 gauss [92]. The observed separation is 0.32 gauss.

Similar to the case of excited-states of the regular H_2 molecule, the two electrons in $H_2(1/4)$ may rotate relative to each other along the [semimajor axis](#) during a spin transition. The relative rotation is quantized in terms of m integer units of $\hbar$ in opposite directions with the spin-orbit splitting in frequency-independent field units equal to $\pm m$ times twice the splitting between the two main lines, that is $\pm m \times 7.9885$ gauss. Additionally, the unpaired electron must link the magnetic flux component corresponding to spin-orbit coupling. This flux contribution increases the magnetic energy and the energy of the combined [spin flip](#) and spin-orbit coupling transition energy for a given spin-orbital [quantum number](#) m . Thus the downfield spin-orbital splitting peaks are shifted further downfield by the corresponding magnetic energies, whereas the upfield spin-orbital splitting peaks are not shifted since they correspond to emission of the spin-orbital coupling transition energies alone.

Furthermore, each of these satellite lines is split through the linkage of magnetic flux during a spin transition, and the exact solution of the splitting is circa 0.62 gauss for $|m| = 1$ and circa 0.93 for $|m| > 1$ where the latter lines follow an intensity pattern $I_{m+1}/I_m = m/(m+2)$. The predicted details [92] of this complex pattern of split satellite lines asymmetrically grouped around a g value of 2.00464 make up a stick spectrum that, when convoluted with a Gaussian derivative, forms a semi-quantitative reproduction of the experimental spectroscopy (Fig. 4b and Table I).

Table I. Comparison of experimental and theoretical EPR peak positions of molecular hydrino. The experimental magnetic-field values are taken from the spectrum at 9.82029 GHz (Fig. 4a) as peak positions of the center line of 11 multiplets. The theoretical values [92] are due to the electron spin-orbit coupling splitting energies for downfield and upfield spin-orbit coupling quantum numbers $m = 0, 0.5, 1, 2, 3, 4$. All values are in gauss.

m	experimental	theoretical	difference
4	3480.5	3481.24	-0.74
3	3486.8	3486.50	0.30
2	3491.7	3491.39	0.31
1	3495.7	3495.93	-0.23
0.5	3498.5	3498.06	-0.44
0	3500.4	3500.10	0.30
0.5	3502.3	3502.10	0.20
1	3504.0	3504.09	-0.09
2	3507.8	3508.09	-0.29
3	3511.5	3512.08	-0.58
4	3517.3	3516.08	1.22
Average (st. dev.):	-0.004 ± 0.550		

Checks on consistency of EPR interpretation

Unequivocal interpretation of complex EPR spectra typically requires analysis of data taken at more than one microwave frequency. The magnetic model of molecular hydrino $H_2(1/4)$, providing a basis for interpretation of the EPR, predicts a number of features to be either dependent or independent of microwave frequency. These predictions can be checked in separate experiments as consistency tests. The g value of 2.0046 in between the two main lines is a real g value and thus its field position should be linear in the microwave frequency. Contrarily, all fine structure splittings are predicted to be constant in field units and thus independent of the frequency.

As a check we have taken data in Q-band at circa 35 GHz. Here, practical complications arise resulting in reduced signal-to-noise ratios. For $S = 1/2$ systems, any spectrometer operating in a frequency band different from X-band is generally found to exhibit a significantly lower concentration sensitivity. Furthermore, the maximal applicable intensity of the microwave is found to be limited (that is, the spectrometer is not tunable at higher microwave powers) apparently due to a relatively high [dielectric](#) permittivity of the Ga(O)OH samples.

Fig. 5 shows two traces resulting from extensive averaging, one taken under over-modulating conditions to emphasize the main two-line pattern, and one taken at lower modulation amplitude in an attempt to resolve fine structure. Consistent with the interpretation of the X-band spectrum we find a doublet of lines whose spectral center has a real g value of 2.0046 and with a frequency-independent splitting of circa 4 gauss. Under the employed conditions, the underlying broad signal has turned dispersive and thus shows up as an absorption-shape feature. A lower modulation amplitude does not afford resolution of the two-lines' fluxional fine structure, which indicates that the [spectral line width](#) has increased with frequency. This is in fact consistent with our previous conclusion (cf. Fig 2c and Fig. S7) that the line shape is Gaussian due to inhomogeneous broadening, which implies a line width in field units linear in frequency [99].

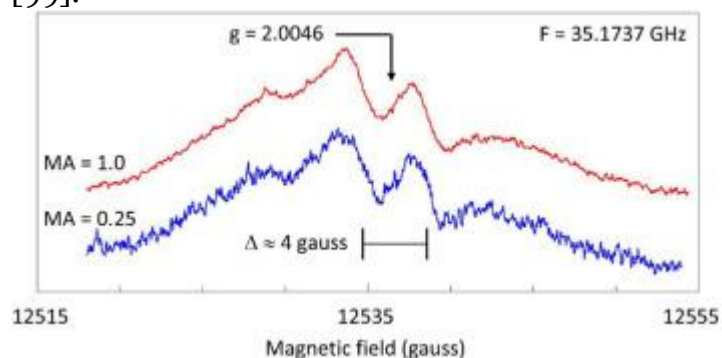


Fig. 5. A 35 GHz frequency experiment as check on consistency of the EPR interpretation: extensively averaged Q-band spectra taken at two different modulation amplitudes (MA) of 1 gauss (red) or 250 mG (blue). No fine structure is resolved in addition to the two main lines consistent with an inhomogeneous line width linear in the microwave frequency. The central g value and the splitting between the two lines in field units are identical to those observed in X-band. See ESI for other experimental conditions.

Since the signal-to-noise ratio in Q-band was insufficient to detect the satellite lines, and since attempts to measure the samples in other frequency bands were hitherto unsuccessful (not shown), we took data at two, well-separated frequencies within the X-band thus allowing for comparison of high-resolution spectra with the trade-off of reduced frequency resolution (Fig. 6ab). Data taken at 9.46 GHz were transformed for comparison with data taken at 9.85 GHz in two ways: (1) frequency-ratio conversion of every digital point of the field axis, and (2) single-valued overall field shift to create maximal overlap of the two spectra. In the first method all real g values will overlay while features constant in the field will mismatch. In the second method all features of a fine-structure pattern constant in the field will overlay when the selected field point of conversion corresponds to the g value of that pattern. Fig. 6a gives the result of the first method: all features mismatch except for the spectral center at $g = 2.0046$, therefore the latter is the only real g value and all other features are from frequency-independent hyperfine interactions. Fig. 6b gives the result of the second method: all lines match, including all satellite lines and all fluxon sub-lines of the two main lines, therefore all features are from frequency-independent hyperfine interactions and they all share a single, common g value.

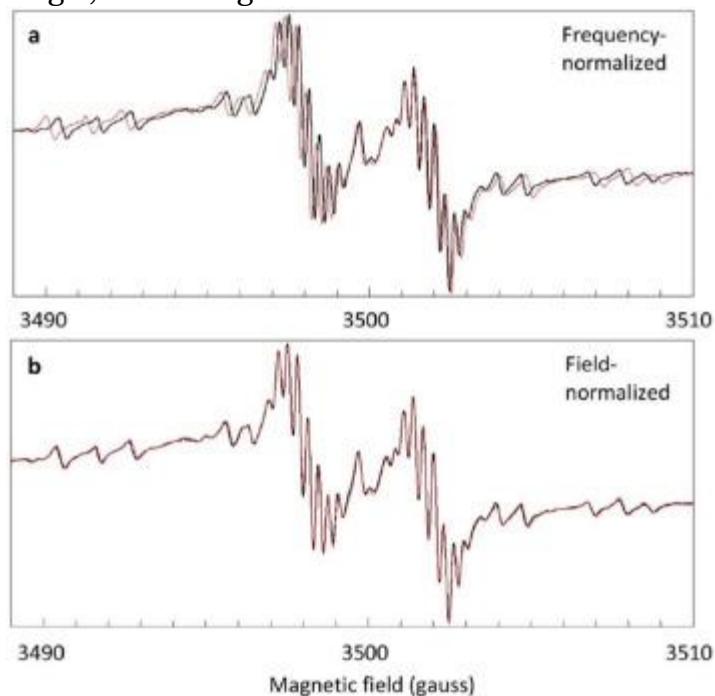


Fig. 6. In-band dual frequency experiment as check on consistency of the EPR interpretation. Trace a: extensively averaged intra X-band experiment at two frequencies, 9.4629 GHz (red) and 9.8209 GHz (black). Each field point of the red spectrum is frequency transformed to that of the black spectrum where the overlay shows that only the center of the two main lines is a real g value. In trace b the red spectrum is shifted in its entirety to a higher field for maximal overlap with the black spectrum. Here the overlay proves that there is only a single real g value and that all other features are constant in the field.

Search for alternative interpretation of the EPR

Alternative to the hydrino analysis in Fig. 4b the spectrum in Fig. 4a can also be approximately reproduced under a conventional phenomenological [spin Hamiltonian](#) assuming an unusual combination of two isotropic radicals of unequal intensity each with a g value of 2.0046. This model would require the two main lines to be due to an isotropic $S = 1/2$ system split by an $I = 1/2$ nucleus with $A_{\text{iso}} \approx 3.9$ gauss with additional [hyperfine structure](#) from a combination of some five nuclei the majority of which has also $I = 1/2$. A second $S = 1/2$ system should give rise to the satellite lines due to a different combination of five nuclei, one of which should have $I = 1$ (e.g. ^{14}N) to account for the repeating triplet pattern (see Fig. S8 for a detailed analysis).

In addition to the improbability of the above combination of spin Hamiltonian parameters we consider this alternative explanation of the EPR highly unlikely on the following grounds. The reaction mixture only contains H_2 , O_2 , H_2O , and Ga. Even in the presence of [trace contaminants](#) we cannot envision how the high-temperature plasma reaction conditions and sample formation in strong aqueous base could lead to the formation of stable radical structures of considerable complexity. The ToF-SIMS, EDS, and XRD analyses also eliminate alternatives. Furthermore, since the sample is a solid, for complex radicals one would expect to see anisotropy in the spectra. In particular absorption-shaped peaks that come with axial or rhombic symmetry of the spin Hamiltonian are not observed. Finally, when the sample temperature is lowered below ambient, relaxation of the two main peaks becomes distinct (Fig. S9), which would be hard to reconcile with a nuclear hyperfine doublet assignment.

Remaining questions

The GUTCP fit to the X-band spectrum of $\text{H}_2(1/4)$ is semi-quantitative with an average error of 0.004 ± 0.550 gauss over the 11 lines assigned to spin-orbital coupling splitting. The actual positions of the satellite lines slightly deviate from their predicted values (Fig. 4a, b and Table I). Also, the fluxon separation for any given position does not quantitatively fit the predicted value; in particular the separation is not a constant. Also, the number and relative intensities of fluxon lines for a given satellite line are presently not understood. Possibly these small irregularities are caused by interactions of the gaseous $\text{H}_2(1/4)$ with the wall of the polymeric Ga(O)OH microspheres.

A broad signal underlies the molecular-hydrino assigned spectrum. Its spectral center corresponds to the g value of 2.0046 within experimental error. Its temperature behavior is very different from that of the hydrino-assigned spectrum (Fig. S10). The origin and nature of the broad signal are presently unknown, however, a reasonable hypothesis would be to assume that there are two phases of Ga(O)OH that encapsulate $\text{H}_2(1/4)$ wherein $\text{H}_2(1/4)$ is a near free gas in only one phase. A scanning/transmission electron microscope (SEM/TEM) used for imaging and selected area electron diffraction (SAED) (Fig. S3) showed that the $\text{H}_2(1/4)@\text{Ga(O)OH}$ sample comprised two different morphologically polymeric crystals of Ga(O)OH , a hexagonal crystalline structure that was very sensitive to the TEM [electron beam](#), and rods having orthorhombic crystalline structure that were not electron beam sensitive. The rod [crystal morphology](#) and crystalline structure match those of the literature for control Ga(O)OH that lacks

gaseous molecular hydrino inclusion [91]. The [XRD crystal](#) system for tsumgallite (control Ga(O)OH) is orthorhombic. The hexagonal phase is likely the source of the fine structure EPR spectrum, and the orthorhombic phase is likely the source of the broad background EPR feature. Cooling selectively eliminates, by microwave power saturation, the observed near free-gas-like EPR spectral behavior of H₂(1/4) trapped in the hexagonal crystalline matrix. In addition to wall interactions, deviations from theory could be due to the influence of the proton of Ga(O)OH and those of absorbed water. Also, matrix orientation in the [magnetic field](#), matrix interactions, and interactions between one or more H₂(1/4) could cause some shifts.

