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Natural hydrogen: the new frontier

Geological hydrogen could revolutionise our low-carbon future. Philip J. Ball and Krystian Czado report on discussions of this little-understood resource during the first international summit on natural hydrogen exploration

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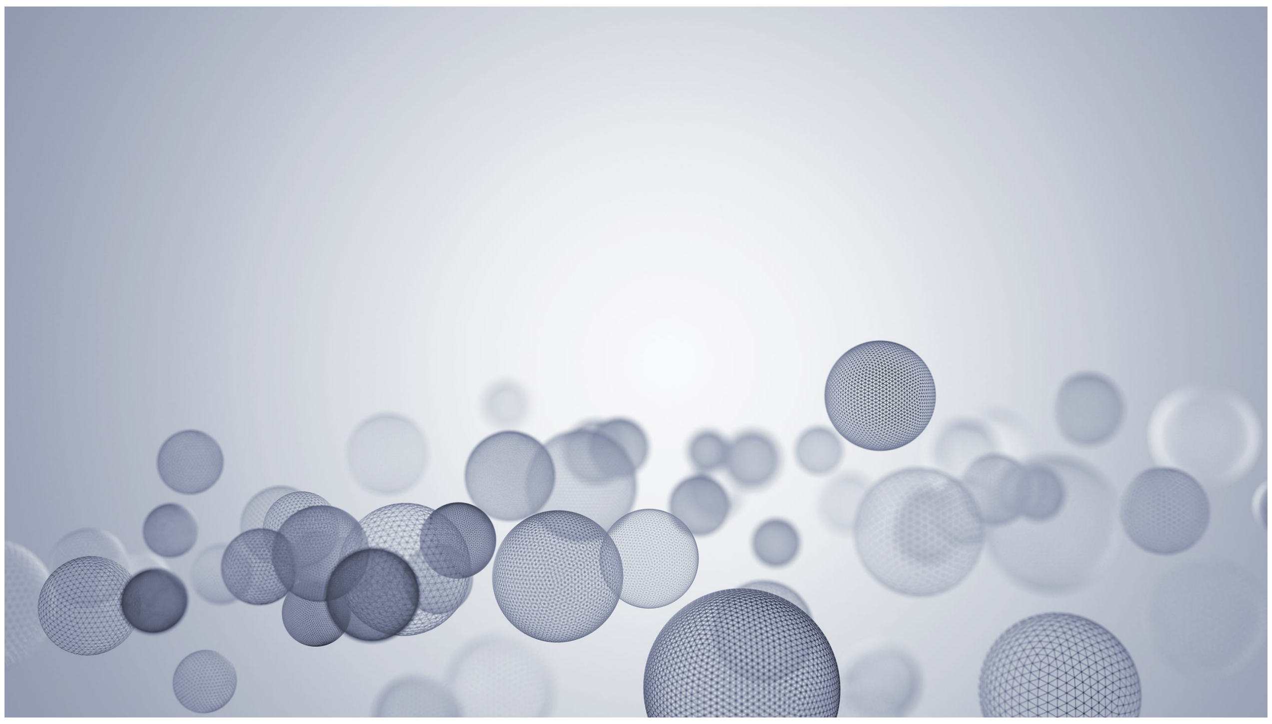
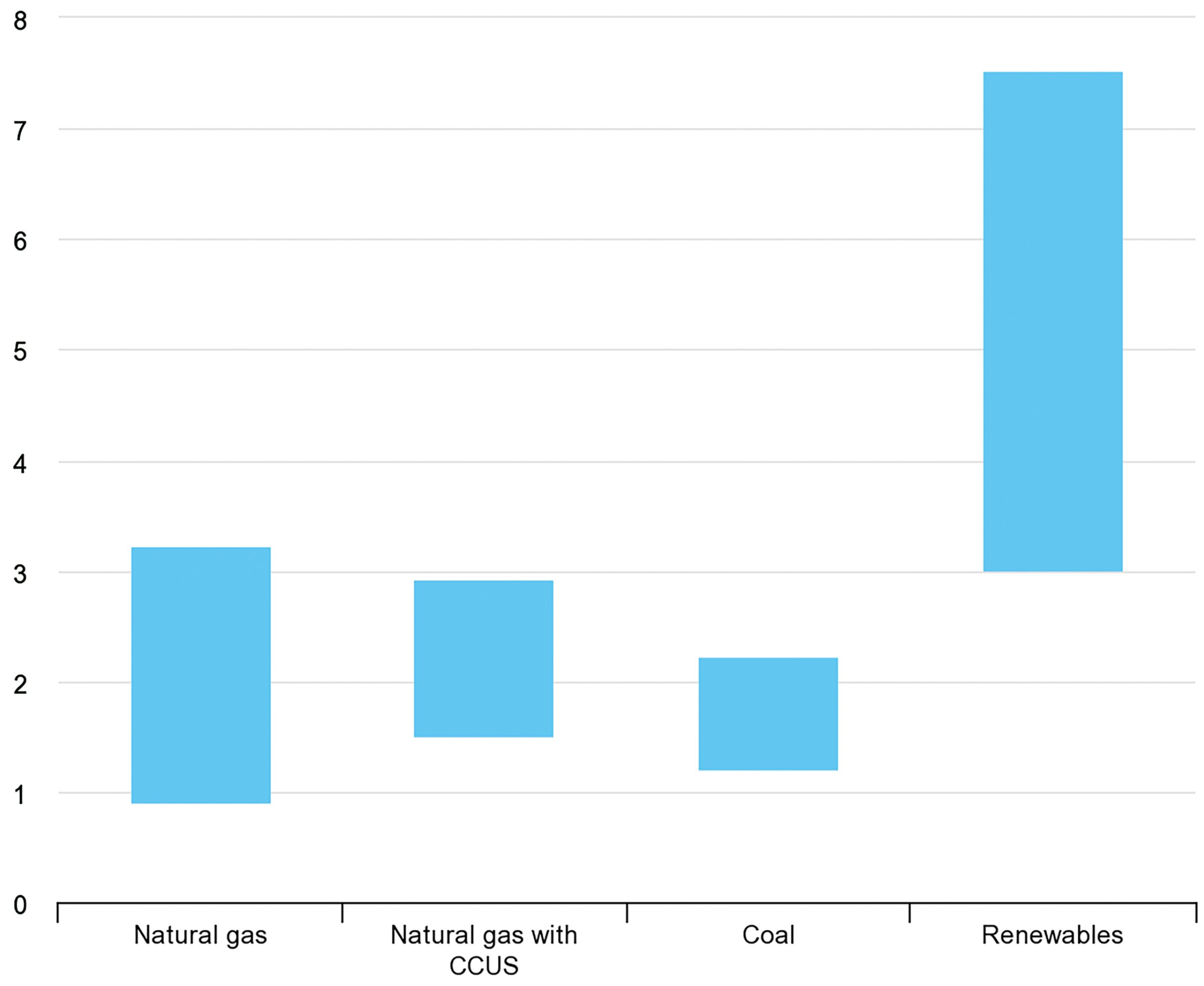


