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INSTITUTE OF GEOENERGY

Natural Hydrogen Exploitation

Global Trends and Prospects for Greece

EMMANUEL STAMATAKIS

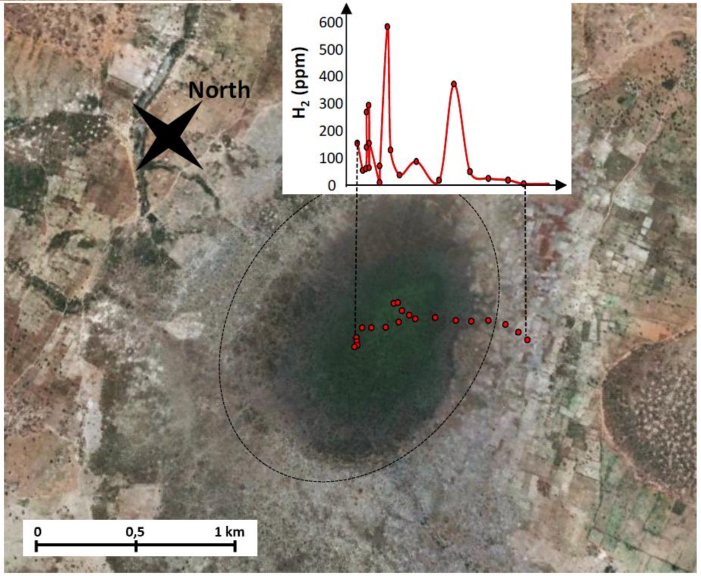
SENIOR RESEARCHER, NCCRD

SPYROS BELLAS

SENIOR RESEARCHER, FORTH

Where It All Begun

Bourakébougou



Alain Prinzhofer, Cheick Sidy Tahara CISSE2and Aliou Boubacar Diallo

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Energy Transition & Why Natural Hydrogen Matters

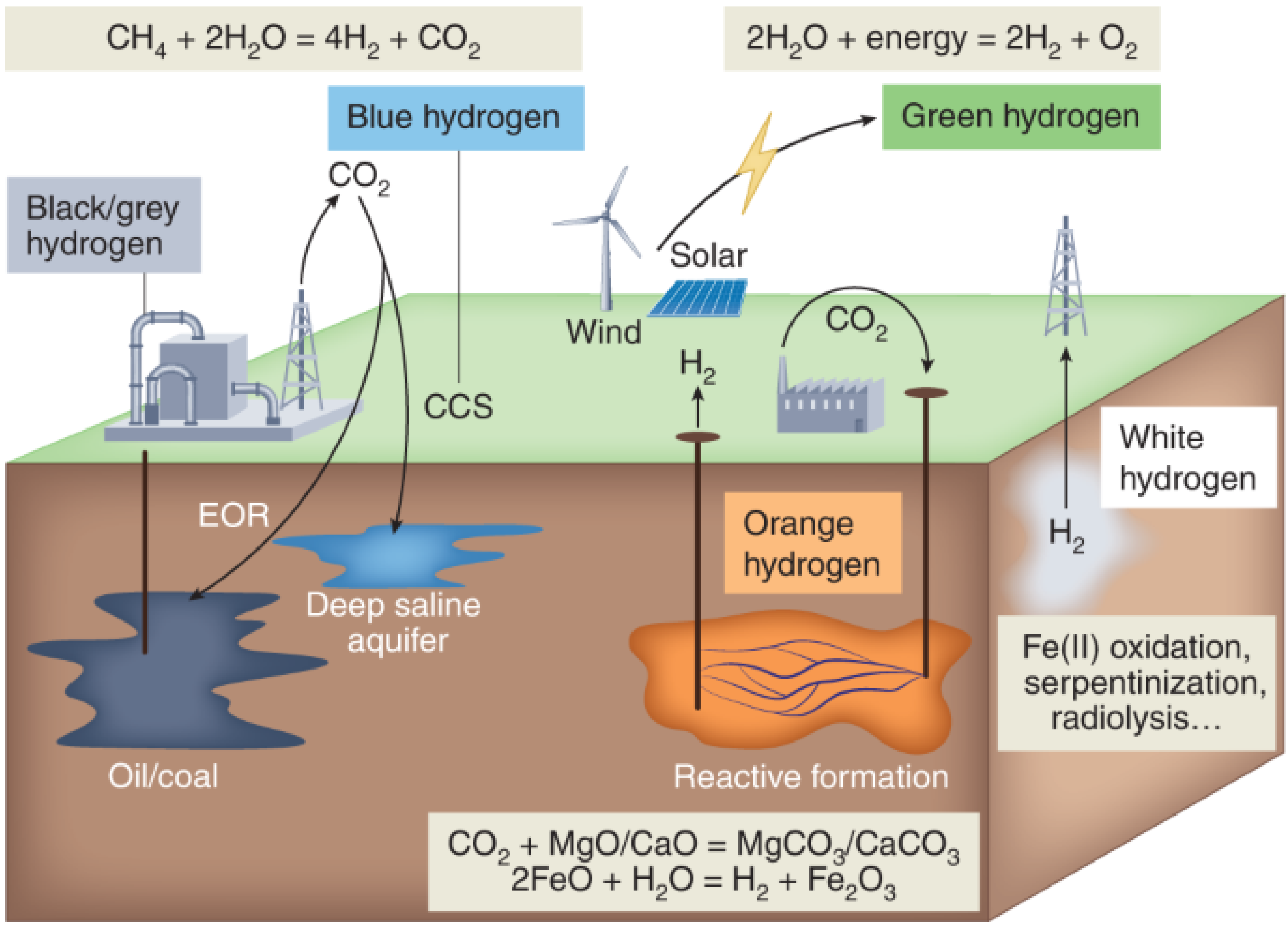
EU targets climate neutrality by 2050; hydrogen is a key **energy carrier** & transition fuel

Focus so far mainly on green H_2 (from renewables) and blue H_2 (from fossil fuels with CCS).

Naturally occurring geologic hydrogen offers a potentially low-carbon, **energy source**.

If scalable, natural H_2 could complement green and blue hydrogen in decarbonising industry and transport.

