Geologic Hydrogen

A Critical Part of a Net-Zero Strategy?

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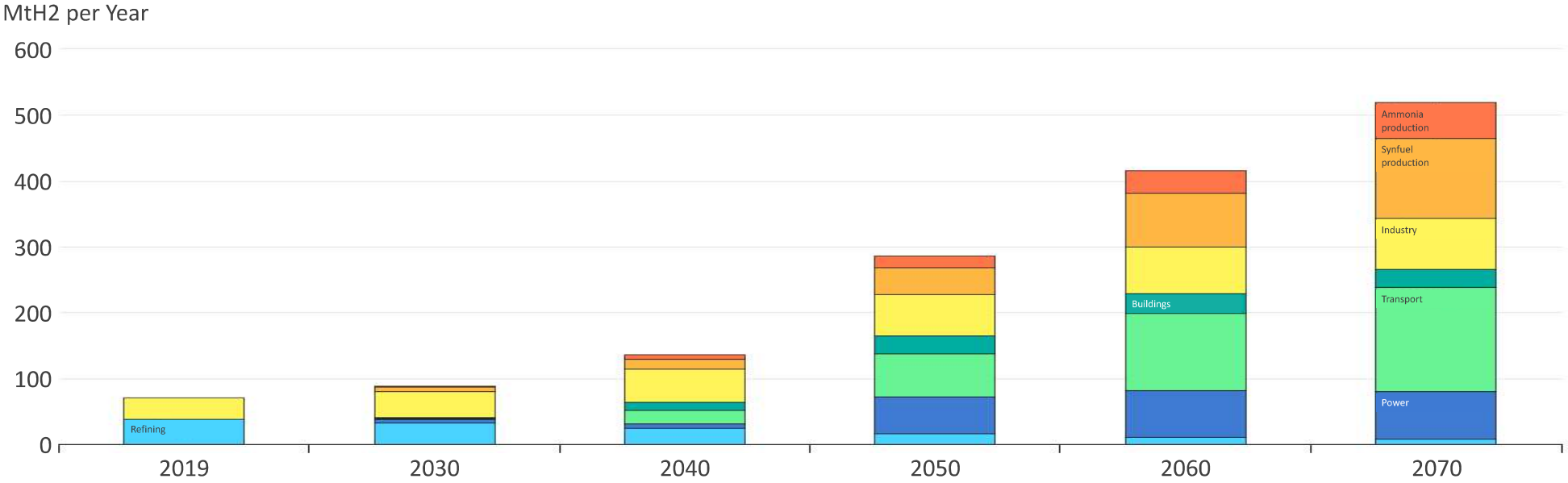
Growth of Global Demand of Hydrogen: from less than 100 MT/yr to 500 MT/yr in a few decades – mainly driven by its potential to abate 4 -12 Gt CO_2/yr



Adapted from: IEA Global Hydrogen Demand by Sector (2020)

- **Current Customers: Mostly for refineries, fertilizers, methanol. Price: ~1 USD/ Kg H_2**
- **By 2050 Current Consumers are < 20% of demand; Most from Steel, Ammonia, Power (fuel cells), Aviation**

A Paradigm Shift?

Most of hydrogen in the Universe is **Atomic Hydrogen**: i.e. bound in molecular structures. To produce it **requires** energy and conversion

Water Electrolysis
Methane reforming
Methane Pyrolysis
Gassification

Hydrogen is a Secondary Energy Source

Molecular Hydrogen is made in the subsurface directly from a reduction of metal rich (mantle) rocks via, for exothermic reactions (serpentinization for example)

Hydrogen is found at many places - recognized since the late 1800s. Only recently "larger" accumulations have been reported (Mail, Australia, NE France, Spain, US)

Hydrogen is a primary Energy Source

- **Growth from Low-Carbon Atomic Hydrogen processes is difficult:**
  - **High Cost 2 – 8 USD/Kg H_2**
  - **Needs lots of Infrastructure: Wind: ~ 190 Tonne H_2/ Yr /Km^2; Solar PV: ~ 970 Tonne H_2/ Yr/ Km^2**

