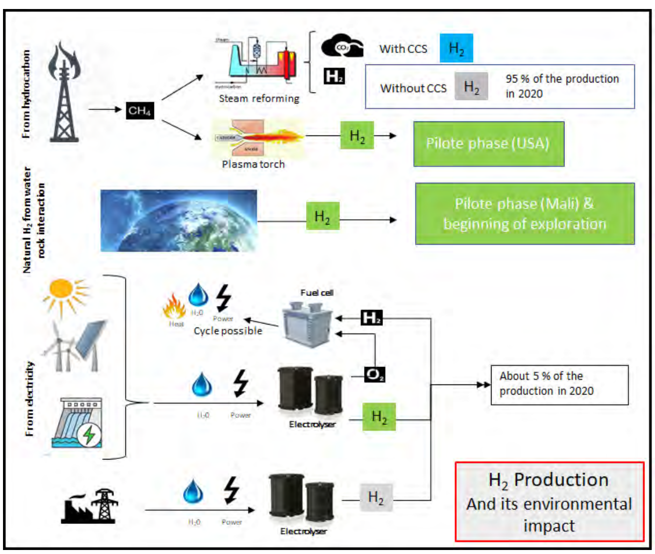
Dr Isabelle Moretti, Univ de Pau et des pays de l'Adour (E2S-UPPA)

L'hydrogène naturel peut-il être un « game changer » ?

L'exploration a commencé à grande échelle.
Où? Quels sont les opérateurs ? Que sait-on de cette nouvelle ressource?
Point d'étape mi 2023

02/10/2023 – Fondation Tuck

Hydrogen: Production mode and environmental impact



- Today we have cheap H_2 from HC and more expensive from electrolyser (roughly 2 vs 8 $/kg)
- Within the steam reforming
  - 1/3 of the price is the gas,
  - 1/3 the energy (to 800°C),
  - 1/3 the cleaning

Natural H_2 could be cheaper and cleaner

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Natural Hydrogen and Mid Oceanic Ridges

- Mid-oceanic ridges
  - East Pacific r.: $H_2 \approx 60\%$ *(Welhan & Craig., 1979)*
  - Rainbow: $H_2 \approx 50\%$ *(Charlou et al., 2002)*
  - Logachev: $H_2 \approx 50\%$ *(Douville et al., 2002)*
  - Lost City: $H_2 \approx 70\%$ *(Kelly et al., 2005)*
  - Ashadze : $H_2 \approx 70\%$ *(Charlou et al., 2008)*

Rainbow

Each vents:
flux~ 5-10 x 10^6 m^3 H_2/an
(Charlou et al., 2008)

Probably thousands of vents
Along 60 000 km
of mid-oceanic ridges

Lost city

➢ Known for long time but do not look easy to produce

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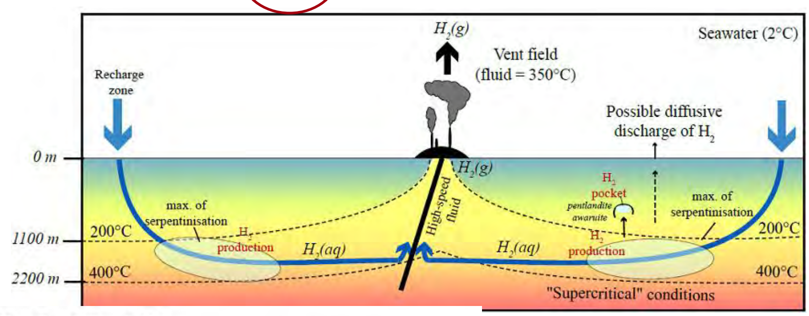
Where this H_2 is coming from ?

Olivine + Water → Serpentine + Magnetite + Hydrogen



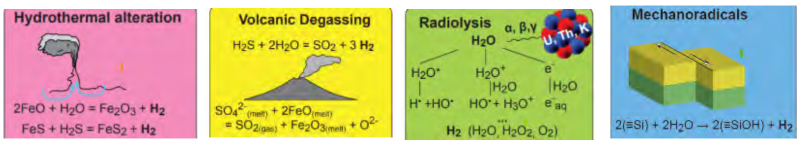
$$30\,\underbrace{Mg_{1.8}Fe_{0.2}SiO_4}_{Olivine} + 41\,\underbrace{H_2O}_{Eau} = 15\,\underbrace{Mg_3Si_2O_5(OH)_4}_{Serpentine} + 9\,\underbrace{Mg(OH)_2}_{Brucite} + 2\,\underbrace{Fe_3O_4}_{Magnétite} + 2\,\underbrace{H_{2,aq}}_{Hydrogène}$$

$$15\,\underbrace{Mg_{1.8}Fe_{0.2}Si_2O_6}_{Orthopyroxène} + 19\,\underbrace{H_2O}_{Eau} = 9\,\underbrace{Mg_3Si_2O_5(OH)_4}_{Serpentine} + 1\,\underbrace{Fe_3O_4}_{Magnétite} + 1\,\underbrace{H_{2,aq}}_{Hydrogène} + 12\,\underbrace{SiO_{2,aq}}_{Silice\ aqueuse}$$