Hydrogen shows promise as a low-carbon fuel. Current debate centres on whether green hydrogen, produced by splitting water via electrolysis, will compete with blue hydrogen, which is produced when natural gas is split into hydrogen and CO_2, and the carbon is captured and stored, or grey hydrogen generated from natural gas, without carbon capture. However, one promising source – naturally occurring or geological hydrogen – has largely been overlooked because it was assumed rare or too difficult to extract.

The first worldwide natural hydrogen conference, H-Nat 2021, took place in June 2021. This virtual event attracted over 500 geoscientists, environmentalists and potential investors. Over two days, speakers elaborated on different aspects of geological hydrogen exploration, development, production (such as purification and separation), storage, transport and utilisation of hydrogen, as well as the legal 'blue-sky' elements related to hydrogen exploration and storage.

If natural hydrogen can be exploited economically, it would remove the need for clean water, which is used during green hydrogen electrolysis, and eliminate the need for expensive Carbon Capture and Storage (CCS) associated with blue hydrogen. Yet, much is unknown about natural hydrogen, and discovery of this potentially renewable resource raises several questions, such as: Are there any known commercial accumulations? How can it be exploited? What are the legal implications of exploring for hydrogen? What are the costs of production? Can it decarbonise and compete with existing (grey and blue) hydrogen feedstock, or even green hydrogen? Can hydrogen be stored in the subsurface? The H-Nat conference set out to answer comparison, Paul Lucchese, International Energy Agency, IEA, presented costs derived from the IEA's 2019 report 'The Future of Hydrogen', which indicate that grey hydrogen costs ~\$0.9-3.2 per kg, blue \$1.5-2.9 per kg, and green \$3.0-7.5 per kg, suggesting that natural hydrogen can compete. In light of natural gas price increases towards the end of 2021, the cost of hydrogen could swing dramatically, if global gas prices remain high. The consensus was that a price of ~\$1 per kg was a key target for many natural hydrogen producers. Given these cost estimates, we could be at the start of a natural hydrogen race that could lead to a discrete pivot of the energy industry in providing low-carbon, cost-effective, natural hydrogen.



