earth2
Initiative for subsurface hydrogen
by avenia

POSITION PAPER

February 2023

THE PLACE OF NATURAL HYDROGEN IN THE ENERGY TRANSITION

www.earth2-hydrogen.com

EXECUTIVE SUMMARY

The ***earth$_2$* *initiative*** aims to create a common forum, operating at a European level, to drive forward the natural hydrogen and underground hydrogen storage sector.

NATURAL HYDROGEN:

- IS A NEW, CLEAN AND LOW-CARBON SOURCE OF HYDROGEN
- IS PRODUCED BY THE EARTH, CAN MIGRATE AND ACCUMULATE
- ITS EXPLORATION BEGINS IN A LOT OF AREAS IN THE WORLD
- ITS PRICE *(<1.5$/kg)* COULD BE SIGNIFICANTLY LOWER THAN OTHER H_2 SOURCE
- REGULATORY EVOLUTION AND APPROPRIATE TAXONOMY ARE NEEDED
- ITS DEVELOPMENT NEEDS INVESTMENTS IN DEMONSTRATORS AND PILOTS

1. What is Natural Hydrogen? Where can we find it?

The Earth continuously produces natural hydrogen (also called native hydrogen) through several chemical reactions that are mainly related to oxidation of ferrous iron minerals, radiolysis of water, organic matter maturation or the outgassing from Earth's mantle.

- **Redox reactions** related to the presence of **ferrous iron** in certain minerals or to ferrous iron dissolved in aquifers are probably the most efficient processes for producing H_2. In these reactions, the ferrous iron rusts and scavenges oxygen from the water, releasing hydrogen *(eq. 1)*.

$$2\ FeO + H_2O = Fe_2O_3 + H_2(aq) \quad eq(1)$$

  These reactions can be made with (a) dissolved ferrous iron, (b) olivine and pyroxene minerals of the Earth Mantle (serpentinization), (c) ferrous iron rich minerals of Earth crust (Biotite, Amphiboles, Pyrite, Pyrrhotite, Magnetite…), and probably to a lesser extent, with ferrous iron rich carbonates (Siderite, Ankerite). *(Klein et al., 2020)*

- The **radiolysis of water** produces hydrogen by splitting the water molecule with the radioactive radiation emitted by the decay of natural radioactive atoms (U, Th…) present in some rocks *(Sherwood-Lollar et al, 2014; Truche et al., 2018)*.
- The planet stored Hydrogen during its primordial accretion, in the form of hydrides that could gradually decompose and support continuous **hydrogen outgassing** over geologic time *(Toulhoalt and Zgonnik, 2022)*.
- Organic matter over-maturation can generate natural H_2 *(Horsfield et al., 2022)*.
- The **decomposition of volcanic H_2S** gas into H_2 and SO_2 explains the concentrations obtained in the fumaroles of volcanos *(Klein et al., 2020)*.

The exploration strategy for hydrogen should then focus on areas where ferrous iron (or natural radioactivity) is present and can react with water *(Gaucher, 2020; Moretti et al, 2021)*. Magmatic rocks are thus of primary importance and many occurrences of H_2 seepages are known on the continents or offshore related to these rocks. *Zgonnik (2020)*, in one exhaustive review, recorded **hydrogen occurrences in 465 geo-references** all around the Earth.

Two emblematic sites can illustrate the interest of natural H_2:

- The Bourakebougou site (Mali) has 12 positives boreholes with pure H_2 (98%) for a surface of 50 km^2 *(Prinzhofer et al., 2018)*.
- In Iceland, geothermal power plants emit a total of 1.2 kt H_2 per year to the atmosphere. If we consider a price of H_2 of 2€/kg, the natural H_2 emitted by the existing power plants corresponds to a value of **€2.3 M/yr** *(Combaudon et al., 2022)*.

Natural hydrogen is a reality and is a resource that is observed, to some extents, as being relatively **well distributed across the Earth's surface**. Economic reserve assessments are underway in some locations.

N.B.: In this position paper, we use the expression "Natural hydrogen" but this is equivalent to Native Hydrogen or White Hydrogen. We also find "Gold Hydrogen" in some publications for the same natural origin.