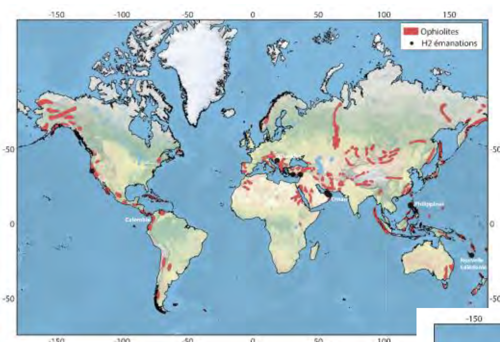
Low pH, High temperature

H_2 sources: mainly H_2O

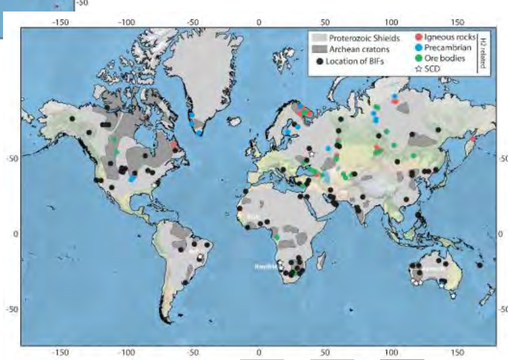
- Fe oxidation with geothermal hot fluids — $2\,FeO + H_2O = Fe_2O_3 + H_2$
- Serpentinization — $3\,Fe_2SiO_4 + 2\,H_2O = Fe_3O_4 + 3\,SiO_2 + 2H_2$
- Hydrothermal context but basic — $2\,FeS_{(pyrrhotite)} + H_2O = FeS_{2(pyrite)} + FeO + H_2$
- Granite peralkaline — $3\,[Na_3Fe_4^{2+}Fe^{3+}Si_8O_{22}(OH)_2]_{(Arfvedsonite)} + 2\,H_2O = 9\,[NaFe^{3+}Si_2O_6]_{(Aegirine)} + 6\,SiO_2 + 2\,[Fe_3O_4]_{(Magnétite)} + 5\,H_2$
- Volcanic — $H_2S + 2\,H_2O = SO_2 + 3\,H_2$
- Radiolysis — $H_2O + \alpha, \beta, \gamma$
- Mechanoradical — $H_2O + \ldots$
- Open question: NH_3
- Late maturation of Organic matter



Modified from Klein et al., 2020 Elements, Vol. 16, pp. 19–24



Maps of 2 of the generating rocks



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Everything changed since we are looking for a decarbonized and cheap H_2





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When oceanic crust outcrops: the ophiolitic nappes

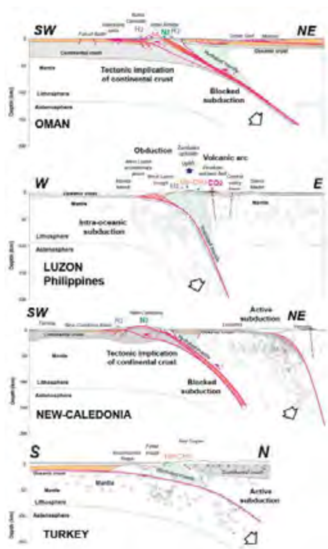
The gas is often a mixture H_2, CH_4, N_2

Serpentinisation at low temperature: High pH and carbonatation

Capture of atmospheric CO_2

Oman

New Caledonia



Vaquand et al., 2018.

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H2NA Hydrogène naturel en Nouvelle-Aquitaine

France: Nouvelle Aquitaine

- Partners
  - CVA
  - UPPA
  - BRGM
  - Engie
  - 45-8
- 3 steps
  - Regional, screening of the full region, based on existing data
  - Focus on 3 areas, new data acquisition
  - Focus on 1 area, involvement of the SHS

CVA	Massif Central (Sud Limousin) Massif Armoricain
brgm	Massif Central (Limousin)
Université	Pyrénées
45-8	Bassin Aquitain Seuil du Poitou

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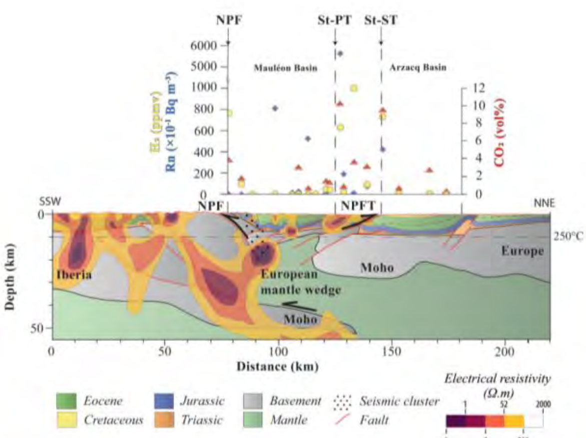
Who and where companies are taking blocks for H_2 sourced by serpentinization

- France (TBH2) & Spain (Helios Aragon)
  - Pyrenees, mantellic wedge and deep rooted faults

H_2 is recognized as a resource by the French law since early 2022



- Cluster of seismicity in the area where serpentinization is likely to took place
- Deep rooted thrust fault
- Salt that could be the seal

Lefeuvre et al., 2021 Native H2 exploration in the western Pyrenean foothills doi: 10.1029/2021GC009917.