Hydrogen production costs by production source, 2018. Image: IEA, Hydrogen production costs by production source, 2018, IEA, Paris iea.org/data-and-statistics/charts/hydrogen-production-costs-by-production-source-2018; IEA. All rights reserved

Gathering momentum

Natural hydrogen is commonly known as native, geologic, white or golden hydrogen. The colour is not yet settled in the eyes of the marketers, although the results of an online poll during the conference suggested that attendees preferred the term 'white hydrogen'.

The processes that create natural hydrogen are not fully understood. It is found in a large range of geological settings – in oceanic and continental crust, volcanic gases and hydrothermal systems (as discussed in talks by Isabelle Moretti, UPPA, France; Kayad Moussa, ODDEG, Djibouti; Eric Gaucher, University of Bern, Switzerland; Eric Deville, IFP School, France; Alain Prinzhofer; Viacheslav Zgonnik). The present known sources of natural hydrogen seem to be abiotic (that is, a non-living source). However, discussions highlighted that natural hydrogen can be considered as both biogenic or abiotic, because source interpretations can be subjective, and there is still much to learn about hydrogen and microorganisms.

There are documented occurrences of hydrogen in geothermal brines

Historically, natural hydrogen has been ignored due to the persistent misconception that it rarely occurs naturally – a view that largely prevailed despite the fact that since the beginning of the 20th century geoscientists have documented natural hydrogen, both in sedimentary and non-sedimentary (igneous) geological settings, often in non-negligible volumes. For instance, over a century ago, Ernst Erdman documented the flow of 128 cubic feet of hydrogen per day for 4.5 years at Leopoldshall Salt Mine in Strassfurt, Germany (Erdmann, 1910). Yet, natural hydrogen did not capture the interests of explorers until recently. The narrative changed in 2012 when Hydroma Inc. (a Canadian company previously known as Petroma Inc.) re-discovered a hydrogen-rich aquifer in Bourakébougou, Mali and, moreover, managed to flow the natural hydrogen to the surface in commercial quantities. It then became clear that we could no longer ignore natural hydrogen.

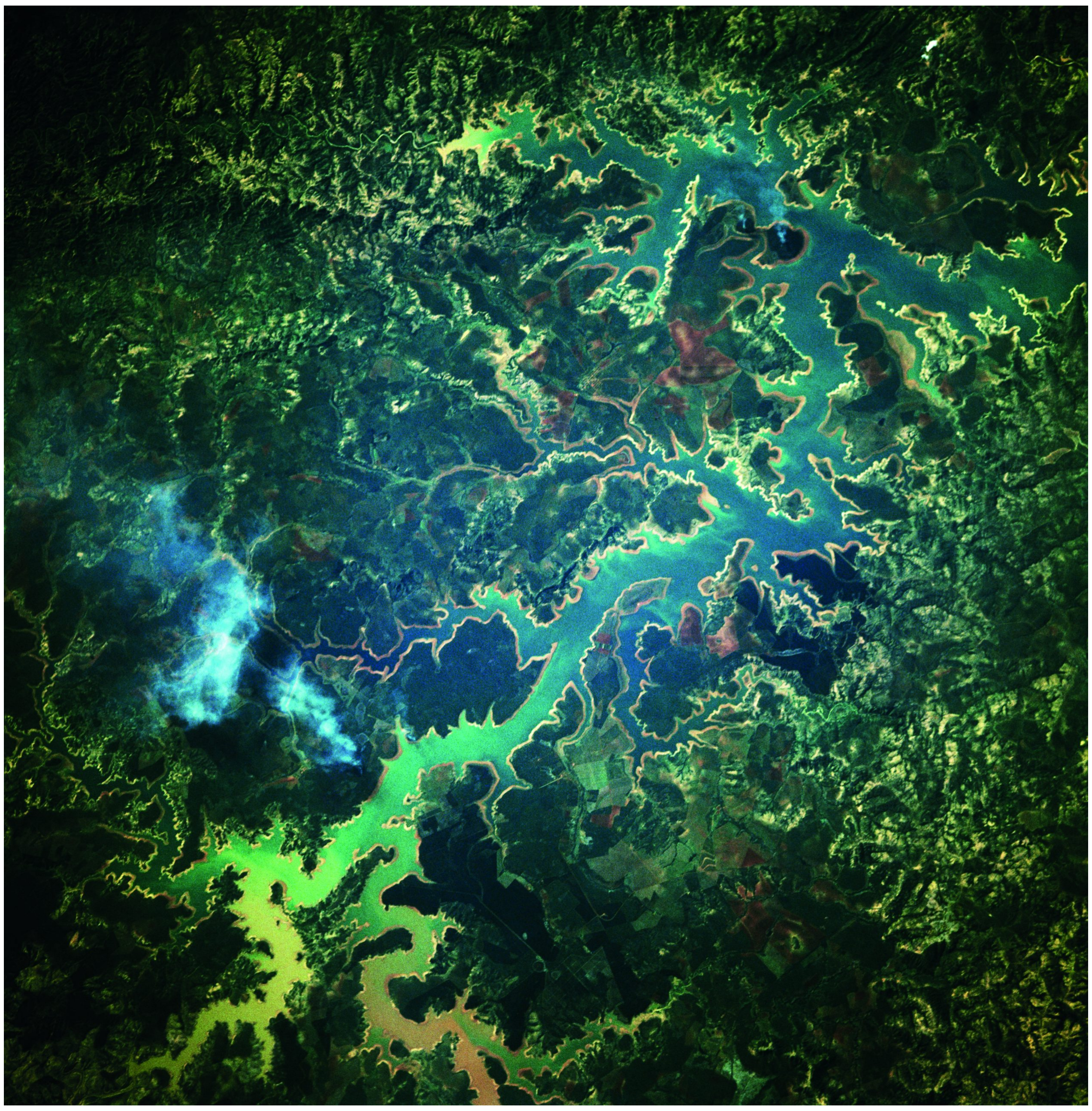
Interest in natural hydrogen has slowly gathered momentum since. As discussed by Viacheslav Zgonnik, the first pure-play hydrogen exploration well in USA, Hoarty NE3, was drilled by Natural Hydrogen Energy LLC, in Nebraska, USA. Initiated in November 2018 and completed in March 2019, information in the public domain shows that hydrogen was reported, but the well is currently shut in (NOGCC, 2022), while the company is completing tests in the well.

