GEOLOGIC HYDROGEN:

A NEW PRIMARY ENERGY SOURCE FOR THE TRANSITION TO CLEAN ENERGY?

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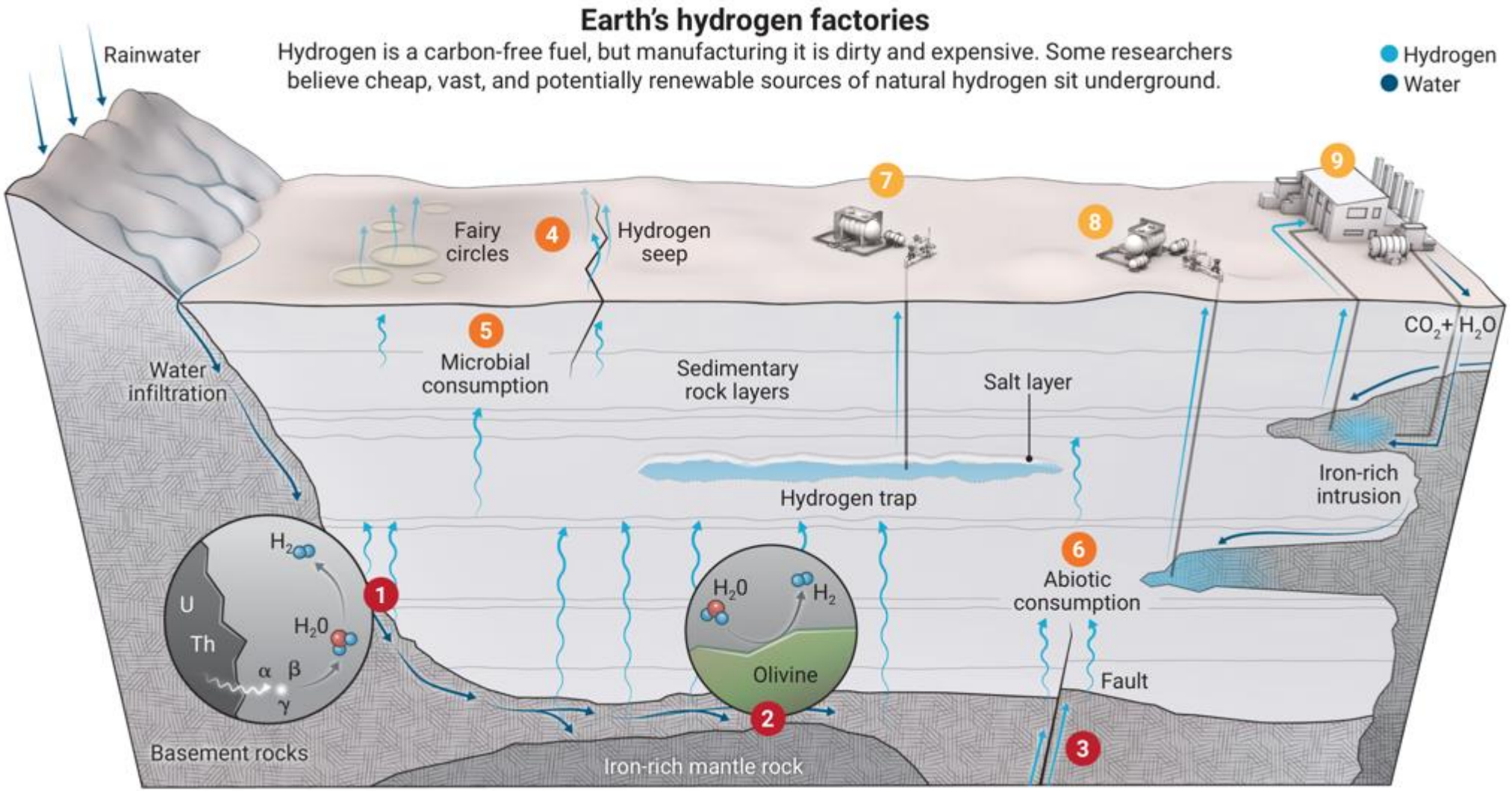
arpa·e
CHANGING WHAT'S POSSIBLE

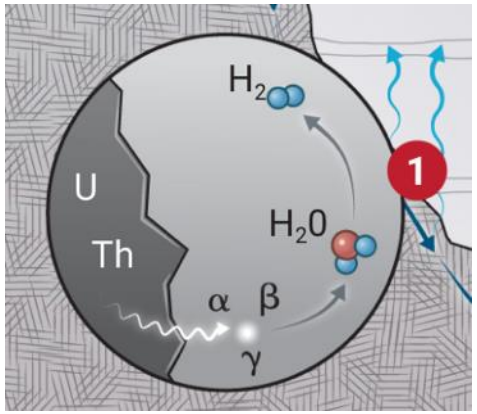
WHAT, WHERE & WHY GEOLOGIC HYDROGEN?

What's happening beneath our feet?



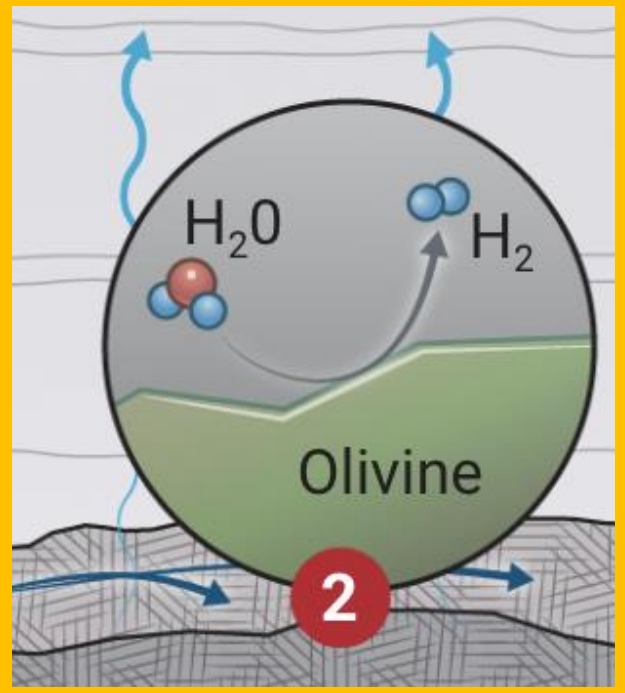
Sources
E. Hand, *Science* **379**, 630–636, (https://doi.org/10.1126/science.adh1477) (Feb. 2023).

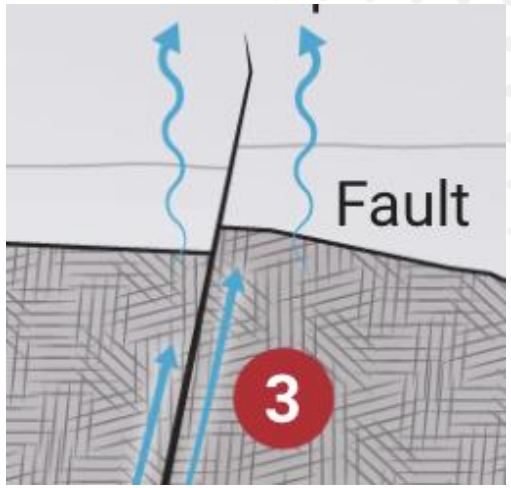
Schematic representation of generation mechanisms