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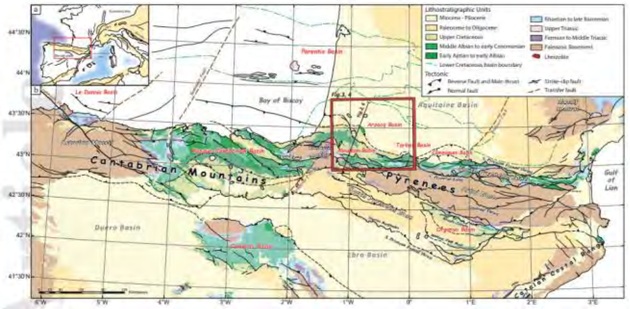
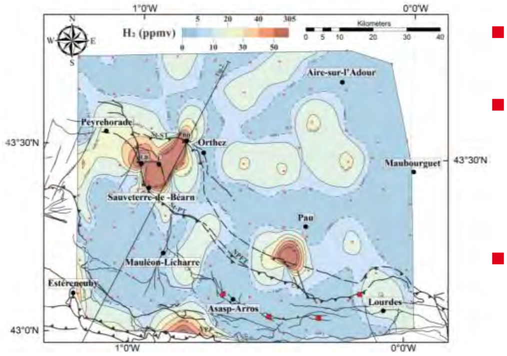
In the Pyrenees



Lefeuvre et al., 2021 Native H2 exploration in the western Pyrenean foothills doi: 10.1029/2021GC009917.



- presence of mantle rocks at shallow depth < 10 km
- The analysis campaign reveals several areas of high occurrence to the north of the Mauléon Basin where H_2, CO_2 and 222Rn concentrations exceed 1000 ppm, 10 vol% and 50 kBq m^{-3}, respectively.
- Most of these hot spots are located along the North Pyrenean Frontal Thrust and other related faults rooted in the mantle body

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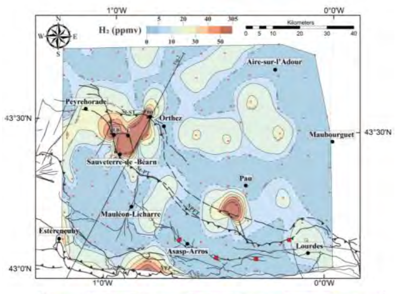
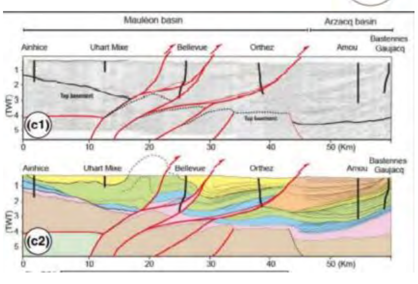
In the Pyrenees: first H_2 exploration block in France

TB-H2 Aquitaine





- Project: data synthesis in 2023
  - Expected source rock the mantle wedge
  - Expected seal : salt
- First step budget 5. 10^6 €, 2st steps 50. 10^6 €

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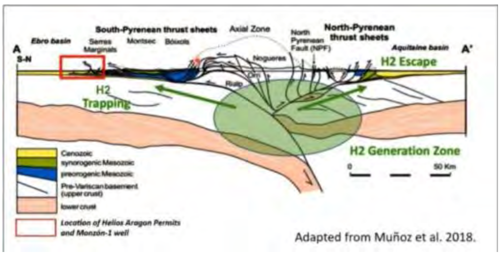
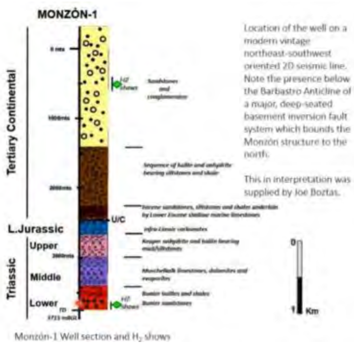
Helios

HELIOS ARAGÓN

- Helios' Aragon project comprises a plan to explore and drill for natural hydrogen and helium in two permits; Barbastro and Monzon covering a land area of 89,536 hectares in Aragon. The two permits were granted to Helios Aragon on June 1, 2020 for a 6-year term
- Based on the results of an existing well (1970, pure H_2 at 3600m)
- Expected source rock: the mantle wedge as in France
- Expected seal: salt
- Migration: deep seated faults and thrusts



Adapted from Muñoz et al. 2018.



Monzón-1 Well section and H_2 shows

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In the Spanish news papers…


HIDRÓGENO DORADO

El primer pozo de hidrógeno europeo está en Aragón y puede cambiar el sector energético

El descubrimiento de reservas de hidrógeno natural, que además podría regenerarse, dispara los estudios y los proyectos: el primero de Europa se abre paso en Huesca


SER

Economía y negocios

Se proyecta la primera extracción de hidrógeno puro de Europa en Barbastro y Monzón

Helios Aragón PTE plantea una inversión de 900 millones de euros para comenzar la extracción de los mate


Monzón y Barbastro, reservas de hidrógeno

Por Colaborador Cinca Medio - 1 marzo, 2023

Facebook Twitter Google+ Pinterest

Helios Aragón PTE, la filial española de British Petroleum, conocida como BP, quiere extraer hidrógeno natural y helio del subsuelo de dos reservas que se encuentran localizadas entre las localidades de Barbastro y Monzón.