2. How do we explore and produce Natural Hydrogen?

The geological exploration of hydrogen follows the same approach as for the hydrocarbons with the identification of the **source rock**, then the **migration pathways**, and finally of the **reservoirs and traps**. For this last point, volcanic sills, clays or salt layers could be formations capable of trapping hydrogen in crystalline or sedimentary rocks, at the bottom of the sedimentary basins for example.

In the case of Bourakébougou, boreholes of less than 1000 m seem to be effective in finding significant quantities of natural hydrogen. Indeed, **hydrogen is a very reactive molecule**, which can be consumed by many oxidants, and therefore, is destroyed during its migration. Bacterial growth can also be promoted by natural hydrogen, which acts as an energy provider for the microbes. Therefore, a temperature above 120°C can preserve this resource by eliminating microbial activity, while increasing kinetics of reactions. Future exploration and production schemes should integrate the chemical and biological reactivity of this molecule. However, if the hydrogen flux is very important, the reactivity of the molecules will be less crucial.

Some players are also contemplating the **co-production** of **He with natural hydrogen** as they are commonly found together. Geothermal power plants could enhance their value chains as well by co-producing natural H_2 and mineral substances like **lithium**, with **thermal energy**. **Coupling hydrogen production** with the **storage of CO_2** in ultrabasic rocks will add additional benefits to natural hydrogen production *(Osselin et al, 2022)*.

3. The benefits of natural hydrogen

The **earth₂** members are convinced that the Energy Transition needs all sources of clean hydrogen to succeed. Natural hydrogen has some specific advantages:

1. Natural hydrogen is **clean**. There is **no carbon** in the chain, no need for anthropogenic electricity nor water and it has a **limited footprint** for extraction and separation at production sites.
2. It is not an **energy vector**. It is a **resource in itself**, which do not need to destroy one energy for another. No need of anthropogenic energy or specific raw material.
3. New research targeting a range of countries across the world suggests there are **multiple viable plays** and a cost-effective exploitable resource
4. The production sites available within European continent (France, Spain, Italia, Poland, Roumania…) would provide diversity and flexibility. It can **complement others low carbon hydrogen** production means and contribute to securing energy and avoiding intermittence of supply.

5. Natural hydrogen has **no need of purified water** (electrolysis-based green hydrogen production), no need of CO_2 storage (blue hydrogen), **no need of waste disposal** (nuclear-driven pink hydrogen).
6. **No production intermittency**.
7. **Costs should be lower** than all other forms of proposed H_2 production and thus participate in unlocking the hydrogen economy *(Lapi et al., 2022)*. The very competitive production cost is reinforced by **joint valorization potential** (helium, geothermy, high-value brines…).

4. Maturity of the technology

Our ultimate goal is to produce a commercial hydrogen resource at a limited price and with minimal environmental impacts. To achieve this, we can use a Technology Readiness Levels scale (TRL) to assess its maturity.

We assign a TRL of 9 to the ultimate achievement of commercial production of natural hydrogen.

The TRL 0 corresponds to the discovery of hydrogen seepages at the Earth's surface with the idea that larger volumes can be produced underground *(Smith, 2002)*.

The TRL 1 corresponds to the systematic search of hydrogen seepages in various geological environments *(Zgonnick 2020)*.

The TRL 2 corresponds to the first short-term monitoring of hydrogen fluxes *(Moretti et al, 2021; Lefeuvre et al, 2021)*.

The TRL 3 corresponds to a global understanding of the origin of hydrogen emission in continental settings with for example the model of production proposed by *Lefeuvre et al, (2022)* for the W-Pyrenees or the potential of economic production of natural hydrogen in the geothermal fields of Iceland *(Combaudon et al, 2022)*.

The TRL 4 is the implementation of permanent monitoring sites coupling hydrogeology, hydrochemistry and gas chemistry in very well characterized geological structures coupled with well tests to determine a reserve volume.

A TRL 5 can be assigned to the Bourakébougou site *(Mali, Prinzhofer et al., 2018; Rigollet and Prinzhofer, 2022)* where perennial hydrogen production is demonstrated with 12 wells showing its presence. However, a reserve estimate at the production site is not reported by HYDROMA.