Natural hydrogen is found in a range of geological settings – oceanic and continental crust, volcanic gases and hydrothermal systems

Mali

Several conference presentations were dedicated to the Mali case study, where natural hydrogen was first discovered in 1987 during the drilling of ~100-metre-deep water wells for the village of Bourakébougo (Denis Briere, Chapman Petroleum Engineering Ltd., Canada). However, it was only in 2012 that Hydroma Inc. began drilling and testing for hydrogen in a controlled environment and discovered that the gas emitted by the reservoir was 98% hydrogen. Over the ten-day production test, reservoir pressure was largely maintained, implying that the source is renewable. The reservoir pressure has now been maintained for nine years and this supply of natural hydrogen led to the first production of electricity in the village.

To estimate the natural hydrogen resource at Bourakébougou, 24 wells were drilled. Hydroma Inc. has identified five reservoirs across an area of 780 km^2, each of which is associated with a doleritic sill that seems to form a seal. The mapped reservoir depths range from 30 – 135 m to reproduced elsewhere, the Mali case represents a significant milestone in the natural hydrogen business.



In the Sao Francisco Basin, Brazil, natural hydrogen seeps at volumes exceeding a few hundred kg per day

Global distribution

A number of the conference presentations detailed the occurrence and exploration of natural hydrogen (as well as the associated legislation activities) across Australia (for example, talks by Emanuelle Frery, CSIRO, Australia; Chris Boreham, Geoscience Australia; Sandra Menpes, SANTOS, Australia), Brazil (e.g. Maria Rosanne, ENGIE, France), Europe (e.g. Jon Gluyas, Durham Univeristy, UK; Isabelle Moretti & Kayad Moussa; Eric Gaucher), Mali, (Denis Briere), Morocco (e.g. Stephane Aver, HYNAT, Switzerland & Mohammed Ghazali, Ministry of Energy, Mines and the Environment, Morrocco) and the USA (e.g. Viacheslav Zgonnik). These talks demonstrated that natural hydrogen is observed in many different geological environments, including rifts, back-arc basins, intracratonic basins, cratonic areas (usually Precambrian in age), within Banded Iron Formations or mineralised zones and ore deposits, mid-ocean ridges, and orogenic settings.

Natural hydrogen is often found in association with brines that also contain helium, carbon dioxide, nitrogen and methane. There are well-documented occurrences of hydrogen within copper mines in Ontario, Canada, and South African gold, platinum and chromite mines (Eric Deville), and in geothermal brines in Iceland (Isabelle Moretti & Kayad Moussa). One talk detailed the long-term monitoring of the Sao Francisco Basin, Brazil, where natural hydrogen seeps at volumes exceeding a few hundred kg per day per km^2 (Maria Rosanne).