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H_2 sources: mainly H_2O

- Fe oxidation with geothermal hot fluids — $2\,FeO + H_2O = Fe_2O_3 + H_2$
- Serpentinization — $3\,Fe_2SiO_4 + 2\,H_2O = Fe_3O_4 + 3\,SiO_2 + 2H_2$
  - $2\,FeS_{(pyrrhotite)} + H_2O = FeS_{2(pyrite)} + FeO + H_2$
- Hydrothermal context but basic
- Granite peralkaline — $3\,[Na_3Fe_4^{2+}Fe^{3+}Si_8O_{22}(OH)_2]_{(Arfvedsonite)} + 2\,H_2O = 9\,[NaFe^{3+}Si_2O_6]_{(Aegirine)} + 6\,SiO_2 + 2\,[Fe_3O_4]_{(Magnétite)} + 5\,H_2$
- Volcanic — $H_2S + 2\,H_2O = SO_2 + 3\,H_2$
- Radiolysis — $H_20 + \alpha, \beta, \gamma$
- Mechanoradical — $H_20 + \ldots$
- Open question: NH_3
- Late maturation of Organic matter

Major recent change in our understanding: The reaction of iron oxide oxidation could be fast at rather low temperature and generate a lot of H2

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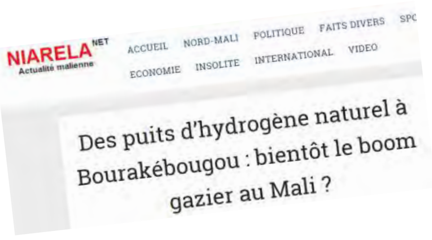
Mali: first production of pure natural H_2


NIARELA NET Actualité malienne — ACCUEIL NORD-MALI POLITIQUE FAITS DIVERS SPO ECONOMIE INSOLITE INTERNATIONAL VIDEO

Des puits d'hydrogène naturel à Bourakébougou : bientôt le boom gazier au Mali ?


CONFIDENTIEL Afrique — Le pouvoir à nos lecteurs — RUBRIQUES NOUS CONTACTER QUI SOMMES-NOUS

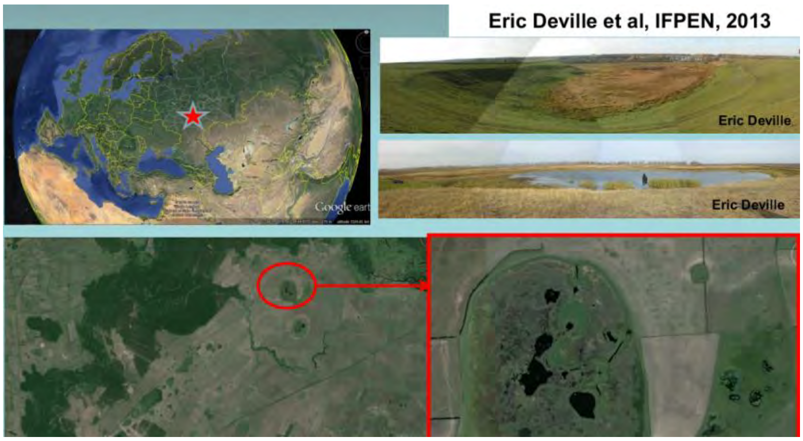
Mali: L'hydrogène de Bourakebougou fascine la communauté scientifique et fait la Une de La Tribune

L'intégration de l'hydrogène comme source d'énergie dans la transition énergétique va assurément bouleverser les modes de vie de la planète. Au Mali, plus précisément dans un village appelé Bourakebougou, niché à 40 km de Bamako (capitale du Mali), se joue une grande partie de l'avenir énergétique africain et mondial. Cette découverte majeure et historique de l'hydrogène naturel (production d'une électricité verte à 100%), a fasciné l'émérite Professeur Alain Prinzhofer, affilié au prestigieux Institut de Physique du globe de Paris et à l'université de Paris VII, Directeur scientifique de GEO4U, qui a expliqué l'importance et les opportunités de cette matière stratégique dans les colonnes du quotidien français La Tribune.

H_2 onshore in basin

Described by Larin et coauteurs since 2010

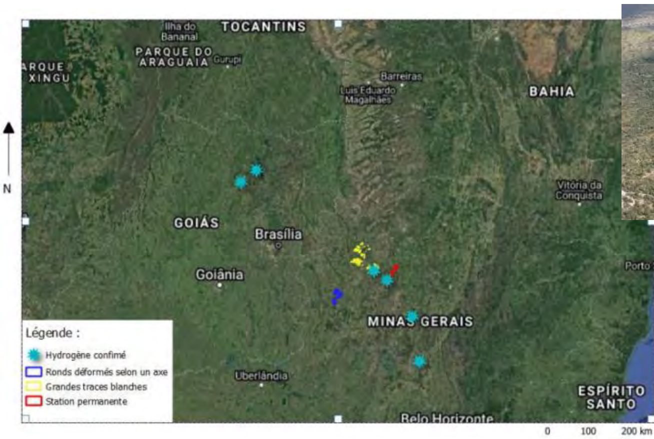
Eric Deville et al, IFPEN, 2013



Larin, N.; Zgonnik, V.; Rodina, S.; Deville, E.; Prinzhofer, A.; Larin, V.N. Natural Molecular Hydrogen Seepage Associated with Surficial, Rounded Depressions on the European Craton in Russia. Nat. Resour. Res. 2014, 24, 369–383.