[Deuterium](#) substitution was performed to eliminate an alternative assignment of any EPR [spectral lines](#) as being nuclear split lines. Rotational-nuclear interaction was predicted to be absent since the experimentally confirmed theoretical rotation energy of H₂(1/4) is 16 times that of H₂, too high to be excited at ambient temperatures [12,13]. The EPR spectrum of the deuterated analog HD(1/4)@Ga(O)OH showed a singlet with no fine structure (Fig S11); thus, eliminating any possible nuclear splitting assignment. The g factor and profile matched that of the singlet of H₂(1/4)@Ga(O)OH wherein the singlet in both cases was assigned to the orthorhombic phase. The XRD of the deuterated analog matched that of the hydrogen analog, both comprising gallium oxyhydroxide. TEM confirmed that the deuterated analog comprised 100% orthorhombic phase [91]. The phase preference of the deuterated analog may be due to a different hydrino concentration and kinetic [isotope effect](#) which could have also reduced the concentration.

Conclusions

A plasma reaction has been carried out intended to produce molecular hydrino using non hydrogen bonded water as the catalyst and with liquid gallium as one of the electrodes. Polymeric Ga(O)OH with a spherical particle structure, presumably containing H₂(1/4), was purified from the reaction mixture. H₂(1/4) is proposed to be an S = 1/2 paramagnet with complex fluxional and spin-orbital coupling sub-level structure. The solid Ga(O)OH compound exhibits a complex gas-phase X-band [EPR spectrum](#) at ambient temperature whose fine structure semi-quantitatively agrees with hydrino-theory predictions. This analysis is consistent with frequency-dependent studies, while alternative, conventional interpretations are judged to be extremely unlikely. In summary, the present study provides compelling EPR spectroscopic and gas chromatographic evidence for the existence of molecular hydrino, and, by inference, for the reality of atomic hydrino, and it provides plausibility of the electron model in GUTCP. In more general terms our results are a significant test against falsification of GUTCP. In view of the possible far-reaching implications of this conclusion for the theory of [quantum mechanics](#), for hydrogen-related [chemistry](#), for astrophysics of [dark matter](#), and for energy transduction and production technology, it is also offered as an urgent invitation to academia at large to repeat and extend the described experiments in lieu of refutation on quantum mechanical theoretical grounds. An early version of the present paper has been posted on a preprint server [100].

Innovators gear up work on 'green' hydrogen plane with plans for nonstop 9-day trip around Earth



France Clean Fuel Flight© Yohan Bonnet

LES SABLES D'OLONNE, France (AP) — When aviation pioneer Bertrand Piccard [a decade ago](#) spearheaded a much-hyped flight around the world in a plane powered by sunlight, it raised awareness about climate change but held little promise of revolutionizing air travel.

Now, the 66-year-old Swiss adventurer behind [Solar Impulse](#) is aiming higher, in hopes of heading toward greener commercial flight than that of fossil fuel-powered planes today — this time using super-cold liquid hydrogen.

From a workshop on France's Atlantic coast, Piccard and partners are ramping up Climate Impulse, a project started last February to fly a two-seater plane around

the globe nonstop over nine days fueled by what's known as green hydrogen. That's hydrogen split out of water molecules using renewable electricity through a process called electrolysis.



France Clean Fuel Flight© Yohan Bonnet

The Climate Impulse team, whose backers include Airbus and a science incubator called Syensqo (pronounced "science-co") born from Belgian pharmaceuticals company Solvay, presented its first-year progress to reporters Thursday in Les Sables d'Olonne, an oceanside town better known as host to the Vendee Globe round-the-world sailing race.

When will Climate Impulse get off the ground?



France Clean Fuel Flight© Yohan Bonnet

First test flights are planned next year, but the grueling round-the-world trip is set for 2028. Made with lightweight composites, the plane is dependent on several untested innovations and is far from a sure bet.

Piccard says a major airplane manufacturer wouldn't take on the risk of producing a prototype such as Climate Impulse in case it fails.



France Clean Fuel Flight© Yohan Bonnet

"It's my job to be a pioneer," he said in an interview. "We have to show it's possible, then it's a big incentive for the others to continue."

Even if the project is successful, experts say green hydrogen-powered flight on a commercial scale would be decades away at best. The project has lured tens of millions of euros of investment, and the team of dozens of staffers is growing.

The solar-powered plane was a technological feat in 2015, but wasn't scalable, said Climate Impulse engineer and co-pilot Raphael Dinelli. Limited in range, that plane had to make more than a dozen stops on its trip around the world.

Climate Impulse is supposed to take off unassisted, fly some 40,000 kilometers (about 25,000 miles) around Earth along the Equator and return to its starting point with no mid-air refueling — and with no stops at all.

How is Climate Impulse supposed to fly?

The controlled release of liquid hydrogen from ultra-insulated tanks under the airplane's wings produces energy that seeps into the membrane of a fuel cell that powers the plane.

"The plane has the wingspan of an Airbus 320: 34 meters (about 110 feet). It weighs 5-1/2 tons and it flies at 180 kilometers per hour — that means 100 knots at 10,000 feet (3,000 meters) altitude," Piccard said Thursday.

One aim is to draw on energy from the "turbulence section" of the atmosphere, which airlines could also use one day to help save fuel, he said.

Because it's hydrogen, the only emissions will be water vapor. Still, outside experts caution that the environmental impact of such water-vapor "contrails" remains unknown in a real-world or large-scale scenario.

The International Energy Agency says air travel is responsible for about 2% of global emissions of carbon dioxide.

Hydrogen has been used in flights for decades but as a gas, not a liquid. Use of liquid hydrogen will take time to scale up. Fossil fuels, which are cheaper and more efficient, still produce most hydrogen today.

Many governments want to [produce more green hydrogen](#), but for now, the world can't make enough clean electricity for power needs on land, let alone to generate enough for wide-scale use by planes in the air.

What's progress like so far, and what's next?

In the last year, the team has built the cockpit shell, started building the wing spar, and finalized interior components. They include swivel seats, a bunk and a stationary bicycle-like workout system to promote blood circulation for the co-pilots who will be cramped in a small cockpit in low-oxygen conditions over the nine days.

The hardest parts await.

Tests are planned this year on the fuel cells and propulsion systems, to see if the electric motor, propeller and batteries could work for an initial fully-electric flight phase.

The trickiest part is to regulate the flow of liquid hydrogen to ensure efficient consumption over the longest range possible, Dinelli said.

Another challenge: the liquid hydrogen must be maintained at minus 253 degrees Celsius (minus 423 Fahrenheit), or nearly absolute zero. Construction of a leak-proof tank is essential. Liquid hydrogen is highly flammable, so any seepage could have devastating results.

What are the prospects for green hydrogen in flight?

Liquid hydrogen, until now, has perhaps most prominently been known as a propellant to blast rockets into space.

Aviation's share of carbon emissions is relatively small, but growing faster than in any other industry because development of electric-powered planes trails far behind electric cars and trucks on the ground.

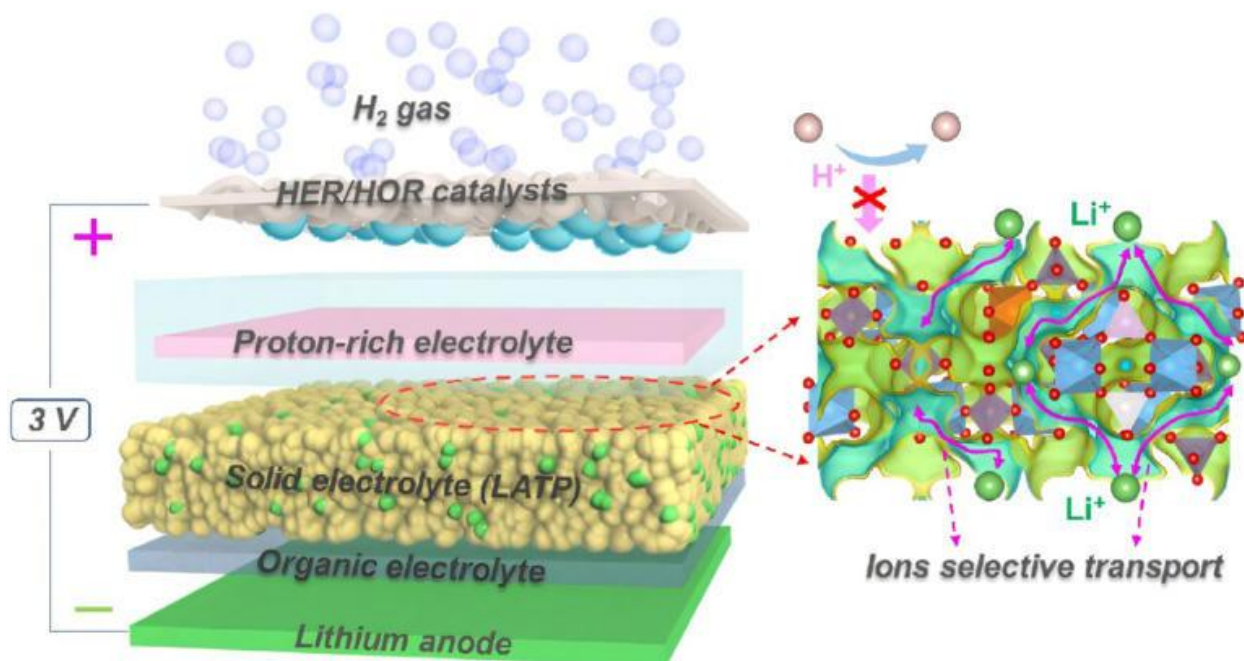
Batteries are heavy in EVs on roads today, and keeping down battery weight in planes will be crucial for electric-powered flight.

"We have not had a 'Tesla moment' in aviation yet," said Nikhil Sachdeva, an expert in how the aviation sector can transition to more climate-friendly technologies at consulting firm Roland Berger. "Hydrogen has the potential to be that for aviation, which is why it's worth doing this right."

Using super-cold liquid hydrogen is "extraordinarily difficult, and we can barely do it for a few minutes right now. And here we're talking about doing it safely for hours," Sachdeva said.

But Solar Impulse faced pessimism too, he added, and Piccard's team has "proven it can do what people would consider impossible."

Hybrid battery design: Lithium-hydrogen system offers high energy density



Schematic of the Li-H battery. (Image by USTC). Credit: CHEN Wei et al.

A research team from the University of Science and Technology of China has introduced a new chemical battery system which utilizes hydrogen gas as the anode. Their study is published in the [*Angewandte Chemie International Edition*](#).

Hydrogen (H₂) has gained attention as a stable and cost-effective renewable energy carrier due to its favorable electrochemical properties. However, traditional hydrogen-based batteries primarily utilize H₂ as a cathode, which restricts their voltage range to 0.8–1.4 V and limits their overall energy storage capacity.

To overcome the limitation, the research team proposed a novel approach: utilizing H₂ as the anode to significantly enhance energy density and working voltage. When paired with lithium metal as the anode, the battery exhibited exceptional electrochemical performance.

The researchers designed a prototype Li-H battery system, incorporating a lithium metal anode, a platinum-coated gas diffusion layer serving as the hydrogen cathode, and a solid electrolyte (Li_{1.3}Al_{0.3}Ti_{1.7}(PO₄)₃, or LATP). This

configuration allows efficient lithium ion transport while minimizing undesired chemical interactions.

Through testing, the Li-H battery demonstrated a theoretical energy density of 2825 Wh/kg, maintaining a steady voltage of around 3V. Additionally, it achieved a remarkable round-trip efficiency (RTE) of 99.7%, indicating minimal energy loss during charging and discharging cycles, while maintaining long-term stability.

To further improve cost-efficiency, safety and manufacturing simplicity, the team developed an anode-free Li-H battery that eliminates the need for pre-installed lithium metal. Instead, the battery deposits lithium from lithium salts (LiH_2PO_4 and LiOH) in the electrolyte during charging.