The TRLs 5 and 6 correspond to investments that will enable to access depths where active hydrogen production processes are taking place. After delineation at a regional scale (TRL7), commercial production tests can be carried out (TRL 8) and finally the hydrogen gas will be commercialized (TRL9). Several exploration companies are making rapid progress towards this ultimate goal.

TRL Native H_2 Exploration/Production	
0 Discovery of H_2 at the Earth surface	Done
1 Systematic research of H_2 seepages in various environments	Done
2 Short time monitoring of sites	Done for 2-3 sites
3 Understanding of the origin of H_2	Done for 2-3 sites
4 Small Scale prototype of permanent H_2 fluxes / Numerical modelling of the H_2 permanent seepages Global understanding of the Hydrogen system	In Progress in Academia
5 Median Scale prototype (1200 m) Perennial production of a demonstrator over several years	Hydroma (Mali)
6 First deep borehole (3000 – 5000 m)	Natural hydrogen energy LLC Desert Mountain Energy
7 First Exploration plan at regional scale First delineation / Several boreholes	In progress Santos (Australia)
8 Prototype of Production of the first discovery	No
9 Scaling-up / Commercial exploitation	No

Figure 1: *Evaluation of the maturity of the technology with the Technology readiness levels method*

5. A very active scientific community

A scientific community dedicated to natural H_2 exists already in France, United Kingdom, USA, Australia... This community comes from research groups working in the past on water-rock interaction processes (serpentinization, radiolysis etc.), or on economic geology (oil and gas or mining industries). The number of publications presenting data showing explicit natural H_2 presence in soils, aquifers or wells is rapidly increasing.

A dedicated congress exists now on this subject (H-Nat 2022, on-line) and a special session have been organized at the AAPG Europe Regional Conference (May 2022) in Budapest and at the Goldschmidt 2022 Conference in Hawaii.

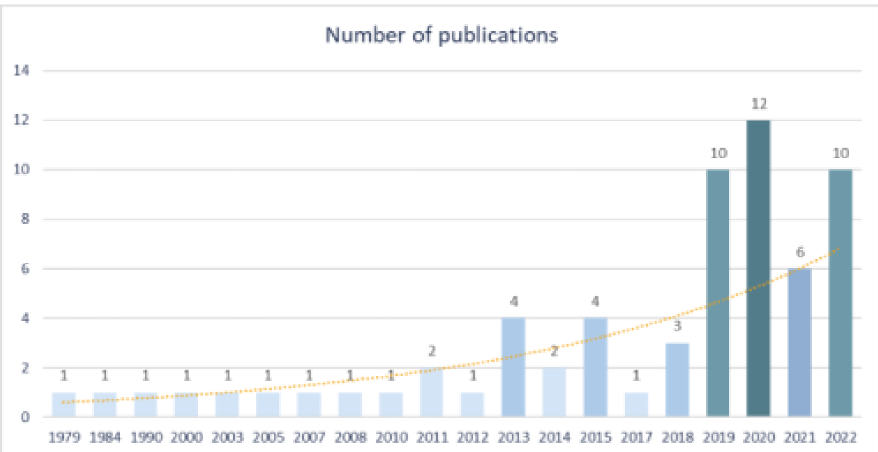

Figure 2: *Scientific articles published that explicitly reference natural hydrogen as energy source*

Figure 3: *Progress of the publications' number dealing with natural hydrogen*

6. Potential growth of a natural hydrogen business

The economic sector is in the process of being structured and the **earth$_2$ initiative** is a good example of this in Europe. The **earth$_2$ initiative** brings together energy groups (Engie), exploration/production start-ups (45-8 Energy, H2Au, Helios Aragon), service providers (CVA group, SLB, …), and independent consultants actively working in this field (40 members). This initiative was born under the aegis of the Avenia cluster. These actors develop exploration methods, geochemical sensors, geophysical methods dedicated to natural hydrogen exploration. **earth$_2$** is a forum for fruitful discussions on the commercial development of natural hydrogen with permanent working groups, workshops, field trips, launching innovative collaborative projects and lobbying public institutions.