Hydrogen Production

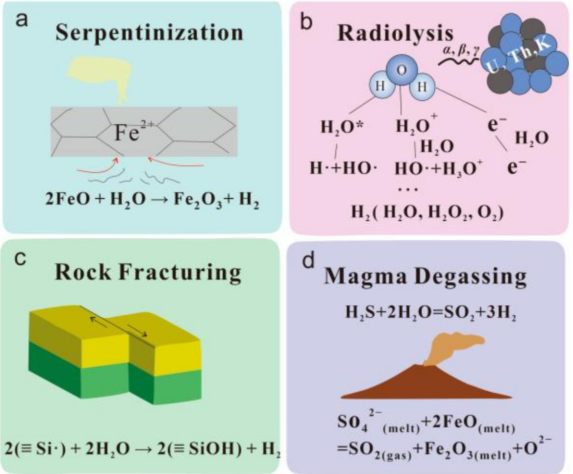


What Is Natural Hydrogen?

- Hydrogen generated continuously in the subsurface by geological and biological processes.
- Can accumulate in traps, similar to conventional oil and gas fields.
- Often associated with ultramafic rocks, ophiolites, deep faults, and geothermal systems.
- Sometimes referred to as “white” or “gold” hydrogen to distinguish it from green/blue.

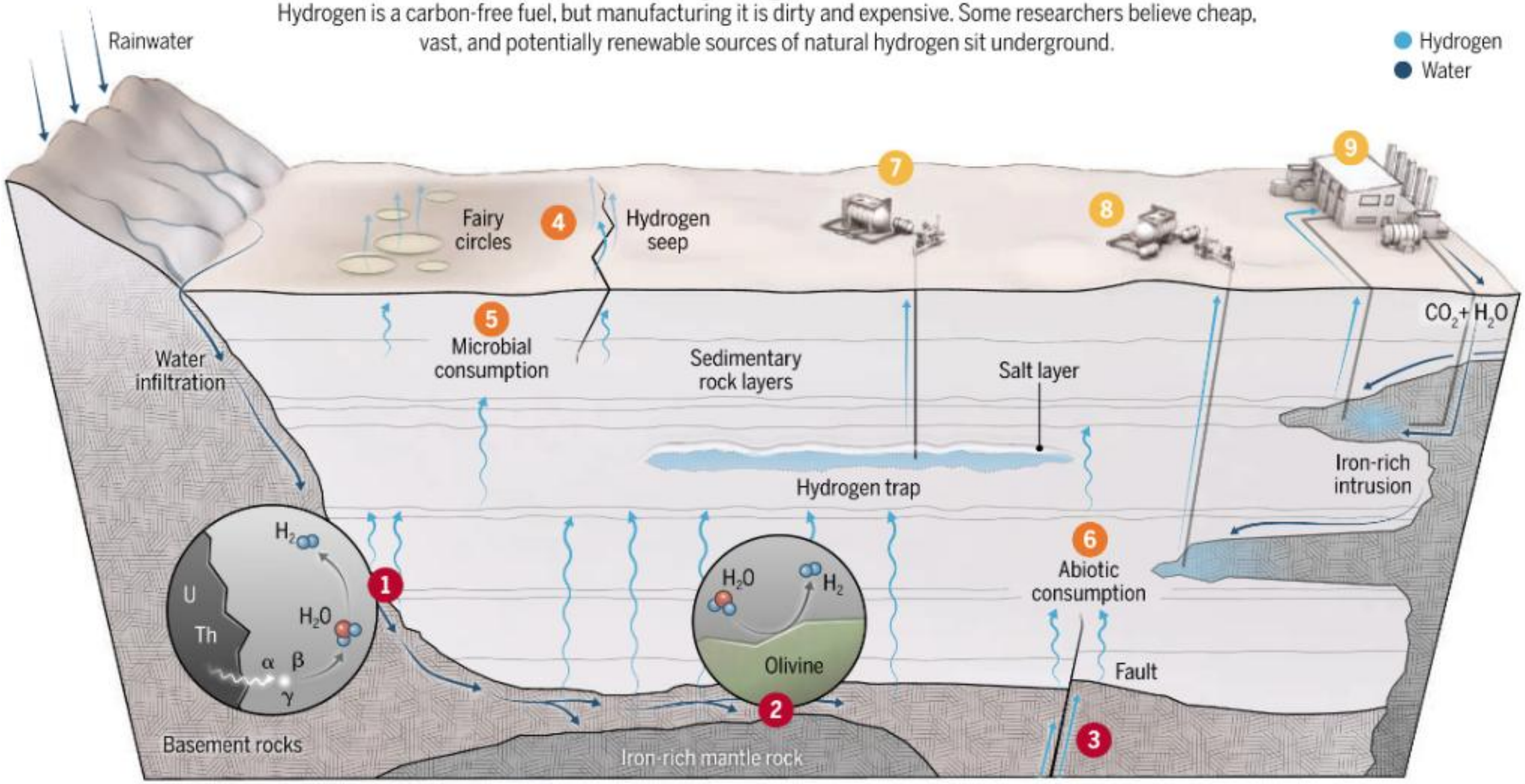
Subsurface Hydrogen Generation Mechanisms

- Serpentinisation: hydration and oxidation of Fe^{2+}-rich minerals (e.g. olivine in ultramafic rocks or ophiolites).
- Radiolysis of water: natural radioelements split water molecules, producing H_2.
- Mantle and magmatic degassing along deep faults and tectonic structures.
- Cataclasis and rock–fluid reactions in fault zones.
- Biogenic and abiogenic decomposition of organic matter.



Earth's hydrogen factories

Hydrogen is a carbon-free fuel, but manufacturing it is dirty and expensive. Some researchers believe cheap, vast, and potentially renewable sources of natural hydrogen sit underground.



Generation

1 Radiolysis

Trace radioactive elements in rocks emit radiation that can split water. The process is slow, so ancient rocks are most likely to generate hydrogen.

2 Serpentinization

At high temperatures, water reacts with iron-rich rocks to make hydrogen. The fast and renewable reactions, called serpentinization, may drive most production.

3 Deep-seated

Streams of hydrogen from Earth's core or mantle may rise along tectonic plate boundaries and faults. But the theory of these vast, deep stores is controversial.

Loss mechanisms

4 Seeps

Hydrogen travels quickly through faults and fractures. It can also diffuse through rocks. Weak seeps might explain shallow depressions sometimes called fairy circles.

5 Microbes

In shallower layers of soil and rock, microbes consume hydrogen for energy, often producing methane.

6 Abiotic reactions

At deeper levels, hydrogen reacts with rocks and gases to form water, methane, and mineral compounds.

Extraction

7 Traps

Hydrogen might be tapped like oil and gas—by drilling into reservoirs trapped in porous rocks below salt deposits or other impermeable rock layers.

8 Direct

It might also be possible to tap the iron-rich source rocks directly, if they're shallow and fractured enough to allow hydrogen to be collected.