1) Radiolysis

2) Mineral Oxidation





3) ”Deep Earth” sources

Focusing on subsurface iron oxidation

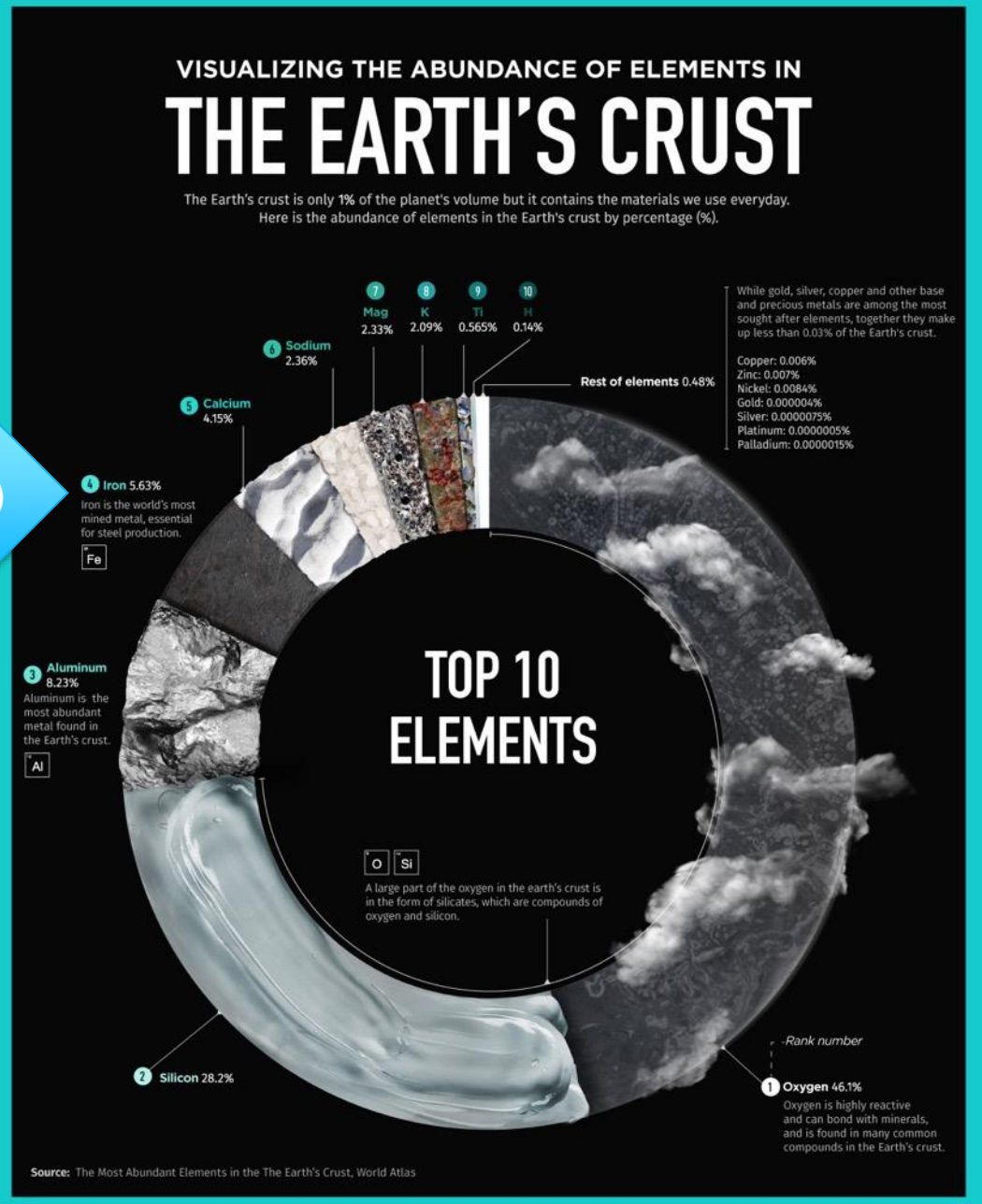
$Fe\ (II) + H_2O$ → 5% of Earth's Crust is Fe (II)

↓

$Fe\ (III)$ oxides and H_2

Within drilling range

The chemical potential of that 5% is **100's of trillions tons of H_2**



What is the current evidence for Geo-Hydrogen?

Joule
Future Energy

The Curious Case of Geologic Hydrogen: Assessing its Potential as a Near-Term Clean Energy Source

Emily M. Yedinak[1,*]

International Journal of Hydrogen Energy 50 (2024) 640–647

Contents lists available at ScienceDirect

International Journal of Hydrogen Energy

journal homepage: www.elsevier.com/locate/he

Trapping processes of large volumes of natural hydrogen in the subsurface: The emblematic case of the Bourakebougou H_2 field in Mali

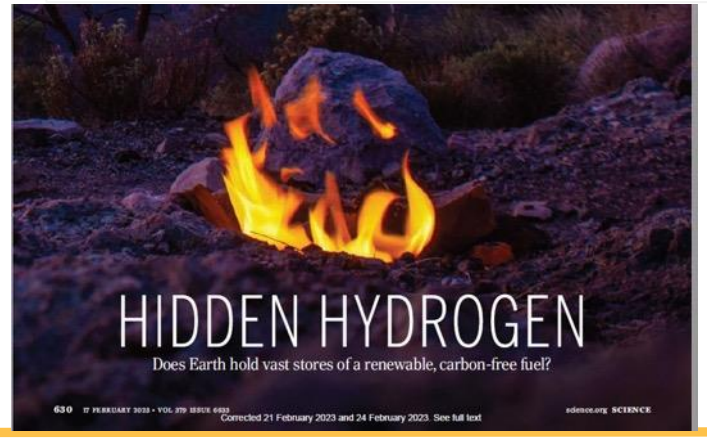
Omar Maiga [a,*], Eric Deville [a], Jérome Laval [a], Alain Prinzhofer [b], Aliou Boubacar Diallo [c]

[a] IFP Energies Nouvelles (IFPEN), IFP-SCHOOL, 1 et 4 Avenue de Bois-Préau, 92852, Rueil-Malmaison, France
[b] GEO4U, Rio de Janeiro, Brazil
[c] HYDROMA INC, Montréal, Québec, Canada

