Gold, Geologic, White, Native, Hidden, Natural Hydrogen: Does Earth hold extensive stores of untapped, carbon-free fuel?

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Hydrogen is rarely recovered in oil operations, and it was not thought to exist in large reserves within the Earth crust.[1]

Historically, hydrogen exploration was not undertaken because of the misconception that it seldom exists naturally in the earth's crust, a view that prevailed even though geoscientists have been recording occurrences of natural hydrogen in both sedimentary and igneous geological settings since the early 20th century.[2]

In the global quest for cleaner and more sustainable energy sources, much of the spotlight has been focused on wind, solar, hydro and industrially produced low emission hydrogen. However, a relatively unexplored but increasingly intriguing prospect lies beneath our feet: natural hydrogen. Despite the burgeoning attention on renewables, there has been growing momentum behind the scenes for harnessing natural hydrogen

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[1] Eric Hand. Science. Hidden Hydrogen. February 2023.

[2] Philip J. Ball. Geoscientist. Natural hydrogen: New Frontier. March 2022.

as a key player in the future energy mix since it was first discovered by accident in a small village in Mali in 2012. The well which was drilled was intended to source for water[3].

The first global conference on natural hydrogen, H-Nat 2021, was held in June 2021, attracting the interest of more than 500 geoscientists, environmentalists, and prospective investors. Across two days, experts presented on various facets of geological hydrogen, including exploration, development, production techniques, as well as storage, transportation, and utilisation of hydrogen.

Major energy corporations such as Shell, BP, and Chevron are collaborating in a consortium established by the U.S. Geological Survey and the Colorado School of Mines to investigate natural or geological hydrogen. Meanwhile, several enterprising start-ups have already begun their quest to explore this resource.[4] In recent months, there has been a surge of interest among prospectors, who are actively drilling for hydrogen in various locations around the world, including northeast France, Australia, Spain, Morocco, Brazil and, within the United States, in Nebraska, Arizona, and Kansas.[5] Initial simulation model suggest that there may be something like 10 trillion tonnes of natural hydrogen buried underground worldwide.[5] However, there is an important caveat: a significant portion of this hydrogen might be inaccessible due to its depth, offshore location, or in small amounts that make extraction unfeasible. If just 1% of this estimated hydrogen were recoverable, it would be enough to supply the world's energy needs for over two hundred years, even considering a potential surge in hydrogen demand according to Geoffrey Ellis, a geoscientist at the USGS.[6] But are such claims well-founded? Will tapping the hydrogen resource be economic? And is there an environmental downside? There is concern among environmentalists that hydrogen emission could have unintended consequences,[4] (Converting hydrogen's full atmospheric radiative efficiencies to per unit mass (3.64 and 5.04 $W m^{-2} kg^{-1}$) and comparing them to the radiative efficiencies of CO_2 and CH_4 (1.7 $W m^{-2} kg^{-1}$ and 2.0 $W m^{-2} kg^{-1}$, respectively) shows that hydrogen's indirect warming potency per unit mass is around 200 times that of carbon dioxide and larger than that of methane, However, like methane, hydrogen's warming effects are potent but short-lived).[7]

There is a considerable amount we need to learn to fully comprehend the potential of natural hydrogen. Furthermore, some remain sceptical as to its accumulation. Stuart Haszeldine, a geologist at the University of Edinburgh, points out, "Hydrogen is prone to

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[3] Prinzhofer et al., International Journal of Hydrogen Energy. Discovery of large accumulation of natural hydrogen in Bourakebougou (Mali). October 2018.
[4] Forbes. Forget oil. New wildcatters are drilling for limitless geologic hydrogen. June 2023.
[5] Fred Pearce. Yale Environment 360. Natural Hydrogen. A potential clean energy source beneath our feet. January 2024
[6] Louise Boyle. Independent. The hunt for holy grail of clean energy buried beneath the ground. Nov. 2023.
[7] Ocko et al., European Geosciences Union. Atmospheric Chemistry and Physics. Climate consequences of hydrogen emissions. Volume 22, Issue 14. 2022.

leakage. It escapes nearly as quickly as it forms, and especially over geological timescales."[4]

Despite the potential, the exploration and exploitation of natural hydrogen face several challenges. The exploration of natural hydrogen is still in its nascent stages. The processes of its formation, migration, and crucially its potential for commercial production is not fully understood by scientists. Major oil companies are currently adopting a wait-and-see approach, allowing independent explorers to undertake the pioneering and risky exploration work. The commercialisation efforts in the Mali field have faced challenges, and exploration has been limited, with only a few test wells drilled. Concerns have been voiced about the possibility of overhyping the potential before solid evidence of safe, reliable access and production is established.[1]

The prospects of natural hydrogen are quietly bubbling under the surface, poised to potentially play a crucial role in sustainable energy future. As technology advances and interest continues to grow, natural hydrogen may emerge from behind closed doors and into the spotlight of renewable energy solutions.