9 Enhanced

Hydrogen production might be stimulated by pumping water into iron-rich rocks. Adding carbon dioxide would sequester it from the atmosphere, slowing climate change.

Exploration and Identification Methods

Geophysical Surveys

Seismic Surveys: Similar to natural gas exploration, seismic surveys are used to map underground structures. High-resolution seismic data help identify potential hydrogen-rich formations.

Magnetic and Gravity Surveys: These methods can detect variations in the Earth's magnetic and gravitational fields, which may indicate the presence of certain minerals associated with hydrogen production.

Geochemical Analysis

Soil and Gas Sampling: Surface soil and gas samples are analyzed for hydrogen concentrations. Anomalies in hydrogen levels can indicate subsurface sources.

Water Chemistry: Analyzing water chemistry in areas with serpentinization or radiolysis can provide clues about hydrogen presence.

The dilemma

Prove that meaningful reserves of hydrogen are possible by understanding the hydrogen system overall

Do we have enough information/knowledge? There is a need of quick and systematic quantification

From Petroleum System to Natural Hydrogen System

- We can adapt the petroleum-system mindset to natural hydrogen exploration.
- Source: rocks and processes that generate H_2 (serpentinising ultramafics, radiolytic zones, etc.).
- Migration pathways: fractures, faults and permeable horizons that transport H_2.
- Reservoir: porous and/or fractured rocks where H_2 can accumulate.
- Seal / trap: low-permeability units (evaporites, clays, tight igneous rocks) that retain H_2.
- Critical condition: absence of oxygen, otherwise H_2 is quickly consumed to form water.

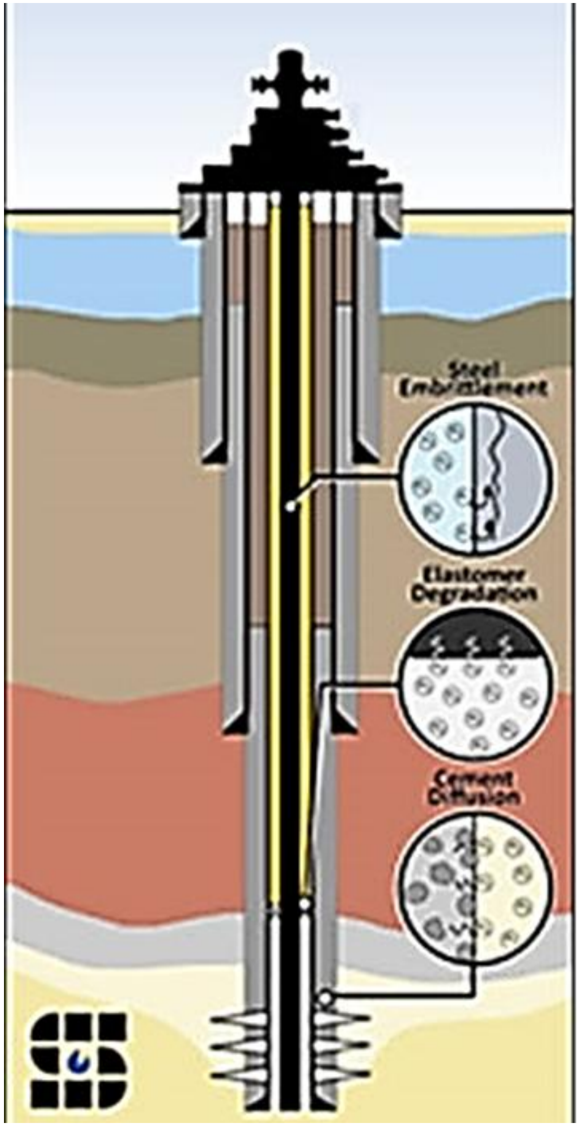
Drilling & Production Issues

Microbial Corrosion: Microorganisms can attack the well casing materials, leading to corrosion and potential leaks.

Hydrogen Blistering and Cracking: Atomic hydrogen can be absorbed by the steel casing, causing embrittlement and eventual failure.

Cement Degradation: The cement used to seal the well can degrade over time, allowing gas to escape.

Elastomer Failure: Elastomeric seals (such as O-rings) can deteriorate due to hydrogen exposure.



Global Natural Hydrogen – Evidence & Case Studies

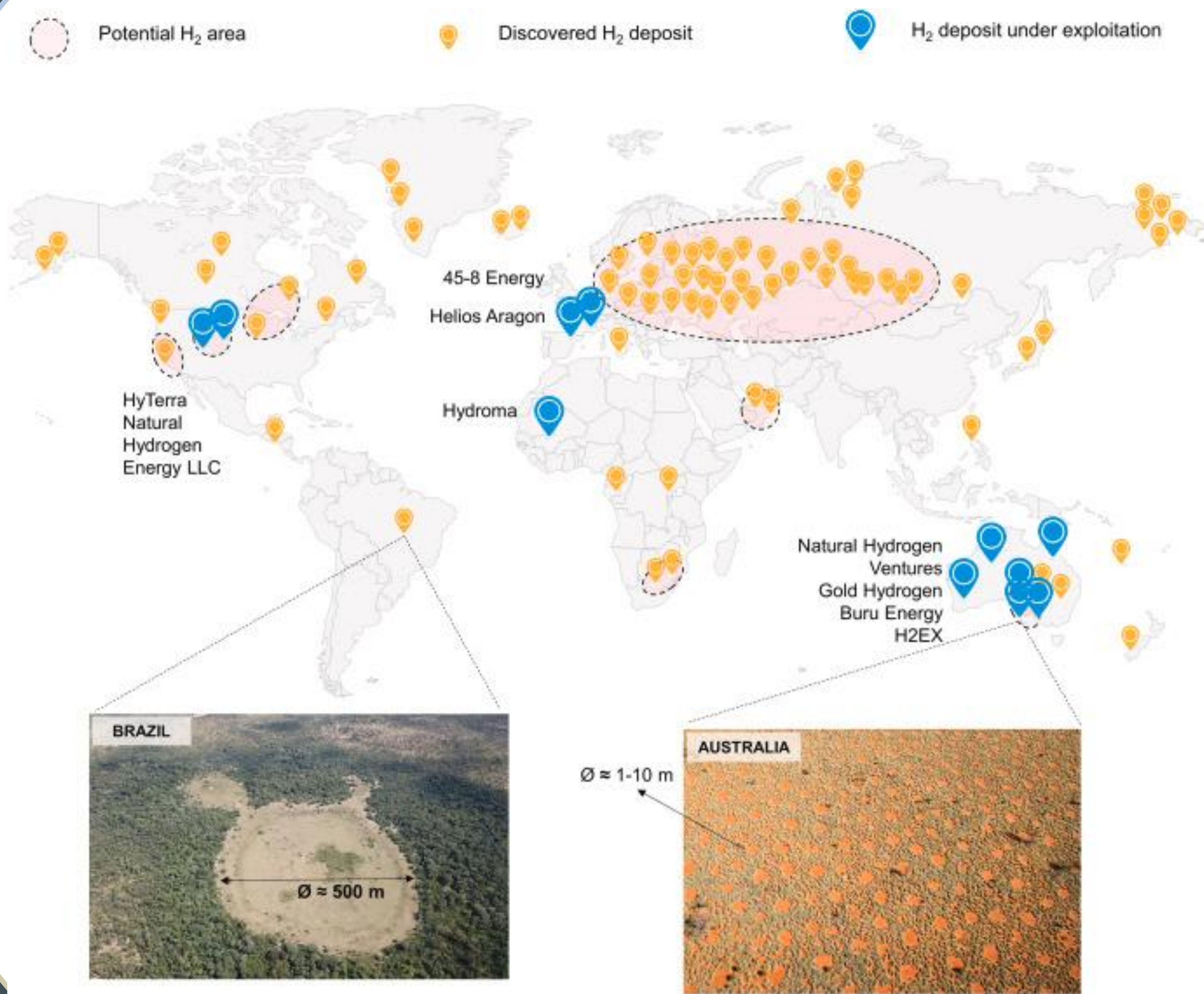
- Hydrogen seeps and accumulations documented on every continent.
- Key tectonic settings: divergent and convergent plate margins, intra-plate orogenic belts, Precambrian cratons.