The New York Times

A Gold Mine of Clean Energy May Be Hiding Under Our Feet

Feb. 27, 2023



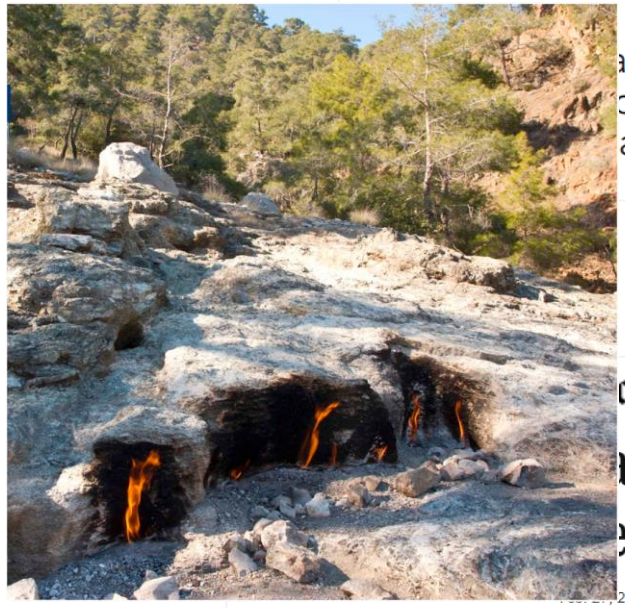
AGA
American Gas Association

NEWS · TRUE BLUE BLOG

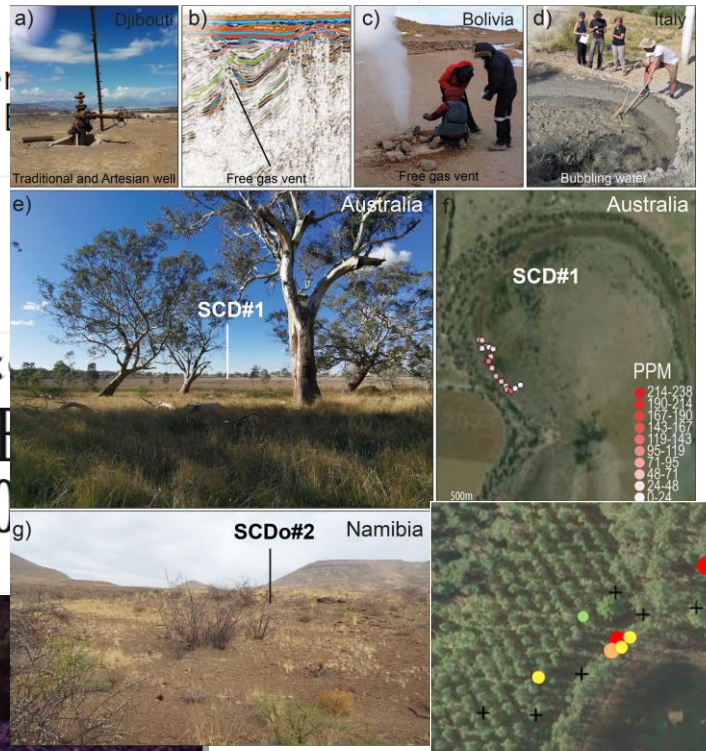
Natural Hydrogen Has Been Underestimated

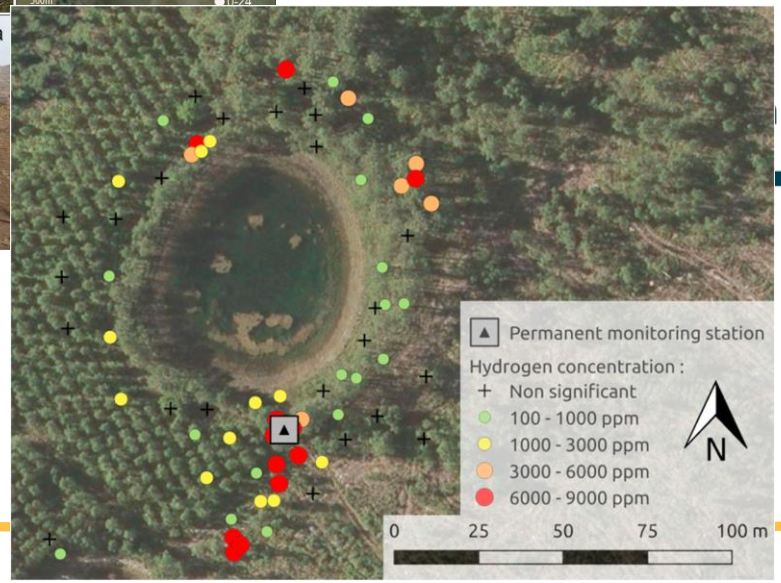
DEC 6, 2023

What is the current evidence for Geo-Hydrogen?



Picture of the continuously burning gas seep at Chimaera, Turkey (7.5–11.3% H_2





Joule

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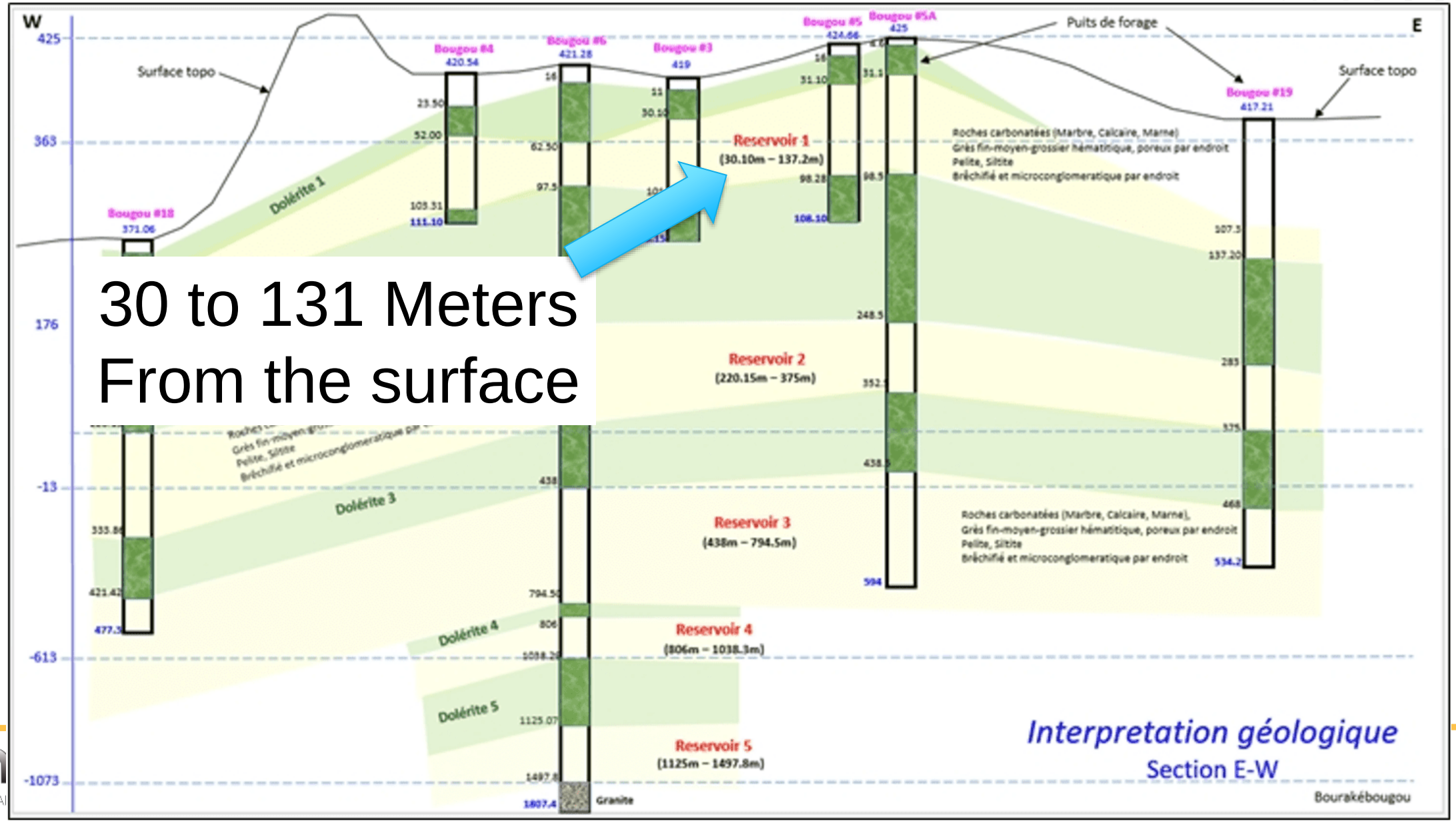
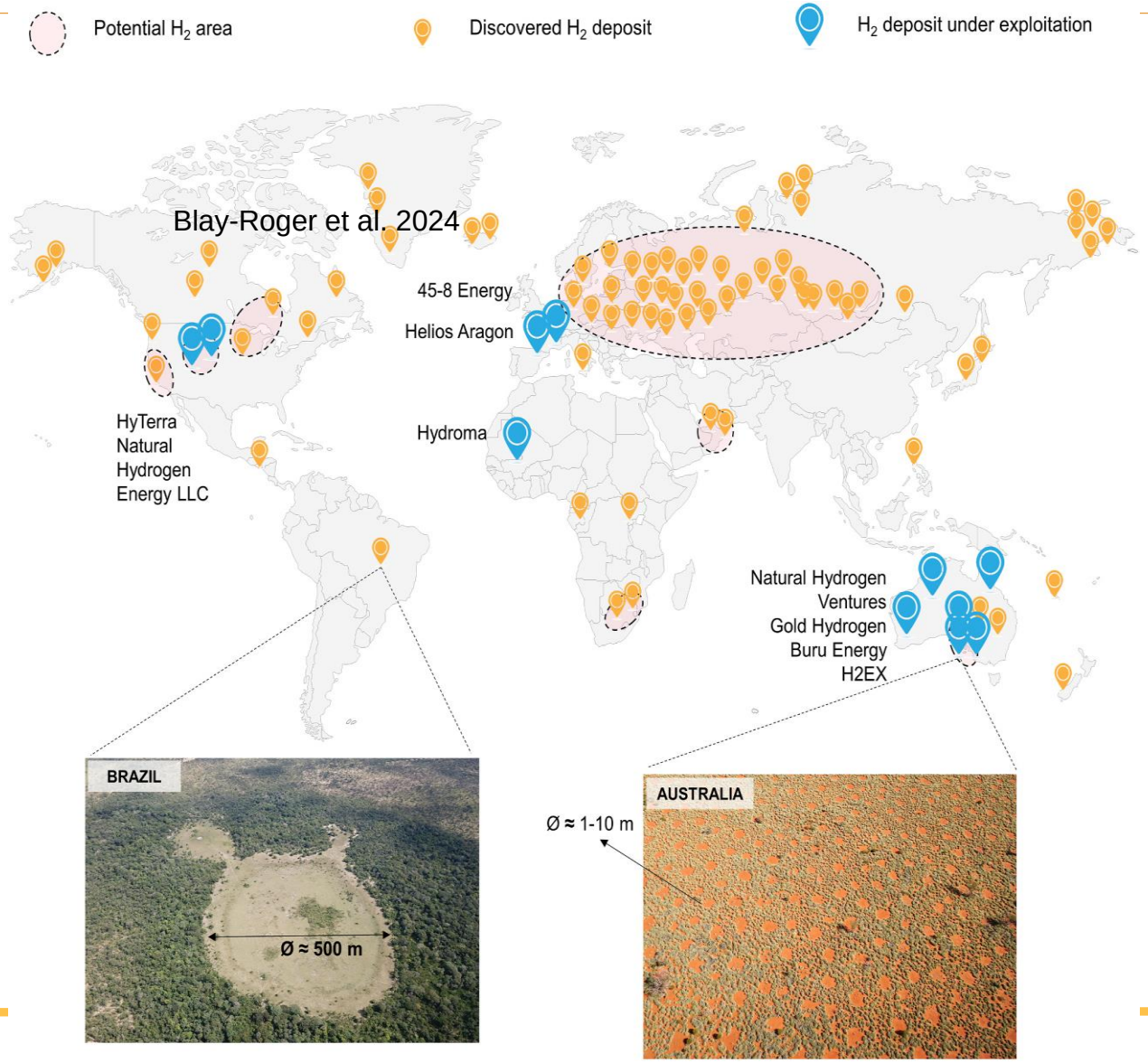
Has Been Underestimated