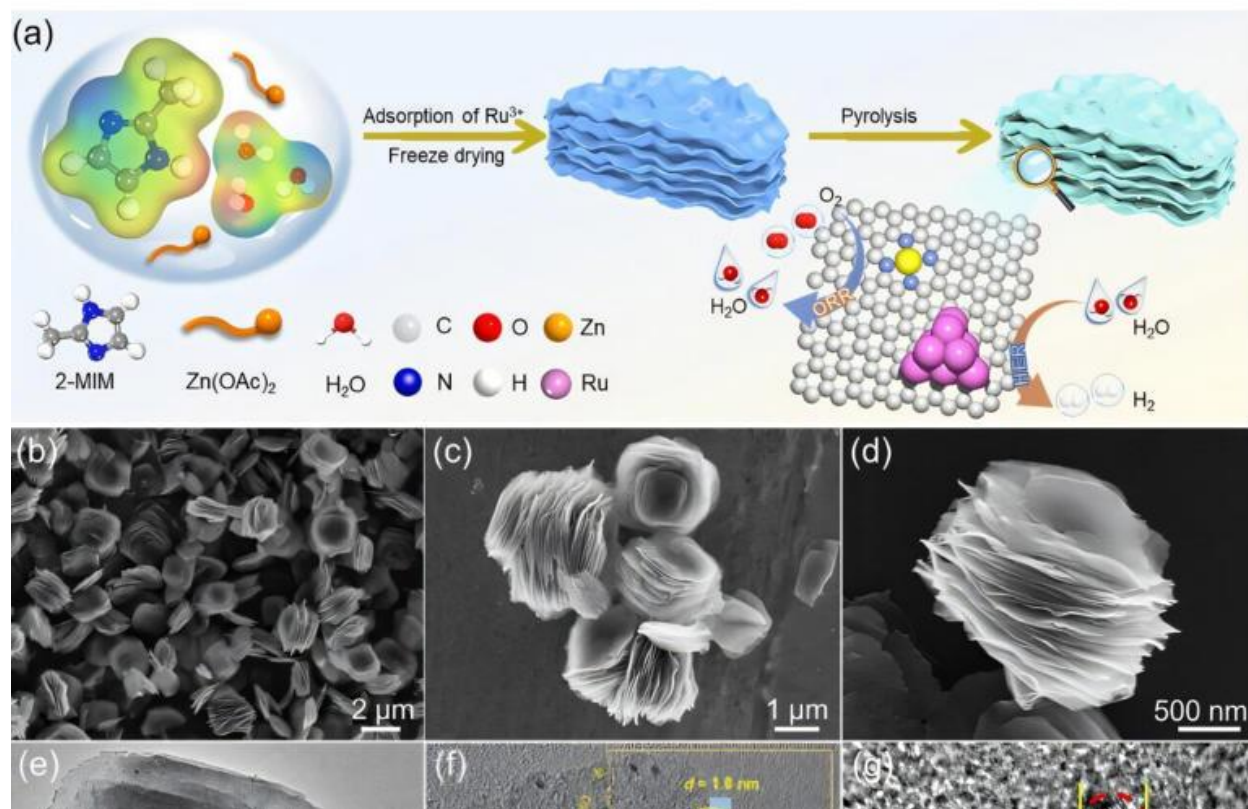
The version retains the advantages of the standard Li-H battery while introducing additional benefits. It enables efficient lithium plating and stripping with a Coulombic efficiency (CE) of 98.5%. Moreover, it operates stably even at low hydrogen concentrations, reducing reliance on high-pressure H_2 storage. Computational modeling, such as Density Functional Theory (DFT) simulations, were performed to understand how lithium and hydrogen ions move within the battery's electrolyte.

This breakthrough in Li-H battery technology presents new opportunities for advanced energy storage solutions, with potential applications spanning renewable energy grids, electric vehicles, and even aerospace technology. Compared to conventional nickel-hydrogen batteries, the Li-H system delivers enhanced energy density and efficiency, making it a strong candidate for next-generation power storage. The anode-free version lays the foundation for more cost-effective and scalable hydrogen-based batteries.

More information: Zaichun Liu et al, Rechargeable Lithium-Hydrogen Gas Batteries, *Angewandte Chemie* (2024). DOI: [10.1002/ange.202419663](https://doi.org/10.1002/ange.202419663)

Provided by University of Science and Technology of China

Electronic fine-tuning unlocks superior hydrogen catalysis performance



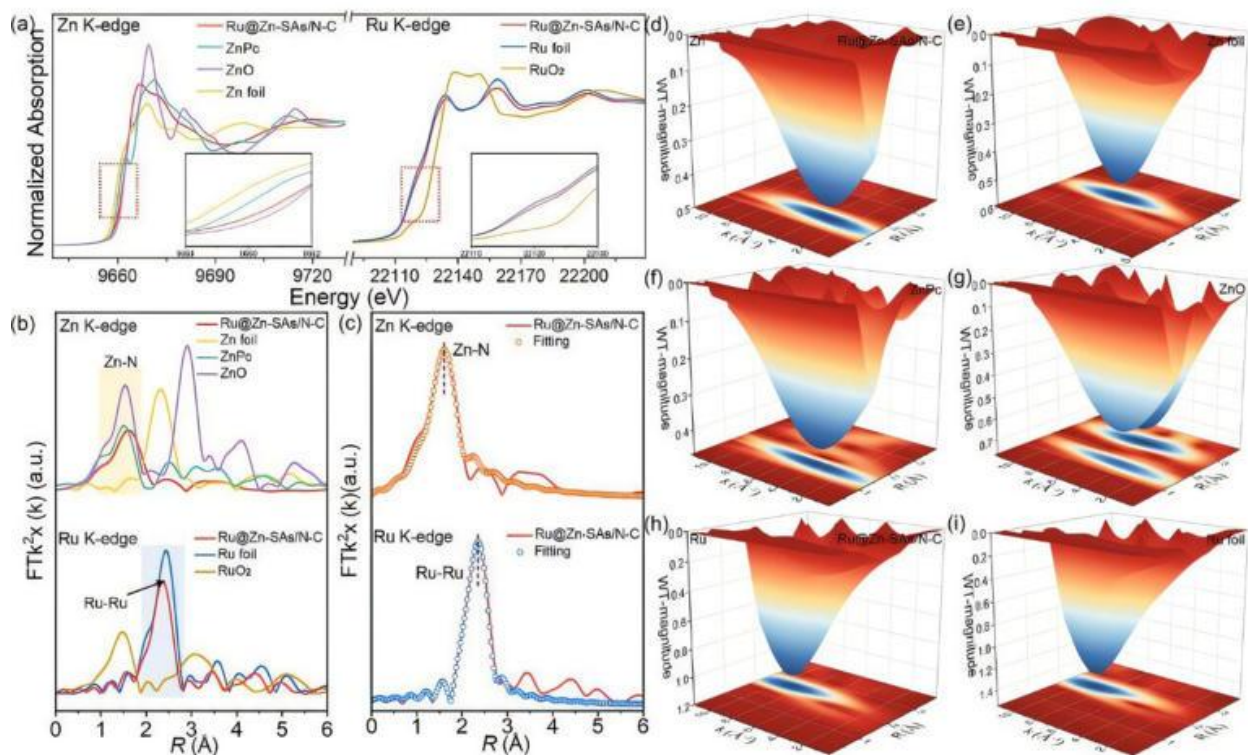
(a) Schematic illustration of synthesis procedure for Ru@Zn-SAs/N-C catalysts, where the electrostatic potential diagram of the iso-surface value is 0.03 e Å⁻³; (b-d) SEM images with different magnification; (e) TEM image; (f-g) HRTEM images, (f) the inset is the corresponding particle-size distribution of Ru clusters and (g) the inset shows the Moiré images extracted from the FFT; (h) AC HAADF-STEM image and integrated pixel intensities; (i) AFM image and corresponding height profiles of Ru@Zn-SAs/N-C. Credit: Advanced Functional Materials (2024). DOI: 10.1002/adfm.202422594

As the world moves toward sustainable energy, hydrogen will likely play an invaluable role as a clean and versatile fuel. Yet, adoption of hydrogen technologies hinges on overcoming key challenges in electrocatalysis, where costly and scarce platinum-group metals have long been the industry standard.

Taking one step to rectify this, a research team has now developed a new strategy that fine-tunes electronic interactions at the atomic level. Their study is [published](#) in the journal *Advanced Functional Materials*.

The study introduces an innovative electronic fine-tuning (EFT) approach to enhance the interactions between zinc (Zn) and ruthenium (Ru) species, resulting

in a highly active and stable catalyst for both the oxygen reduction reaction (ORR) and hydrogen evolution reaction (HER). By anchoring Ru clusters onto hierarchically layered Zn-N-C nanosheets (denoted as Ru@Zn-SAs/N-C), the team has designed a material that outperforms commercial platinum-based catalysts.

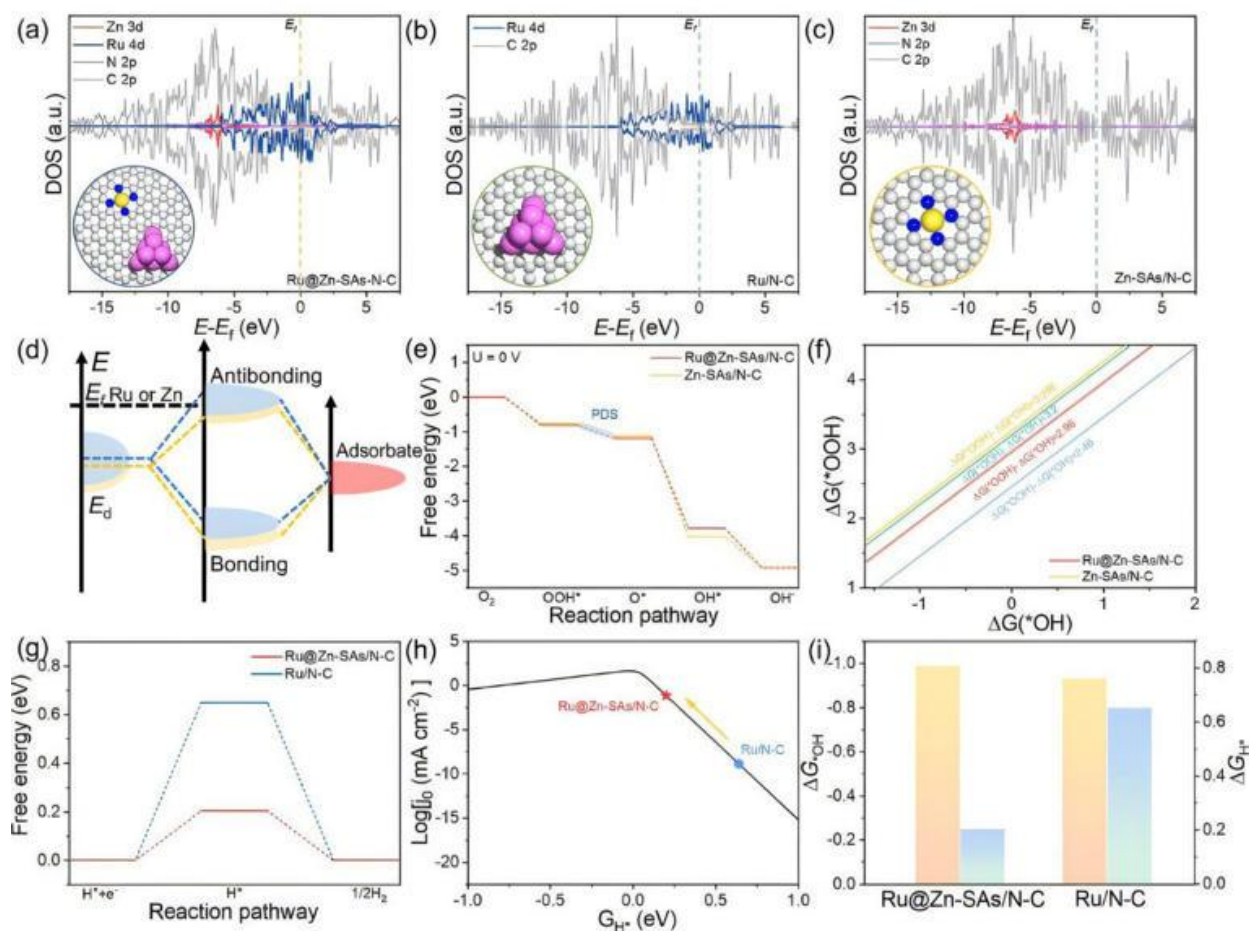


X-ray absorption spectroscopic characterization of Ru@Zn-SAs/N-C. Credit: Advanced Functional Materials (2024). DOI: 10.1002/adfm.202422594

"Our work demonstrates how precise control over electronic structures can fundamentally reshape catalytic performance," says Hao Li, associate professor at Tohoku University's Advanced Institute for Materials Research (WPI-AIMR) and corresponding author of the paper. "By leveraging the synergy between Zn and Ru, we have developed a cost-effective alternative to conventional platinum catalysts, offering new possibilities for sustainable hydrogen production."