Bourakébougou, Mali: long-lived H_2 production powering a local village – proof of concept.

Athabasca, Canada: H_2 associated with hyperalkaline springs and serpentinised rocks.

Chromite mine in Bulqizë, Albania: significant H_2 degassing linked to deep faulted ophiolites.

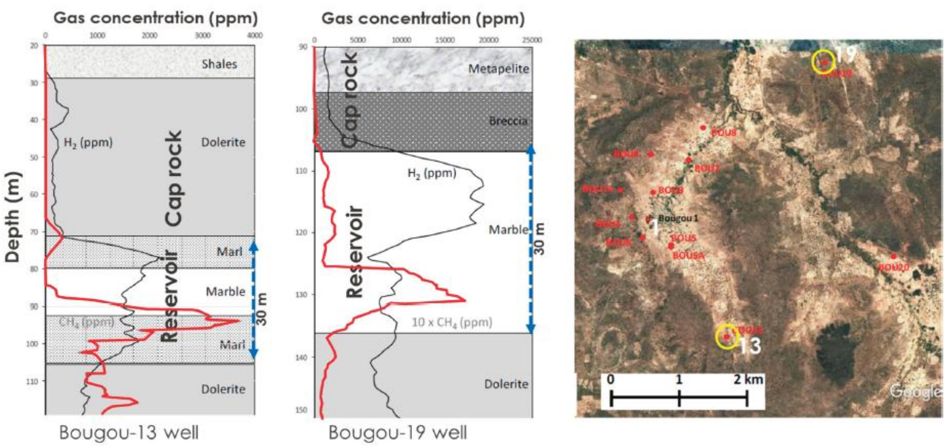
Natural Hydrogen Global Distribution

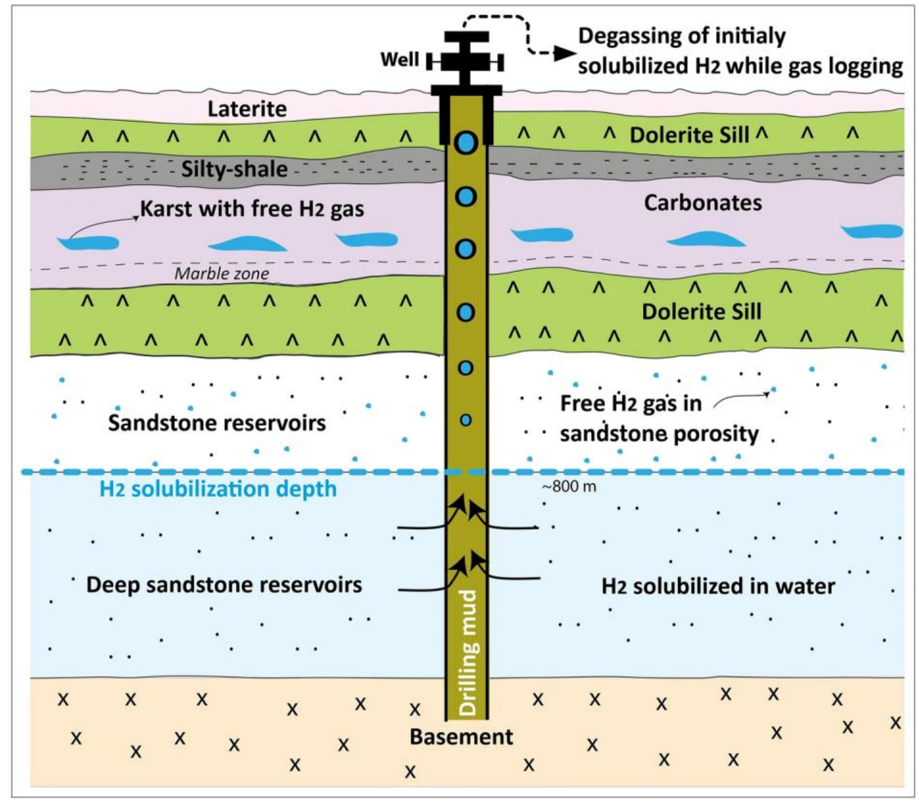


R. Blay-Roger, W. Bach, et al., RSER, V.189, part A, 2024

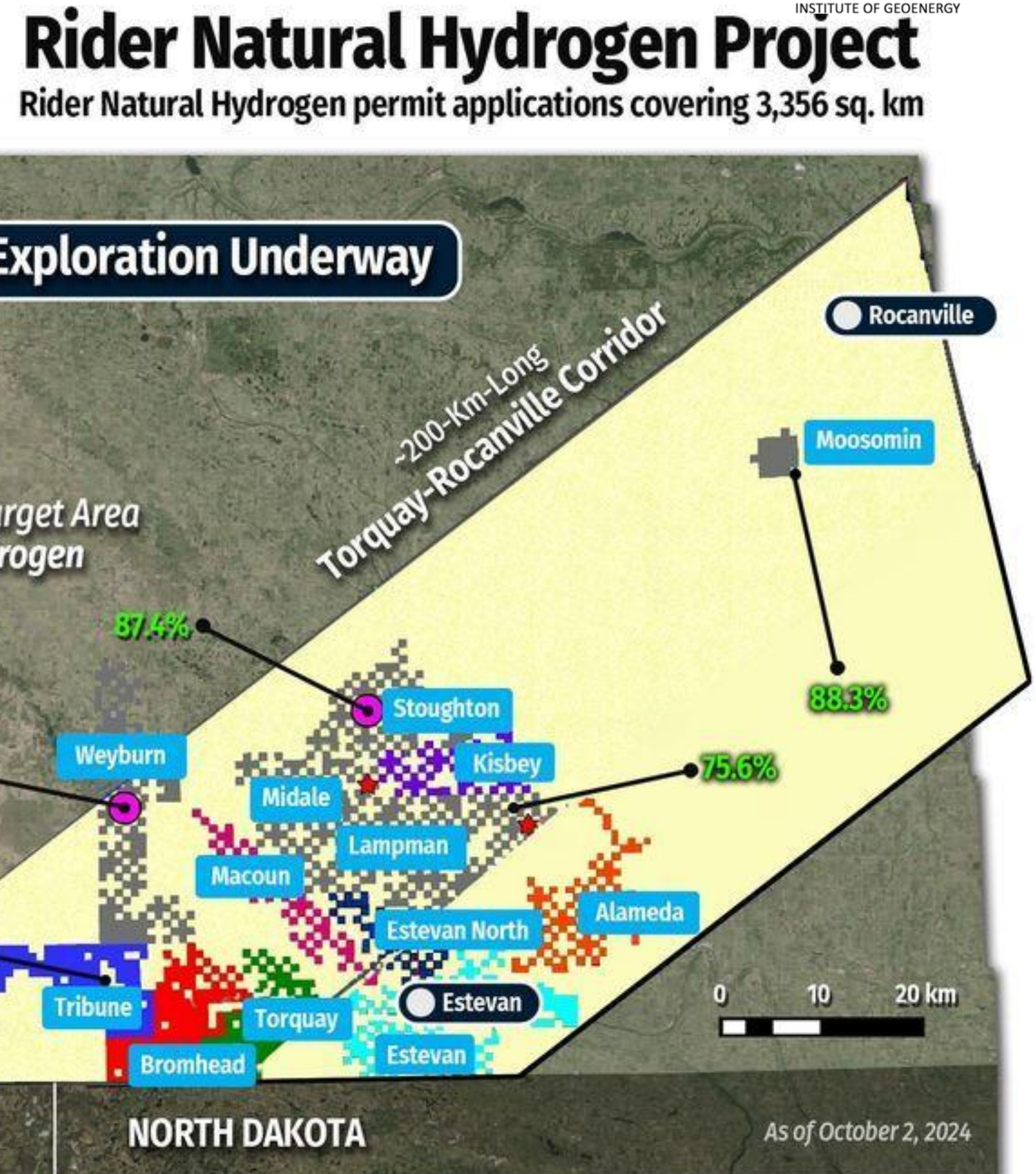
Bourakebougou Field, Mali

Meju, Max & Saleh, Ahmad. (2023). Minerals. 13. 745. 10.3390/min13060745.