Brazil, Mina Gerais

- H_2 emanations have been measured in various places (Geo4U in collaboration with ENGIE)
- Statistic on the geometry of the fairy circles has been carried out in 3 zones including Sao Romao



Moretti, I., et al. 2021. Hydrogen emanations in intracratonic areas: new guide lines for early exploration basin screening. . Geosciences, https://doi.org/10.3390/ geosciences11030145

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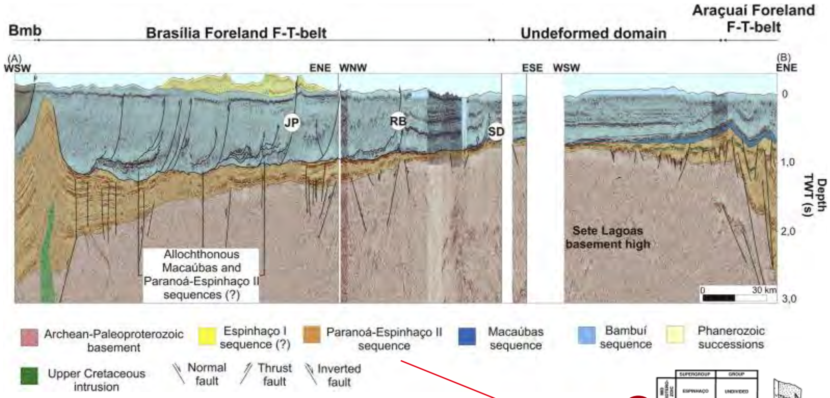
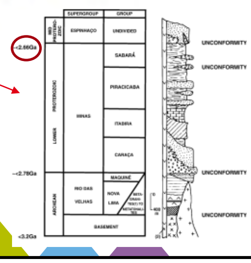
San Francisco Basin



BIF banded Iron Formation
Quadrilatère de fer



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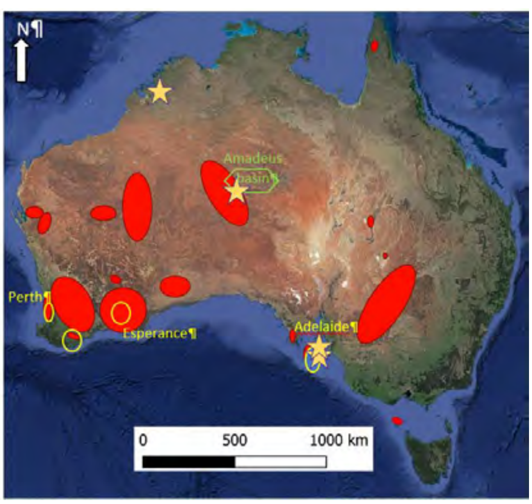
Fairy circles are very numerous in Australia (red zones)

Yellow stars wells with H_2



South of Perth, serpentine area

Moretti, I., et al. 2021. Hydrogen emanations in intracratonic areas… https://doi.org/10.3390/geosciences11030145

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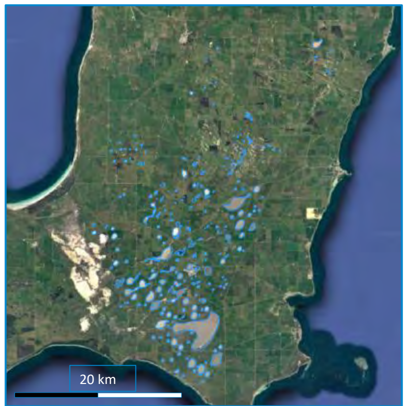
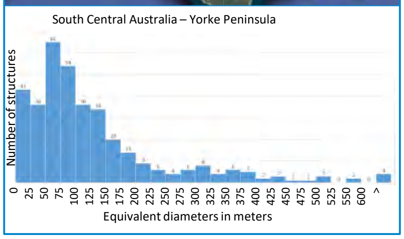
Yorke peninsula

Original values	Yorke Peninsula					
Depth (m)	240	240	262	262	262	508
CO_2 (%)	0.8	0.2	0.8	0.8	0.6	0
O_2 (%)	0	0	3.2	2.4	3	1.2
H_2 (%)	74	76	60	64.4	60	84
CH_4 (%)	7.5	7.5	5.4	7	5.6	0
N_2 (%) by difference	17.7	16.3	30.6	25.4	30.8	14.8
Air corrected values						
CO_2 (%)	0,8	0,2	1,0	0,9	0,7	0,0
H_2 (%)	**74,0**	**76,0**	**71,3**	**73,1**	**70,5**	**89,3**
CH_4 (%)	7,5	7,5	6,4	7,9	6,6	0,0
N_2 (%)	17,7	16,3	21,3	18,1	22,3	10,7





Moretti, I., et al. 2021. Hydrogen emanations in intracratonic areas…
https://doi.org/10.3390/ geosciences11030145