Key to this breakthrough is the strong electronic metal-support interaction (EMSI) between Zn and Ru, which optimizes the adsorption energy of critical reaction intermediates. X-ray absorption spectroscopy and computational modeling confirm that this synergy shifts $^*OOH$ and $^*OH$ adsorption energies to an optimal balance, enhancing ORR efficiency. Simultaneously, Ru sites achieve near-ideal

hydrogen binding free energy, placing the catalyst at the peak of theoretical HER activity.



Theoretical calculation analysis. Credit: Advanced Functional Materials (2024). DOI: 10.1002/adfm.202422594

"This research is not just about replacing platinum," Li explains. "It's about understanding how electronic properties at the atomic level dictate catalytic efficiency. That knowledge allows us to design better, more accessible materials for real-world applications."

These findings have significant implications for the affordability and scalability of hydrogen energy. By reducing dependence on expensive platinum while improving performance, this research contributes to the development of cost-effective hydrogen fuel cells, water electrolysis systems, and sustainable industrial processes.

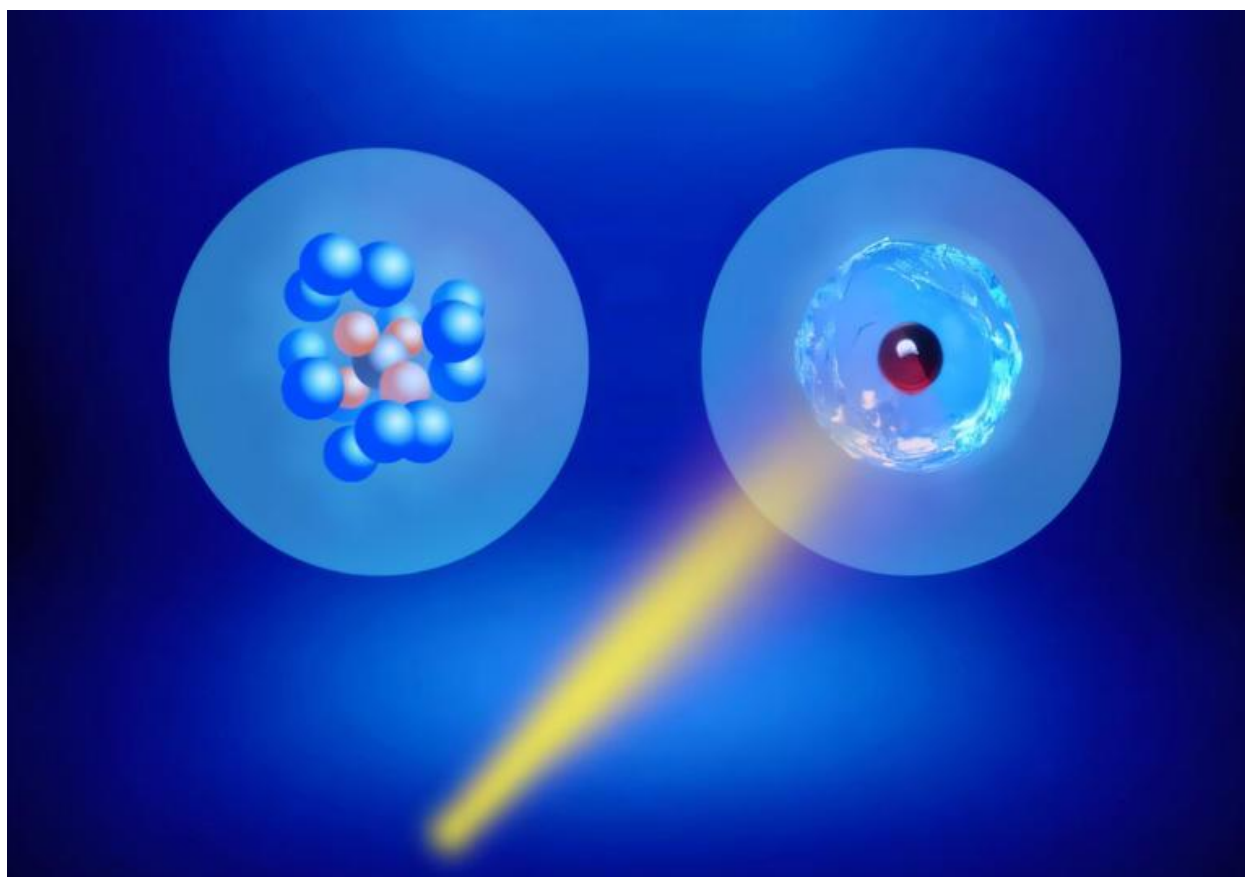
Looking ahead, the team plans to further refine the EFT strategy, improve catalyst stability under real-world conditions, and develop scalable production methods. Applications in zinc-air batteries, fuel cells, and carbon and nitrogen reduction reactions are also under investigation.

The research has been made available through the Digital Catalysis Platform ([DigCat](#)), the largest experimental catalysis database to date, developed by the Hao Li Lab.

More information: Tingyu Lu et al, Synergistic Effects of Ruthenium and Zinc Active Sites Fine Tune the Electronic Structures of Augmented Electrocatalysis, *Advanced Functional Materials* (2024). DOI: [10.1002/adfm.202422594](https://doi.org/10.1002/adfm.202422594)

Provided by Tohoku University

Hydrogen becomes a superfluid at nanoscale, confirming 50-year-old prediction

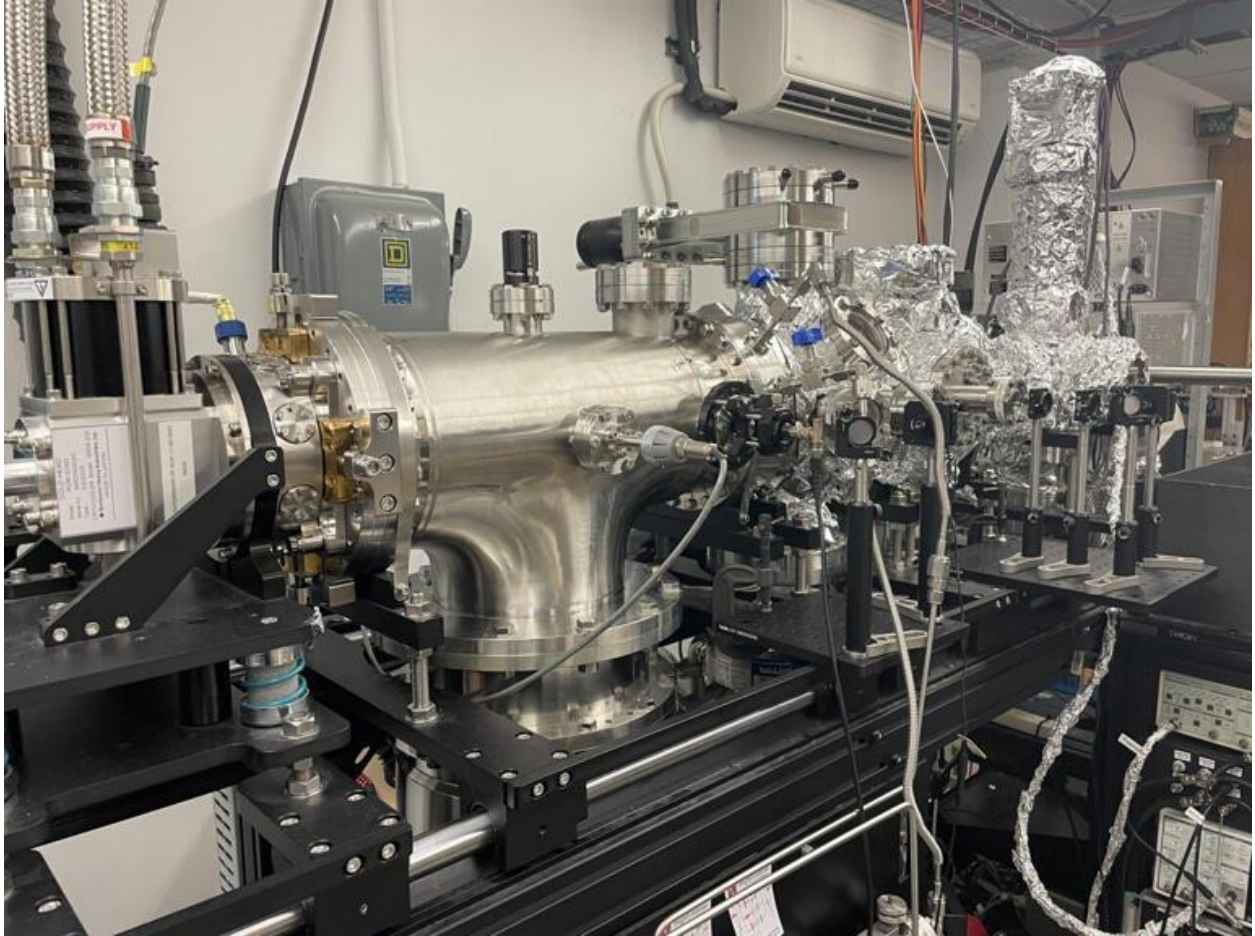


Researchers at the University of British Columbia, RIKEN, and Kanazawa University created nano-size, ultra-cold labs to demonstrate superfluidity in hydrogen. Credit: Dr. Susumu Kuma, RIKEN

Hydrogen nano-clusters at low temperatures display 'superfluidity'—a quantum state of frictionless flow only previously observed in helium.

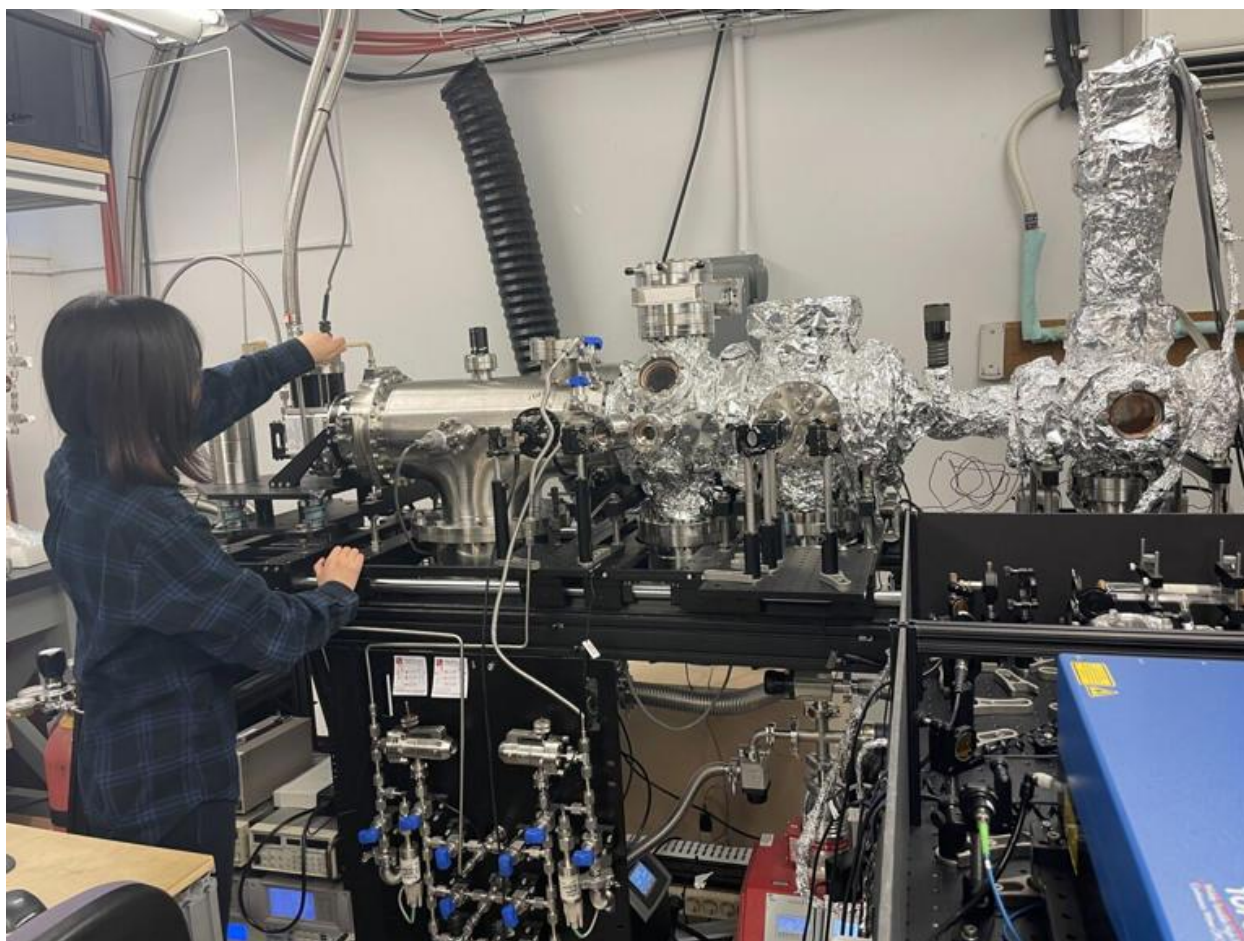
The new research is [published](#) in *Science Advances* by an international team led by chemists at the University of British Columbia (UBC).

