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Environment

The gold hydrogen rush: Does Earth contain near-limitless clean fuel?

Prospectors around the world are scrambling to find reserves of "gold hydrogen", a naturally occurring fuel that burns without producing carbon dioxide. But how much is really out there and how easy is it to tap into?

By James Dinneen

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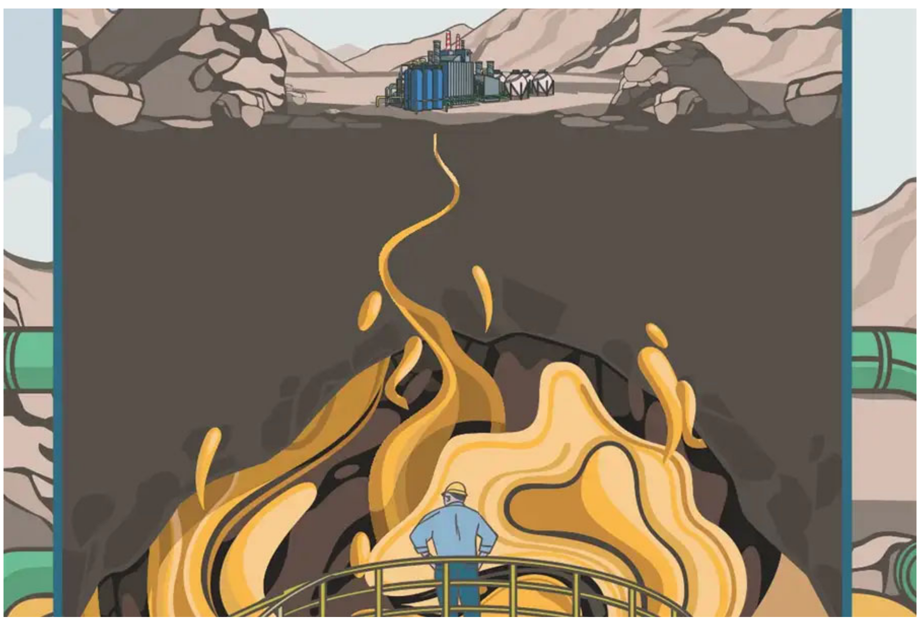

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AS WE drive out of Muscat, the white buildings of Oman's capital give way to an expanse of open sand ahead of the foreboding Hajar mountains. It takes us 2 hours to reach our destination, a journey that includes our SUV nearly getting stuck in the narrow back alleys of a town. But, eventually, geophysicist Ammar Alali and I arrive at a peaceful spring in the desert, surrounded by golden grasses and date palms. Alali frowns disapprovingly at a stream of bubbles in a pool of water. "It's energy going to waste," he says.

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× I have come here because Oman's mountains are at the forefront of a global search for a new and potentially transformative fuel, sometimes called "gold hydrogen". Colourless and odourless, this gas has good environmental credentials because it burns cleanly, producing nothing but water. Usually, however, we have to make it in an emissions-intensive process. But here in the mountains of Oman – and in places with similar geology across the world – it is naturally generated underground, potentially in vast quantities.

Read more Net-zero living: How your day will look in a carbon-neutral world

Proponents of using this form of hydrogen say it could dramatically accelerate our transition to net zero, which explains why researchers and start-ups are prospecting for it far and wide. Many questions remain, though, not least how much of it there really is and whether it can be easily tapped. For his part, Alali, co-founder of geological resources firm Eden GeoPower, wants to test something even more ambitious: can we stimulate the ground to boost the amount of hydrogen it produces?

Dreams of a…

hydrogen-powered economy have been around for decades. It would mean a world in which trucks, ships, planes and heavy industry run on the clean-burning gas instead of dirty fossil fuels. The trouble is, we currently have to make the hydrogen ourselves, which requires energy and produces pollution. Today, almost all of the 100 million tonnes the world uses annually is supplied by reacting natural gas with steam, a process that releases massive amounts of carbon dioxide. There are cleaner ways of making hydrogen (see "The hydrogen rainbow" below), including "green hydrogen", which is made from water using renewable energy, but these methods are currently minor players in the industry.