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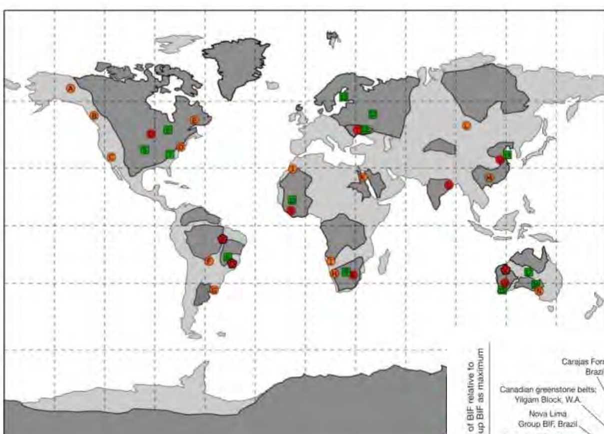
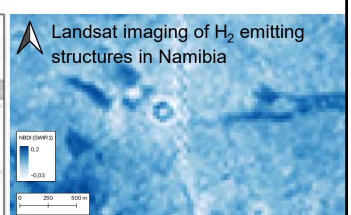
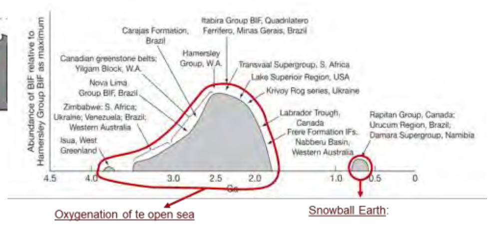
Archean and Neoproterozoic basins / iron / H_2





NDBI with SWIR 1 (data from Landsat 8, 2016)



Ramanaidou (2014)

Geymond, U. et al.. 2022. Can weathering of Banded Iron Formations generate natural hydrogen? Evidences from Australia, Brazil and South Africa. **Minerals**, 12, 163. https://doi.org/10.3390/min12020163

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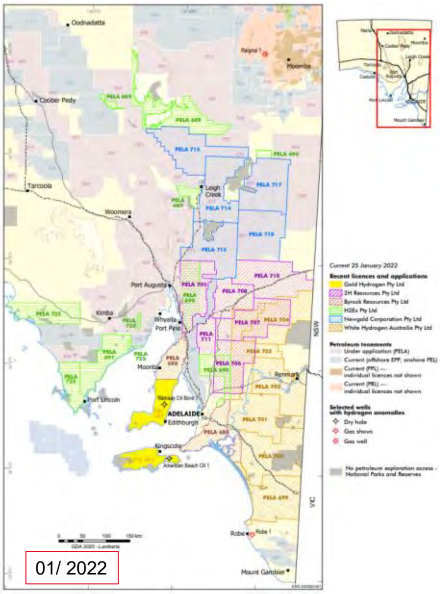
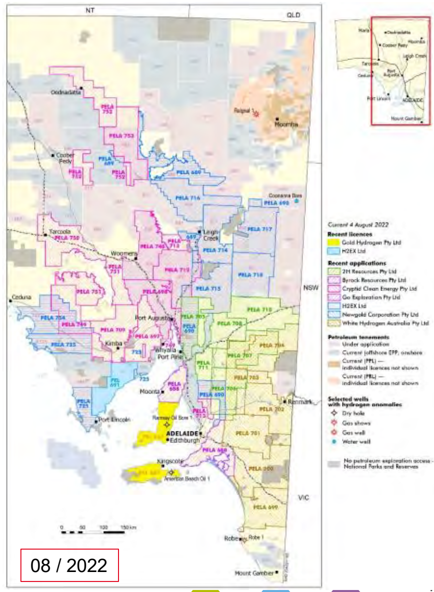
South Australia: the big race





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Lorraine: un nouveau permis… et beaucoup de bruits et d'attentes

Un gigantesque gisement d'hydrogène découvert en Lorraine !

ÉNERGIE RENOUVELABLE · TRANSITION ÉNERGÉTIQUE

FRANÇAISE DE l'Energie

Testing a new sensor for dissolved gases, developed in collaboration with the Lorraine university, Nancy

25 Les Echos Jeudi 22 juin 2023

La sonde, mise à disposition des chercheurs par la Française de l'Energie, est capable de descendre à 1.100 mètres de profondeur et a permis de détecter de l'hydrogène, pour une teneur de 1 % à 600 mètres puis de 17 % à 1.100 mètres.