Some key processes for hydrogen production include: (a) deep hydration and radiolysis of water associated with the radioactive decay of uranium, thorium and potassium-bearing minerals; (b) oxidation of ferrous to ferric iron and mineral hydration, for example, during the serpentinisation of olivine (e.g. ophiolites); (c) decomposition in metamorphic areas; (d) very late organic matter maturation; and (e) primordial hydrogen originating from Earth's core and mantle (as discussed in talks by Viacheslav Zgonnik; Chris Boreham; Isabelle Moretti; Eric Gaucher; Alain Prinzhofer).

> **Natural hydrogen has the potential to cause the biggest disruption to the global energy system in the coming decades**

Nascent field

The possibilities for natural hydrogen exploitation are significant, but only if we can understand how natural hydrogen is generated, how or if it traps, or how it seeps (such as, via advective versus diffusive migration) to the surface. Key points that rose from the discussions are that natural hydrogen frequently occurs in areas that have not been explored by the oil-and-gas industry and that the science underpinning its exploration is very immature.

Past observations of natural hydrogen were mostly accidental, a side effect of geothermal, water, and oil-and-gas wells that were drilled with other objectives in mind. These wells are unlikely therefore to be optimally located for hydrogen exploration and production, so significant questions remain.

For example, the hydrogen community is split: one contingent views hydrogen as a seep, which can be tapped and produced, the other contingent views hydrogen as (possibly) being trapped in the sub-surface in a similar way to how oil and gas accumulate. Hydrogen trapping and storage in the sub-surface, at least temporarily, is an important component of the future hydrogen storage business.

Denis Briere introduced the concept of Hydrogen System Logic (as opposed to the traditional approach of Petroleum System Logic). Derived from his work on the Bourakébougou discovery in Mali, in the Hydrogen System Logic model the hydrogen reservoir is not a pressurised stagnant reservoir trapped under impervious shale barrier, but a slowly flowing accumulation being regenerated in the fractures and matrix. Natural hydrogen is periodically replenished via migration of hydrogen through fractures and then the subsequent diffusion into a host rock.

While the jury is still out on whether or not hydrogen is stored over geological timescales, salt or halite are recognised as viable sealing lithologies, and it is possible that igneous rocks (like diorite in Mali) could also work as seals. Clay-rich rocks could also act as barriers to hydrogen migration.

For the emerging hydrogen industry, further studies are required that monitor, log and even drill hydrogen seeps and potential reservoirs. Furthermore, to enable hydrogen production and safe geological storage, technological developments are also required.

Legalities

On a global stage, the natural hydrogen explorers are getting organised and have been applying for exploration permits in various places around the world. However, while the companies behind green hydrogen exploration can count on government support and subsidies for their projects, the natural hydrogen explorers have not been shown much love. Some legislative support has been offered in South Australia, where a third of the state is already covered by natural hydrogen exploration permits, but elsewhere the legal framework is less clear, and the landscape is evolving fast.

Andrea Rigal-Casta (Geo Avocats, France) and Jeffrey Haworth (Government of Western Australia) noted that no current regulation explicitly takes into account the exploration and production of natural hydrogen. For example, in the UK, hydrogen is not specifically legislated and is instead captured under the Gas Act 1986, while in the EU hydrogen is captured within existing mining or gas legislation, as an after-thought. In the EU, where the political environment is complex and often drilling is not viewed positively by politicians or communities, and elsewhere, existing hydrocarbon laws are being repealed and these policy changes are inadvertently impacting hydrogen exploration.

The current lack of understanding of what is natural hydrogen is a key factor in this confusion.

In general, legislation relating to hydrogen and other renewable energy sources requires a fresh approach. The modification of existing or the creation of new exploration laws will dictate the speed with which natural hydrogen reserves can be unlocked and exploited.

New frontier

Natural hydrogen may represent a new frontier in the energy transition, but engineers and geoscientists, globally, must first work to understand where and how this potentially valuable gas is produced, and how to get it to market cheaply and safely. What is the average size of a natural hydrogen resource? What is the carbon footprint of exploring and producing it? Can natural hydrogen supplies decarbonise the existing grey hydrogen feedstock? What is the cost of exploration, development and production? By answering such questions, we will gain a better understanding of the contribution natural carbon can make to our low-carbon future.

Judging by the energy and interest this conference generated, as well as the continued emergence of natural hydrogen companies and projects, we should have answers to these questions within the next few years. As presenter Michael Webber (ENGIE, France) argued, “natural hydrogen has the potential to cause the biggest disruption to the global energy system in the coming decades”. Time will surely tell!

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Further reading

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