How much natural hydrogen does Earth hold?

In all cases, synthetic hydrogen is best seen as an alternative way of storing energy. A natural supply might instead be a genuine source of energy. Yet despite hydrogen being the most abundant element in the universe, most researchers thought Earth's stocks of it in its gaseous form were scarce. Drillers in search of fossil fuels sometimes found it in their wells and ocean explorers saw it trickling from sea-floor vents. But no one was actively looking for hydrogen and these discoveries were considered exceptions; hydrogen was thought too reactive to accumulate in large amounts.

That assumption was challenged in 2012, when a water well close to the town of Bourakébougou in Mali was found to contain a large reserve of hydrogen. This gas occurred naturally, meaning the only energy input required in its production is that needed to collect it. This kind of hydrogen goes by several names – white hydrogen and natural hydrogen, as well as gold hydrogen – but it is most usefully called geologic hydrogen. Since that find, a flurry of prospecting has led to the discovery of what may be significant underground reservoirs in France, Spain and Australia. We have also found hints of such hydrogen across swathes of the globe (see map, below).

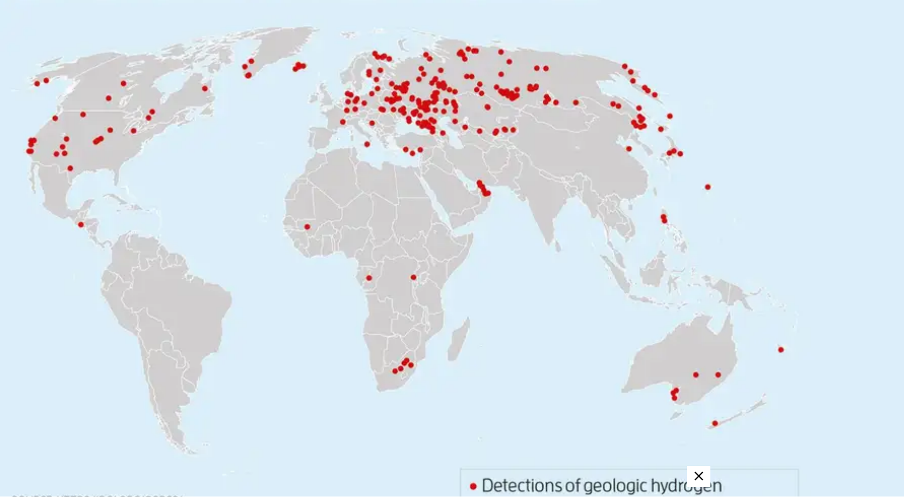
Read more World's first drilling project to seek natural hydrogen hits a snag

A handful of companies are drilling exploratory wells in the US, including a tight-lipped start-up called Koloma, backed by nearly $100 million from Bill Gates's venture capital firm. "There are a lot of people searching around the planet," says Eric Gaucher, an independent consultant in France who left a large oil and gas firm to pursue natural hydrogen. "One of them will find something that is very big and economic. I am convinced."

In the past decade or so, excitement over geologic hydrogen was largely confined to a few true believers in industry. Then, in 2022, researchers at the US Geological Survey revised their estimates of how much such gas there could be in the ground based on the little that was understood about how it is formed. Their modelling suggested there could be trillions of tonnes available, far more than anyone had previously suspected. If just a fraction of that could be recovered, it would be enough to meet our projected hydrogen demand for centuries. These results generated widespread media coverage. "It's gone from a fringe novelty to squarely getting everyone's attention," says Avon McIntyre at HyTerra, an Australian company focused on geologic hydrogen.