(Source: Ingersoll, Smit 2022)

https://www.science.org/content/article/hidden-hydrogen-earth-may-hold-vast-stores-renewable-carbon-free-fuel

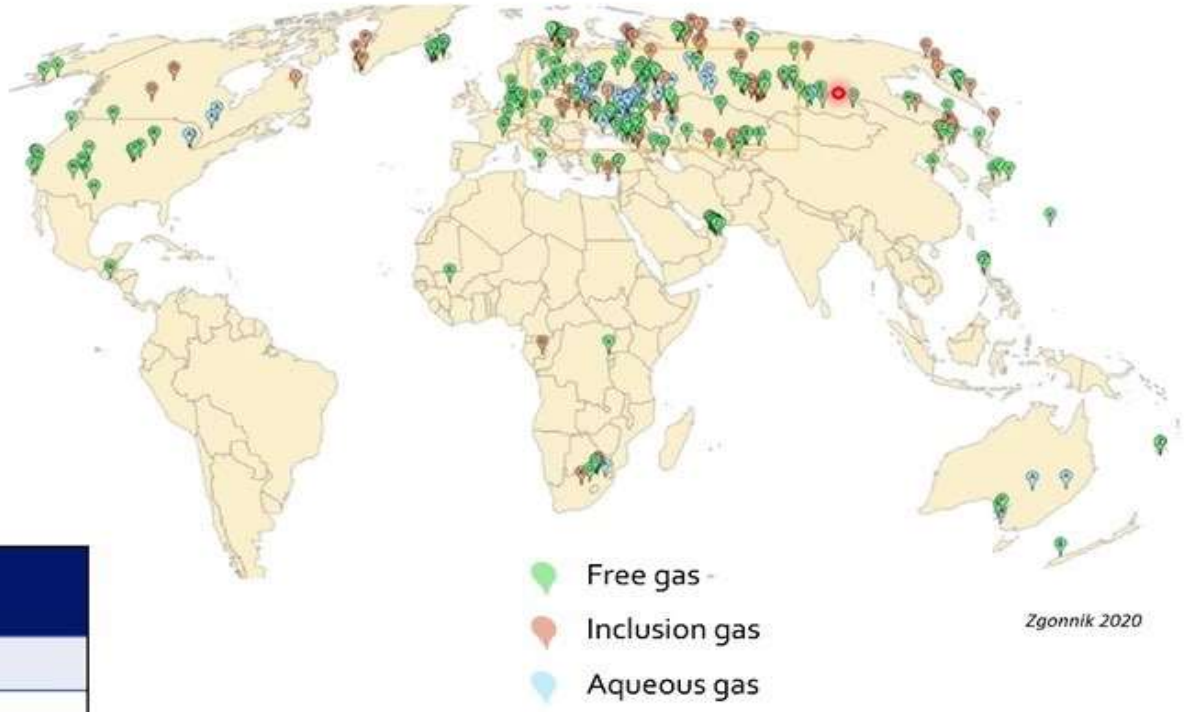
Onshore Locations with Measured Hydrogen concentrations > 10%

Surface observations of high concentrations of hydrogen are ubiquitous

Local flux can be large (~1 Mmcf/day)

Dense area on map related to increased effort to discover seeps

Deep bore holes and underground mines consistently encounter H_2



Estimates of annual flux of H_2 to the atmosphere

10^9 m^3 H_2 yr^{-1}	10^6 t H_2 yr^{-1}	Reference
0.3	0.027	Su, 1992
6	0.54	Voitov, 2000
67	6	Gilat, 2005; Gilat, 2012
254	23	Zgonnik, 2020

Geologic Hydrogen Exploration - A Venturable Start-Up Game?