Natural Hydrogen Field in Mali



Global Activities

- Governmental efforts
  - France
  - Spain
  - Columbia
  - Australia
  - …
- Commercial efforts
  - Multiple companies actively drilling
  - Significant amount of private capital ready to be deployed



First Unicorn out of the Gate

First Unicorn out of the Gate

Bill Gates Backs Stealth Startup with $91M for Hydrogen Revolution

By Jennifer L

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Forbes

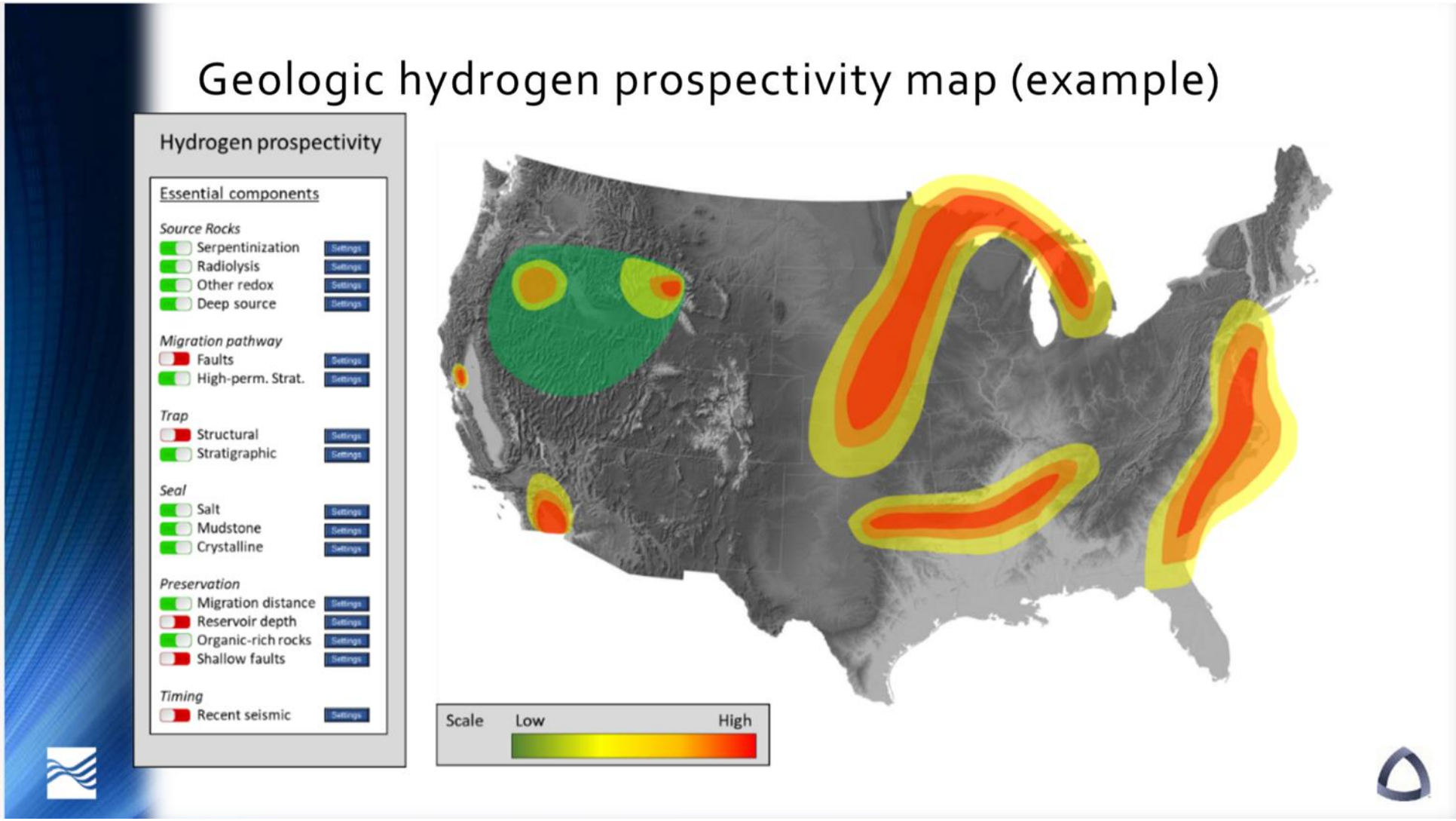
FORBES > INNOVATION > TRANSPORTATION

EDITORS' PICK

Bill Gates-Backed Clean Fuel Startup Raises $246 Million To Aid Plans To Drill For Hydrogen

Koloma, which extracts naturally occurring hydrogen from underground deposits, added Khosla Ventures, Amazon and United Airlines as key backers in its biggest funding round.