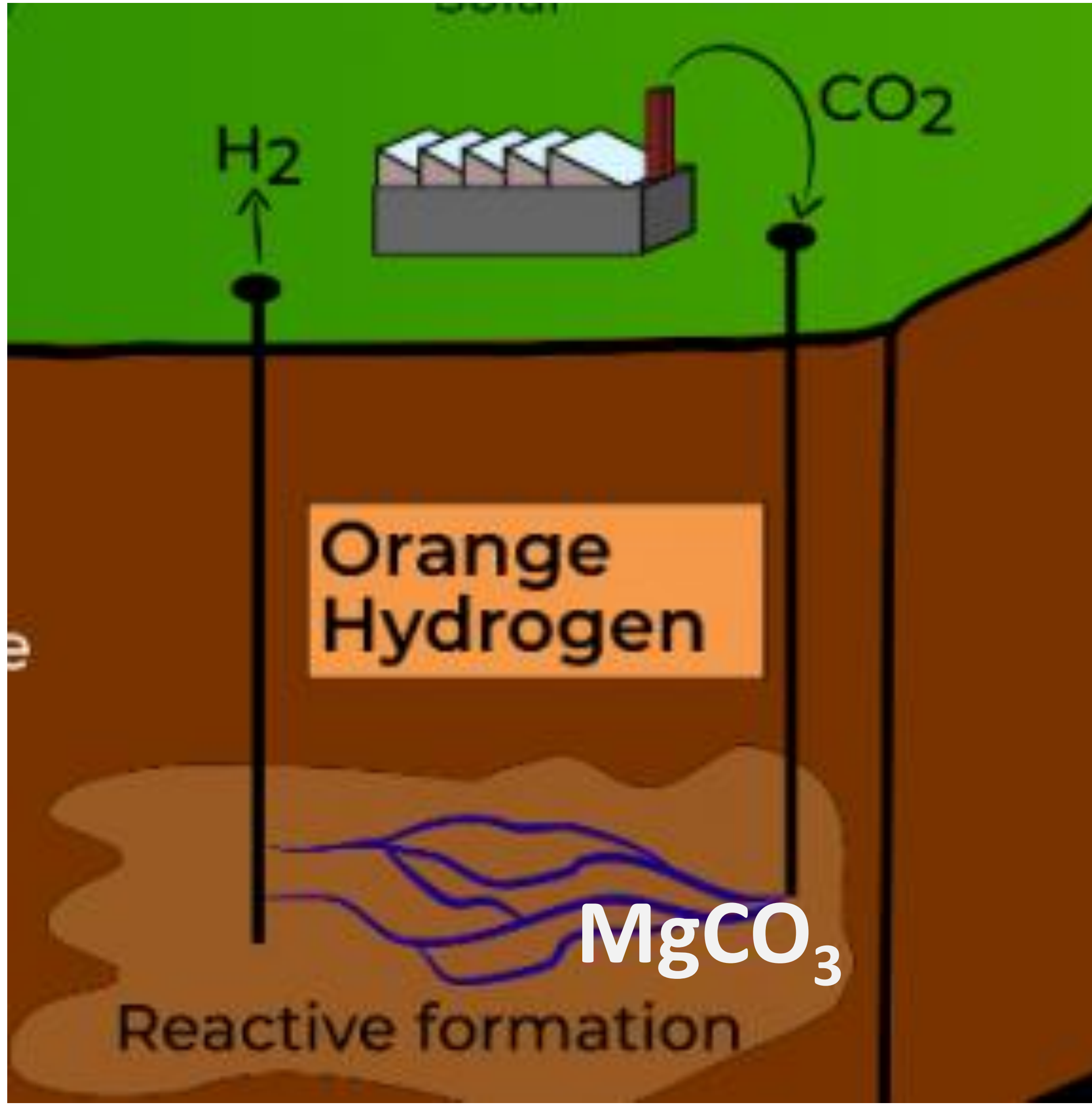




Athabasca Canada

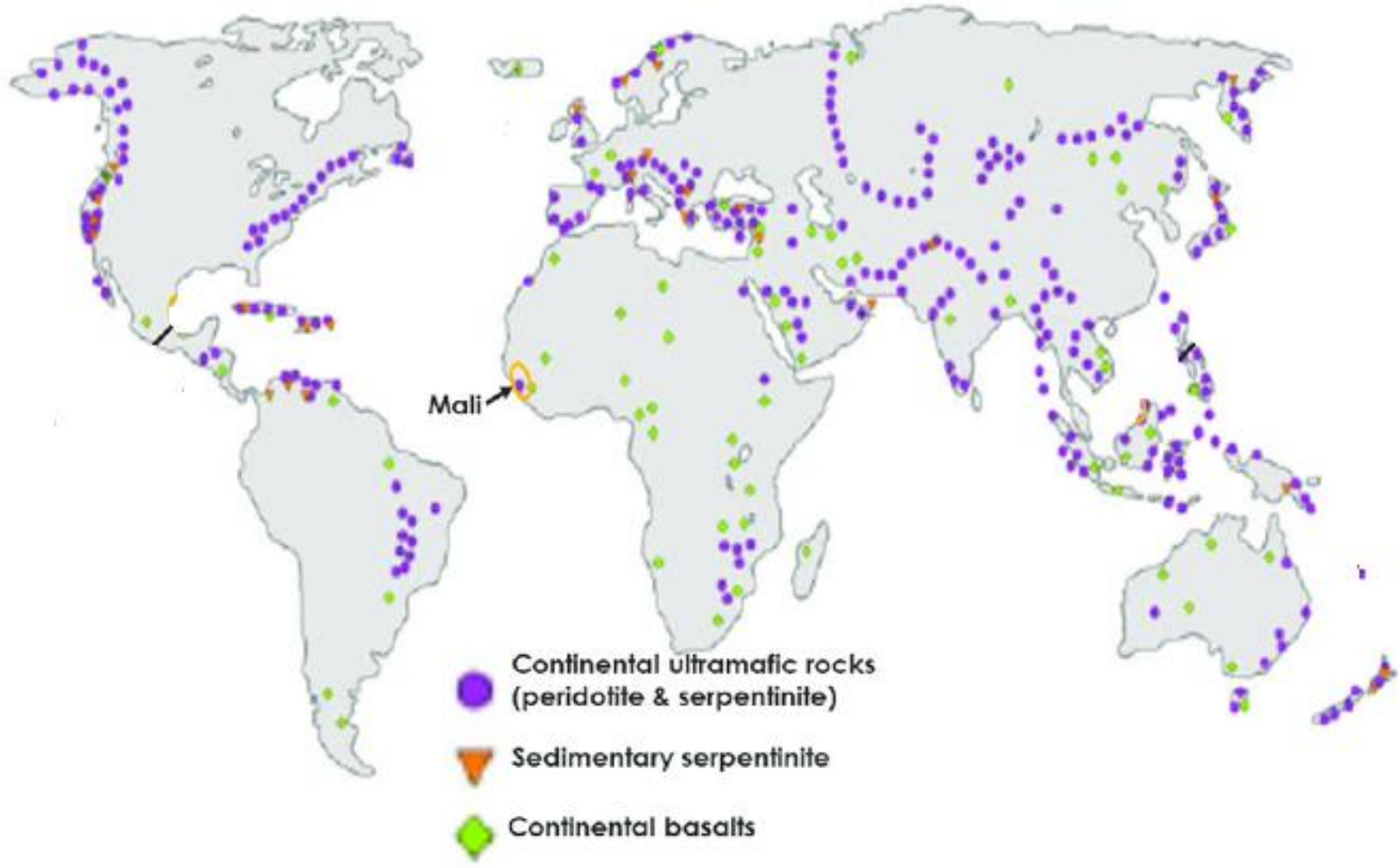


Orange Hydrogen Generation Concept



Global Distribution of Potential Hydrogen Source Rocks and Reservoirs

Meju, Max & Saleh, Ahmad. (2023). Minerals. 13. 745. 10.3390/min13060745.



Parameters Affecting H2 Generation

A critical property of ultramafic rocks that enables substantial H2 production is their low silica content

The rate of serpentinization is mainly controlled by three variables: temperature, pressure, and the water-to-rock mass ratio.

The optimal temperature range for the process is between 200 and 300 ◦C.

Studies at ≤500 bar show that below 200 ◦C, the process occurs at very low rates, while at temperatures higher than 320–350 ◦C, olivine remains stable

At high pressures, the optimal temperature increases but also the serpentinisation rate (4 times).

Source rock composition and impurities. The serpentinisation rate increases in the presence of Aluminum, Nickel and when there is pyroxene together with olevine.