"This discovery deepens our understanding of quantum fluids and could inspire more efficient hydrogen storage and transport for clean energy," says Professor Takamasa Momose, an expert on cold molecules at UBC and senior author of the paper.



Experimental apparatus and laser used by researchers at the University of British Columbia, RIKEN and Kanazawa University to demonstrate superfluidity in hydrogen. Credit: Chie Nakayama, University of British Columbia

Helium was discovered to possess superfluid characteristics at low temperatures in 1936—helium atoms flowed through extremely narrow channels without friction or viscosity. Some atomic gases can also behave like superfluids.



A student working with an experimental apparatus and laser used by researchers at the University of British Columbia, RIKEN and Kanazawa University to demonstrate superfluidity in hydrogen. Credit: Chie Nakayama, University of British Columbia

Physicist and Nobel laureate Dr. Vitaly Ginzburg did predict liquid hydrogen might also be a superfluid in 1972—but until now, direct observations of hydrogen molecules that can become a superfluid have eluded scientists.

Creating nano-size ultra-cold labs

Hydrogen is typically impossible to study in liquid form—it becomes a solid at -259°C (-434°F). But by confining small clusters of hydrogen molecules inside helium nanodroplets at -272.25°C (0.4 K), Dr. Momose and colleagues at RIKEN and Kanazawa University in Japan were able to keep the hydrogen in liquid form even at low temperatures.

Then the team embedded a methane molecule in the hydrogen cluster and set it spinning with laser pulses. The spinning methane molecule acts like a canary in a coal mine for superfluidity—if it rotates faster without resistance, the surrounding hydrogen was superfluid. When enough hydrogen molecules (15 to 20 molecules) were placed in a cluster, the methane rotated without resistance, indicating the hydrogen was acting as a superfluid.

"We were thrilled when we first observed the strikingly clear methane spectrum in a tiny droplet of liquid hydrogen," said Dr. Hatsuki Otani, who conducted the work while a Ph.D. student in chemistry at UBC. "It was a strong sign of hydrogen's superfluidity. Then theoretical results from colleagues at Kanazawa University matched our experimental data perfectly."

Hydrogen is used in fuel cells, which only release water as a byproduct—but production, storage and transportation challenges has limited infrastructure advances for the clean fuel. The frictionless flow of superfluid hydrogen could inspire new technologies for more efficient hydrogen transportation and storage in the future.

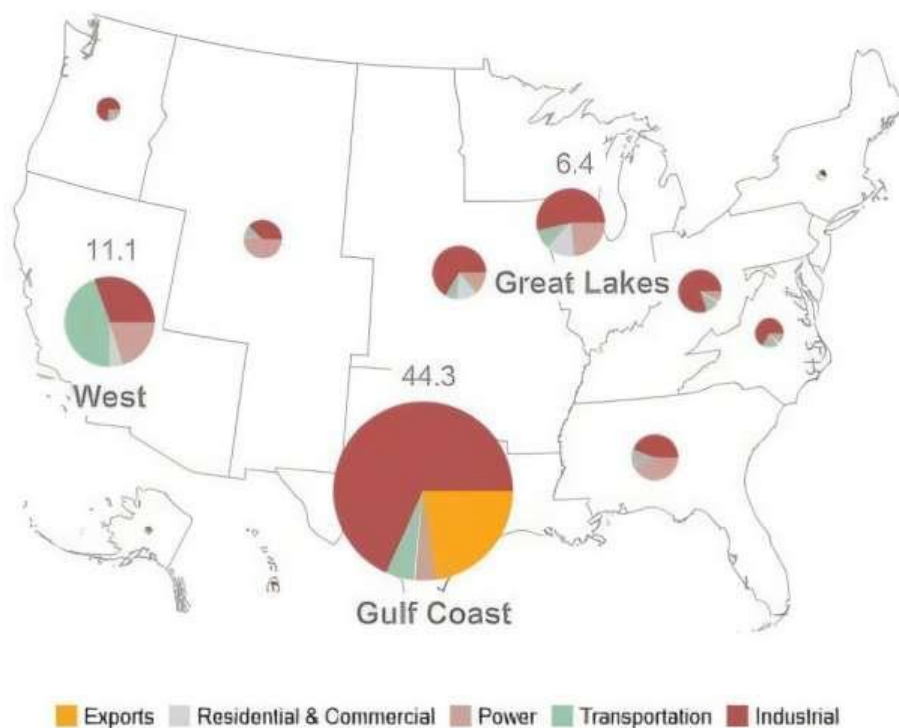
More information: Hatsuki Otani et al, Exploring molecular superfluidity in hydrogen clusters, *Science Advances* (2025). DOI: [10.1126/sciadv.adu1093](https://doi.org/10.1126/sciadv.adu1093)

Provided by University of British Columbia

MARCH 5, 2025

The Texas hydrogen industry needs water: New study provides details on how much

by [University of Texas at Austin](#)



The Gulf Coast is projected to need 44.3 million metric tons of hydrogen by 2050 in a net-zero emissions scenario, according to a study by the National Petroleum Council. Producing that hydrogen requires a lot of water. Credit: National Petroleum Council

There are many ways to make hydrogen—a carbon-free energy source and petrochemical ingredient. But no matter the method, all hydrogen production requires a lot of water.

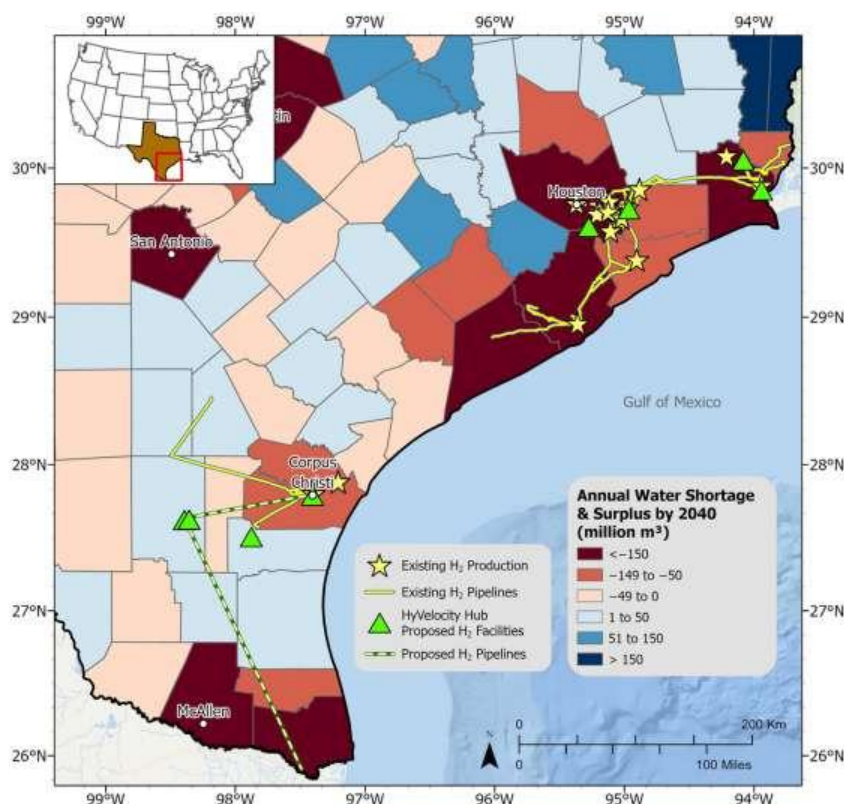
In a recent study, researchers from The University of Texas at Austin examined just how much water the growing Texas hydrogen economy might need. They found that by 2050 new hydrogen production facilities could account for 2–6.8% of water demand in the state.

In comparison to big water draws, such as irrigation or municipal use, hydrogen's demand is relatively small, said the study's lead author Ning Lin, an energy economist at UT's Bureau of Economic Geology. But it has the potential to disproportionately affect communities that face future water issues.

This includes the Gulf Coast, where most current hydrogen infrastructure is built and where most new hydrogen infrastructure is planned. The State Water Plan projects this region to face large annual shortages of fresh groundwater by 2040.

"Where you put a project can make a huge difference locally," Lin said. "With multiple hydrogen facilities planned in water-stressed Gulf Coast counties, this study highlights the urgent need for integrated water and energy planning and provides a solid foundation to help policymakers, industry, and communities make informed decisions about hydrogen and [water management](#)," she said.

The research is [published](#) in the journal *Sustainability*.



Existing and proposed hydrogen infrastructure as of 2024 in the Gulf Coast region of Texas overlaying projected water needs by 2040 per county. Credit: Lin et al.

Eight new hydrogen production facilities are planned for the Gulf Coast and in South Texas as part of the HyVelocity Hub project, a collaboration between industry, academia and non-profits that seeks to build up the hydrogen economy in Texas.

To estimate future water demand, Lin and her colleagues used data from a 2024 National Petroleum Council study that estimated the regional hydrogen demand from 2030–2050 based on two policy scenarios: a net-zero scenario and a stated policy scenario.

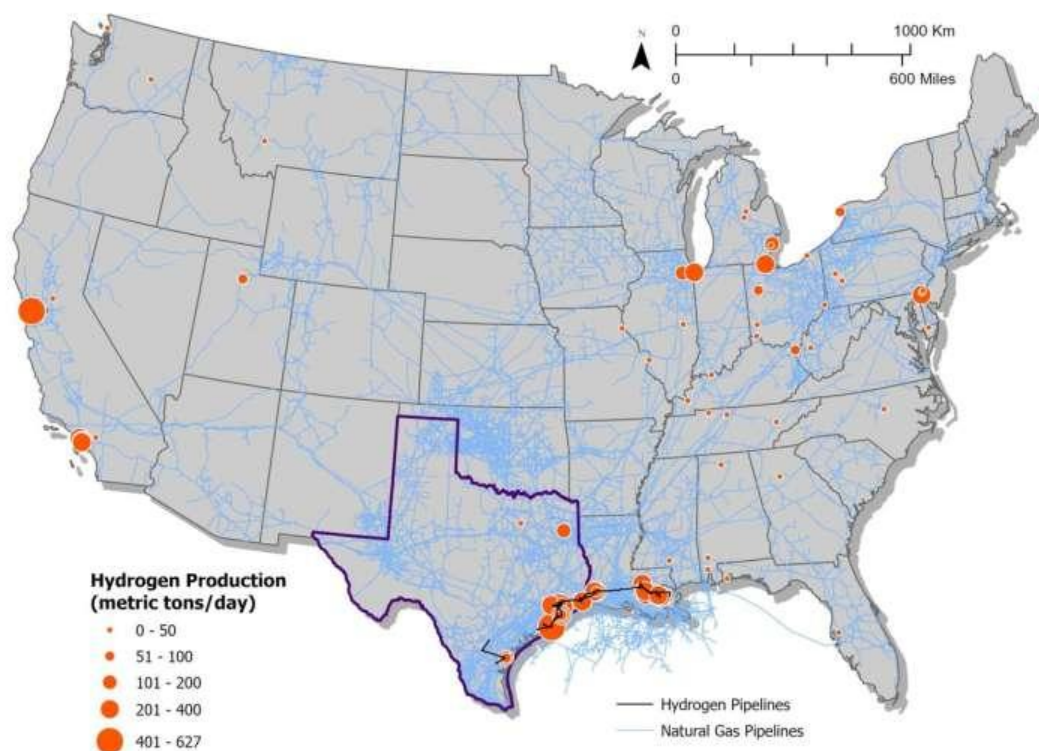
The UT researchers examined the water requirements of all aspects of hydrogen production, including water used for cooling. They also examined the water needed for different mixes of "blue hydrogen" and "green hydrogen." Green hydrogen is produced from water using electricity without carbon dioxide emissions. Blue hydrogen produces emissions

and is made by burning natural gas. It can be made low-carbon by trapping its emissions underground using carbon capture and storage technology.