Hints of hydrogen

Some of the spots where we have measured hydrogen coming from the ground, with more in areas that have been extensively prospected



SOURCE: HTTPS://DOI.ORG/GGRC94

The interest may be justified. Gaucher says meeting even 20 or 30 per cent of our growing hydrogen needs with such sources would free up huge amounts of clean energy that would otherwise be used to make green hydrogen. It may even be a renewable resource if it is continually generated below the surface.

But, on the other hand, there are reasons to be cautious about what has been called "gold hydrogen fever". The true amount of hydrogen the planet contains, as well as how much might be feasible to extract, remains uncertain. It is also unclear precisely how geologic hydrogen is made. Researchers think at least some is gradually seeping into the crust from the mantle below, where it built up during Earth's formation. Some may be generated by radioactive rocks splitting water into oxygen and hydrogen. Then there is the process of serpentinisation, in which groundwater reacts with iron-rich minerals in rock, such as olivine, to create iron oxide and hydrogen gas.

Most geologic hydrogen hunters have this serpentinisation process in their crosshairs. The thinking is that places with a lot of iron-rich rock may also generate lots of hydrogen, says Viacheslav Zgonnik, whose company, Natural Hydrogen Energy, drilled a well in search of the gas in Nebraska last year. The canniest prospectors look for an area of iron-rich rock capped with an impermeable layer, so the precious fuel might be sealed in and build up underground.

Other companies looking for hydrogen in the US Midwest, including Koloma and HyTerra, are following this rationale. Similarly, Gaucher says newly identified deposits in the Pyrenees mountains straddling France and Spain that could contain tens of millions of tonnes of hydrogen may occur due to a bulge of iron-rich mantle rock sitting unusually close to the surface.

In Oman, this iron-rich geology is even more accessible thanks to the region's unique tectonic past. Just under 100 million years ago, the tectonic plate beneath the Arabian Sea collided with another under the land. Such events usually result in the crust being forced down into the mantle, but here it was thrust upwards, a process known as obduction. The Hajar mountains are the result. They are the largest exposure of mantle rock on the planet, mostly made up of iron-rich peridotite that you can't help but walk upon. During my visit, in a valley strewn with boulders of this green and white-streaked material, we took off our shoes to cross a stream flowing over rocks that were once on the boundary between Earth's mantle and crust.

How to find natural hydrogen

There may be another way to identify areas ripe for hydrogen extraction. A session at the American Geophysical Union conference last December featured research on using machine learning to identify rings of bare soil – sometimes called fairy circles – in satellite images. Joachim Moortgart at Ohio State University, who contributed to that work, says hydrogen has been measured in soil at more than 50 such circles, although the relationship between the gas and these mysterious formations remains unclear.

Despite the excitement, however, geologic hydrogen would have shortcomings as a fuel, especially when it comes to being transported long distances. For starters, the gas is explosive. And because it occupies large volumes, it needs to be compressed or converted into other chemicals, such as liquid ammonia, before it can be easily moved. We might need to build new pipelines to carry it from remote locations to ports or cities.

A hydrogen fuel revolution is coming – here's why we might not want it

Hydrogen is widely touted as a green fuel for everything from cars and planes to heating homes. But all too often it has a dirty secret

It would help if we could avoid relying on happenstance accumulations of hydrogen and instead stimulate the ground to reliably produce the gas in more convenient areas. That is what a number of researchers and companies are now working on. The US Department of Energy (DoE) is involved too, putting up $20 million for such efforts. The idea is to explore ways of speeding up the serpentinisation process and so conjure hydrogen from the ground. "We can greatly expand the regions from which this resource will be available," says Doug Wicks, who directs the DoE programme.

With their well-understood geology, iron-rich peridotite rock and clear evidence that hydrogen is bubbling from the ground, the Hajar evidence that hydrogen is bubbling from the ground, the Hajar mountains are an ideal place to test the idea. Following a workshop involving the DoE and the Omani government in November 2023, there are now plans to drill the world's first stimulated hydrogen well here later this year.