Credit: G. Ellis USGS (2023)

Semail Ophiolite, Oman
Stimulate H2 project planned for 2024

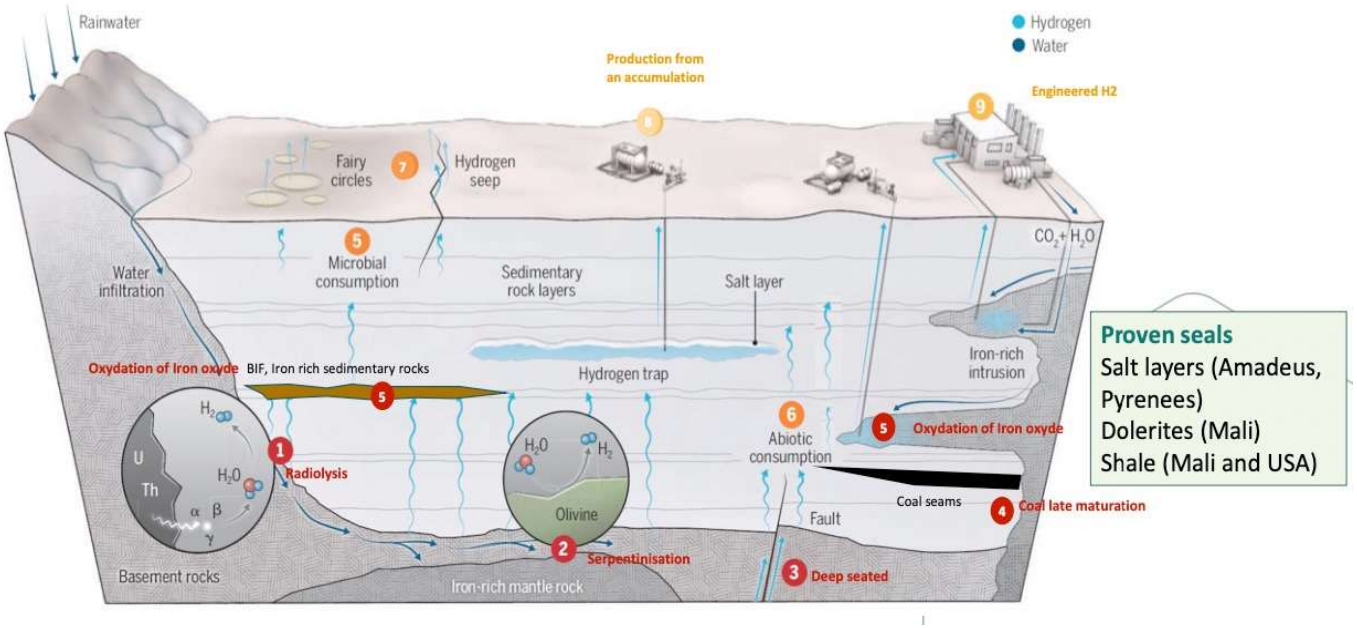
Nebraska, USA
First intentional H2 well drilled in 2018

Yorke Peninsula, Australia
Ramsay 1 & 2 wells >70% H2 flow tests in 2024

Wells drilled and planned in the midcontinent rift

Bourakébougou, Mali
Accidental discovery in 2012

Hydrogen Factories



Source: USGS (2022)

- **Generation Processes:**
  - Radiolysis
  - Mineralogical (Serpentization)
  - Tectonics: subsducting Plates
- **Trappings/Losses**
  - Seeps (Loss to Atmosphere)
  - Microbes
  - Abiotic Chemistry
- **Production/Extraction:**
  - Direct from proven Traps
  - Stimulated Fracturing, Flow enhancement
  - Generated (injection of water etc)

- A rich and complex Geologiccal and Geo-chemical/physical play;
  - (Continetal, Failed) Rift systems may be attractive to explore for relatively shallow iron rich minerals
  - Large Hydrogen deposits almost never close to Petreoleum systems (HC systems consume all H2)

Subsurface Hydrogen = A Hydrologic + Mineral System

Built on understanding Serpentization processes

Serpentinization is a "slow" hydrolysis and transformation process of primary ferromagnesian minerals e.g. **olivine** ($(Mg,Fe)_2SiO_4$) and pyroxenes ($(Mg,Fe)SiO_3$)

Water reacts with iron-rich mantel rocks (**peridotite**) to form hydrogen and **serpentine**