Based on a 50:50 mix of blue and green hydrogen, the researchers determined that water demand for net-zero hydrogen is about 3.4 times more than status-quo hydrogen: 6.8% compared to 2%. Much of the additional water demand is associated with capturing and storing the [carbon dioxide emissions](#) from blue hydrogen production.

"Decarbonization is expensive," Lin said. "You don't get rid of carbon for free."

As part of the study, the researchers also provide an overview of water use and [water quality](#) for a range of production methods, which affect whether water left over after hydrogen production can be recycled.



Hydrogen production and pipelines in the U.S. Credit: Lin et al.

For example, green [hydrogen production](#) requires ultrapure water that undergoes extensive filtering, so leftover water could be potentially returned to the water supply without much treatment. Blue hydrogen doesn't have the same level of high purity requirements for incoming water. But the leftover water it produces usually requires more treatment.

Lin said that by taking stock of different water needs and requirements, both communities and companies can understand the potential options available to them.

Robert Mace, the Executive Director of the Meadows Center for Water and the Environment at Texas State University, said the hydrogen water requirements described in the paper are substantial and that the study could help with future planning.

"In order to plan for water needs, somebody has to figure out what those future demands might look like, and this paper puts some numbers to this that I think will be very helpful," said Mace, who was not part of the study.

The study was co-authored by Mairan Arzumanyan, Edna Rodriguez Calzado and Jean-Philippe Nicot. They are all researchers at the Bureau of Economic Geology, a research unit at the UT Jackson School of Geosciences.

More information: Ning Lin et al, Water Requirements for Hydrogen Production: Assessing Future Demand and Impacts on Texas Water Resources, *Sustainability* (2025). DOI:

[10.3390/su17020385](https://doi.org/10.3390/su17020385)

Provided by [University of Texas at Austin](https://www.utexas.edu/)

MARCH 5, 2025

Preventing hydrogen vehicle accidents in advance: Equipment monitors hydrogen fuel quality in real-time

by [National Research Council of Science and Technology](#)



'Real-Time Monitoring Equipment for Hydrogen Fuel Quality' Developed by KRISS. Credit: Korea Research Institute of Standards and Science (KRISS)

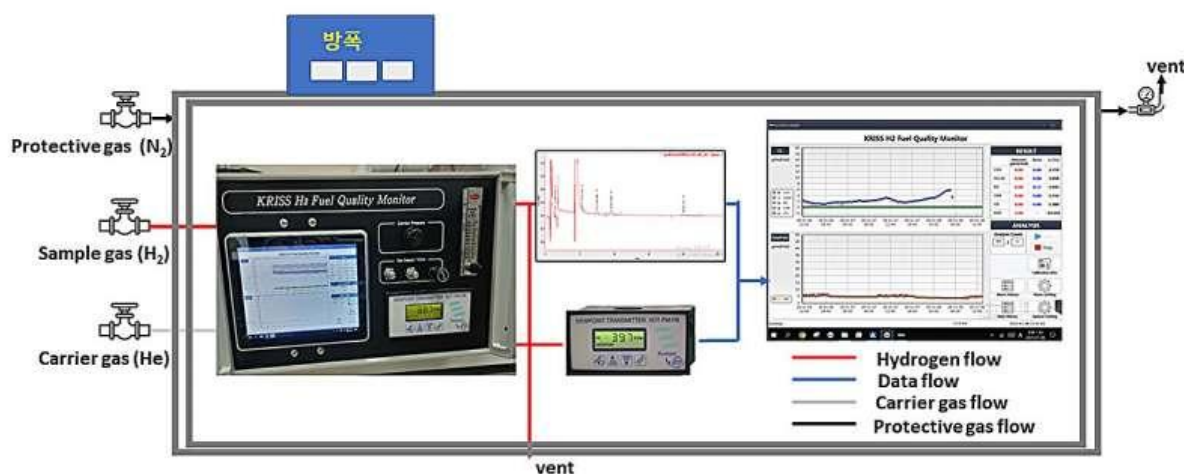
The Korea Research Institute of Standards and Science has developed equipment that monitors the quality of hydrogen fuel supplied to vehicles through hydrogen refueling stations in real-time. This equipment is expected to prevent hydrogen vehicle accidents caused by impurities in the hydrogen fuel and improve the quality of hydrogen production. The study is [published](#) in the *Journal of Separation Science*.

Hydrogen fuel is more prone to contamination during production, transportation, and storage compared to conventional fuels. This is because [hydrogen production](#) is more complex than conventional fuel production, and the high-pressure processes involved in storage, transportation, and usage increase the likelihood of impurities being introduced.

If contaminated hydrogen fuel is injected into a hydrogen vehicle, the risk of explosion and accidents significantly increases. Impurities in the fuel damage the catalyst in the [fuel cell](#),

causing overheating and a decline in performance. This can trigger unexpected chemical reactions, raising the risk of hydrogen explosions. Additionally, there is concern about secondary accidents due to a decrease in engine performance.

In Korea, the quality of hydrogen fuel is monitored by inspection agencies that visit fuel production sites quarterly, collect fuel samples, and measure impurities using specialized [equipment](#). However, this process presents significant challenges. Detecting impurities that occur outside the scheduled inspection periods is difficult, and identifying the root cause and nature of the issue proves to be even more complex, making it hard to provide effective, real-time assistance.



Schematic of the 'Real-Time Monitoring Equipment for Hydrogen Fuel Quality' Developed by KRISS. Credit: Korea Research Institute of Standards and Science (KRISS)
Although expensive foreign equipment is used on-site for testing impurities in hydrogen production, these devices can only analyze one or two components at a time. Additionally, the maintenance of such equipment is problematic, complicating the process of conducting thorough and continuous quality inspections.

As hydrogen infrastructure—including refueling stations and [production facilities](#)—continues to expand, the demand for hydrogen fuel quality analysis has grown substantially. This surge in demand has highlighted the need for easy-to-use, domestically produced, real-time monitoring equipment that can ensure the quality of hydrogen fuel at all times.

Recently, KRISS's Semiconductor and Display Metrology Group successfully developed equipment that monitors, in real-time, the components and concentrations of impurities in hydrogen fuel supplied to vehicles through refueling stations.

Dr. Lee Jeongsoon, Principal Research Scientist at KRISS's Semiconductor and Display Metrology Group, who developed the [real-time](#) monitoring equipment for hydrogen fuel quality, explained, "The equipment displays both the measurement values and their uncertainty (the degree of doubt in the results). The analysis values and uncertainty, obtained using standard materials, are traceable to standards, ensuring the reliability of the results."



KRISS Principal Research Scientist Lee Jeongsoo (left) and Postdoctoral Researcher Kim Sang Woo (right) are inspecting the monitoring equipment installed at the hydrogen bus refueling station in Chungju City. Credit: Korea Research Institute of Standards and Science (KRISS)

The equipment developed by the research team is capable of accurately measuring eight of the fourteen impurities that are regulated by ISO. If the concentration of any [impurity](#) in the hydrogen fuel exceeds the standard threshold, the management system sends a warning signal, allowing the operator to detect and take action before contaminated fuel is injected into the vehicle.

By applying the newly developed equipment at hydrogen refueling stations, it will be possible to continuously monitor and maintain the quality of hydrogen fuel, which is expected to enhance the safety of hydrogen vehicles and reduce user concerns. Additionally, at hydrogen production facilities, the equipment will enable easy and accurate inspection of the quality of the [hydrogen fuel](#) being produced, which is expected to further improve the quality of domestically produced hydrogen.

Dr. Lee Jeongsoo stated, "We are currently conducting a demonstration of the equipment at the hydrogen bus refueling station in Chungju City, and after the demonstration is completed, we plan to transfer the technology to domestic companies."

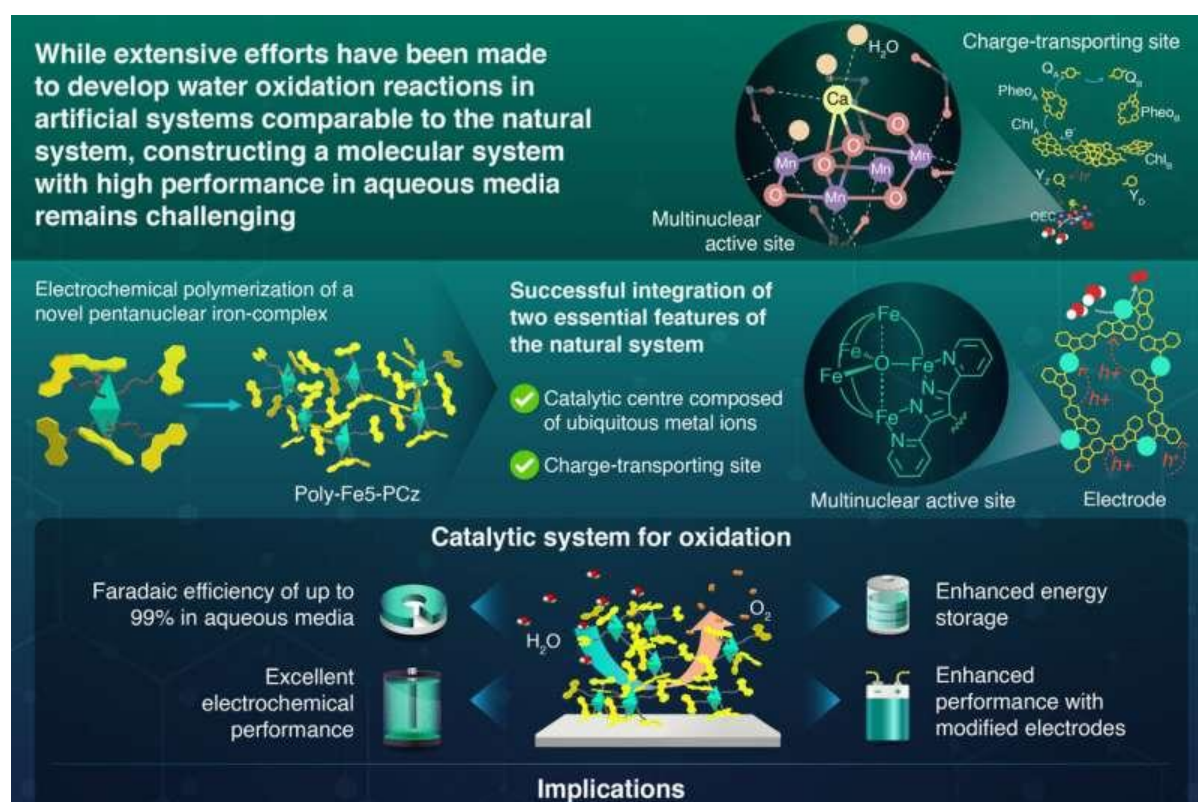
More information: Dongkyum Kim et al, Development of an online hydrogen fuel quality analyzer with gas chromatography-pulsed discharge helium ionization detector for applying hydrogen infrastructures, *Journal of Separation Science* (2024). DOI: [10.1002/jssc.202400088](https://doi.org/10.1002/jssc.202400088)

Provided by [National Research Council of Science and Technology](#)

MARCH 5, 2025

Iron-based catalyst achieves near-perfect efficiency for water oxidation, offering sustainable hydrogen production

by [Institute of Science Tokyo](#)



Poly-Fe5-PCz is a promising and efficient catalyst for water oxidation, offering a viable solution for hydrogen production and energy storage. Credit: Science Tokyo

A newly developed pentanuclear iron complex (Fe5-PCz(ClO₄)₃) can offer an efficient, stable, and cost-effective solution for water oxidation. By electrochemically polymerizing the complex, researchers from the Institute of Science Tokyo obtained a polymer-based catalyst, poly-Fe5-PCz, and achieved water oxidation with up to 99% Faradaic efficiency and exceptional stability, even under rigorous conditions.