De l'hydrogène blanc découvert dans le sous-sol lorrain

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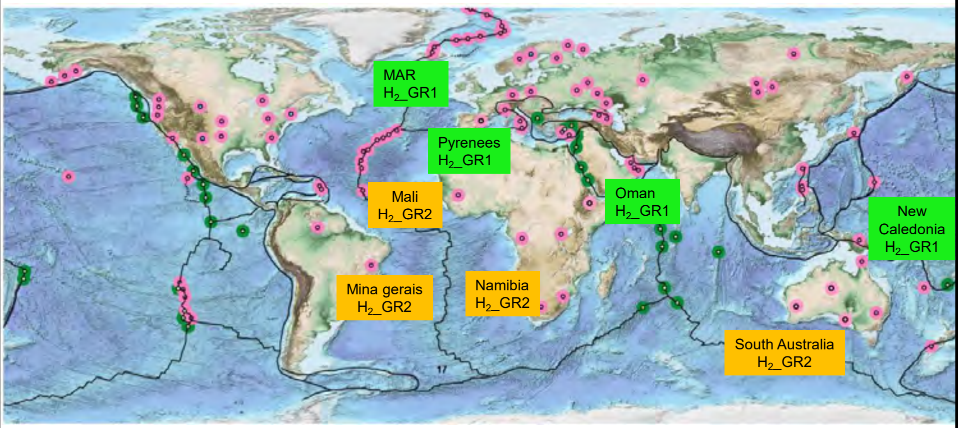
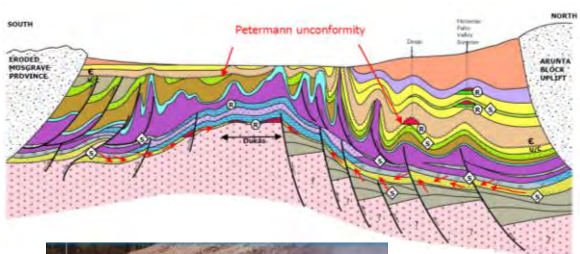
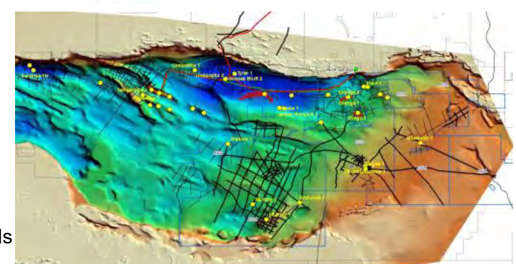
H2_GR2 : H2 and Iron rich sedimentary rocks and intrusive



Prospective Provinces : He & H_2





Mt Kitty 1 - gas: 9% Helium 11.5% H_2

Discovery done by Santos, 3 new wells will be drilled in 2023

- Others companies are targeting these blends
  - USA: **Desert Mountain**
  - Australia: **Santos**
  - Europe: **45-8**

Johns, D.; Menpes, A.; Walshe, P.; Bache, F. Exploration of a Sub-Salt Play in the Southern Amadeus Basin, Central Austra-lia—Searching for Big Gas in Proterozoic Réservoirs; Seapex Presentation; Seapex: Singapore, 2017.

Mc Cauley Field, Arizona, Desert Mountain

Discovery Well #4 (Chevlon Well 11-1)

A flow rate of 1587 MCFGPD water-free

The average gas analysis showed:
Helium- 1.137%
Nitrogen- 94.6536%
Methane- 3.1311%
Ethane- 0.2732%
CO2- 0.1428%
O2- 0.6623%

DESERT MOUNTAIN ENERGY CORP.

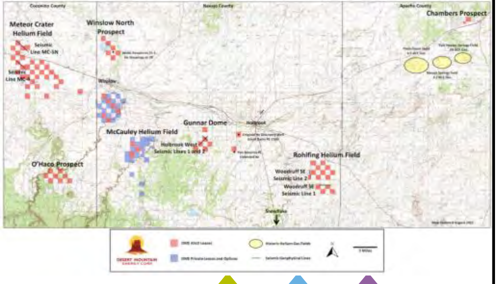
Offset Wells #5, 6 &7

Average starting flow rates:
Nitrogen – 96.4689%
Helium – 3.511%
Carbon Dioxide – 0.0201%

Well #2

Nitrogen – 91.97%
Helium – 4.171%
Hydrogen – 3.832%
Carbon Dioxide – 0.019%

DME's Lease Holdings and 2-D Seismic Geophysical Lines, Holbrook Basin, Arizona



Drilling Wildcat Wells in the Holbrook Basin

- A large salt basin approximately 160 mi. by 100 mi. with thickened Permian sedimentary rocks.
- Situated in east-central Arizona near the South margin of the Colorado plateau.
- Highly prospective for He, H_2 and Noble Gases.
- First two wells have a Flow Rate 24,214 MCFGPD @ 7.13 % Helium, and 1,251.2 MCFGPD @ 4.0904% Helium

H_2 sources: mainly H_2O

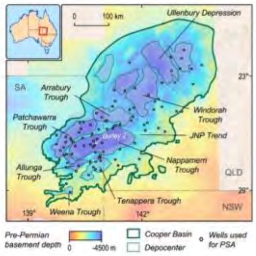
- Fe oxidation with geothermal hot fluids — $2\,FeO + H_2O = Fe_2O_3 + H_2$
- Serpentinization — $3\,Fe_2SiO_4 + 2\,H_2O = Fe_3O_4 + 3\,SiO_2 + 2H_2$
- Hydrothermal context but basic — $2\,FeS_{(pyrrhotite)} + H_2O = FeS_{2(pyrite)} + FeO + H_2$
- Granite peralkaline — $3\,[Na_3Fe_4^{2+}Fe^{3+}Si_8O_{22}(OH)_2]_{(Arfvedsonite)} + 2\,H_2O = 9\,[NaFe^{3+}Si_2O_6]_{(Aegirine)} + 6\,SiO_2 + 2\,[Fe_3O_4]_{(Magnétite)} + 5\,H_2$
- Volcanic — $H_2S + 2\,H_2O = SO_2 + 3\,H_2$
- Radiolysis — $H_20 + \alpha, \beta, \gamma$
- Mechanoradical — H_20 + …
- Open question: NH_3
- Late maturation of Organic matter

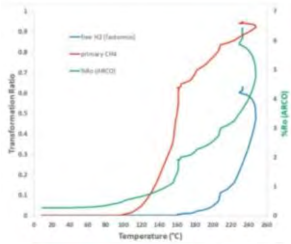
Modified from Klein et al., 2020 Elements, Vol. 16, pp. 19–24

Provinces prospectives: Late maturation of source rocks (Thermogenic H_2)

Borham, forum HNat 2022.