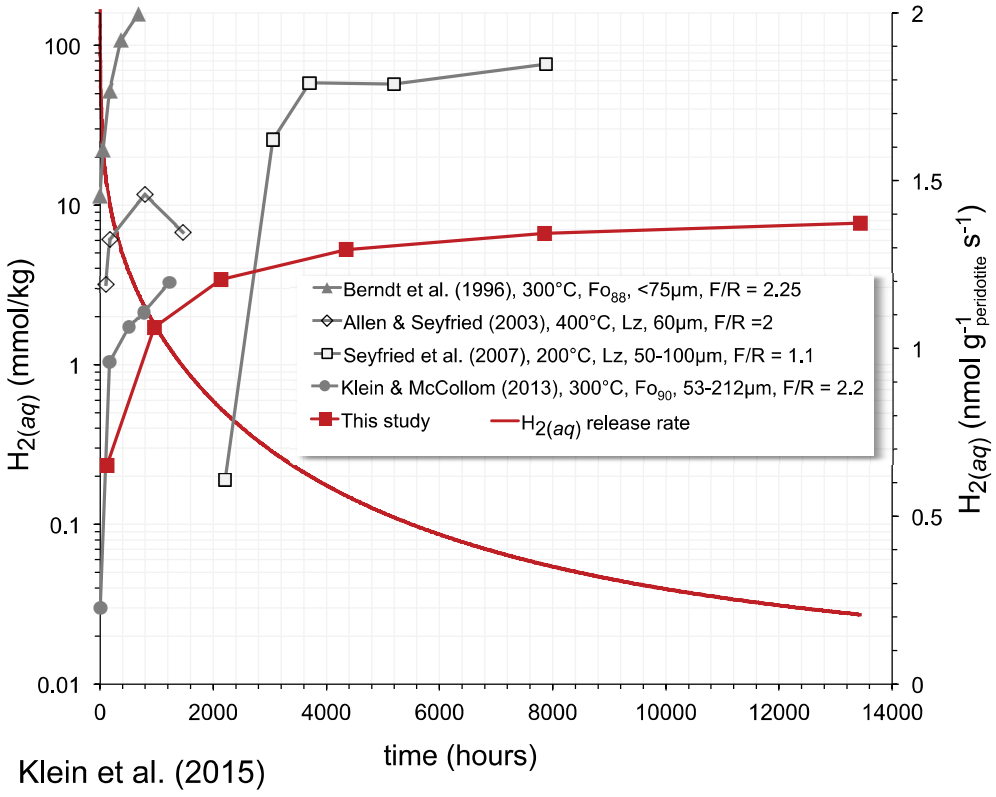
$3\ Fe_2SiO_4 + 2\ H_2O \rightarrow 2\ Fe_3O_4 + 3\ SiO_2 + 2\ H_2$ **ΔH_f = -179 Kj/mol**

Thermodynamics/Physics:

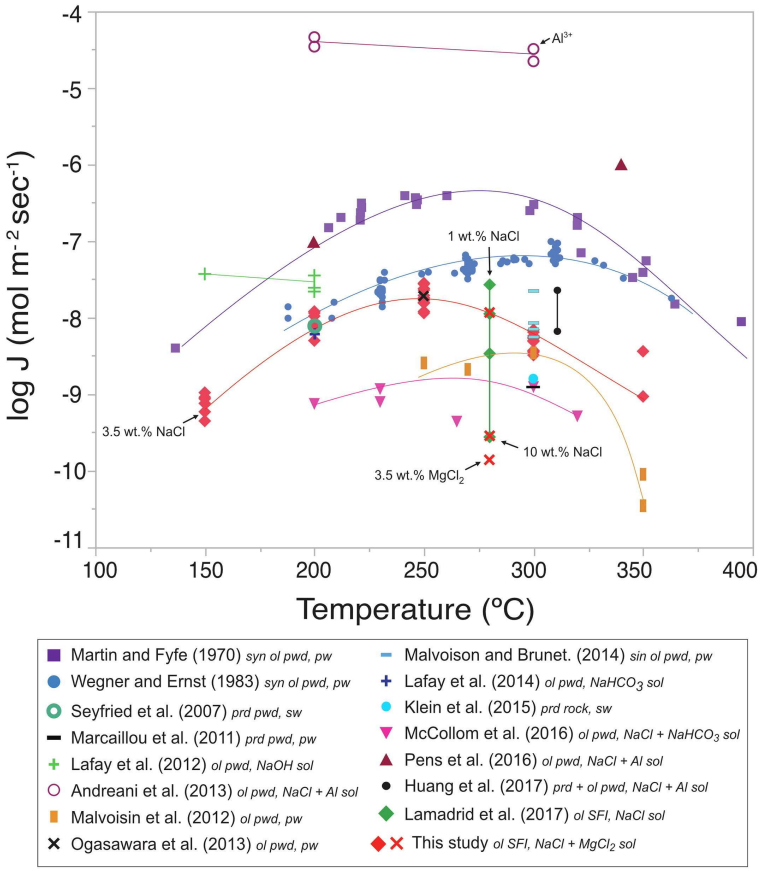
- **Serpentinization is exothermic**: It consumes 300 l / m^3 of rock producing 6.6 MJ of heat /m^3
  - The temperature of the rock is raised by 260 Deg C if heat conductivity is low.
- **The Density changes**: 3.3 to 2.7 g/cm^3
- The surrounding water has *pH > 11*
- During the reaction the serpentinite rock can get highly magnetic and is strongly oxidized
- For Mg/Fe ~ 9, 10 -20 mol of olivine produce 1 mole hydrogen