This breakthrough offers a scalable alternative to rare metal catalysts, advancing [hydrogen production](#) and energy storage for renewable energy.

Water oxidation plays a vital role in renewable energy technologies, especially in hydrogen production and artificial photosynthesis. By splitting water into oxygen and hydrogen, it provides a clean, sustainable energy source.

However, replicating the efficiency and stability of natural photosynthetic systems in artificial catalytic setups—especially in aqueous environments—remains a significant challenge. Catalysts based on rare and expensive metals like ruthenium have shown high activity for [water oxidation](#) but are not practical for large-scale use due to their cost and limited availability.

To address this, a team of researchers led by Professor Mio Kondo from the Institute of Science Tokyo (Science Tokyo), Japan, developed a more sustainable and cost-effective catalytic system using abundant metals. Their findings are [published](#) in *Nature Communications*.

The study introduces a novel pentanuclear iron complex, $\text{Fe}_5\text{-PCz}(\text{ClO}_4)_3$, which possesses a multinuclear-complex-based catalytically [active site](#) and precursor moieties for charge transfer sites.

Kondo explains, "By electrochemically polymerizing this multinuclear iron complex, we create a polymer-based material that enhances electrocatalytic activity and long-term stability. This approach combines the benefits of natural systems with the flexibility of artificial catalysts, paving the way for sustainable energy solutions."

The researchers synthesized the $\text{Fe}_5\text{-PCz}(\text{ClO}_4)_3$ complex using [organic reactions](#) like bromination, nucleophilic substitution, Suzuki coupling reactions, and subsequent complexation reactions. The synthesized complex was characterized by mass spectrometry, elemental analysis, and single-crystal X-ray structural analysis.

The researchers then modified glassy carbon and indium tin oxide electrodes by polymerizing $\text{Fe}_5\text{-PCz}$ using [cyclic voltammetry](#) and controlled potential electrolysis to afford a polymer-based catalyst, poly- $\text{Fe}_5\text{-PCz}$.

The charge transfer ability and electrocatalytic performance of poly- $\text{Fe}_5\text{-PCz}$ were evaluated through electrochemical impedance spectroscopy and oxygen evolution reaction (OER) experiments with oxygen production quantified by gas chromatography, respectively.

The results were highly promising. Kondo explains, "Poly- $\text{Fe}_5\text{-PCz}$ achieved up to 99% Faradaic efficiency in aqueous media, meaning nearly all the applied current contributed to the OER. The system also exhibited superior robustness and a reaction rate under rigorous testing conditions compared to relevant systems."

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"Additionally, poly-Fe5-PCz demonstrated enhanced energy storage potential and improved electrode compatibility, making it suitable for a wide range of renewable energy applications."

Its high stability was further confirmed by long-term controlled potential experiments, a key advantage for hydrogen production and energy storage technologies.

The study's findings have significant implications for sustainable energy. The use of iron—an abundant, non-toxic metal—ensures the system is both eco-friendly and cost-effective, offering a viable alternative to precious metal-based catalysts.

Its stability under operational conditions addresses a major challenge in artificial catalytic systems, where long-term catalyst degradation often limits performance. Moreover, the system's performance in aqueous environments makes it suitable for applications in water splitting.

"Optimizing poly-Fe5-PCz synthesis and scalability could further enhance its performance, paving the way for industrial-scale hydrogen production and [energy storage](#). Our study opens new possibilities for integrating the system into broader energy technologies, paving the way to a more sustainable future," concludes Kondo.

More information: Takumi Matsuzaki et al, Iron-complex-based catalytic system for high-performance water oxidation in aqueous media, *Nature Communications* (2025). DOI: [10.1038/s41467-025-57169-y](https://doi.org/10.1038/s41467-025-57169-y)

Journal information: [Nature Communications](#)

Provided by [Institute of Science Tokyo](#)



HYDROGEN BREAKTHROUGH: NEW PALLADIUM NANOSHEET TECH COULD ACCELERATE GREEN ENERGY REVOLUTION

RYAN WHALEN · MARCH 4, 2025

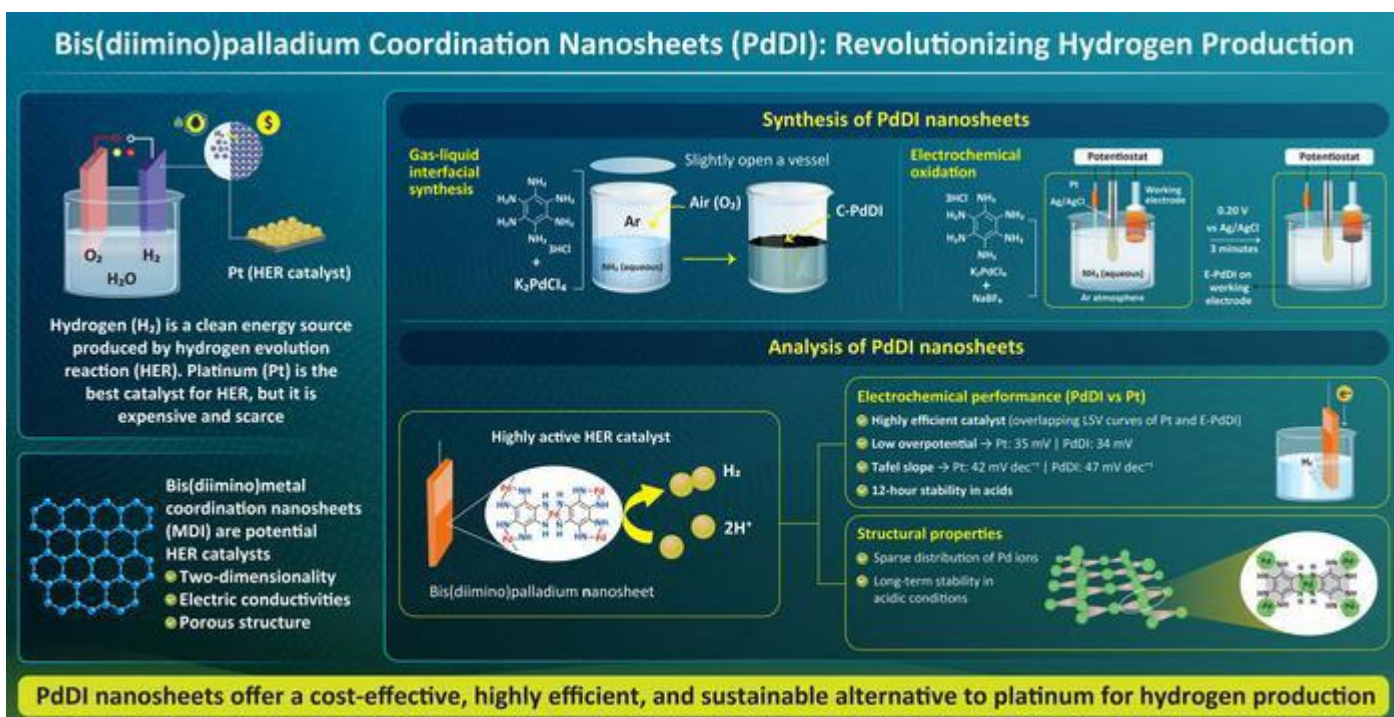
Scientists have developed a cost-effective alternative to [platinum](#) for use in hydrogen production, replacing the expensive metal with palladium [nanosheets](#) to reduce costs and accelerate the shift to clean energy.

As global temperatures surpass the preindustrial benchmark outlined in the 2015 Paris Climate Agreement, the need for large-scale hydrogen production has become more urgent to accelerate the

transition to zero-emission alternatives. However, the widespread adoption of **hydrogen** technology has been hindered by its dependence on costly platinum-based catalysts, making it economically unfeasible for everyday use.

NOVEL HYDROGEN DEVELOPMENT

Dr. Hiroaki Maeda and Professor Hiroshi Nishihara of the Tokyo University of Science (TUS) led a team consisting of other researchers from TUS, as well as contributors from Japan Synchrotron Radiation



Synthesis of Bis(diimino)palladium Nanosheets as Highly Active Electrocatalysts for Hydrogen Evolution
Maeda et al. (2024) | Chemistry – A European Journal | DOI: 10.1002/chem.202403082

Research Institute, Kyoto Institute of Technology, RIKEN SPring-8 Center, and the National Institute for Materials Science, Japan. The team produced a breakthrough in hydrogen evolution reaction (HER) technology with their bis(diimino)palladium coordination nanosheets (PdDI), nearly duplicating platinum's efficiency at a significantly lower cost.

CREDIT: HIROAKI MAEDA FROM TOKYO UNIVERSITY OF SCIENCE, JAPAN

Maeda and Nishihara's team further advanced their work by developing two versions of their PdDI nanosheets; each produced through a different fabrication method. They fabricated the C-PdDI variant with gas-liquid interfacial synthesis and the E-PdDI variant through electrochemical oxidation.

Exploring multiple avenues for fabrication benefitted the work by identifying the E-PdDI's performance testing as being extremely close to that of platinum, within 1mV of overpotential. In addition to similar energy usage, the exchange current density matched between E-PdDI and platinum, marking the solution as one of the most efficient catalysts ever developed.

HYDROGEN EVOLUTION REACTION TECHNOLOGY

HER is an essential process in manufacturing green hydrogen energy, which involves the electrolytic splitting of water into hydrogen and oxygen components. Catalyst electrodes convert the hydrogen generated at the electrode surface into hydrogen gas (H_2). Traditionally, the process relies on platinum, which is highly effective but extremely expensive, limiting its utility for large-scale production.

Despite cost challenges, HER is currently still considered the most sustainable and environmentally friendly hydrogen production method.

Through a simple synthesis process, the TUS-led team limited the amount of precious metal required to produce highly efficient catalysts as an alternative to pure platinum. The method enabled the team to fabricate palladium-based nanosheets, reducing HER's reliance on expensive platinum.

“Developing efficient HER electrocatalysts is key to sustainable H_2 production. Bis(diimino)metal coordination nanosheets, with their high conductivity, large surface area, and efficient electron transfer, are promising candidates,” [says lead researcher, Dr. Maeda.](#)

“Additionally, their sparse metal arrangement reduces material usage. Here, we have successfully developed these nanosheets using palladium metal.”

PUTTING PDDI NANOSHEETS TO WORK

Manufacturing costs aren’t the only issues impacting economic feasibility. The PdDI Nanosheets also displayed strong durability through 12 hours under acidic conditions. This degree of reusability further drives down costs and enhances sustainability, indicating a strong use case for real-world manufacturing.

“Our research brings us one step closer to making H₂ production more affordable and sustainable, a crucial step for achieving a clean energy future,” explains Dr. Maeda.

MEETING GLOBAL GOALS

The nanosheets offer many carryovers to global environmental goals. The new process meets the United Nations’ Sustainable Development Goals (SDGs), particularly SDG 7—promoting affordable and clean energy—and SDG 9—industry, innovation, and infrastructure. Beyond cost-effectiveness, the nanosheets are highly scalable for hydrogen production, fuel cells, and large-scale energy storage systems.

Removing platinum from HER could also reduce mining-related emissions, limiting the hidden carbon costs that could potentially erode green gains from the switch to hydrogen fuel. Palladium’s density, one-tenth that of platinum, further increases the cost-effectiveness, driving down the need to mine platinum.

The researchers continue optimizing PdDI nanosheets for commercial production to move toward a hydrogen fuel economy.