- Type I SR and coal have been studied, so far
  - China
  - Australia
  - Colombia

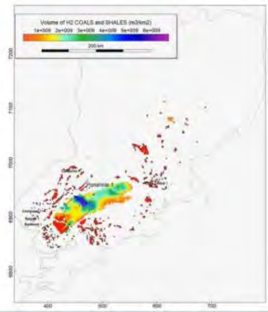




Estimated Ressource :

Geoscience Australia, Fm Tachawara : 850 tcf (2.12 Gt)
GFZ & **China University of Mining and Technology** Songlio Basin, China : 1819 tcf (4.6 Gt)

=> Global resources (based on the shale estimation already done for the shale gas) : 32 000 tcf i.e. 6.4 10^{11} t (about 8500 yr of the current world H_2 consumption)

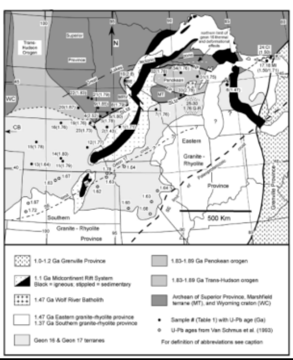


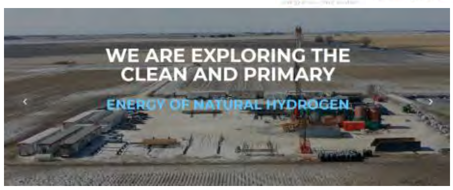
Horsfield et al., 2022, Molecular hydrogen from organic sources in the deep Songliao Basin, P.R. China
Mahlstedt et al; 2022, Molecular hydrogen from organic sources in geological systems, https://doi.org/10.1016/j.jngse.2022.104704

I Moretti 2023 –

USA: NHE - Nebraska

- New partner: Hyterra (Australian company)
- The Joint Venture includes the worlds first wildcat well specifically targeting natural hydrogen (Hoarty NE3) as well as 3,891 acres of exploration leases across Nebraska and South Carolina. The Hoarty NE3 well and surrounding lease holdings are located near Geneva city in Nebraska, USA and are known as **Project Geneva.**





I Moretti 2023 –

ACADÉMIE DES TECHNOLOGIES

Koloma:

Well funded by BreakthroughEnergy (=Bill gates fundation)

Confidential for long time and in the first page of the news paper for 1 week
CTO Tom Darrah, geochemist from the Ohio state University

Bill Gates investit discrètement le marché colossal de l'hydrogène naturel

Koloma cofounder and CTO Tom Darrah, left, COO Carrie Hudak, cofounder and CEO Pete Johnson, and cofounder and chief business officer Paul Harraka at the company's Denver office.

ACADÉMIE DES TECHNOLOGIES

What happening worldwide-continuous

This first forum has been an **opportunity** for all stakeholders to showcase their **latest products & services**, build partnerships, establish and grow business relationships, raise financing, assemble teams… 750 attendees

Second edition took place in June 2022, 3nd is scheduled in Perth Nov 2023

AAPG included the topic in their International meetings of 2022 (ICE- April Cartagena-Colombia; May Budapest-Hungria), special AAPG about natural H2 in south America in December 2022
Distan

Side event at the COP 26 organized by the Glasgow Uni

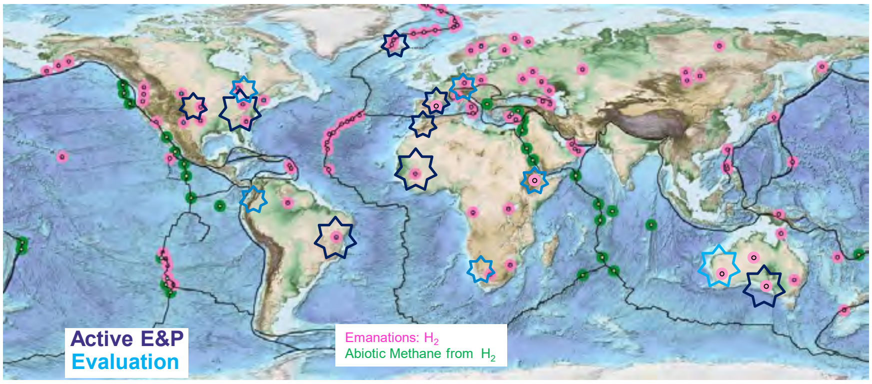
TID at IEA

Earth2: Initiative to federate the European ecosystem of H_2 in subsurface

earth2

ACADÉMIE DES TECHNOLOGIES

Main issue today: the regulation,
In many countries, H_2 is not yet defined as natural resource in the law



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