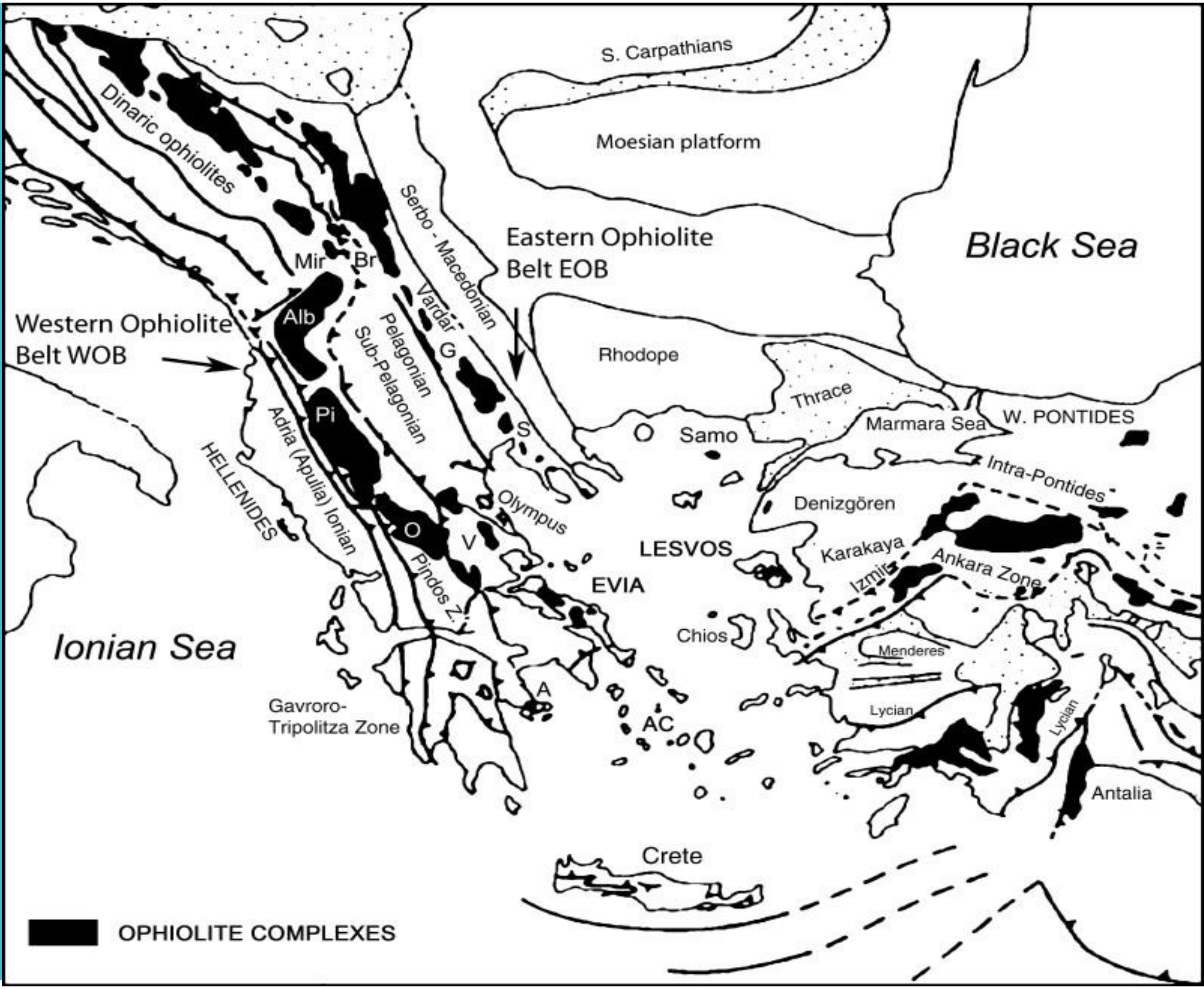
Greece in the Balkan Ophiolite Belt

A multi-ophiolitic belt extends from Croatia through Albania to Greece and Turkey.

Recent discovery of strong H_2 degassing in Bulqizë chromite mine (Albania) highlights the belt's potential.

Similar ophiolitic complexes, deep faults and active tectonics are present within Greek territory.

These geological analogies motivate a focused exploration effort in Greece.

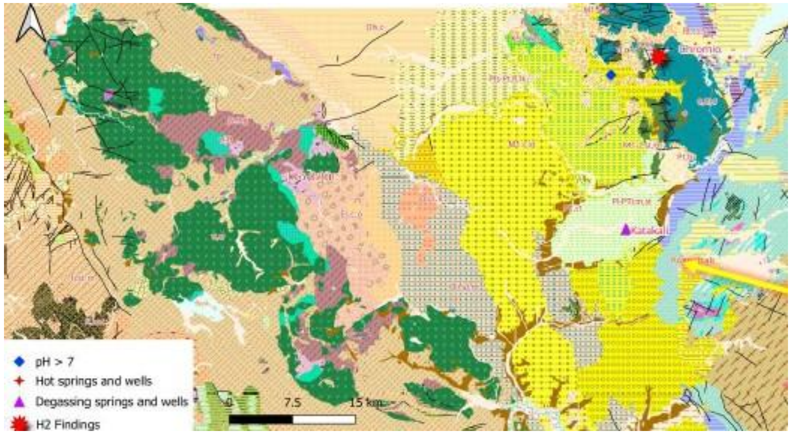


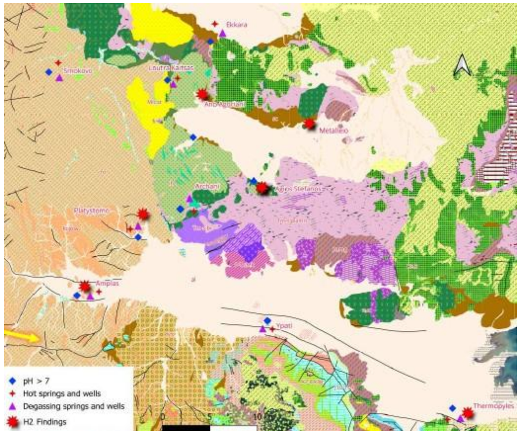
F-V. Donzé

Deposit of natural hydrogen gas detected deep in Albanian chromite mine

Insights from the Greek Case Study

- Several promising areas identified where geologic hydrogen generation may occur.
- In Orthrys and Vourinos, serpentinisation is likely the dominant H_2 generation process.
- In Spercheios, H_2 may result from a blend of tectonic, serpentinisation and geothermal processes.
- Methane in these areas probably forms through H_2 consumption via biotic or abiotic reactions.
- Deeper exploration is recommended to evaluate the actual H_2 potential.





Key Target Areas in Greece

- Study by **Bellas et al**. synthesises structural, geological and geochemical data for several Greek regions.
- Spercheios graben (central Greece): active deep faults, transtensional regime and geothermal occurrences.
- Adjacent Orthrys ophiolites: peridotite, serpentinite and chromite, including the Tsagkli mine.
- Vourinos ophiolitic complex: ~27 km long belt with peridotite and serpentinite, including Aetoraches chromite mines.
- Both regions host strongly alkaline and hyperalkaline springs with degassing of CH_4, CO_2, He and H_2.