- ***Geo-physically detectable?***
- ***Stimulating Production is Key***

Production from Serpentinization and Effects of Temperature

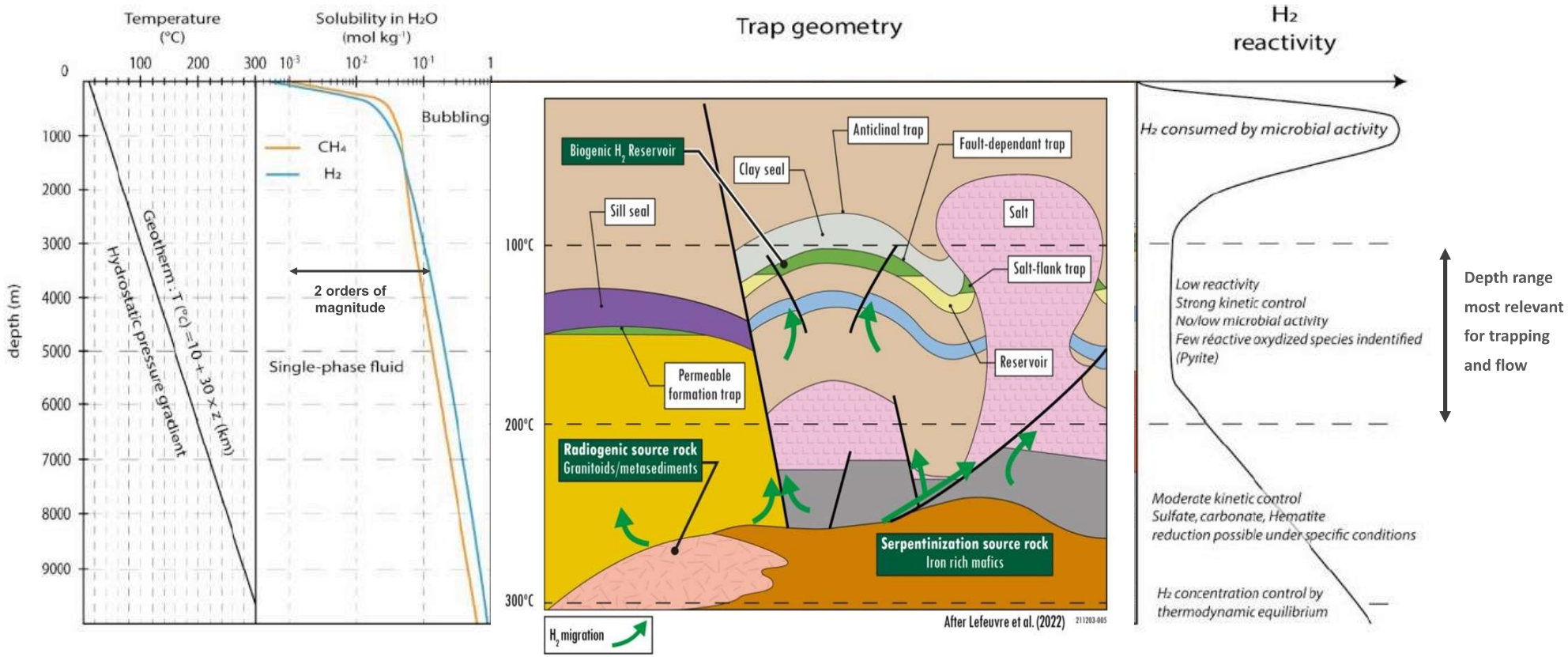


Klein et al. (2015)



Lamadrid 2020 et al

Geological H2 Trap settings



Source: Lefeuvre et al, Applied Geochemistry, 2022

A Few Conclusions

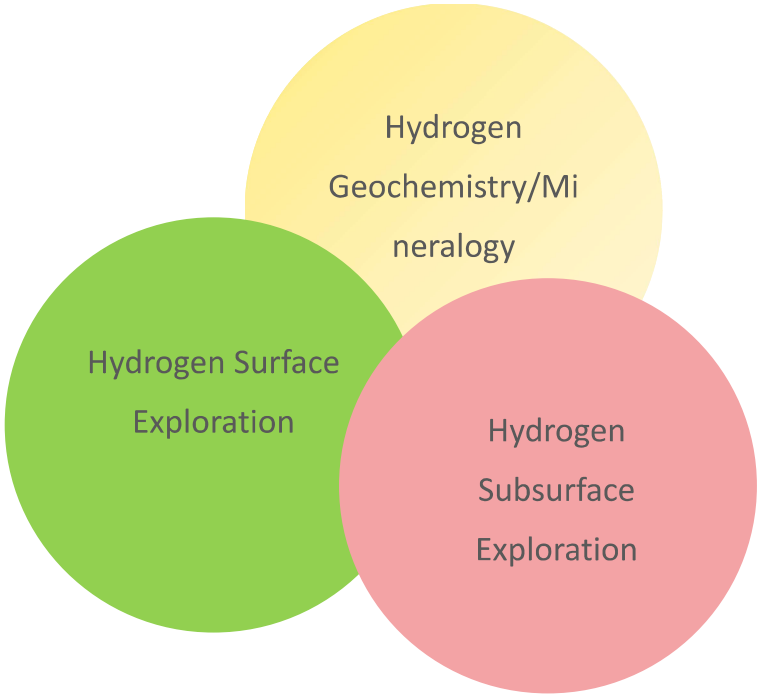
see also G. Ellis AAPG talk 2023

- Hydrogen Generation is rate limited by fluid access (impacted by significant volume increase)
- Serpentinization and Hydrogen production likley needs to be stimulated e.g. by fracturing and injection
- Reaction pathways and Hydrogen generation is dependent on temperature and protolith composition
  - specfically distribution of ferrous and ferric minerrals
  - Hydrogen generation peaks at about 300 deg C, but subject to catalytizing effects (CO_2, pressure, metals distribution)
- Stratographic traps may be very effective to hold significant volumes of hydrogen

Research Needed in three Areas in a System's Approach

- **Hydrogen Production Systems** (Hydrology, Mineralogy, (geo)Chemistry, Geology)
- **Production Engineering** – build on shale gas production experience
- **Sub-susrface Hydrogen Exploration Techniques** - Heat Flow (Basin) Modelling, Geophysical, Geochemistry, Geology
- **Understanding Atmospheric Impact: Hydrogen Flux systems** (atmospheric chemistry, (geophysical) observation)

➢ **Build Partnerships:** Academics, Start-Ups, Companies



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