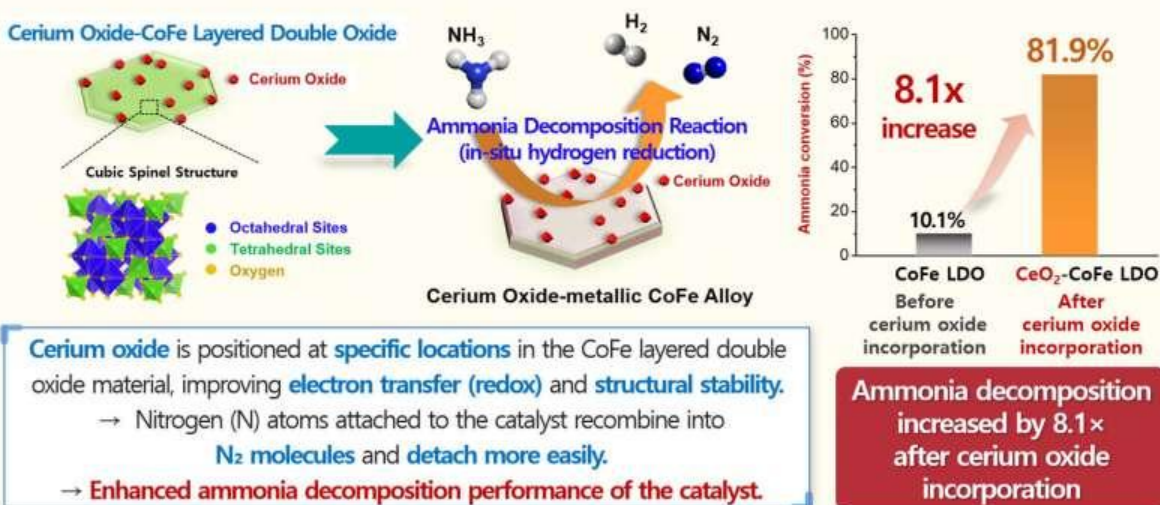
The team's new paper, "[Synthesis of Bis\(diimino\)palladium Nanosheets as Highly Active Electrocatalysts for Hydrogen Evolution](#)," appeared on November 28, 2024, in *Chemistry*.

MARCH 5, 2025

Efficient hydrogen production achieved with CoFe-based ammonia decomposition catalyst

by [National Research Council of Science and Technology](#)

Enhancement of Ammonia Decomposition Performance in Non-Noble Metal CoFe-Based Layered Double Oxide with Cerium Oxide Incorporation



Enhancement of ammonia decomposition performance in non-noble metal cofe-based layered double oxide with cerium oxide incorporation. Credit: Korea Research Institute of Chemical Technology (KRICT)

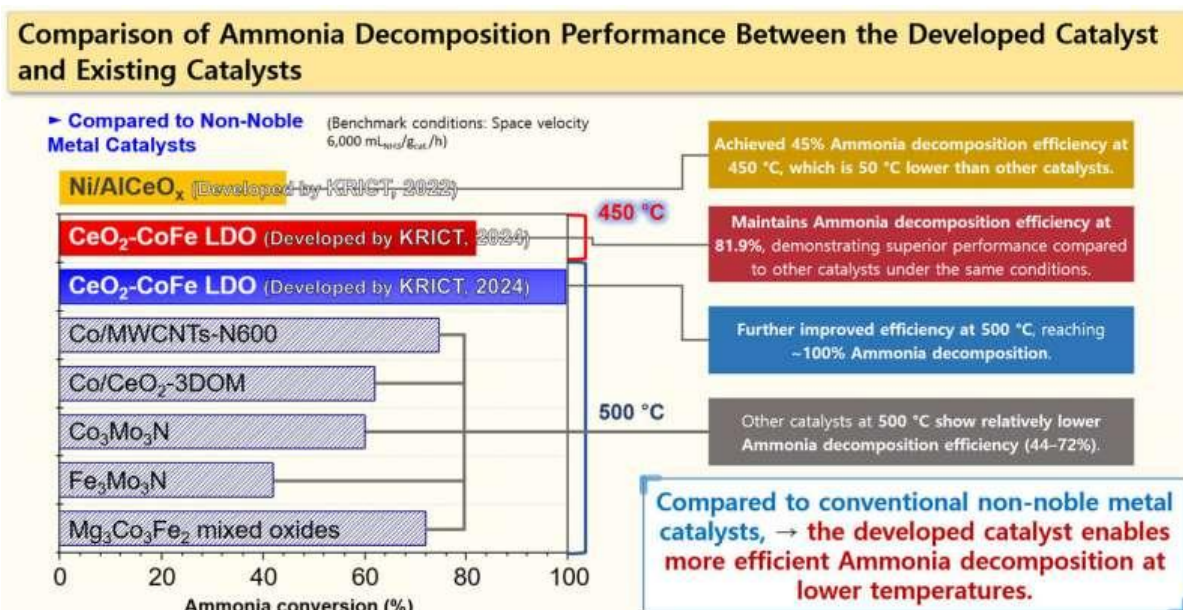
Researchers in South Korea have developed a cobalt-iron (CoFe)-based non-noble metal ammonia decomposition catalyst, advancing eco-friendly hydrogen production. The work is [published](#) in the *Chemical Engineering Journal*.

The research team led by Dr. Su-Un Lee and Dr. Ho-Jeong Chae from the Korea Research Institute of Chemical Technology (KRICT) has successfully developed a high-performance ammonia decomposition [catalyst](#) by incorporating cerium oxide (CeO₂) into a cobalt-iron-based layered double oxide (LDO) structure. This innovation enables high ammonia decomposition efficiency at lower temperatures.

Ammonia (NH_3) is gaining attention as a carbon-free **hydrogen** carrier due to its high hydrogen storage capacity and transport efficiency.

However, extracting hydrogen from ammonia requires a high-temperature decomposition process, typically facilitated by catalysts. Ruthenium (Ru) catalysts demonstrate the highest efficiency in this reaction, but their high cost and the need for elevated temperatures pose significant barriers to large-scale application.

To overcome these challenges, the research team developed a CoFe-based non-noble metal catalyst enhanced with cerium oxide (CeO_2). This catalyst offers high ammonia decomposition efficiency at lower temperatures, ensuring **cost efficiency** and long-term stability.



Comparison of ammonia decomposition performance between the developed catalyst and existing catalysts. Credit: Korea Research Institute of Chemical Technology (KRICT)

Advantages of cerium oxide incorporation:

- Prevents particle agglomeration: Adjusts the surface structure of CoFe-based LDO catalysts, preventing metal nanoparticle sintering.
- Enhances catalytic properties: Utilizes $\text{Ce}^{3+}/\text{Ce}^{4+}$ redox transitions to modulate the electronic characteristics of the catalyst.

Facilitating the rate-determining step:

- The rate-determining step in ammonia decomposition is nitrogen recombination-desorption from the catalyst surface.
- The newly developed catalyst optimizes this process, significantly accelerating ammonia decomposition even at lower temperatures.

Thanks to these advancements, the catalyst achieved 81.9% ammonia conversion at 450°C, surpassing previous non-noble metal catalysts.

This marks a significant improvement compared to a 2022 nickel-based catalyst, which exhibited only 45% conversion at 450°C.

Furthermore, long-term stability tests at 550°C demonstrated that the catalyst maintained [structural integrity](#) and hydrogen production efficiency even after prolonged operation.

The research team aims to further enhance low-temperature hydrogen production efficiency through additional studies, targeting commercialization by 2030.

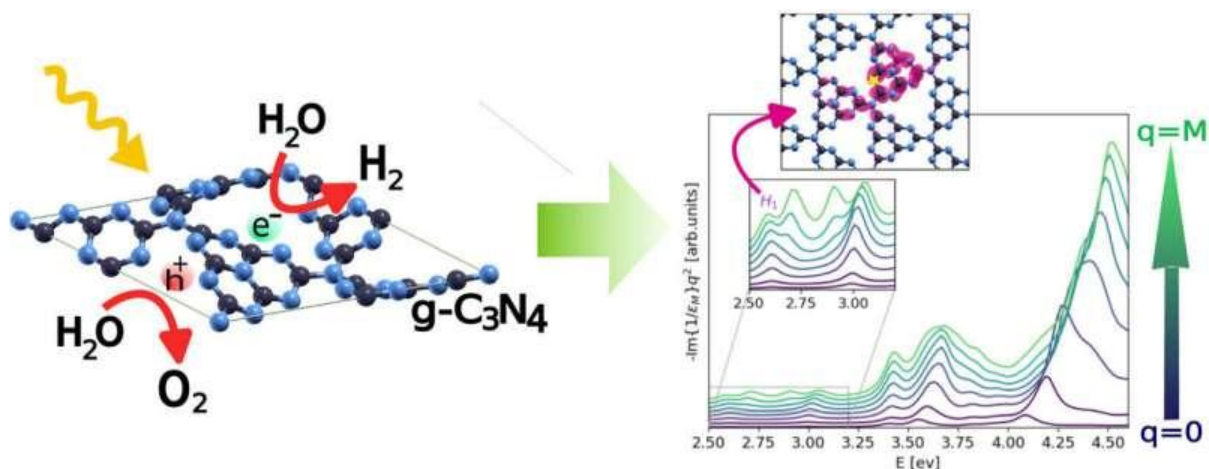
"This catalyst can be applied to large-scale [ammonia](#)-based hydrogen production, hydrogen power plants, hydrogen fueling stations, and maritime industries," Dr. Su-Un Lee stated.

More information: Su-Un Lee et al, CeO₂-conjugated CoFe layered double oxides as efficient non-noble metal catalysts for NH₃-decomposition enabling carbon-free hydrogen production, *Chemical Engineering Journal* (2024). DOI: [10.1016/j.cej.2024.156986](https://doi.org/10.1016/j.cej.2024.156986)
Provided by [National Research Council of Science and Technology](#)

MARCH 5, 2025

Artificial photosynthesis research represents a step forward towards green hydrogen

by [University of Trento](#)



Credit: *Carbon* (2024). DOI: 10.1016/j.carbon.2024.119951

How can we produce clean hydrogen without burning fossil hydrocarbons or other non-renewable energy sources? We can do so through photoelectrochemistry, or artificial photosynthesis, a method that—just like photosynthesis—uses sunlight and water, as with electrolysis, to obtain hydrogen, without generating harmful emissions. A group of researchers from the Department of Physics of the University of Trento has focused precisely on this approach.

The research is [published](#) in the journal *Carbon*.

One of the most innovative aspects of their research project is the use of photocatalysts ([semiconductor materials](#)) based on [two-dimensional materials](#), and in particular, on graphitic carbon nitride (g-C₃N₄). This material is lightweight and sustainable and is used to break the chemical bond of the water molecules to produce hydrogen.

The research has shown that when used in the form of a single atomic layer, these photocatalysts offer superior performance compared to the thicker and less orderly structures previously tested. This discovery could open the way to a more efficient use of these materials in the production of green hydrogen.

Hydrogen is considered one of the most promising solutions for energy transition. But most hydrogen produced today is made via the "steam reforming" method, where methane (a fossil fuel) is heated to high temperatures; a process that is not fully sustainable. The Trento-based research team instead focuses on the production of hydrogen through photoelectrochemical cells.

This is a clean process that does not use hydrocarbons or other non-renewable energy sources to break the chemical bond of the water molecules to produce hydrogen.

"The graphitic compound based on graphitic carbon nitride has been suggested as a possible photocatalyst. In contact with water, this semiconductor absorbs visible sunlight and transforms it into chemical energy to allow the movement of electrons within matter. Before our work, little was known about these mechanisms," explains Francesca Martini, lead author of the study.

"By studying the formation and propagation of excitons (a bound electron-hole pair), particles produced by sunlight in carbon nitride formed by a single layer of atoms, we realized that they have a very low speed and move in the photocatalyst thanks to a combined motion that includes the vibrations of the atoms."

The authors of the study are surprised by this result. The electrons are more than two thousand times smaller than the atoms of the photocatalyst. Therefore, they move faster, just as a swarm of insects (the electrons) moves around a person (the atom). This, however, does not happen in carbon nitride. It is as if the swarm of insects agrees with the person to walk arm in arm like a couple, until they meet a hydrogen ion together.

"When this happens," explains Matteo Calandra, study coordinator, "the atom bows and lets the electron that binds to the hydrogen ion pass through. Just as the father (the atom) of the bride (the electron) does when he takes her to the altar (hydrogen ion)."

The work of researchers will continue as they will perform [numerical simulations](#) on a database of over five thousand materials to which they have access, to perform a computational screening and identify better catalysts than the current ones.

"We hope that this research will lead to a strong innovation in the production of hydrogen from photoelectrolytic cells. Thanks to this methodology, we can now systematically identify better-performing materials and accelerate progress in the production of green [hydrogen](#)," concludes Pietro Brangi, co-author of the study.

This project represents a significant step towards energy sustainability.

More information: Francesca Martini et al, Ultraflat excitonic dispersion in single layer g-C₃N₄, *Carbon* (2024). DOI: [10.1016/j.carbon.2024.119951](https://doi.org/10.1016/j.carbon.2024.119951)

Journal information: [Carbon](#)
Provided by [University of Trento](#)