Alali, who has played a central role in coordinating this work, showed me one of four possible sites for the well. We drove through the alleys of a small town called Hailain – this was where our vehicle almost got stuck – and out into a valley. Several of the pools bubbling with hydrogen were covered by what resembled a layer of ice (pictured, below). This was actually a powdery mineral film formed from reactions between calcium leached from the peridotite and carbon dioxide in the air.

Mineral films coat pools of water in the Hajar mountains in Oman
James Dinneen

Alali told me the pilot stimulation project will involve drilling at least one borehole to a depth of between 400 and 600 metres. The rate of geologic hydrogen production will be measured and the team will then try different methods of stimulating the hydrogen-generating reaction, including injecting water and heating the rock. Adding chemical catalysts is another option, though not one the researchers plan to test yet. "There really are a lot of knobs to turn," says Alexis Templeton at the University of Colorado Boulder, who is the lead researcher on the project. She says the goal is to increase the rate of hydrogen production by 10,000, the point at which it would be commercially viable.

Can we stimulate natural hydrogen production?

To help get there, the team will try a novel strategy for breaking up rocks deep underground to increase the surface area exposed to the injected water. The method, developed by Eden GeoPower, is akin to fracking for natural gas, but with electricity instead of water. Sending a high-voltage current between electrodes lowered into the ground should heat microscopic pores in the rock, causing them to expand in "a spiderweb of lightning fractal patterns underground", says Paul Cole, Eden GeoPower's head of subsurface engineering.

There are several reasons the project may not work as well as hoped. The pores in the rock could get clogged, trapping the hydrogen. The required energy input could end up being unfeasibly high. Plus, Templeton says there are communities of bacteria living in Oman's rocks that feed on hydrogen. No one knows how they will react when the amount of hydrogen increases. It is possible their numbers will swell, creating a mob of microbes that gobble up much of the fuel before it can be collected. This may not be an issue for projects drilling in hotter, deeper wells, but in Oman "the rocks are alive", says Templeton.

Read more Is climate change accelerating and is it worse than we expected?

Outside researchers say the goal of upping the rate of hydrogen production in such wells by 10,000 is feasible, but there is no guarantee of success. "It will take some clever chemistry to make it work," says Toti Larson at the University of Texas at Austin, who isn't involved in the project.

There are also some environmental risks. For instance, it is unclear how much water the project will require. Using substantial amounts in an arid place like Oman could raise eyebrows, although Alali says the plan is to use non-potable wastewater or groundwater for the tests. We also must be alive to the risk of small earthquakes from injecting water, says Mengli Zhang at the Colorado School of Mines, who also isn't a part of the work.

If all goes well, Oman, a nation known for its oil and gas, could find itself leading the field of geologic hydrogen. The impacts might even spread far beyond its borders and give our efforts to power the planet without fossil fuels a serious boost. "There are a lot of really smart people working on this now," says Wicks. "I'm expecting some audacious and potentially earth-shattering ideas about how to get hydrogen out of the ground."

The hydrogen rainbow

Hydrogen may be a colourless gas, but those in the industry think of it as coming in a number of shades depending on its environmental credentials.

Black

This hydrogen is produced by degassing coal. The process produces a lot of carbon dioxide and is no longer common.

Grey

This method starts with natural gas and generates hydrogen and carbon dioxide, making it a significant producer of greenhouse gas. It is by far the most common way to make hydrogen because it is cheap.

Blue

Just like grey hydrogen, except the carbon dioxide is captured and stored underground, meaning it contributes less to global warming.

Turquoise

A relatively new innovation, this approach breaks down natural gas into hydrogen and solid carbon, meaning no carbon dioxide is emitted. It is potentially cheaper than green hydrogen (below), but the technology needs development.

Green

The most environmentally friendly way to make hydrogen. This method uses electricity generated from renewable sources to electrolyse water into oxygen and hydrogen.

Gold

Sometimes called white hydrogen (or natural or geologic hydrogen), this is when

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