Where might we find in the US?

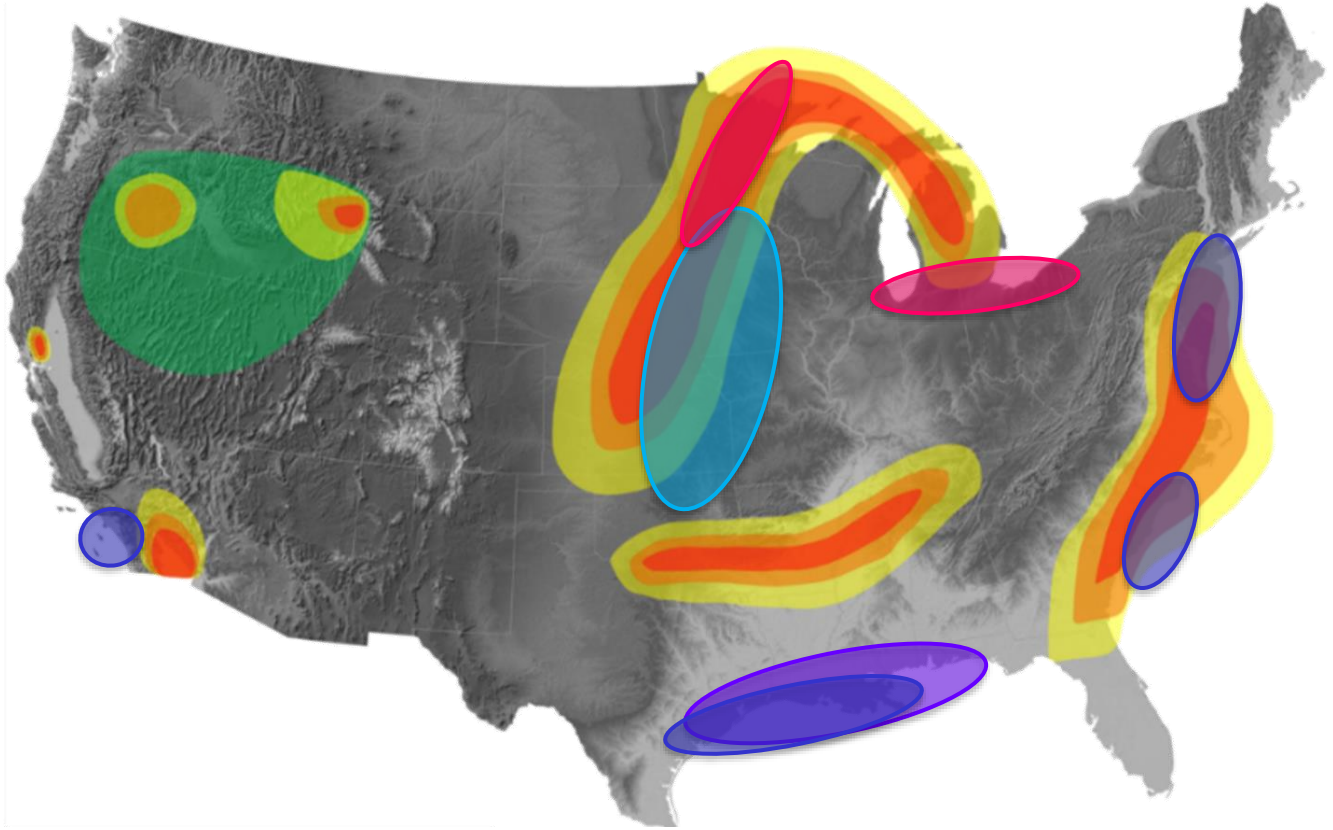


Geoff Ellis - USGS

What is the pathway to practical impact? How will barriers to commercialization be overcome?

Geologic hydrogen resources may be close to demand sectors, including:

- Petroleum Processing
- Ammonia
- Iron & Steel
- Shipping



Example **Geologic Hydrogen Prospect Map**

Sources
G. Ellis, 2022, (Geologic Hydrogen Presentation). (By courtesy)

GEOLOGIC HYDROGEN PROGRAM @ ARPA-E

Role of ARPA-E on development of Geo-Hydrogen

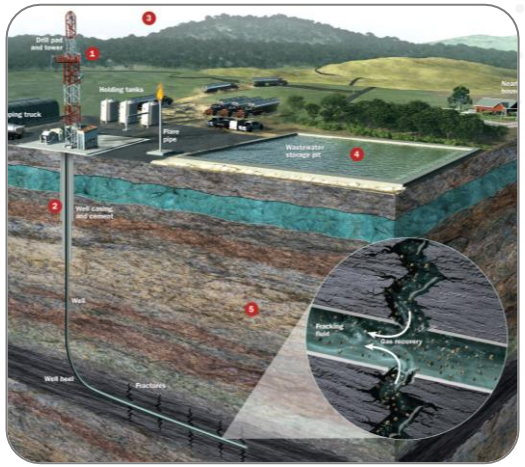
- Unleash American ingenuity to assess the challenges and opportunities of Geo-H2 as a new primary source of energy.
- Rapidly answer the question “Is there a there there?”.
- Create the environment that enables the fast deployment of the technology; address risks and develop mitigation strategies early on.
- Establish US global leadership in the development GeoH2

Current state of the technology

Despite all recent activity, GeoH_2 technologies are ***high risk*** and ***TRL is low***

Establish exploration and characterization methodology, technology

Develop know-how to stimulate H_2 evolution



Engineering for subsurface H_2 development

Why is now the right time? ARPA-E Approach

Sources
D. Yergin, *The prize: The epic quest for oil, money & power* (Simon and Schuster, 2011).