In Australia, several start-ups and oil and gas companies now have an exploration strategy for natural hydrogen (Petrex, Buru Energy, Gold Hydrogen). In South Australia, more than 20 permits have been applied for; two have already been granted to Gold Hydrogen and one to H2EX. The first wells are expected in 2023. Further north, in the Amadeus Basin, an oil company, Santos, has "accidentally" encountered a mixture of methane, helium and hydrogen and will drill three wells in 2023 to evaluate the resource.

In USA, two companies have reported significant discoveries: Natural hydrogen energy LLC in Kansas (2019), Desert Mountain Energy in Arizona (2022).

By the end of 2022, 27 companies have been identified as active in natural hydrogen exploration, up from 3, three years ago.

The American Association of Petroleum Geologist have also established a "Natural Hydrogen" task force led by the US Geological Survey. Meanwhile, the International Energy Agency has accepted a technical task on natural hydrogen in its hydrogen collaboration program.

The costs of the natural hydrogen production will be necessarily lower than the costs of production by steam-methane reforming (brown hydrogen: 1.5$/kg). Indeed, the exploration/production costs of natural hydrogen will be very similar to those of natural gas, but without the need to transform it in a refinery or to store CO_2 (blue hydrogen: 3$/kg = brown hydrogen + costs of CO_2 storage). Currently, green hydrogen from renewables has a price above $6/kg and requires a transformation of electricity that could be used directly for other purposes. **Our best estimate of the price of natural hydrogen is less than $1/kg.**

7. Regulatory aspects of hydrogen exploration

The development of hydrogen exploration requires changes in legislation to allow companies to take out permits and perform exploration works. A pioneer country is the Mali, where the first permit was delivered in 2017 in the area of Bourakébougou. South Australia has opened its mining code to natural hydrogen exploration in 2021. In April 2022, it is France's turn to include natural hydrogen in its mining code. Apparently, the US law on natural substance is flexible enough to allow for hydrogen exploration licences.

8. Recommended next steps of natural hydrogen development

- Natural hydrogen is a topic that is now moving from pure research to economic development.
- Natural hydrogen is a clean and very low-carbon source of hydrogen that should be considered as a renewable hydrogen in European taxonomy.
- Its interest is already demonstrated and significant volumes have been identified (Iceland, Mali, Pyrenees…).
- Public support is still needed to develop demonstrators and pilots in promising areas.
- Access to financing means, available for the hydrogen economy, would accelerate the maturity and the number of projects.
- Changes in regulation will be needed for this exciting potential new green energy vector to be developed.

The members of **earth$_2$ initiative** are optimistic in the potential for this new resource and seek support in order to realise its contribution to the Energy Transition.

earth$_2$ INITIATIVE IN A NUTSHELL

Hydrogen appears today as one of the solutions to be massively deployed in order to reach our energy and ecological transition's objectives. On the one hand to decarbonise industry and heavy mobility and on the other hand to allow the storage of intermittent renewable energies (solar, wind). Nowadays, 95% of hydrogen, which is mainly used in petrochemicals, is produced by steam reforming, greenhouse gases' releaser. It is therefore necessary to find alternatives and develop the production of low-carbon hydrogen.

In France, and more widely in Europe, strategic plans put in place for low-carbon hydrogen are mainly oriented towards green hydrogen, produced by water electrolysis, and mobility.

The subsurface's contribution to this transition deserves to be better known since it is an essential component of the low-carbon hydrogen sector, without being in opposition to other solutions.

In this context, the AVENIA cluster aims to create a common forum, **the earth$_2$ initiative**, operating at a European level, to drive forward the natural hydrogen and underground hydrogen storage to the development of a future hydrogen economy and showcasing how geological knowledge can facilitate this revolutionary new low-carbon energy vector.

earth$_2$'S OBJECTIVES

Bring together actors from industry and research working on subsurface hydrogen keen to work together to spark innovation and the emergence of funded collaborative projects.

Promoting the contribution of the subsurface to the hydrogen sector as whole, which is still largely unknown to policy and decision-makers at all levels.

For more information, contact us at: *earth2@pole-avenia.com*