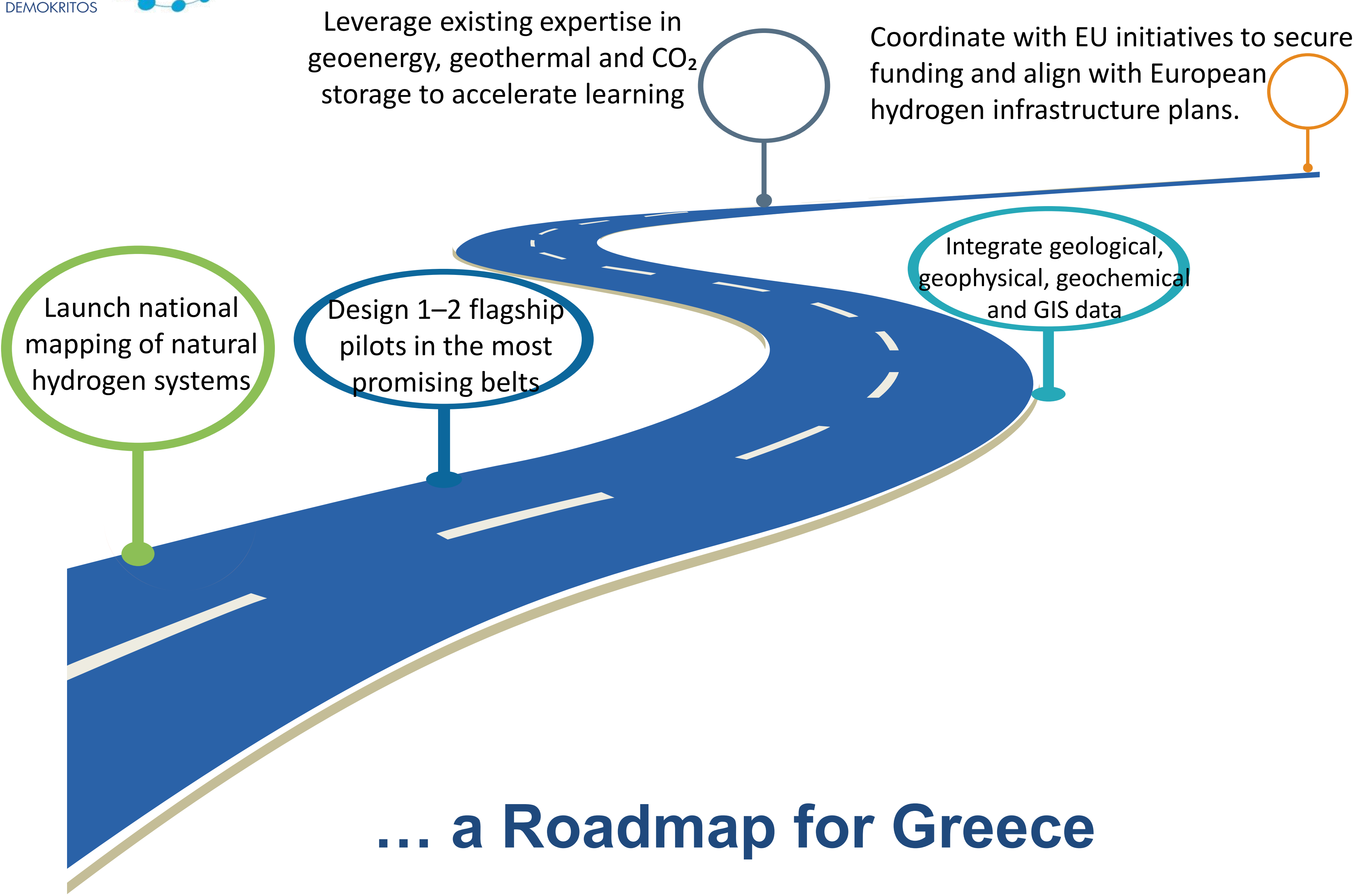
Technology Readiness Level

TRL	Status
Discovery of Underground Natural H_2	Done
Systematic Research of H2 seepages	Done
Short time monitoring of sites	Done for a few sites
Understanding of source	Done for a few sites
Understanding of natural hydrogen systems	In progress
Production over several years	Mali
Regional scale exploration	In progress, Australia
Proto type large scale production	No
Commercial Exploration	No

Modified from: Eiichi Setoyama, 2023 EGI Annual Technical Conference

Challenges & Environmental Considerations

- Subsurface H_2 reservoirs could double as storage sites for green hydrogen.
- Natural hydrogen needs to connect to industrial clusters, power plants and mobility corridors
- Transport options: repurposed or new hydrogen-ready pipelines, or truck transport.
- Regulatory frameworks for natural hydrogen are only now emerging worldwide.
- Need to integrate mining, hydrocarbon and groundwater legislation for safe and transparent development.
- Some studies suggest atmospheric H_2 could affect the chemistry of greenhouse-gas-destroying molecules.
- Robust environmental baselines and monitoring are essential to avoid unintended impacts.
- Social acceptance: engagement with local communities in prospective areas is critical.



… a Roadmap for Greece

Key Messages

- Natural hydrogen is one of the few genuinely new primary energy resources identified in decades.
- Greece sits on highly prospective geology within a proven regional natural hydrogen belt.
- The opportunity is to move from observer to first mover through targeted exploration and pilots.
- Our approach must be curious but disciplined: science-based, well regulated and socially inclusive.
- Now is the right moment to invest in understanding Greece's natural hydrogen potential.

This study is funded by the EU Project TWINN2SET "Twinning to Sustainable Energy Transition", GA 101079246

Enhancing Hydrogen Technology Understanding

Enhanced Understanding
Achieving a deeper understanding of hydrogen applications.

Reliability Assurance
Ensuring the overall reliability of hydrogen technologies.

Performance Testing
Evaluating performance under various conditions.

Material Characterization
Ensuring accurate assessments of material properties.

Expertise Development
Training personnel in specialized testing protocols.

Equipment Provision
Providing advanced analytical tools for hydrogen research.

Dr Emmanuel Stamatakis

Senior Researcher - *Guest Editor of Special Issue*

"Hydrogen and Fuel Cells Technologies for the Realisation of a Resilient and Zero-Carbon Economy"

NATIONAL CENTRE FOR SCIENTIFIC RESEARCH "DEMOKRITOS"

INSTITUTE OF NUCLEAR & RADIOLOGICAL SCIENCES & TECHNOLOGY, ENERGY & SAFETY

manos@ipta.demokritos.gr
Tel.: +30 210 6503742
Mob.: +30 6973982493

"Πιστεύω ότι το νερό θα είναι, μία μέρα καύσιμη ύλη"

- Cyrus Harding, 1874
hero of Jules Verne's novel
"The Mysterious Island"

https://inrastes.demokritos.gr/laboratories/integrated-hydrogen-laboratory-h2lab/