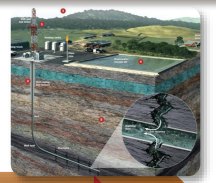
250 Years for Oil and Gas

Opportunistic Exploitation

Geophysical Exploration

Hydraulic Stimulation

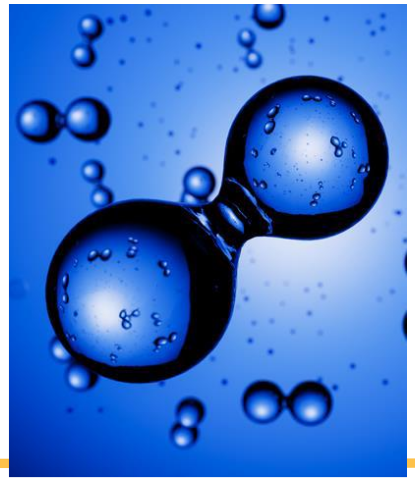
20 Years for Geological Hydrogen



Targeted Exploration

Stimulation

Subsurface Engineering

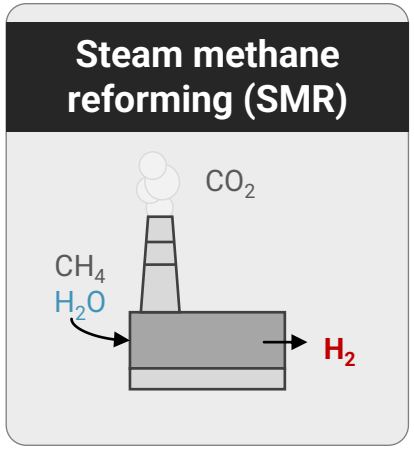


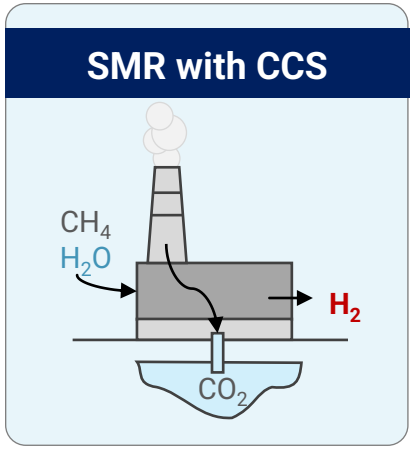
CHANGING WHAT'S POSSIBLE

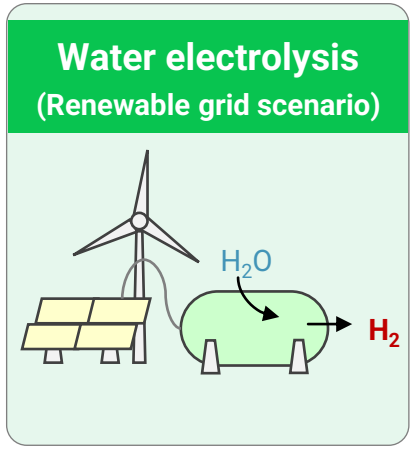
Program Aspirations

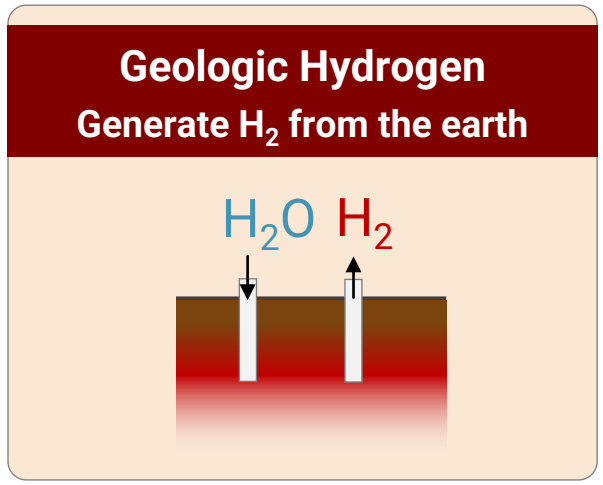
	Target
Cost @ wellhead	**<$1/kg H_2**
Wellhead purity	>20% (volumetric) H_2
GHGe footprint	<0.45 kg CO_2e/kg H_2
Target deposit potential	>10 million tonnes of H_2
Potential production/deposit	>1 million M^3/day (82 tonnes/day or 30,000 tonnes/year)

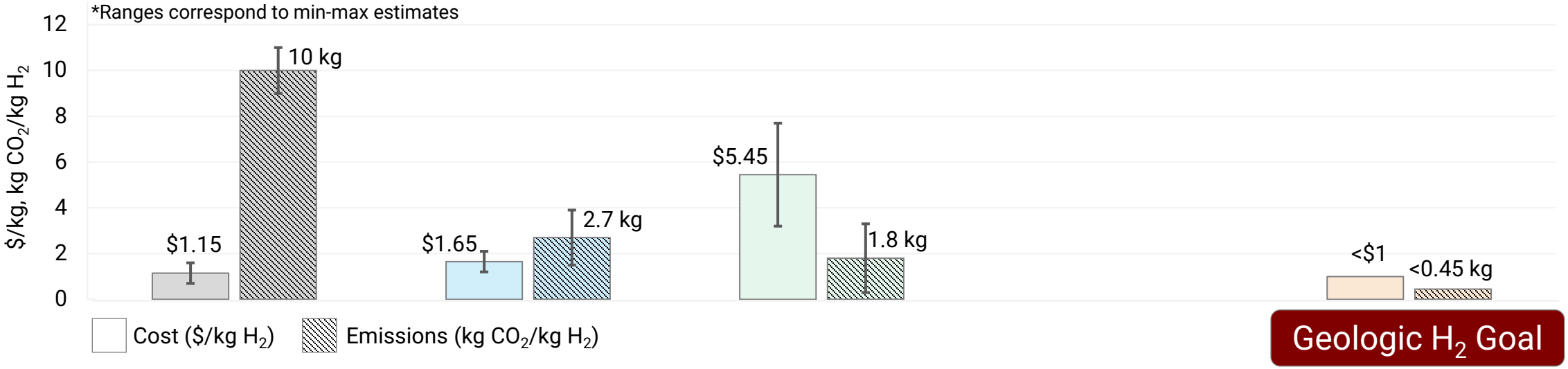
Comparison to the current state of the art?







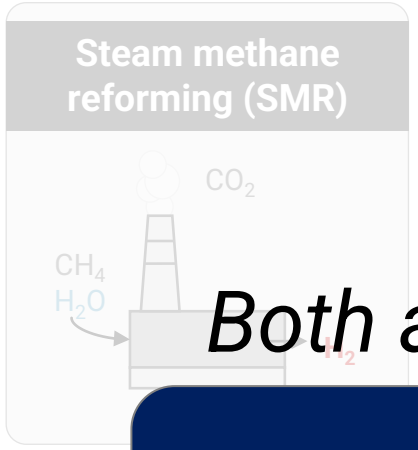




Sources

International Energy Agency, 2022, (Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050).
Hydrogen Council, 2021, (Hydrogen Decarbonization Pathways | Hydrogen Council).

What is the current state of the art?