If economically viable methods for harnessing natural hydrogen were developed, it could eliminate the requirement for clean water currently used in the electrolytic process for producing green hydrogen (note that 20 kg of tap water is required to produce 1 kg of hydrogen[8]). Additionally, it may negate the need for production of CCS-abated (blue) hydrogen. Several stakeholders (Michael Levy, Aqius/Hynat, Switzerland & Alain Prinzhofer, HYNAT, Brazil; Viacheslav Zgonnik, Natural Hydrogen Energy LLC, USA) have suggested that the costs of producing natural hydrogen would be low, with estimates ranging from USD 0.5 and USD 1.0 per kg.[2] For comparison, the cost of producing hydrogen via SMR with CCS in the Netherlands in 2020 is USD 2.84 per kg[9]; and via Steam Naphtha Reforming (SNR) in UAE in 2020 is USD 4.42 per kg[10]. Using renewable electricity to produce hydrogen costs between USD 3 and USD 8 per kg.[11] Site-boundary baseline (contains 85 mol % H_2, 12% N_2, and 1.5% CH_4) GHG intensity is ~0.4 kg CO_2 eq./kg for natural H_2[12]. In comparison, the carbon footprint of unabated SMR hydrogen and CCS-abated (90% capture) SMR hydrogen is 10.13 and 2.45 kg CO_2eq. / kg respectively.[9] **The emissions intensity of hydrogen produced with electrolysis via renewables is** ~0 kg CO_2-eq/kg on site.[13]

[8] IEAGHG. Comparative analysis of electrolytic hydrogen pathways with CCS-abated hydrogen. Ongoing study.

[9] IEAGHG, "Blue Hydrogen: Global Roadmap", 2022-07, April 2022.

[10] IEAGHG, "Blue Hydrogen: Beyond the Plant Gate", 2022-06, March 2022.

[11] IEA, Global Hydrogen Review 2021. November 2021.

[12] Brandt et al., Joule, Brandt et al., Joule, Greenhouse gas intensity of natural hydrogen produced from subsurface geologic accumulations, Volume 7, Issue 8, 16 August 2023, Pages 1818-1831, July 2023.

[13] IEA. Towards hydrogen definitions based on their emissions intensity

Note: Green hydrogen applications with higher-end total value chain emission rates (10 %, worst case scenario) per amount of hydrogen consumed may only cut climate impacts from fossil fuel technologies in half over the first 2 decades, which is far from the common perception that green hydrogen energy systems are climate neutral. However, over a 100-year period, climate impacts could be reduced by around 80 %. For CCS-abated hydrogen, associated methane emissions (including venting, purging, and flaring) can make hydrogen applications worse for the climate than fossil fuel technologies for several decades if emissions are high for both gases; however, blue hydrogen yields climate benefits over a 100-year period. While more work is needed to evaluate the warming impact of hydrogen emissions for specific end-use cases and value-chain pathways, it is clear that hydrogen emissions matter for the climate and warrant further attention from scientists, industry, and governments.[7] These findings underscore the prudent need to lock in the hydrogen production value chain emissions.

While around 40 companies are currently assessing the natural hydrogen resource globally, no commercial extractable reserves have yet been proven.[14] Meanwhile, geologists announced in 2023 that they had stumbled upon what could potentially be the largest deposit discovered so far, with an estimated 250 million tonnes of hydrogen of 98% purity in northern France.[4]

As optimists and sceptics debate the commercial viability of natural hydrogen, hydrogen explorers continue to scout for its natural occurrences, making advances in research, development, and demonstration, and gaining valuable insights. Time will tell if natural hydrogen emerges as a dark horse in the pursuit of the Net Zero Economy.

The title of this paper reflects the nomenclature used to describe naturally occurring hydrogen in the literature. Moving forward, IEAGHG intends to adopt the terminology used by the IEA Hydrogen TCP, specifically 'natural hydrogen,' to refer to hydrogen that occurs naturally in the Earth's crust. This approach moves away from the colour-based terminology and ad hoc names coined by some to describe naturally occurring hydrogen.

[14] Polly Martin, Hydrogen Insights. Natural hydrogen exploration and usage being examined by Brazil's national oil company Petrobras. March 2024.