Both are energy carriers

Blue H_2

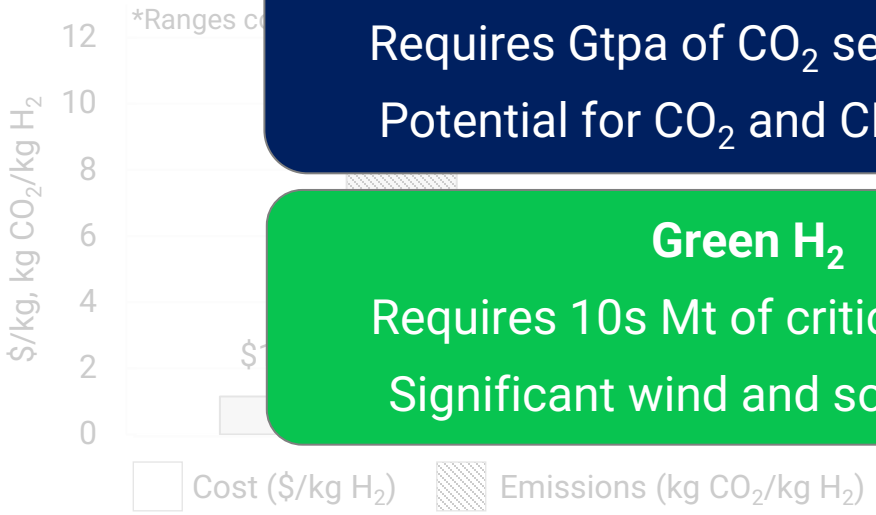
Requires Gtpa of CO_2 sequestration

Potential for CO_2 and CH_4 releases

Green H_2

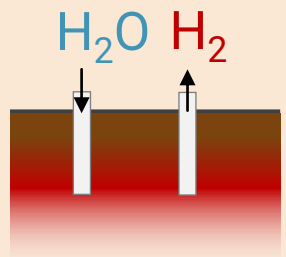
Requires 10s Mt of critical minerals

Significant wind and solar needed



Geologic Hydrogen

Generate H_2 from the earth



Primary energy

Geologic H_2

No critical minerals

No added CO_2 sequestration

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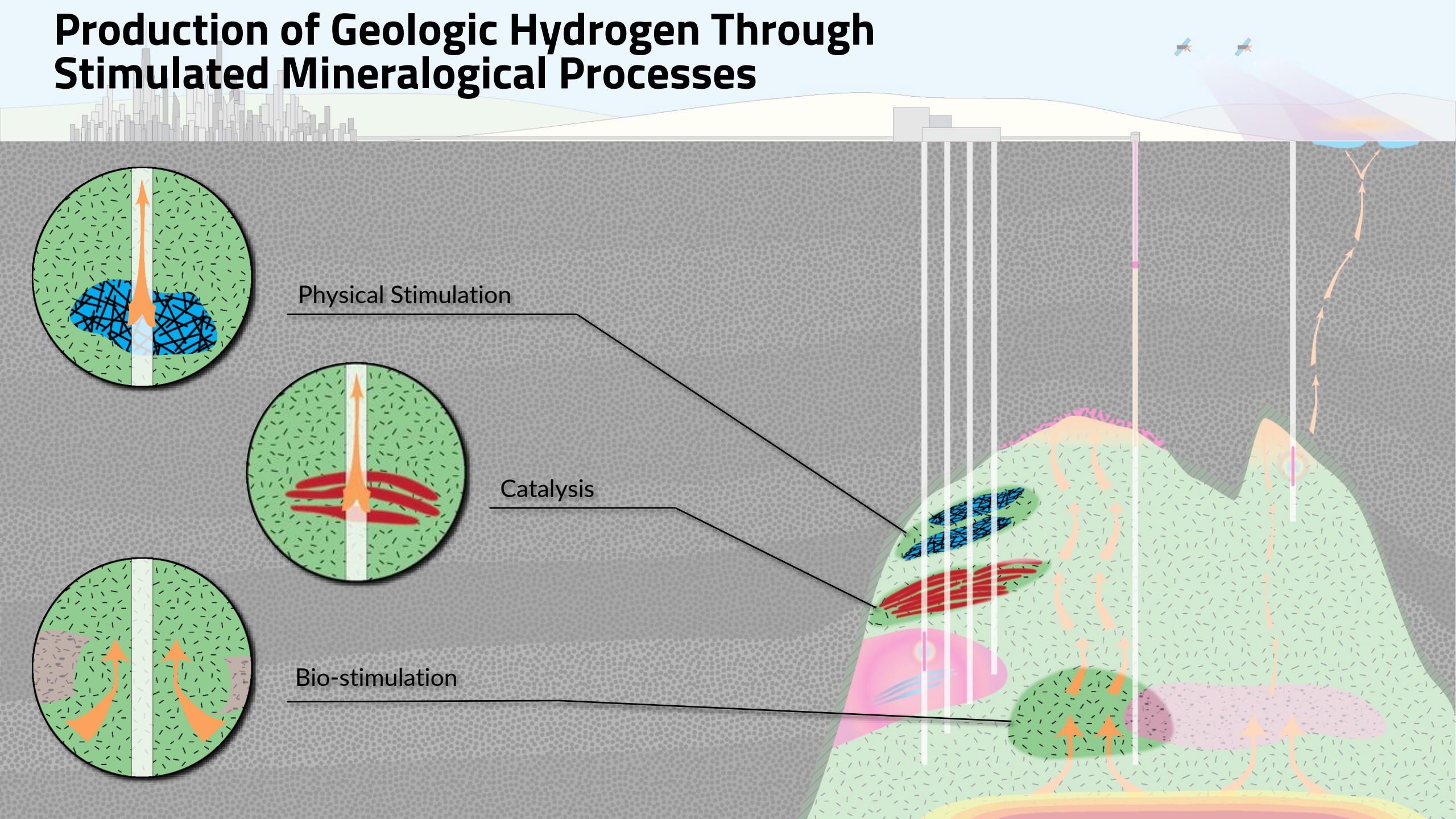
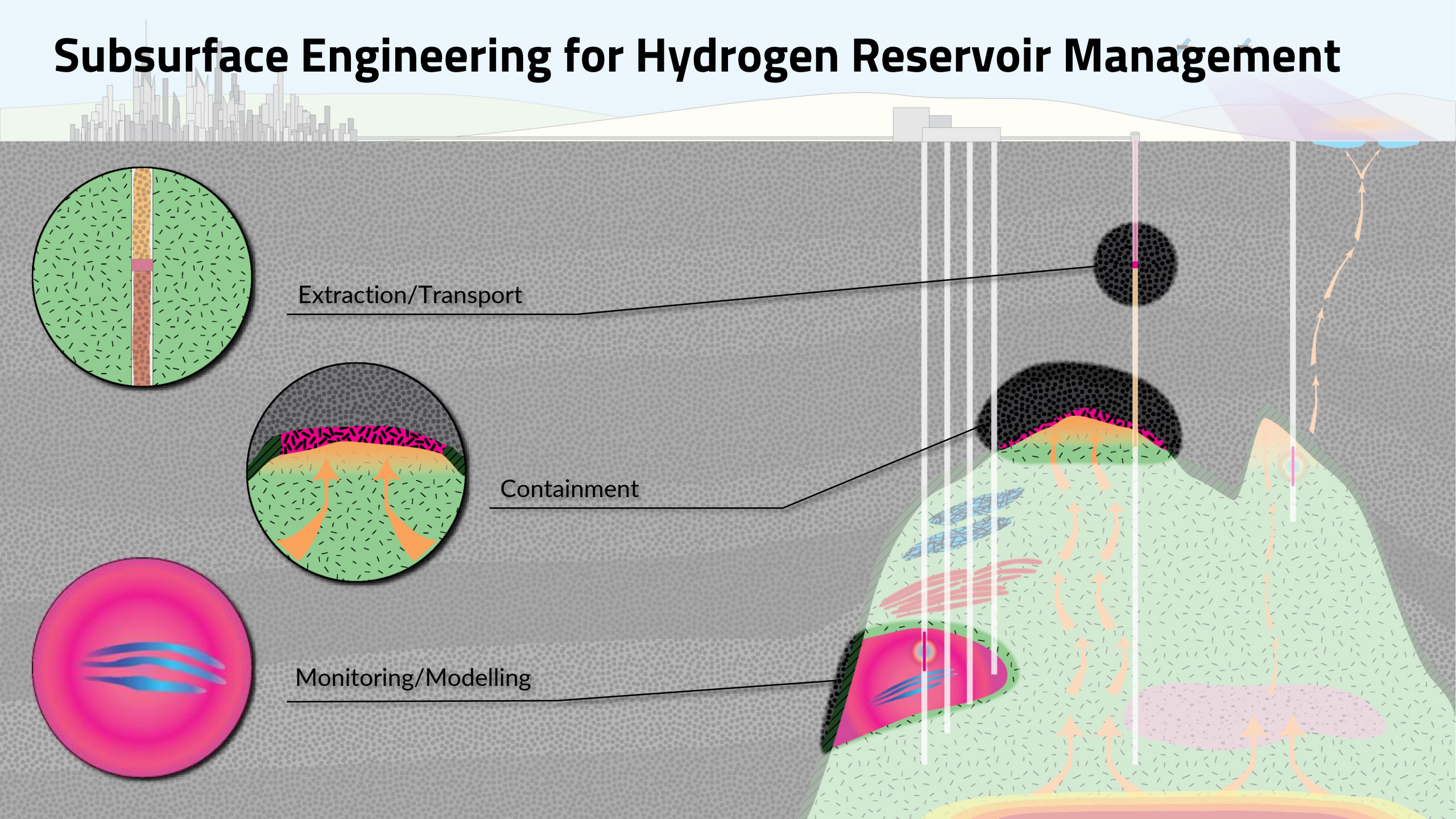
Hydrogen Council, 2021, (Hydrogen Decarbonization Pathways | Hydrogen Council).

Production of Geologic Hydrogen Through Stimulated Mineralogical Processes



Subsurface Engineering for Hydrogen Reservoir Management



ARPA-E Program Awardees: $24 M

Production of Geologic Hydrogen through Stimulated Mineralogical Processes

Subsurface Engineering for Reservoir Management

Methodology for Life-Cycle Analysis for Geological Hydrogen (GREET)

GEOLOGIC HYDROGEN PROGRAM

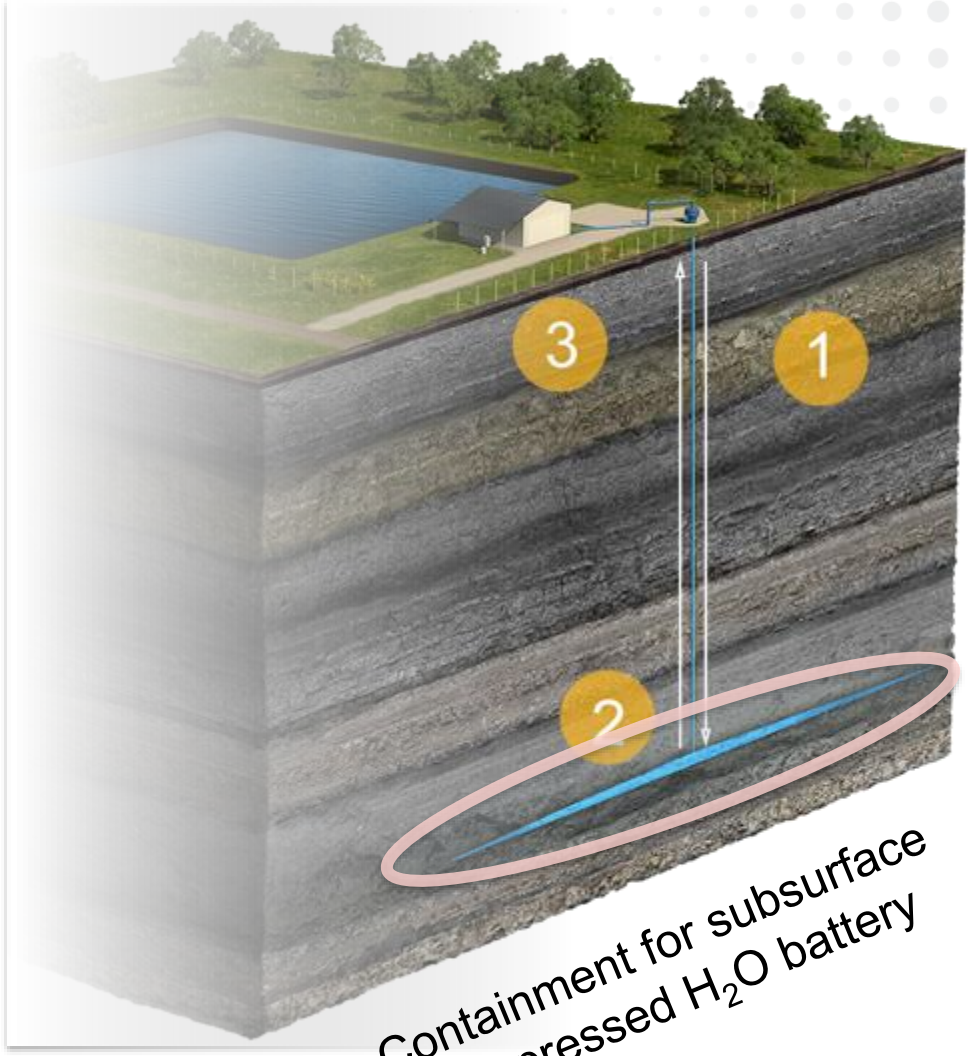
QUESTIONS TO BE ADDRESSED

Chemical challenges

- Can the oxidation of Fe(II) to Fe(III) be catalyzed in situ?
- How important is the equilibrium, can it be shifted?
- What is the impact of mineralogy?
  - Impact of trace elements?
  - Microstructure?
- Are there other H_2 forming reactions to be developed?

Physical challenges

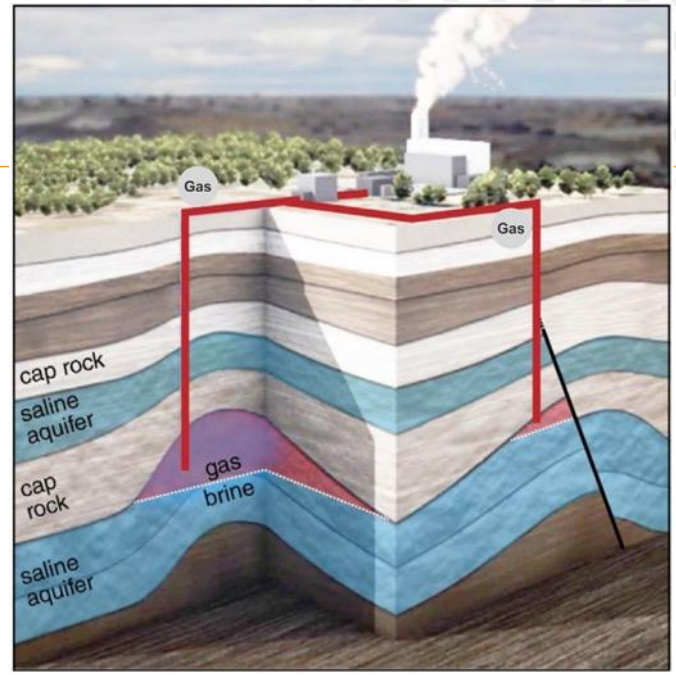
- How to increase/maintain surface area?
- Volume expansion from the reaction
  - Olivine to serpentine: 30%
  - Wuestite/Fayalite/Siderite: ?
  - Ferro magnesite: ?
  - Inducing seismicity?
- Can we separate H_2 from water in situ?
  - Engineer voids to collect?

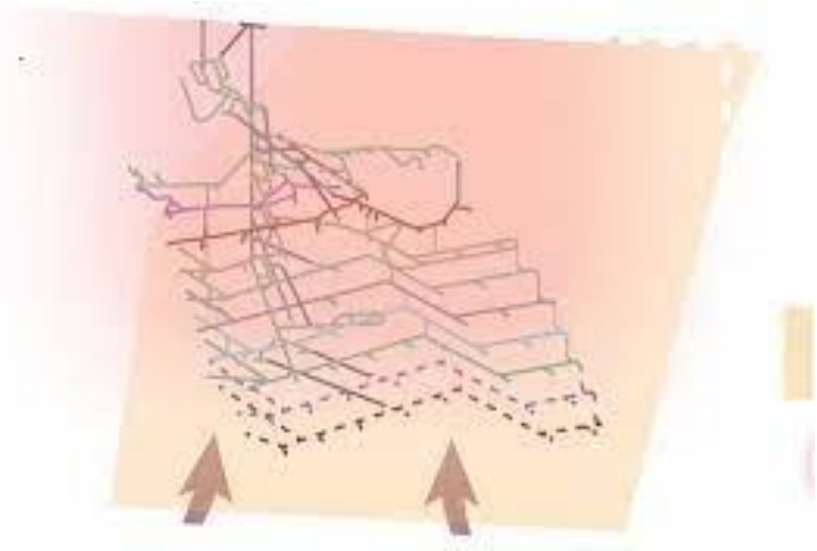


Sources
Quidnet Energy, (Quidnet Energy - Technology).

Natural accumulation challenges

- What happens when we begin to pull out H_2?
- How fast does it replenish?
  - How pure is the gas source?
  - Will concentration increase with withdrawal?
- Can we force it out with a sweeping gas?
- Can we drill down to the natural source in the basement?





THE FUTURE

Can we unlock it?

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